Sir Albert Howard in India

by

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Faber and Faber Ltd
24 Russell Square
London

First published in mcmliii
by Faber and Faber Ltd
24 Russell Square London W.C.1
Printed in Great Britain by
Latimer Trend & Company Ltd Plymouth

Author's Note

No attempt has been made to bring the scientific work done by Sir Albert Howard into relation with modern plant-breeding or modern soil science. Such great advances have been made in both directions since he left India that this would imply a survey of scientific achievement on these two topics such as would be out of place in the present book. My task has been limited to presenting his work as a human achievement complete on its own terms. I have throughout referred to him by the title under which he became so well known to the English-speaking world; the knighthood was actually conferred after the completion of his career in India.

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1953

Acknowledgements

Acknowledgement is hereby made for permission to reprint many passages from Sir Albert Howard's writings: to the Government of India (from the *Agricultural Journal of India, Wheat in India,* and other official publications); to the International Labour Office, Geneva (from the *International Labour Review);* to the Oxford University Press (from *The Waste Products of Agriculture, Crop Production in India, Indian Agriculture, The Application of Science to Crop Production*); to Messrs. Faber and Faber (from *Farming and Gardening for Health or Disease*); to the Royal Society of Arts (from the *Journal of the Royal Society of Arts*). Other sources are acknowledged in the various notes.

Further, I wish to record my most grateful thanks to Mr. H. Martin-Leake, Sc.D. , formerly Director of Agriculture, United Provinces and sometime Principal, Imperial College of Tropical Agriculture, Trinidad, for his great care in reading the proofs of this book and for many suggestions; and to Mrs. V. M. Hamilton, for help in preparing the manuscript and for drawing up the index.

Quotations in the text are throughout drawn from books and papers by Sir Albert and Gabrielle Howard; the bibliographies at the end of each chapter are built up from the same sources.

L. E. H.

Glossary

zamindar = an Indian landholder
ryot = an Indian peasant
rabi crops = cold weather crops
maund = 82. 28 lb.
seer = 2 lb.

> 'The agriculturist is the servant of the plant.'
> -- Gabrielle Howard

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By Louise E. Howard

Chapter 1
Career and Work in India

The Two Scientists

The year 1905 was a good moment for an approach by a Western scientist to the Indian agricultural problem. Unco-ordinated previous research, in some cases dating back many years, had been carried on in the separate Provinces; it was indeed still being argued that, in view of the wide range of climate, soils, and crops in this huge country, agricultural investigations ought to continue thus localized and dispersed. But Lord Curzon's insistence on an all-India research station, to serve his newly founded Imperial Department of Agriculture, had prevailed, and the Agricultural Research Institute of Pusa had been set up in the previous year, 1904, in the fertile Province of Bihar, to comprise thirteen separate sections.

It was a good moment because one of the best periods of scientific investigation into agricultural problems had begun. The rediscovery of the Mendelian laws of inheritance and their working out at Cambridge under Professor Bateson and others was proving an inspiration; twenty to thirty years of intensive and exciting plant breeding lay ahead. As a student Albert [Howard had shared in this awakening, which had its general effect on all scientists in biological fields. Indeed, there was a very powerful uprise of scientific effort during these years and not only agricultural botany, but other applied sciences, were developing on vigorous lines.

Meanwhile very favourable conditions prevailed in India itself. The worst incidence of famine and plague had been surmounted; the material benefits of British rule were now plain to see. The political situation was only latent, nationalist aspirations not yet being so far advanced as to cause difficulty. Before Sir Albert Howard left India he saw these begin to gather force, but for many years his work was tranquilly carried out without question, it being taken for granted that it was the function of the British Government in India to confer on the peoples of India all the advantages of Western scientific discovery. The last part of his career was spent in the independent State of Indore, where personal contact with the Ruling Prince and advice on agricultural problems both to this and other Rajput and Central Indian States was allied with a wise and just abstinence from any comment on State affairs; relations continued on the happiest basis.

In these conditions Albert Howard arrived in India. He came as a young man but not as an untried investigator. He had two different types of experience and some highly successful work to his credit. In the West Indies he had been particularly successful with arrowroot, and generally had done well, though his years in Barbados were more in the nature of a scientific apprenticeship than anything else; however, he had obtained a very good insight into the growing of cacao, sugar-cane, and other tropical and semi-tropical crops. At Wye College, where he held an appointment on the staff for two and a half years, he had scored an outstanding success in his work on hops. His demonstration that the female hops of commerce could not be cultivated without the presence of the male plant alongside was an example of an instinctive awareness of the importance of natural principle. There had been much controversy among growers on the point, it being held by some that the male hop harboured disease. Sir Albert Howard was able to prove the contrary, namely, that the presence of the fertilizing male plant was a safeguard towards health; this was, in fact, the first stone in the future edifice of his theory of health in plants. Owing to the great value of the British hop industry the result so quickly and clearly arrived at was much noted at the time and gratefully received by the growers.

In addition to the advantage of arriving with so creditable an achievement to his name, Sir Albert Howard was highly favoured in his marriage. The woman who stood at his side during the long years of research in the East was not only the able housewife, the dignified hostess, and the wonderful companion, but she was also a highly trained botanist, launched on her own career of research at Cambridge, of great intellectual endowment and altogether fitted to be the comrade and inspirer of a pioneer in science, one on a level with himself, as Sir Albert never ceased to emphasize. Possibly a very few personal remarks may here be admitted, though it is not my intention to make the present account biographical. Sir Albert Howard's first wife was my eldest sister, Gabrielle Louise Caroline Matthaei. She was educated at the North London Collegiate School for Girls and at Newnham College, Cambridge, where after an excellent career as a student she held, first, a junior appointment as Demonstrator in Chemistry and then a Fellowship; during her tenure of the latter she was associated with Professor F. F. Blackman in research on transpiration and respiration in plants. Her engagement to marry broke off this work to introduce her to years of investigation shared with her husband into the agricultural problems of the East -- she came to love India and never felt so well as when she was in that country. She had enormous capacity for patient detail and carried out a very large part of the finer minutiae of plant breeding with her own hands in the area of the Botanical Section at Pusa, at Quetta, and at Indore; with this she combined, what is rarer, a comprehensive insight into and grasp of fundamental principle. Indeed, her mind was masterly and energetic, as was shown in a smaller way in her ability to run her Indian household to perfection in the intervals of her scientific labours, to the astonishment of the ladies of the Station, who prophesied either a complete breakdown in household arrangements or at least sunstroke from so many hours spent in the field. But her chosen way of life gave her supreme happiness and her comradeship in investigation with her husband was perfect. Their combined power of work was colossal nor could the results of their efforts ever be disentangled, as they themselves stated to me on more than one occasion. In due course Gabrielle Howard received the almost unknown distinction of being recognized by the proud and conservative administration of India for an official appointment. She was first Personal Assistant and then Second Imperial Economic Botanist to the Government of India. These rather ugly titles were replaced in popular parlance by the current description of the two investigators as 'the Sidney Webbs of India', and a few years later *The Times* summed up the partnership by stating that 'seldom in the sphere of economic investigation has there been a more fruitful collaboration between husband and wife than that of Mr. Albert Howard, for many years Imperial Economic Botanist at the Agricultural Research Institute, Pusa, and Mrs. Howard.' (*Trade and Engineering Supplement,* 5th May 1921.)

This initial advantage of the perfect marriage partnership, allied with the right age, good health, a cheerful disposition, and the wonderfully useful heritage of a farming boyhood, together with confidence in his capacity to carry out scientific discovery, was counterbalanced on arrival at Pusa by some disadvantages. The Botanical Section was the last to be formed and Sir Albert's appointment was slightly later than other appointments. Any who have had to do with official scrambles for such things as equipment and location will appreciate that this Section got the worst served. This was of importance in one respect; land on which to grow the crops to be investigated was stated already to be taken up and in any case not necessary for a worker deputed to deal with plants and not with the soil, which was to be the duty of another Section, thus at the outset laying down the vicious principle of departmentalism. Sir Albert embarked on the first of many tussles with officialdom, prophetic of a long fighting career, to obtain seventy-five acres for the furtherance of his experiments, convinced as he already was that work confined to the test tube and the walls of the laboratory was useless to the agricultural botanist; his later cruel phrase -- 'the laboratory hermit' -- was his own and not borrowed from another speaker. Possibly this early attempt at refusing him a facility essential to good work stimulated his natural obstinacy. He was the first to acknowledge help received from superiors whom he respected, notably men like Sir Reginald Glancy, Lord Meston, and Mr. Bernard Coventry, but any suspicion that he was being met by mere obstructionism roused the lion. His official Minutes could be devastating and even more so his self-confident refusal to waste time on unnecessary administrative minutiae. That 'amiable brutality' which became so characteristic later was well known and feared by many in the ranks of the Indian Civil Service.

On the other hand, his relations with the nationals of India, which seldom involved the boredom or vexations of official routine, gave ample scope to the opposite trait of kindness and good humour, which was no less inherent in him than his obstinacy. He possessed throughout his life and in a supreme degree the happy capacity to enter immediately into pleasant fellowship with any human being. This genius for human intercourse clearly derived from his great honesty, sincerity and cheerfulness, which were recognizable within the first few minutes of conversation; the rather marked lack of what might be called an awareness of conventional social limitations made him equally at home with the cultivators and the Princes of India, with the workman mending his fence at Blackheath or the member of the House of Lords. No doubt many possess this quality and it is the usual endowment of a mind sufficiently open to be above social restrictions; it is noted here because it deeply affected and helped Sir Albert as a scientific worker and had a most important bearing on the character of his work. It was because he was honest enough and humble enough to note what the Bihar peasants were doing, what the Baluchistan tribesmen grew and how they grew it, because he loved talking to West Indian planters and Kentish hopgrowers, to a Westmorland smallholder equally with a French millionaire wishing to purchase a million hectares in the Sahara, that all who cultivated the earth's surface, of whatever calibre, or education, or station, became his instructors: he was able to learn from all because he wanted to learn from all. More especially did he acknowledge the lessons to be got from the century-old experience of the Indian peasants, whom in later life he most happily named his 'professors'. In one ostensibly paid to teach a predominantly illiterate population it was an unusual point of view.

Work at Pusa and Quetta

The first eighteen years of appointment were spent at Pusa, already mentioned as the Agricultural Research Institute founded by Lord Curzon to serve the needs of Indian agriculture. This important Station brought together a corps of British scientists of considerable but varying merit, each in charge of a separate Section and responsible to a Director and through him to the Department of Agriculture. It was an advantage that these scientists were instructed to be in contact with the Provincial research officers already at work and to give and receive information. Immediately on arrival Sir Albert was sent on a tour of the Provincial botanical gardens and areas, a very useful undertaking, which gave him a bird's-eye view of Indian flora; many other journeys followed in the course of the early years; even the honeymoon had been spent in part on touring. When he started work Sir Albert was also responsible for reporting annually on the results obtained throughout the country by the agricultural research officers attached to the Provincial governments. In this way a wide and comprehensive grasp of tropical plant problems was built up and, what was equally important, personal relations with other workers in the same field were begun. Sir Albert was fortunate in securing the lifelong friendship of Mr. George Clarke, C.I.E. , Dr. H. Martin-Leake, and Mr. Fairlie Watson, O.B.E. In general, the feeling that he was appointed to serve the whole of India with its immense populations and vast possibilities was very stimulating to him. He responded at once, and from that time on conceived a great distaste for any parochial or localized outlook, beginning to see agricultural problems for what they truly are -- world problems of universal import.

This broad outlook made him impatient of the restrictions at Pusa. If the work was to be imperial and the staff put in a front-ranking position, it was a most unfortunate mistake to have selected a location, uncommonly isolated and to which access was most inconvenient and awkward. This was an error stigmatized at all costs to be avoided when in later years Sir Albert sketched the conditions for his ideal Research Station. The following passage puts the argument cogently. It refers to the Station created by Sir Albert himself at Indore.

> 'Such an Experimental Station must be easily accessible by road and rail, it must be close to a large town so that such amenities as schools, hospitals, post and telegraph offices, a market for the purchase of ordinary commodities and for the sale of surplus produce are all automatically provided. The acquisition of a suitable area close to a centre of population will, in the majority of cases, add to the capital cost, nevertheless such a site may prove to be the cheapest in the end. Even when the site is only a few miles from a large town, the Experiment Station suffers from great disadvantages. Land at a considerable distance from a large town, and far removed from good roads and the main railway systems of the country, is naturally cheaper and easier to acquire than a suitable area close to a large city. The saving in the initial cost is, however, often dearly purchased. A large amount of time, energy and money is consumed by the staff in getting to and from the nearest main railway line. The purchase and transport of supplies and of produce suffer from a similar disadvantage. Visitors must of necessity be few. Every ordinary amenity required by the staff, such as schools, hospitals, post offices and domestic supplies, has to be created on the spot at great cost. There is no social intercourse for the workers beyond that provided by the Experiment Station itself. For these reasons the pay of each member of the establishment is higher than would otherwise be the case, while long periods have to be spent on leave in connection with family affairs. Apart from the general loss of efficiency, which follows from these causes, there remains a still graver disadvantage. The workers tend to lose a proper sense of proportion, and difficulties of all kinds arise. In the selection of a site for an Experiment Station, therefore, the greatest care must be taken to keep in mind not only the agricultural but also the human factors which are involved.'

These words were written with the difficulties at Pusa vividly in mind. It had been only too obvious that the Pusa scientists and their families had far too limited opportunities for social intercourse; there was no relief from the weariness of the same faces day after day. The Howards were so busy in their work -- the wife equally with the husband -- that they had devoted the minimum of time to social engagements. This, incidentally, in so restricted a group had not added to their popularity, while with the others they themselves had suffered from the monotony of the Station entourage.

But the work offered every possible stimulus and excitement. It started with a most important project, the improvement of the wheats of India. The success of this work is described in the next chapter. So essential did Government consider the wheat programme that there was initially a suggestion not to assign Sir Albert to the general botanical work of the Pusa Institute, but to make him a specialist officer on wheat only; fortunately, this suggestion was dropped. At the same time, investigation was at once started on a number of other crops, and many kinds of fruit trees planted; all this experience proved invaluable and formed the basis of much future research. An initial practical success was registered in eliminating the plague of the flax dodder, which had unfortunately been imported into India. The vigorous and sensible advice given by the new Imperial Economic Botanist was carefully followed by the Bihar planters and the danger disappeared (1908). This was no doubt encouraging.

Otherwise the early years were divided between intensive botanical studies of varieties -- the proper work of the plant breeder -- and learning how to grow the crops which were to be thus subject to examination. The first ten years of work may be said to have had this double aspect. The botanical studies were foreseen in the appointment and are distinguished by the very fundamental character which they had to assume. Practically nothing of a satisfactory kind had been done on the sorting out of the varieties of many tropical crops and the Howards found themselves compelled to go back to the beginning and undertake an enormous amount of work in classifying wheat, tobacco, linseed, gram, fibres and other crops; the work on tobacco was undertaken by Mrs. Howard and eventually gave rise to four long and elaborate monographs. Later her work was repeated by the U. S. A. Federal research authorities and confirmed in every respect. In such work the Howards joined the international body of scientists who were working on Mendelian principles.

From the very beginning it was decided that the crops to be investigated must be grown on a field scale. It was for this purpose that the seventy-five acres had been fought for. At once the investigators were plunged into practical difficulties of cultivation, which had to be solved alongside the plant-breeding work. In undertaking to grow the crops to be improved Sir Albert may be said to have given himself a number of unusual problems. The plant-breeding work was assigned to him: his other tasks he found for himself.

The first practical essay was to arrange an ingenious system of irrigation for the fruit trees planted; this furrow irrigation was a great improvement on current methods (1908). But there were more serious problems. The fields at Pusa were wet and subject both to surface flooding and to the dangerous effects of the rise of the subsoil waters during the monsoon. A careful system of field contouring (the 'shaping' of fields), accompanied by well-devised surface drains, all work carried out by manual labour and with the tools at hand, proved a contribution of the utmost value to Indian agriculture, and would alone have justified Sir Albert's appointment. The system eventually was copied over a large part of India. This initial work led directly to a prolonged study of soil aeration. Here the

Howards were pioneers and broke entirely new ground in tropical investigation. As time went on, they attributed more and more importance to this question, which in their opinion was at the root of much under-cultivation in India. They foresaw enormous possibilities of increased production if attention could be directed to soil aeration. It was from the aeration studies that the later theory of disease resistance took its birth.

In another direction also most useful practical work was started at an early stage. The investigations on tobacco, as well as some of the investigations on wheat, involved some application of the methods of green-manuring current in Bihar. An innovation was tried and it was soon found that manuring with a specially sown crop of green *sann* was far less expensive than manuring with oil-cake or the residue of the indigo plant, *seeth;* by the new method, in spite of wet seasons, very good crops of tobacco, far superior to any in the neighbourhood, were produced (1911-12). This pointed to more enquiry into the subject of green-manuring generally, and the way lay open to the study of soil fertility.

In May 1910, after five years' work at Pusa, a step was taken which was symptomatic of the energy, vigour, and initiative of the Howards. Mr. Fairlie Watson has left it on record that the inspiration which impelled Sir Albert to spend the half-year only of the growing season at Pusa, and then to rush off his seed and transfer himself and his wife for the other six months to Quetta in the Baluchistan desert was 'a stroke of genius'. (*Soil and Health Memorial Number*, 1948, p. 29.) A special Station was here opened, and Sir Albert had the advantage of being in sole charge. Wheat and fruit, including tomatoes, were grown with great success. The arrangements implied the most strenuous work. Two crops of wheat were grown in one year, at Pusa and at Quetta, which meant that the period required for breeding new varieties was exactly halved. This accounts for the rapid advance in the wheat-breeding programme between the years 1910 and 1916.

But if by his own act Sir Albert deliberately doubled his task, he reaped the advantage of a further widening of his outlook. The work at Quetta was very different from the work at Pusa; only one thing was the same -- the knowledge to be gained by the usual lessons of observation in watching the hill tribesmen as he had patiently taught himself to watch the ryot of the Bihar plains. It was in Kashmir that Sir Albert noted vines sprawling in low trenches in a way which seemed inevitably to invite mildew and yet escaping all trace of disease because grown on ancient methods of soil conservation, a fact which impressed itself deeply on his mind. Otherwise the technique to be applied was entirely different, desert conditions being encountered. At Pusa the problem had been the waterlogging of fields, to be overcome by clever drainage; at Quetta the fields had to receive their irrigation water before they could bear. This led to prolonged investigations on irrigation, which somehow fitted in remarkably with those on drainage and aeration of the soil and proved to be a logical continuation of these. Most unusual conclusions were reached, of far-reaching importance, providing something like a sensation among the authorities, as in India irrigation problems are also revenue problems.

Quetta is an important military station and residence there brought contact with the army.

Two very useful pieces of work were added to the main projects of wheat and fruit, namely, the drying of vegetables for men on the march and the drying of fodder for army transport mules; the nature of the military operations in the districts comprised in the North-west frontier made these supply questions of unusual importance and much difficulty had been experienced. The improvements were great; it was estimated, for example, that a week's supply of vegetables for a thousand men could now be accommodated on the backs of two mules only.

Long before this the position of the Howards as leading investigators on tropical agriculture had been established. The phenomenal success of the Pusa wheats left the computators behind. Track could not be kept of the way in which they were spreading; the demand for seed far exceeded the supply. They were in demand by scientists and growers in the most distant parts of the world and were despatched to Burma, Java, Uganda, Nigeria, South Africa, the Soudan, the Argentine, Canada, and France; in Australia, at the Sydney agricultural shows, they won first prizes several years running. They were mentioned in Parliament as an argument justifying the expenditure of more money on agricultural research. (Lord Henry Cavendish-Bentinck, H. of C., 14th August 1917. *Hansard,* H. of C., Vol. 97, No. 116, c. 1008.) Sir Albert himself, when on leave, attended the Mark Lane and Liverpool corn exchanges and had the felicity of hearing his wheats described as 'equal to any in the world'; the formal reports from the British milling industry were conceived in the most flattering terms; the milling and baking tests were more than satisfactory. If anything more were needed, it was supplied by the reports on fibre, sent in by the head of one of the biggest firms in these products in the world, describing the sample supplied as 'the best specimen of fibre from the *Hibiscus cannabinus* plant which has ever been submitted to me', capable of being sold 'in almost unlimited quantities'.

It could not be surprising that the Indian public responded to these successes. In a subsequent chapter it is stated that Sir Albert would never agree that the peoples of India did not know how to make full use of the improvements offered to them. Almost from the beginning the wealthier and the ruling classes followed his lead. They did more: they supported and assisted his work. His suggestion to hold the Tirhoot Agricultural Exhibition at Pusa itself and show the actual growing of crops *in situ* set up immediate intimate relations with the Bihar planters, who offered to take over some of the work of growing wheat seed under his supervision; this sensible and generous suggestion, which was useful to both parties, was accepted (1911). He had already been asked to visit Kashmir and report on the hop industry, on general agricultural development, and on agricultural education (August-September 1910). (A brief notice of the reports, which were not publicly issued, in *Report of the Imperial Economic Botanist for the Year 1910-11,* pp. 5-7. The last subject could not be dealt with.) Following on his representations to the Administration in Baluchistan, the irrigation policy there was revised. In 1917 the Maharajah of Kapurthala asked for the loan of his services, and the creation of an Agricultural Department and a State Development Fund was the result of his advice.

Bhopal was visited in 1921 and other advisory work undertaken in these years. Many of the Hill States, the Central Indian States, and other States adopted the new wheats and the new methods. Assisted by the Provincial officers, themselves highly trained and able scientists, Sir Albert was able to lead India, both British India and the Indian States, a huge step forward in the direction of supplying her peoples with their daily bread.

A most unusual feature of the work was the intrusion into marketing. Here Sir Albert's inherent business capacity came into play. He knew it was no use to grow grains, seeds, fodders, fibres, fruit, tobaccos, indigo, vegetables, unless these products reached the consumer or the merchant in good condition and at reasonable prices; he realized further that it was the scientist's duty to fit himself into current trade requirements where these had been established over a long period and on a stable basis. An investigation of local methods of storage of grains convinced him that these were rather more efficient for the home consumer than was currently supposed, but when it came to the export trade in grains he did not spare his criticisms of the haphazard, mixed, and unclean character of the Indian shipments of wheat, which pushed such consignments to the bottom of the markets. Again, with the launching of the new Pusa wheats, the greatest care was taken to think out successful principles of seed distribution. Owing to the risks of cross-pollination throughout the country the only successful plan was to insist on substituting a new variety over the whole of each selected area, until such improved variety dominated. This was therefore arranged. The same principle was advised for cotton and other partly cross-pollinating crops.

It was, however, in investigating the fruit marketing position at Quetta that Sir Albert found the best opportunity for the exercise of his great practical abilities. His success is described in a subsequent chapter. The beautiful fruits and tomatoes grown in the high arid area of the Baluchistan desert were able to reach the great cities of India, after a journey of nearly 2, 000 miles, in perfect condition, so admirable were the baskets, crates, and containers invented for the purpose and so efficient the training of the Indian staff in good methods of wrapping and packing.

In the course of these successes certain honours and promotions were earned. After five years' work as a volunteer Gabrielle Howard, as already stated, received her first official appointment as personal assistant to her husband in 1910; the honour of the Kaiser-i-Hind Gold Medal, at that time rarely given to a woman, was conferred in 1913, and she was advanced to the rank of Second Imperial Economic Botanist. In 1914 the Companionship of the Indian Empire (C.I.E.) was given to Sir Albert. In 1918 two special silver medals were conferred at the Calcutta Food Products Exhibition. In January 1919 the Viceroy paid an official visit to the Pusa Research Institute and it was reported that he could not be got to leave the fascinations of the Botanical Section, where there was so much to be shown to him. The silver medal of the Royal Society of Arts in London followed in 1920, and the Barclay Memorial Medal of the Royal Asiatic Society of Bengal in 1930.

Meanwhile the Howards were taking a leading part in founding the Indian Science

Congress in 1914, a vigorous body which met annually for scientific discussions. In 1923 the Howards contributed no less than five separate papers to the discussions, Gabrielle Howard being in that year President of the Section of Botany, and in 1929 President of the Section of Agriculture and Chairman of the Joint Sections of Botany and Agriculture; in 1926 Sir Albert was elected President of the whole Congress, a position which would probably have been conferred on his wife had she lived a few years longer.

Problems of Agricultural Research in India

An opportunity came, when the work at Pusa and at Quetta was drawing to a close, to give a summing up of the situation. This took the form of two lectures delivered to the Royal Society of Arts on 16th and 23rd July 1920. For these lectures the silver medal of the Society was awarded, as already stated.

In these lectures two independent topics are combined in that easy and lucid fashion which became so characteristic of Sir Albert's later work, namely, a summary analysis of Indian agriculture and a sketch of the ideal qualifications which should be exhibited by any scientist seeking to serve communities like the Indian peoples. Almost all the points on which Sir Albert later insisted so vehemently are included: the need for the most complete understanding of, and regard to be paid to, climatic conditions: for sympathetic and wise consideration of peasant mentality and intelligence: for respect for an empiric knowledge of cultivation methods accumulated in the course of several thousand years of tradition and experience: the care necessary in launching among such cultivators, or indeed among any cultivators, the results of Experiment Station research: finally, the pronouncedly critical note rejecting the application to agriculture of mathematical principles ('the score-card method') and the confidence which places the individual researcher as leader high above the trammels of systems of organization. The salient passages of these discourses are here appended. They embody the knowledge gained after fifteen years of intensive effort.

> 'Agriculture is, and for many years to come must remain, India's greatest industry. In comparison with the value of the annual produce of the soil and the trade in raw materials, the remaining industries of the country are, with few exceptions, relatively unimportant.
>
> 'When we examine the agricultural products themselves, it is at once evident that crops are of far greater importance than animals. The Indian cultivator is a grower of crops, and he usually regards his livestock as mere aids to cultivation and in the feeding of the family. The country does not export meat, wool, or dairy products. When, therefore, the present Indian Agricultural Department, founded by Lord Curzon in 1904, began operations, the attention of its members was mainly directed to the study of the crops of the country... As is well known the agricultural conditions of India and its problems are entirely different from anything to be

found in the West. The investigators speedily realized that they were in a new world. The crops were seen to be raised by a multitude of small cultivators, conservative, for the most part poor and unable to command much credit. The average yield per acre was low but remarkably constant.

'While the average production showed no change, the seasonal variations in yield were considerable. India was found to be a country of climatic extremes not only as regards the rainfall, but also with reference to temperature, to floods and high winds. Except in certain favoured localities the annual crop was always at the mercy of a variety of circumstances quite beyond the control of the cultivator. It was not surprising therefore, to find him conservative in outlook, and to discover that his leading idea was to play for safety. The easiest line of advance in improving production lay through the plant. The problem was successfully attacked in two directions, namely, by the provision of improved varieties and by the study of the factors which influence plant growth...

'The importance of yield in any new variety cannot be overestimated in India. The cultivator is conservative and is not prone to change either his methods of agriculture or the local varieties of crops to which he is accustomed... Every cultivator, however, can understand the meaning of a good crop and of a variety which can be relied on to produce a yield above the average. Once this is assured, the success of any new variety is certain, and no difficulties in obtaining his co-operation need be feared.

'While yield is of such paramount importance in India, it must never be forgotten that the growing period of the crop is much more strictly limited than in countries like Great Britain. Generally speaking, in England there is a fair degree of latitude at both ends of the season. In India this is not the case. For example, the sudden change from the monsoon to cold weather conditions in Northern India, and from the cold season to the hot months, impose temperature limits which restrict growth to a definite period. Thus in Bihar, the period during which wheat must be sown to ensure a full crop is less than ten days. Early sowing is impossible, as the soil is too hot for the seedlings; late sowing means a great slowing down in growth due to the rapid falls in temperature, and the crop cannot ripen in time. More important than the time of sowing are the factors which affect the crop during the ripening period. A rapid rise in temperature takes place in March, the hot weather is ushered in with dry hot winds, and the transition from a period when wheat can ripen to one in which it merely dries up is a matter of a few days only. Once the hot winds begin, ripening ceases, the crops wither and shrivelled grain is the result. Early hot winds or a spell of hot weather may reduce the yield by half. Experience proves that a variety which ripens well within the growth period of any particular locality gives the best return over a number of years...

'... another interesting aspect of yield has arisen in India, where the standard of agriculture and the general resources of the Experiment Stations are far in advance of those of the people. Particularly is this the case with irrigation facilities. When yielding power is studied under these favourable conditions, varieties come to the front which prove very disappointing when tried by the cultivators. One of the highest croppers of the local Punjab wheats -- No. 9 -- is a variety which gives good yields if well cultivated and provided with sufficient water at an Experiment Station. Under cultivators' conditions, however, it is apt to prove disappointing, and to yield less than earlier types of lower potential yielding power. Similar experiences have been met with at Pusa. It therefore follows in India that the variety which possesses the highest potential yielding power is not necessarily the best for introduction to the cultivator. A great deal of judgment is required in selecting the most likely kinds for such a purpose. It is a safe rule to discard all types which show the least tendency to mature late or require special treatment. For these reasons, accurate mathematical investigations to determine which of a set of varieties is the highest yielder, which may prove of great use in a country like England, are often inapplicable to Indian conditions where the results are only of academic interest...

'Like many other successful things, the improved variety is a compromise and does not depend on excellence in a single character. Such things as yielding power and adaptability represent a combination of characters which it is practically impossible to analyse on the score-card principle. No one has yet given a satisfactory quantitative expression to the various units which make up yielding power. A plant breeder, working on score-card principles, might easily reject a really good variety. Being a compromise, it follows that too much attention must not be paid to single characters. Rust resistance in wheat is a good case in point. Before the present Agricultural Department was started, a great deal was heard about the desirability of obtaining rust resistant wheats for India. It was thought that once these could be secured, all would be well with the wheat crop. Many rust resistant wheats have passed through my hands at Pusa which were quite useless for any purpose beyond plant breeding. The quality of rust resistance was united with so many weakness in other respects that the wheats were little more than curiosities. Naturally the ideal wheat will be highly rust resistant, but in practice it is better to unite with vigour, adaptability, good yielding power, good quality, and good straw, a fair degree of rust resistance than to pay too much attention to this one point.

'While single characters by themselves are generally useless, nevertheless a trivial colour character, when in combination with others, may be of great use when the seed of an improved kind has to be distributed among the cultivators. In the systematic replacement of the country crop, the Agricultural Department must be able to check the work. The replacement must be carried out according to plan, and admixture with inferior types must be easily detected. For this purpose, the improved kind must be readily recognized in the field. It is a great advantage, therefore, if it possesses some distinctive colour characteristic by which it stands out clearly from the ordinary crop. In cotton, any peculiarity in the colour or shape of the flower is important, while in wheat, chaff and straw colour are most helpful...

'In working out improved methods of producing a crop, the physiological aspect is the one which concerns the economic botanist... Perhaps no country in the world offers better scope than India for such work. We have before us an old civilization, with a corresponding volume of traditional experience in the growth of crops. This has helped to crystallize and define the agriculture of the country to a much greater degree than has been possible in our modern tropical possessions, or in new countries like the United States of America. In India, things agricultural have had time to settle themselves. The great growth factors have left their impression on the characters and distribution of cultivated plants. Besides this, the range in conditions between the various parts of the country is very considerable. These circumstances greatly assist the investigator in the study of the physiology of crop production and in the deduction of some of the factors which are in operation. To any one who can read his practice in the plant and has acquired an intimate knowledge of crops, India presents in her agriculture a number of natural experiments repeated year after year...

'The wide range of the problems presented by the country has been indicated. The problems are obviously complex. Their solution involves a knowledge of science, of practical agriculture, and of trade requirements as well as the faculty of combining these very different points of view. The country is large and the questions still to be attacked are very numerous. The mere size of the country and the large areas under any particular crop mean that even a small improvement in the yield per acre, when multiplied by the area to which the improvement applies, soon runs into lacs of rupees.

'What is the best means of getting such work done? The State is anxious that the volume of results should be increased. Should we rely on organization, or should we trust to the individual? Both systems have their advocates. The answer, I think, is given by experience and by history. All notable advances in agriculture up to the present time have been initiated by individuals and not by systems of organization. This [has] applied to creative work of every kind. The individual has always triumphed over the committee or the organization. Further, all organizations sooner or later become affected by disease. In India, this often takes the form of acute departmentalism.

'What are the qualifications of the men who are to carry out the work? I think the subject to be investigated supplies the answer. The men must obviously be more than laboratory workers. They must look at the questions from three points of view -- that of the scientific investigator, that of the cultivator, and that of the trade. Science is the instrument by which the advance is made. A first-hand knowledge of

> practical agriculture and the cultivator's point of view suggest the problems to be attacked. The uses to which the final product can be put or, in other words, the requirements of the trade, gives the direction in which the advance can be most profitably made.'

Four years later, in a small book written for students of Indian conditions, Sir Albert re-emphasized the difference between academic research and work for practical ends. The warning note is even more emphatic and it is pointed out that the economic situation is dominant and that scientific advance is inevitably limited by the condition of the country.

> 'The general nature of the problems of Indian agriculture has been indicated. These questions are complex and are quite unlike the ordinary subjects of academic research, where the factors and conditions can be accurately controlled. For their solution they manifestly require every aid that a wide knowledge of science can give. In agricultural investigations we can never get rid of the ever-changing environment. The prejudices of the cultivators, the smallness of the means at their disposal, and the general labour conditions impose a further set of limitations. In all directions the investigator meets with well-defined working conditions. It is little wonder, therefore, that the improvement of Indian agriculture is such a difficult matter and that progress is so slow... Often improvements are possible but they are not economic. The trouble and cost involved are prohibitive. Such discoveries, therefore, are only of academic interest and cannot affect practice. To be successful, the game must always be worth the candle. In India the cultivators are mostly in debt and the holdings are small. Any capital required for developments has to be borrowed. A large number of possible improvements are barred by the fact that the extra return is not large enough to pay the high interest on the capital involved and also to yield a profit to the cultivator. It is this economic complication which makes it so difficult to improve production in India.'

Wider Ideas

Perhaps what has most interested me in reading my husband's many papers from India is to find embodied in them from time to time the enunciation, often quite definite, of the new ideas which, linked up later and shown to be each an item in a comprehensive conception of what agriculture should be and what agriculture should conform to, are now popularly known as the teachings of 'organic husbandry'. Most of the doctrine which we of the Organic School stand for appear in these papers, with the one exception that no objection is as yet stated to the use of artificial fertilizers. (But see passage quoted at the end of Chapter 3. The subject is discussed in Chapter VIII.) There is intense and ever-repeated emphasis on observation in the field. This advice comes again and again and the importance attributed to it does not lessen with the years. Yet if their habit of patiently focusing their attention on what was to be seen with the eyes imprinted on the minds of the two investigators a lasting impression of the significance of Eastern agriculture, they could not depend on this alone. Their intellectual heritage was from the West: observation would have been useless without prolonged scientific training. It was at Cambridge and not in India that other inspirations were born. That master conception of the whole plant, as a live thing, knowing no divisions of science but 'in carrying out its functions using all', simultaneously and obstinately a problem for chemist, botanist, physicist, entomologist, mycologist, and micro-biologist, who, unless they are willing, in their separate investigations, to keep a regard for the whole organism confronting them will never penetrate very deeply into its mysteries, that conception comes early, from Gabrielle Howard and not from Sir Albert, in a letter written in haste from Newnham College during their engagement, evidently in relation to some scheme of work which he had sent to her. She writes hurriedly, without commas, rather frankly, but sure of her ground. The letter, though simple, is so interesting as the first expression of this all-important idea, that I reproduce it here.

> 'The part on plant diseases could be vastly improved and made much more effective if taken rather differently, being rather taken on the complexity of the physiological processes which follow no science. I will outline what I think and send it you and you can consider it. This would also help your ending which is quite good but you want to bring out the point that the plant knows no division of science, in growing and carrying out its functions it uses all. Therefore men with good insight in all will be most likely to make real advances in the biological sides which after all is agriculture. Don't condemn this idea outright but think about it -- it is what we intended when we made the scheme.' (28th July 1905.)

It is interesting that this idea should have been enunciated thus early and with such simple clarity. It did not immediately affect the work; the wheat-breeding campaign was carried out on formal botanical principles. The same is true of some other studies, on tobacco, for instance. But it was not long before that habit of observation, already mentioned, gave a definite extension to enquiry. When the baffling problem of indigo wilt was handed over to the Howards -- it had eluded the efforts of four or five other departments -- there was nothing for it but to plunge into the whole history of this plant, above and below ground. When once this step was taken, the way was marked out for all future investigation.

Research was pushed below ground to the roots and root systems of all crops studied; the Howards were pioneers in India in drawing attention to the need for doing this. It may seem incredible that such studies of one whole half of the plant should have been neglected, but in fact agricultural botanists were commonly satisfied to examine foliage, flower, and fruit and to leave it at that. The Howards came to make a habit of careful examination of the roots of their crops at all stages of growth, a practice which helped them to solve some intricate and difficult problems. The most prolonged investigations were the ten years' detailed work on the roots of eight varieties of fruit trees, pursued by means of an adapted knapsack sprayer to anything from ten to forty feet below ground.

Such studies, though now a commonplace, were then most original, and enabled Sir Albert to prove so intimate a connection between the state of the soil and the life of the tree as more than justified his first use of the happy phrase, 'the gearing together' of plant and soil, in the paper presented to the Royal Society on 'The Effect of Grass on Trees' (1925).

The work on root systems had throughout been inextricably bound up with the supremely important problems of aeration and drainage of the soil. That Sir Albert should have been led from a contemplation of the plant into a contemplation of the medium in which it grew -- the soil -- was inevitable unless he was to put himself in blinkers, but -- it was an undeniable departure from the strict botanical field. It made for a point of view infinitely wider than that given to the systematic or even the economic botanist. From that time onwards Sir Albert was altogether unable to separate plant from soil; the soil came within his vision as the great originator of all things growing or alive, as 'Mother Earth', the nurse of life and mistress of decay.

The final great step forward in the investigation of the plant as a living organism was to note its enemies, the diseases and the pests, but not in order to hand them over to the mycologists and entomologists, rather to do the exact opposite, to bring to light the vital connection between their attacks and the condition of the plant itself. A good many years passed before the idea was definitely formulated, in a paper contributed to an English journal at home. (*Annals of Applied Biology*, Vol. VII, 1921.) By 1926, in the Presidential Address to the Indian Science Congress, the idea is firmly laid down that prevention must be by growing healthy crops, capable of resisting their destroyers.

Gradually there came to be something like a shifting of emphasis. Not that the Howards wished to dissociate themselves from the advances of orthodox science, rather that a parallel and increasing interest was awakening in what age-old tradition and practice could offer: the solid achievements of an ancient culture emerged in their imaginations as an integral part of the agricultural complex. As President of the Indian Science Congress just mentioned Sir Albert was bold enough to suggest to his fellow workers in the research field that practice could teach a great deal to science. The mighty contribution made to human living by the peasant agriculture of the East, in spite of many inadequacies and weaknesses, began to make a kind of pattern in his mind.

The Creation of the Indore Institute of Plant Industry

In summing-up the work done at Pusa and Quetta towards the end of his service with the Department of Agriculture in India, Sir Albert took an occasion to reckon up the money value of what had been achieved. He had a special object in view -- to counter the campaign for financial stringency, known as the 'Geddes axe', from the name of two highly placed Government officials who, after the First World War, were deputed to cut down expenditure at home and throughout the Empire. At that time the additional income accruing to India from improvements in wheats, tobacco, and fruits alone was estimated at well over a million and a quarter pounds per year; this, as Sir Albert was at pains to point out, was twenty-nine times the total cost of the Botanical Section during its existence from 1905 to 1922, or 315 times its current annual expenditure. Moreover, these figures made no reckoning of the incalculable profits which would arise out of the investigations on many other crops and above all from improvements in method. (*Work done by the Botanical Section, Agricultural Research Institute, Pusa, from May, 1905 to January, 1923*. Further figures for wheat are given in Chapter 2.)

By that time ninety-three published papers or books had appeared under the signature of the Howards and eleven others were in the press. (By 1929 there were 128 papers or books in all.) The Botanical Section was openly credited with having contributed more to the development of Indian agriculture than any other Section at Pusa, with having taken the lead in research work throughout India, with having stimulated research everywhere on sound lines, broadened its basis and succeeded in fostering the intelligent interest of Government and the public in the work of the Agricultural Department. (Letter of 2nd December 1919 from Mr. Bernard Coventry, C.I.E., one time Director of the Pusa Research Institute, to Sir Albert Howard [text printed in *Work done by the Botanical Section, Agricultural Research Institute, Pusa, from May, 1905 to January, 1923*.])

This had not been done without some controversy. It was unquestionably at Pusa that Sir Albert began to feel that revolt against 'fragmentation' of knowledge which in later life made him so impatient of orthodox research. He was accused of invading fields not his own, and a study of his published papers must largely confirm the truth of this accusation. In fact, his intelligence was too powerful to fit into his environment and towards the end of his Pusa career he felt completely out of the picture and thoroughly impatient and rebellious. That freedom 'which is so essential to the scientific investigation of economic questions' was hopelessly stultified by the Pusa departmentalism, and the Howards actually went so far as to stigmatize the current organization of agricultural research there as 'obsolete'. A very deep dissatisfaction is made plain in this unqualified statement. They added that, as it is impossible to change any organization from within, the only thing to do was to create something new; and freedom of action was at length secured when Sir Albert was appointed first director of a new Institute of Plant Industry at Indore, which was to be planned, built, and organized entirely on lines indicated by himself.

The basis of research was obviously to be investigation directed to the whole existence of a selected crop, namely, 'the plant itself in relation to the soil in which it grows, to the conditions of village agriculture under which it is cultivated, and with reference to the economic uses of the product'; in other words, research was to be integral, never fragmented. It was very unfortunate that there should have been a delay of five years, from 1919 to 1924, in the plan originally sanctioned for creating the new Institute. This delay was due to the Geddes axe mentioned above. Indeed, had not the Central Cotton Committee stepped in to vote two lacs of rupees for capital expenditure and one lac thereafter for recurring annual costs,the proposed venture would never have materialized.

This offer was supplemented by the generosity of the Indian States of Central India and Rajputana. The Darbar of the State of Indore offered 300 acres of land for ninety-nine years at a nominal rent, supplementing this later with the loan of valuable buildings; seven other States agreed to support the Institute, the Director of the Institute to continue the advisory services which for some time past had been at their disposal under Mr. Bernard Coventry, C.I.E.; in fact, the Institute arose out of that previous work.

Under these arrangements the financing of agricultural research passed away from Government and was undertaken by a commercial body, the moneys being obtained from the 'cess' or small tax on every bale of cotton leaving India. The Howards express approval of this principle as leaving more autonomy to any given research undertaking and as an answer to the reproach that in India and the Empire generally all work was carried on and paid for by official agency and not, as in Western countries, by autonomous bodies supported by independent benefactions, such independence allowing of far more intimate relations between research workers and the farming world and also encouraging easier and more rapid development than is possible under the strictness of bureaucratic control. (At the Indore institute the Government of India was so far interested in that the Agent to the Governor-General at Indore was *ex-officio* Chairman of the Board of Governors; the accounts of the Institute were also government-audited for the first few years, until Sir Albert obtained permission to substitute a commercial audit.) The point is noted because since that date the trend in the home countries has been entirely in the opposite direction, agricultural research now being government-sponsored and very definitely directed from above.

Work on planning and design was begun on 24th October 1924, but years of thought had preceded; the amount of care put into every detail by the Howards was tremendous; they were responsible for the whole lay-out. On 25th February 1925 actual construction started and a very beautiful set of buildings, both farm buildings and extensive laboratories, a library and a model village, were created, but it was characteristic not to wait for the completion of any material structure but to sow the first crop of cotton at once, in June of that year. Within the next three years eight more States joined in the scheme, bringing the total number of States interested to sixteen. The Institute was to include in its programme the training of post-graduate students and in general was to be 'an object lesson' for advance in the whole of that part of India; the authorities of the contributing States were to be able to 'see for themselves how their dominions could be developed'. Thus the guiding principle of the closest contact between research and those to be served was at once stressed; there was repudiation of the conventional isolation and withdrawal of research staff into the sacred precincts of some laboratory where none could follow; it was also at Indore, where Sir Albert was able, as an independent director, to follow the instincts of his own generous nature, that a most notable experiment in applying progressive principles in the management of Indian labour was worked out. It was, however, especially with a view to the interests of the higher staff that a site was chosen quite close to the city of Indore. The arguments have already been referred to which point out how great is the mistake which places the research worker away from an ordinary social centre; they need not therefore be repeated here.

Although the offers of the Central Cotton Committee and of the Indian States had been generous, money for buildings was somewhat limited; Sir Albert laments the lack of an extra half-lac of rupees for capital expenditure which would have provided thicker walls to keep down temperatures and wider verandas. The expense of director's quarters was saved, the old Residency being lent by the State for the purpose. The model village for some of the staff included also nine furnished quarters for visiting officers from the States and six for visiting cultivators; these were constantly occupied and were all part of the general idea of keeping in the closest possible touch with the people and showing the work to all who could be sent to see it. The farm buildings themselves were designed with the greatest care and proved completely successful; indeed, they became a model for various demonstration farms started by the contributing States. They were sited in the centre of the area.

> 'The advantage of having the farm and other buildings in the centre of the Experiment Station needs no emphasis, but the relative position of the laboratories and farm buildings required some consideration. It is most essential that the scientific and agricultural aspects of the work on crops should be as closely co-ordinated as possible. In all institutions of this nature a cleavage tends to develop and opposition between the staff employed on the two aspects of the work often arises. One of the tasks of the director is to weld these two aspects of one subject into a real working unit instead of a combination in name only. For this reason we wished to place both laboratories and farm buildings together. Several practical difficulties, however, intervened. The noise and dust inseparable from a farmyard are not conducive to quiet work. The presence of laboratories next to the farmyard is apt to discourage the purely agricultural visitor. Eventually the laboratories and farm buildings were arranged on opposite sides of the main road, the farm buildings being to windward.'

If it was an asset to start from the beginning and to design one's own buildings, the uncultivated state of the land was another matter. It was, of course, much to have 300 acres instead of the 75 at Pusa, which with the expansion of work over the years had proved altogether inadequate and hampering, to have twenty pair of oxen instead of six. Rut the land was in a very bad state, rough and undrained, one-third of it so badly waterlogged that it had been abandoned by cultivators, infested with an almost ineradicable weed, *kans,* and scored with erosion nullahs, due to run-off from the higher ground. Drains were laid on an Italian model to deal with the latter evil; then roads with bridges and culverts made, eventually to an extent of 20,062 feet, though the final area assigned to this work, together with buildings and all non-agricultural uses, was less than 5 percent of the total. With the making of the roads the opportunity was seized for a visual demonstration, for each road and area was grass-bordered, in the manner which had been so successful at Pusa; protected by their grass borders each field was separately shaped on a gentle slope rising in the middle to drain towards the edge. This work occupied a long time and was not finished until 1930. But the results at once aroused the keenest interest and officers of the States were eager to apply it to their villages. Only a very simple leveller was used, which could be drawn by a pair of oxen; the Indian peasant proved singularly capable of doing exact grading with the simplest means, his instinct and eye being the surest of guides. Not only was he thus directly benefited, but the system held other advantages.

> 'Besides increasing the yield of cotton and other crops, the provision of surface drainage is proving an important factor in removing the experimental error in variety trials and in other field tests. For some years it has been the custom to deal with the well-known experimental errors in field work by repeating the trials a number of times, and by subjecting the figures to mathematical treatment. The results of experiments, when carried out under such conditions, are not always visible to the eye but only emerge after the actual results have been freed from error. The defects of this method of testing varieties and new methods of agriculture in a country like India are obvious. As no very striking results can be detected by the eye, the work cannot possibly appeal to the unlettered cultivator. The repetition of the plots, necessary to eliminate errors, introduces a number of practical difficulties in the lay-out, in sowing the plots, and in harvesting and handling the crop. Unless the experimenter is a master of the mathematical principles and methods involved in the calculations, it is difficult for him to avoid a number of material fallacies while attempting to work out his results. In some respects the conventional remedy for dealing with experimental errors in field work is almost as bad as the disease itself. One difficulty merely leads to another. The question arises: Is it possible, by improving the surface drainage, to reduce the experimental error and to make the land yield more uniform crops? The results obtained during the last two years at Indore indicate that such a result is certain. A number of plots, on which at first the crops were exceedingly uneven, were taken in hand in 1927, and roughly graded. In a single year a marked improvement took place. Plot 1 is a good case in point. In the rains of 1927 this was sown with *sann* (*Crotalaria juncea* L.). The height of the crop varied from 9 inches to 56 inches. During the cold weather of 1927-8 the plot was roughly graded and then sown with ground-nuts. The results showed that the unevenness was very materially reduced. After the removal of the ground-nuts in October 1928, the grading of the plot has been improved and the surface drainage perfected. It will be sown with cotton in 1929, and the uniformity or otherwise of the field will be determined. The results already obtained on a number of plots at Indore point to the supreme importance of correct grading and good surface drainage on the black soils before any experimental work of any kind and before any variety trials are undertaken.'

Although the whole Station in the course of a very few years came to stand out from the neighbouring countryside 'like a green jewel', yet the self-denying resolution was taken to use no power other than what an ordinary well-to-do Indian cultivator could command. The small machines employed, levellers, threshers, fodder-cutters, and feed-grinders, could be worked either by a simple oil engine or by bullock power. (An exception was made for the machinery needed in the ginning factory; this was an essential part of the experimental work, but not part of any cultivator's duties.) This unusual decision at the outset put the Howards face to face with a severe problem -- the eradication of two most troublesome weeds, *kans* (*Saccharum spontaneum* L.) and *kunda* (*Ischaemum pilosum* Hack. Monogr.), but more especially of the first. *Kans* is a weed which has a terrific root system, thick underground rhizomes, which grows very rapidly in the rains and is capable of putting fields wholly out of cultivation; indeed, areas were not infrequently abandoned 'when *kans* was master'. This weed was rampant on the Experiment Station area when it was taken over in 1925.

How to deal with this pest, on the terms laid down, was a problem. The solution was found in an American ridging plough, from which the wings and sole were removed, which could be drawn by two pair of oxen abreast on a single yoke -- this concentration of power was found sufficient. The 'Kans Erradicating Outfit', as it was called, was exhibited at the Poona Agricultural Exhibition in October 1926; it attracted immediate attention, was improved, cheapened, and came to be one of the most successful initiatives launched from Indore. (An additional effect was that the deep cultivation bringing better soil areation so improved the crop of cotton that the plants made twice the ordinary growth.) It was sold to cultivators direct from the Station, together with a number of other simple improved appliances or tools. These had at first been obtained for Institute purposes, and no one had foreseen how instantly popular they would become by being used in front of visitors. The demand was such that the very unusual step was taken of setting up a separate trading account apart from the Institute budget, for the purchase and sale of implements. This commercial venture was financially successful.

Another harassing problem was surmounted in the feeding of cattle. The months of the hot weather see the cattle of India half-starved. During the first half-year even the Institute animals suffered. There was no green food for them at all and they had to subsist on an unsuitable diet of dried stuff. The solution was found in the following years in the growing of green fodder for silage, to be used during the dry months. The details of silaging the indigenous crop, *juar,* were perfected during the years 1927 and 1928, and it was further planned to teach the cultivators to grow lucerne. The way was led at the Institute itself, with the result that the cattle, which had had 'to be kept in the background', by 1927 were in such wonderful condition that they could be exhibited as type specimens of their breed and were in request for religious processions. In the course of two years these adult animals had been 'transformed', and Sir Albert asks the pertinent question as to what might not have been the results of similar treatment on younger beasts. In later years Sir Albert repeated his advocacy of silaging as the obvious remedy in all hot countries for dry-season shortage of grass.

Thus in every way the Institute was proving the thesis that no mere improvement of varieties of crops should suffice to fill the programme of the research worker in agricultural botany. Ten per cent of increased yield might perhaps be looked for from such variety work, but what was that when measured against 'the enormous increment made possible by better agricultural conditions'? All circumstances affecting the plant's growth and life history must be taken into account, nor was anything alien to the botanist's duties which bore on the final picture. Consonant with this was the determination to take up at Indore the study of the enemies of plants -- diseases and pests. It was at Indore that the idea became most clearly formulated which traced the arrival of a disease or pest as the final symptom of a breakdown in the plant's resistance due to adverse soil conditions. The following few words are illuminating as showing the wonderful standard of crop growing which had been achieved on this originally derelict land in the amazingly short space of four years.

> 'One difficulty, however, will have to be surmounted in these studies [of disease -- red leaf in cotton is mentioned]. As the lands of the Institute are brought into order and drained, the general health of the cotton crop is improving to such an extent that insect and other diseases are becoming very rare. It will be necessary to cultivate cotton on a portion of the area in the direction of disease rather than of health; otherwise these interesting investigations will come to an end for lack of material.'

The setting up of the Indore Institute undoubtedly profited from the long experience at Pusa and at Quetta; as Sir Albert states, this was not really the first, but the third, experimental botanical area which he had had to create. The key notes were two: the study of the whole crop within its environment, and the care and attention paid to the duty of conveying results to those to be served. The ideas appeared sufficiently novel to justify the writing of an account:, which appeared in 1929 under the title *The Application of Science to Crop Production.* The wide nature of the title betrays the hope that the Indore Institute would not remain the sole venture of its kind, but might lead to something like a reform in Experiment Station management, might indeed, in the words of Professor Engledow (now, Sir Frank Engledow), provide 'a rare and valuable guide for future undertakings'. (Review of the book mentioned in the text in *Nature*, 1924, 1929, p. 974.) It is doubtful whether this hope has ever been realized or whether enough attention has been given to what was so excellently conceived and planned.

Final Investigations on Composting and Retirement

The work planned at Indore was to have included, on a comprehensive scale, variety investigations in cotton similar to those so successful in wheat. These were started and some interesting results obtained. But time was running short. Sir Albert was already a pensioned official, although this did not deter him from continuing his work. Of greater moment was the fact that his wife's health necessitated treatment under European doctors. She had the work so greatly at heart that she could not contemplate relaxation, and was writing and planning new projects within a week or two of her death, which took place while on leave at Geneva in August 1930.

This severe blow brought the great partnership to an end. Though Sir Albert returned from Geneva to Indore and was pressed to continue his work he could not face the prospect. The future was indeed to prove that there would be years of strenuous endeavour in front of him, a period calling for at least as much vigour as the years in the East. But for the time being he could only wind up current affairs and hand on to a new Director.

It is to be attributed to his sense of duty to the peoples of India, a sense of duty which was straightforward, business-like, and unsentimental, that he should have made up his mind to complete one final task. This was the analysis and description of a problem which had been in the back of his mind for years.

The very success of the breeding of wheats had early raised the problem of whether the soils of India could stand the extra strain imposed by improved varieties of crops. Sir Albert's estimate has already been quoted: that a better variety of a crop might yield, say, 10 per cent of increase, but the better cultivation of that variety anything up to another 90 per cent. How was such better cultivation to be achieved in India where three-quarters of the cow-dung needed for raising soil fertility was being put to non-agricultural uses as fuel, etc.?

Sir Albert had for many years investigated the practices of green-manuring carried out by the Indian cultivators, but a further step was needed. It had always been a matter of simple observation, an experiment, as he says, repeated many thousand times over, to notice the intensely fertile belt round any Indian village, due to the depositing of night-soil, as contrasted with the much poorer fields beyond. This gave an obvious clue. He had intended to visit the Far East to study on the spot the age-old systems of soil replenishment -- the systems of composting -- practiced in China and Japan but not known in India. The World War, the effort of creating the Indore Institute, and other circumstances had intervened, but enough information was got together from various sources, F. H. King's famous book, *The Farmers of Forty Centuries*, proving a great inspiration. Previous experiments for the treatment of organic wastes had engaged his serious attention from time to time; at Indore he systematized the work and deputed Mr. Yeshwant Wad, a member of his staff, to handle the chemical side. The experiments were very thorough. The principles of composting are sometimes believed to have sprung complete out of Sir Albert's mind, like an Athene out of the head of Zeus, as it were by a sudden inspiration. The reverse is the case. The work was developed slowly and along with the experiments went a testing of results in the field. Eventually 1,000 carts of compost were being made at Indore each year, and the extraordinary fertility of the Experiment Station area was the visual proof of its value.

To convey this lesson to India became Sir Albert's last duty. With all the work of leaving the country, winding up an official appointment, and breaking up a household in front of him, without the ever-present help of his wife, Sir Albert could only make time by rising at four, or even three o'clock every morning at the cost of an extreme physical effort even for so strong a man: *The Waste Products of Agriculture: their Utilization as Humus* got itself written and was barely completed when the author took ship at Bombay in a state of such prostration as to alarm his cabin companion. This book, the subject-matter of which is discussed below in Chapter VI, came to be a valuable last gift of science to the peoples of India; the work of composting both town and village wastes in that country has since been initiated on a nation-wide scale by the Government of India under Dr. A. C. Acharya, D.Sc.

That it was destined also to become the starting point of a new outlook in world agriculture could not, at that time, have been foreseen. It will probably remain for many years one of the most signal and successful instances of the marriage of Western knowledge to Eastern wisdom. It was indeed a most fitting conclusion to so brilliant a career.

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Sir Albert Howard in India

By Louise E. Howard

Chapter 2
The Work on Wheat

The Problem

The first problem was wheat. This crop was the staple food of many of the peoples of India and was also exported, the amount exported constituting, however, only about one-tenth of the whole crop; nor did these exports rank high on world markets, Indian wheats being soft and white and greatly inferior to the strong Canadian and Australian wheats. The problem was therefore looked on almost entirely as one of improving the food supply of the country; from this point of view it was of extreme importance.

At the second annual meeting of the newly formed Board of Agriculture, held at the Pusa Research Institute in January 1906, Sir Albert Howard, as head of the Botanical Section, was asked to prepare an outline of future work which could apply to the whole of India. Barely four years after this first official assignment, in December 1909, the book entitled *Wheat in India* appeared. So much information had been collected and there was so much to say that publication was pushed on to fill 288 large-quarto pages, but the work undoubtedly suffers from having appeared before research was completed. That research was immensely stimulated when in 1910, as already described, the Howards doubled their efficiency and trained themselves in a new set of conditions, those of dry farming and irrigation, by transferring their residence each summer to the hot dry climate of Quetta in Baluchistan, where a second set of investigations was carried on. By 1924 no fewer than thirty-one papers (a few items were printed twice, once as Research Station Bulletins and again in the *Agricultural Journal of India*, so that the actual number of papers is less than 31) exclusively on wheat had appeared, some of a very elaborate nature, all based on original and prolonged experiments.

Possibly in view of these papers the investigators never proposed to themselves to sum up their final results on the same comprehensive scale as that in which they had set out the original problem: no second book appeared. However, a survey of work was presented to the Royal Society of Arts in 1920, while a rather longer *Bulletin* was published in 1928 after final surrender of the post at Pusa.

The work on wheat was not only outstanding on account of its results, but was of great importance to the Howards themselves. In the course of it they acquired their first fundamental conception of the agricultural needs of the East. It introduced them to problems of drainage, irrigation, and manuring, which had to be solved if progress was to be made. It proved to them that little was known of Indian agriculture, that what had been said was often wrong, and that plant breeding for Indian crops would have to start at the beginning with the huge task of sorting out a great confusion of varieties before any attempt at improvement could be made. It tempted them, very rightly, to merchandise their harvest and to seek a verdict in the severe competition of a Western world market; to go further and test final quality in the form of the baked loaf on the breakfast table, thus pursuing their product to the mouth of the consumer. Moreover, owing to the fact that wheat is a staple crop of the West as of the East, their researches kept them in intimate touch with scientific work along the same lines, especially with the Mendelian school at Cambridge, where some of the Pusa seed was grown on their behalf at the University farm. Finally, the extraordinary success of their efforts ensured their position as leaders in tropical agricultural work and was altogether heartening and encouraging.

The impression gained on reading of the first proposals made is one of great boldness and great assurance; comprehensive ideas are set out and are stated each and all to be necessary. These were embodied in the outline programme which Sir Albert Howard was asked to put before the Agricultural Board meeting of 1906, in which the following points were enunciated. It is stated that the researcher must acquire at first-hand experience of the growing of Indian wheats in the field: he must study the soils of India: he must make a careful survey of indigenous practices -- the antiquity of these was already inspiring Sir Albert with respect: he must take into consideration the prevalent habit of growing mixed varieties and of combining wheat with a legume: must aim at adaptability to very varying conditions of any new variety to be launched: must realize that such new variety would have to be easily distinguishable in the field by some one simple characteristic of colour or appearance: must secure that his crops should be free of rusts and other diseases: must not consider this task accomplished until he had dealt with storage of the grain: until he had followed its career both on home and on export markets: until he had seen it milled, baked, and had discovered the qualities of the actual loaf which was the end result of all his labours. Above all, the investigator must consider with whom and for whom he was working: he must take into consideration India and the peoples of India.

> 'The preliminary work to be done before the improvement of the Indian wheat crop can be effectively undertaken is very considerable. A wide outlook is essential at the outset. The general agricultural conditions of the various wheat tracts have to

> be studied in detail and experience of the actual growing of the crop has to be obtained at first-hand. The soils most suitable for wheat, the methods of irrigation and the agricultural practices in regard to cultivation, rotation of crops, harvesting and storage of the grain must be mastered. The needs of the local and export markets as well as the general trade conditions are matters of great moment as well as the diseases to which wheat is subject in India. These details are much more important than appear at first sight. The present condition of Indian agriculture is the heritage of experience handed down from time immemorial by a people little affected by the many changes in the government of the country. The present agricultural practices of India are worthy of respect, however strange and primitive they may appear to Western ideas. The attempt to improve Indian agriculture on Western lines appears to be a fundamental mistake. What is wanted is rather the application of Western scientific methods to the local conditions so as to improve Indian agriculture on its own lines.'

The Conditions

The need for studying the conditions of the country became even more obvious as the great range and variety of circumstances in which this crop had always been grown emerged.

> 'While considering the various agricultural practices concerned in the production of wheat in India, it is necessary to bear in mind the fact that there is a great range in climatic conditions in the various tracts in which this crop is grown. Wheat is cultivated from Quetta to Mandalay and from Peshawar to Coimbatore, and is moreover one of the most important crops in the Indo-Gangetic plain. In Baluchistan sowings take place in October and the crop is reaped in July, the young wheat being covered by snow in the winter as in northern Europe. In the Punjab the growth period is shorter and the crop is reaped in April and May. Passing eastwards down the Gangetic plain, the harvest becomes earlier until in Bihar the crop is ripe in March. On the black cotton soils in Peninsular India wheat ripens in February. While the harvest time, which depends on the onset of the hot weather, is earlier towards the east and south, there is very little range in the sowing period and the second half of October roughly represents the sowing time of most of the Indian wheat crop.
>
> 'The length of the growth period and the moisture conditions are the chief factors in the production of Indian wheat, and these materially influence the varieties grown and the practices of the various agricultural tracts. A comparison of the practices in vogue in the various wheat-growing regions reveals how often the smallest differences in procedure are closely bound up with differences in local conditions.'

How much there was to be learnt in this direction became clear when a review was made of the methods adopted in the course of centuries for fitting wheat into the general cropping schemes of the different regions.

> 'The principle of the rotation of crops is well understood in India and widely adopted in practice. Instead, however, of growing his crops in a definite order, the Indian cultivator usually grows them mixed, and this practice is well exemplified in the case of wheat. A considerable proportion is grown mixed with gram, barley, linseed, and mustard, and fields containing all five of these crops at the same time are commonly to be seen in Bihar.
>
> 'On the inundation canals in Sind the rotation is usually *juar* (*Sorghum vulgare*) or *bajra* (*Pennisetum typhoideum*) one year and wheat another, but in some cases wheat alone is grown. On the Jamrao canal the rotation is cotton one year and wheat the next with catch crops of *juar* and *bajra*. In all cases long fallows are given periodically.
>
> 'In the Punjab wheat is either grown alone or mixed with gram, barley, or mustard or with both gram and barley... In the south-western corner, in the Jhelum and Chenab river colonies and in the district of Rawalpindi the crop is generally grown unmixed as well as in the districts of the North-west Frontier Province... (In the United Provinces) in 1906-7 the area under wheat grown alone amounted to 5, 537,712 acres and that of wheat grown with gram and barley to 1,501,385 acres. There are two common mixtures in this province: (1) wheat-barley (*gujai*) frequently met with in the eastern half of the province where the two grains are harvested and threshed together and ground together into flour, and (2) wheat-gram (*birra*) which is common in the western districts and is the usual crop in Bundelkhund where water is not often available for irrigation and where it is risky to sow wheat by itself... In Bengal the practice of growing mixed crops is very common. Wheat is found mixed with barley, gram, peas, linseed, and rape... In the Central Provinces and Berar... on the black soils to which the wheat crop is practically confined, the common practice is to leave the land fallow during the *kharif* and sow wheat alone or wheat mixed with gram (called *birra*) for the *rabi*... The proportion of gram sown with wheat is not constant and varies in the different districts from about 5 to about 25 per cent of the crop... (In Bombay) the extent to which the wheat crop is grown mixed... is stated to be as follows: dry crop wheat is either grown alone or with subordinate rows of safflower; sometimes linseed occupies the headlands. Wheat and gram mixed are grown in the Panch Mahals. Irrigated wheat is usually unmixed.
>
> 'It will be seen that in all the important wheat-growing districts of India, except the irrigated districts of the Punjab, the practice of growing leguminous crops on wheat lands is universal. In this important matter, therefore, the Indian ryot has nothing to learn from Western practice.'

Fallowing and rotation were also relied on, rotation crops including maize, millet, cotton, tobacco, indigo, rice, sugar-cane, gram, gram with peas, pulses or a pulse-mixture. All the methods adopted, rotation, fallowing, and the growing of leguminous crops, were designed for one end -- to maintain the fertility of the soil so as to enable it to meet the demands of this nitrogen-consuming crop. Even an apparent exception was on examination found to conform to the general principle.

> 'In the canal colonies of the Punjab, however, wheat is grown year after year without manure, apparently without producing any diminution in the fertility of the soil. Judging from the dark green colour of the leaves and the general vegetative vigour of the crop, no nitrogenous manures are necessary. The question arises whence do the large wheat crops derive their nitrogenous manure? Apparently the answer is to be found in the leguminous weeds which thrive so luxuriantly as a bottom growth in the wheat fields of the Punjab.
>
> 'There are three common leguminous weeds among others in the Punjab wheat fields: (1) yellow-flowered *senji* (*Melilotus indica*), (2) white- flowered *senji* (*Melilotus alba*), and (3) a creeping clover-like plant with curious curved pods (*Medicago denticulata*). These three plants also grow and seed freely on the banks of the water channels, and are very probably distributed by the irrigation water. In the wheat-fields they ripen their seeds and dry up by the early part of April before the wheat is cut and thus give no trouble at harvest time. At flowering time in March their roots are covered with nodules. Their general vigour shows that they are admirably adapted for bottom growth with wheat.
>
> 'It would appear, therefore, that these weeds confer on the soil of some of the irrigated wheat lands of the Punjab all the benefits of a leguminous rotation and supply the nitrogenous manure required by the wheat crop. In this respect the wheat growers of the Punjab seem to be especially favoured by circumstances as they are able to obtain all the benefits of leguminous crops without the diminution of wheat output entailed in the usual rotations practised on wheat lands in other parts of India. No difficulty would be experienced in obtaining seeds of these leguminous plants. They grow and seed freely among the wheat, in waste places and on the banks of the water channels. Yellow-flowered *senji* mixed with the other two weeds is grown as a cold weather fodder crop in the Punjab and is sometimes left to ripen for seed purposes.'

This striking instance of the role which weeds can play in keeping up soil fertility can be cited as an illustration of very recent ideas on the subject of weeds, which, it is argued, should be allowed to play their own part in our general cultivation schemes (F. C. King, *The Weed Problem*, Faber & Faber, 1951); once again the tradition of the East links up with modern Western knowledge. Sir Albert Howard noted the facts and grasped their general significance. They evidently struck him, for he refers to them again in later life; he must have stored them in his mind as among the many varying aspects of the nitrogen problem.

There can be no doubt that this most thorough survey of Indian practices in wheat growing formed an excellent starting-point for experimental work. But what is most striking is the attitude of mind of the investigator, so careful to note every item in the local practices and consider their bearing. Not in the case of every crop was Sir Albert so respectful of what the Indian cultivators had achieved. As there will be occasion to state in a subsequent chapter, when it came to a survey of Indian fruit growing, or even of indigo, he was a severe critic. But wheat had been grown in India for more than two thousand years; it was a crop essential to existence, every grain of value: the practices of the Indian peasants were the result of generations of hard experience, and though it was to be hoped, and in the event justly hoped, that science could add a great deal, yet the first essential was to understand and appreciate the teachings of these centuries of effort.

In spite of the enormous extent of this crop, valued above all other food crops where it could be cultivated, it was not really easy to grow wheat in India. There was a very great limiting factor in the shortness of the time both for sowing and again for harvest, two separate risks which had to be faced. This the cultivator knew very well.

> 'The restricted supply of soil moisture and the short period of growth make it impossible to cultivate high yielding types. The concentration of the monsoon rainfall into a period of between three and four months limits the growth-period of the crops cultivated. Only rapidly maturing varieties can be grown in the rains. Such varieties must of necessity be low yielders. In the cold season, when crops are raised either on irrigation or on moisture stored in the subsoil, the temperature factor limits the growth-period and the choice is again restricted to rapidly maturing types. Both monsoon and cold weather crops, therefore, have one feature in common -- early maturity and low potential yielding power.'
>
> 'Cultivators... often sow too early and also favour the cultivation of varieties which ripen on the late side. These tendencies are probably the result of poverty and of the temptation to strive after the maximum crop. In favourable seasons they are successful, but... to some extent wheat growing in India is a gamble in temperature.'

Finally, the wheat had to be harvested and stored. But there was no machinery and few buildings. The methods were perforce in a category utterly different from those employed in Western agriculture. Once again the investigator's judgment is curiously sympathetic. He seems to have had from the outset a rare faculty for putting himself in the place of the peasant without sacrificing his trained scientific point of view.

> 'The methods employed in India in the harvesting and threshing of the wheat crop and in the storage of the produce may appear very primitive at first sight, but they

are simple and efficient if the means of the cultivators and the average size of the holdings are borne in mind.

'In the Punjab, North-west Frontier and Sind harvest begins about the middle of April and extends well into May, except in the Frontier districts where it is not over till the end of June. The grain is cut by hand by means of a sickle, the workers usually squatting on the ground. Large bundles are made so that they may be readily counted and are usually stacked roughly for threshing. (In Sialkot the district authorities require the stacks to be made close together to prevent the cultivators wilfully setting fire to each other's wheat.) The extreme dryness of the straw makes this possible and no loss is suffered by the wheat in the bundles heating. Indeed, so dry and brittle is the straw that the straw bands for tying have to be soaked in water to make them tough enough for the purpose. The labourers are paid usually in kind, but in the Canal colonies where labour is scarce, as much as 16 annas a day is paid for hired labour. The scarcity of labour and the large holdings in the Canal colonies have had a marked effect on the choice of the variety of wheat grown. Bearded wheat is generally grown in preference to beardless, as this kind is less liable to the depredations of birds and sheds its grain less easily, thus suffering less damage if it remains standing in the field.

'The grain is generally trodden out by the feet of cattle assisted by the *phala* or threshing frame. This frame consists of a hurdle covered with brushwood and weighted with bricks or clods of earth. The bullocks are yoked to the *phala* and fastened to a post in the centre of the threshing floor of beaten earth. They are driven round and round the stake about which the wheat is heaped and in a short time the brittle straw is broken up into short pieces and the grain is freed from the chaff. One pair of bullocks with the *phala* will tread out the produce of an acre in four days. In the hills, where stones are available, the threshing floors are carefully paved, but in the plains they are always of earth. The grain is separated from the chaff by being thrown into the air by a pitch-fork when the hot winds which prevail at this time carry the dry chaff to a distance while the grain falls back on the threshing floor. The winnowing basket (*chhai*) is then used to clean the grain so obtained. Its use is almost universal except in Rawalpindi where the *phio* -- a flat spade-like instrument -- is used. Winnowing is done by low-caste workmen, rarely by the cultivators themselves, who in some cases would prefer to see their grain destroyed by rain rather than winnow it themselves. The chaff (*bhusa*) is used for fodder and is especially valuable when mixed with gram chaff when it is known as *missa*. When grown with gram, the two plants are threshed together and the resulting grains are often ground and eaten together.

'The yield naturally varies according to the season and other conditions, so that an average produce estimate is difficult. On well lands about 10 to 14 maunds per acre is obtained; on Canal lands the yield is somewhat less, while on *sailaba* lands (land inundated by the rise of a river) 8 maunds and on *barani* (land dependent on rain)

> soils about 6 maunds to the acre are obtained. In Sind the average yield is stated to be 10 maunds to the acre.
>
> 'Wheat is stored in the houses of the cultivators as a rule, but the old practice of keeping it in pits is still in vogue in some of the districts. The pits are lined with wheat chaff, but after about a year grain so kept is apt to darken and deteriorate. For household use the grain is kept in large earthen jars (*bharolas*). The well-to-do cultivators have granaries of mud or even of brick in some districts. After the monsoon the wheat is sunned and dried as a protection against weevils which, however, in the Punjab are not serious pests.'

Methods in the United Provinces, Bengal, the Central Provinces and Berar, and in Bombay are briefly described as very similar.

The Sorting Out of Varieties

Wheat was so important in India that it would have been strange if there had been no previous investigations. These, however, had been misdirected and for that reason had been unsuccessful.

> 'The majority of the experiments carried out in the past have been devoted to the effect of manures. Considering the smallness of the holdings, the means of the cultivators, and the scarcity of manure, especially of artificial manures, it is likely that any lessons to be learned from long and elaborate manurial experiments must remain, for many years to come, mere counsels of perfection. There are, however, other directions in which much important work may be done, for example, experiments on the conservation of soil moisture, on the most efficient methods of cultivation, and on the water requirements of wheat would probably yield important and interesting results.'

An obvious first duty was an examination of existing types of Indian wheats and their improvement by plant breeding. Previous investigations on this point had been desultory and local and had committed the unpardonable error of trying to solve the situation by a short cut, namely, by the introduction of foreign varieties. These had proved a complete failure. Much more fundamental work was required. The only way to master the situation was to examine, review, and classify all the wheats of India, a colossal task.

> 'The botanical survey of the wheats of India is not without interest apart from its importance in the improvement of the wheat crop. The wheats at present in cultivation in this vast Empire, in which a civilized agriculture has been practiced from time immemorial, represent the survival of types most fitted for the conditions of the various tracts. Nature has eliminated the unfit, and the experience

> of past centuries, handed down by tradition, has taught the cultivator what soils and what tracts are most suitable for this crop. Varieties of wheat introduced by sea from Western countries have, in recent times at any rate, had no influence on the crop and have not been adopted by the cultivators. No new forms have been introduced by selection or hybridization as has been done in Europe and America. It will be more than interesting therefore to find what has resulted under such conditions and how the characters and grain qualities of the Indian wheats compare with those of Europe and America.'

It was practically an uncharted field, and meant sorting out a chaotic confusion of types, in part cross-fertilized, and grown under all sorts of different conditions in this vast country. (Cross-fertilization of wheat in India is frequently mentioned by Sir Albert Howard. Other workers do not appear to have noted it and have attributed the confusion of varieties to initial mixed sowings.) In the course of the intensive examination undertaken, involving thousands of specimens, a mass of data on the inheritance of characters was arrived at, covering such points as bearding, grain colour, felting, grain consistency, and shattering of the ear. These data were embodied in three long and elaborate papers, which were a contribution to botanical knowledge of obvious scope and importance. Research on plant breeding has since then advanced out of all knowledge; there would be little point in conveying the botanical bearing of what was discovered in these years. The reader is therefore asked to take this work for granted or to consult the papers in the original. (The same applies to the long botanical monographs on tobacco, fibres, and some other crops.) The present section will concentrate on conveying the practical results of what was achieved in a little investigated field. The lesson lies precisely in this -- that a problem which had baffled many workers by reason of its utter confusion and vastness was rapidly solved by the exercise of exact knowledge, good judgment, and very great and strenuous industry. None of the infinite labour of this kind of work was shirked in a climate where outdoor operation has its own inconveniences for a European. Here the partnership between husband and wife, each at the height of their powers in these early years, proved its exceeding value. Wearing a topee and with a double-lined sunshade held over her head Gabrielle Howard continued to carry out the minutiae of the cross-fertilization and similar work; Sir Albert has left it on record that she was a veritable mistress of this kind of detailed labour, and also that she was a genius at training Indian workers to assist her and obtained from them a co-operation which surpassed even what he himself was able to evoke. The difficulties were not lessened by the fact that the classification of wheats in other parts of the world was a disputed matter. Several rival systems existed, German, French, American, or Australian, based on widely different principles. After careful consideration of all this work the Howards came to the conclusion that there was nothing for it but to proceed to their own classification of the wheats of India. The results occupy sixty pages of botanical definition in *Wheat in India.*

> 'Owing to the very mixed character of the Indian wheat crop, as ordinarily grown, the first step in improvement was a botanical survey of the varieties already in

> cultivation. Samples of seeds from the chief wheat-growing areas were sown and the results observed in 1906 and succeeding years. The wheats of the Punjab were studied separately at Lyallpur and a number of unit species were isolated between 1906 and 1909.
>
> 'Nearly forty different botanical varieties were found in the Indian wheat crop. Ten of these belong to the macaroni wheats (*Triticum duram* Desf.), six to the group of dwarf wheats (*T. compactum* Host.); there is one variety of Emmer (*T. dicoccum* Schrk.) and nineteen varieties of bread wheat (*T. vulgare* Vill.). No spelt wheats were found...
>
> 'Subsequently the wheats of Baluchistan were examined and classified. Interesting forms, intermediate between *T. turgidum* L. and *T. vulgare* Vill. were found, but nothing of economic importance emerged. In 1922 the classification of the wheats of Bihar was carried out as far as the unit species. Very interesting and valuable types were found in this series ...
>
> 'These preliminary studies led to isolation of large numbers of varieties and of unit species which formed the basis for subsequent work. Some of the unit species found were distinctly superior in general vigour and yielding power to the mixtures ordinarily grown.'

This, however, was only the beginning of the work. Each botanical variety was liable to be composed of several types. It is important to grasp what is meant by this term, and the following passage explains this, under the title 'The Constitution of a Wheat Field'.

> 'An examination of an ordinary wheat field in India at harvest time discloses the fact that the crop consists of a mixture of botanically different varieties sometimes belonging to two or three sub-species. These botanical varieties can be readily distinguished from each other by an examination of ripe ears. The variety represents the lowest limits to which wheats can be divided in the laboratory with precision and is, as it were, the botanical unit of the species or sub-species. Each variety may, however, compose several agriculturally distinct types. Such types, while botanically identical, differ in field characters, such as length and strength of straw, earliness or lateness, tone of colour of chaff and straw, erectness of the ear and susceptibility to rust. These differences between types can only be readily distinguished in the field in plots grown side by side. The types are the agricultural units of the variety in a similar manner as the varieties are the botanical units of the species or sub-species.
>
> 'The type itself, however, is formed of an assemblage of individuals which may differ from each other to a very slight extent. Such an assemblage of individuals is termed a population and forms the raw material, as it were, of the selectionist. If individual plants of this population are selected and grown separately, their

> progenies are termed pure lines... The mean values of any particular character such as yield may differ, however, in the various pure lines composing a population, and it is on these differences that the possibility of any improvement by selection depends.'

The upshot of this survey of wheats was, in fact, to prove that it was not enough to identify a botanical variety. What would satisfy the systematic botanist would carry the agricultural experimenter only a little way: his true work began where the other left off. This point is insisted on and is the explanation of why the growing of crops in the field is so earnestly advocated.

The differences between agricultural types only emerges when crops are grown in the large. Then the details mass themselves together and can be picked out by the eye; they usually consist of very trifling nuances of colour, shape, and stand, but they are unmistakable and a sure guide to the plant breeder. Thus in a curious way the delicacy of judgment of the practical investigator has to surpass even that of the worker in the laboratory; but it is based on rather different means.

The Breeding of the New Wheats

The new Indian wheats, known as the Pusa wheats, were perhaps the greatest practical achievement of the Howards. Some fifty named varieties were eventually produced by brilliant and sustained work. Even these were the result of severely imposed restriction of choice. It was, indeed, a matter of great judgment to use the vast material to the best advantage. Faced by the unlimited possibilities in front of them the investigators had decided at an early date 'to concentrate from the beginning on the best only', and their advice on this point is insistent.

> 'As a result of twenty years' experience we are convinced that in plant breeding for economic purposes the more rigid the selection in the early stages of the work the better. It was invariably found that whenever a doubtful case was carried on to the next generation it was rejected. The only result of this caution was a loss of time and of labour. The amount of land available for cultures and the shortness of the working period between the harvest and the rains made it essential to reject everything except the very best. Any attempt to carry on too much material is more a hindrance than a help. Experience showed that the only profitable and possible procedure was to concentrate from the beginning on the best only.'

The methods open to the investigators were, first, selection and, then, hybridization by cross-fertilization. Selection included both isolation of an existing good agricultural type in the mass and also the creation of a new type by breeding from a single chosen plant of promise; thus this word covers two distinct operations.

The first results were encouraging. It became clear that Indian wheats existed of a quality which had been entirely overlooked. It did not seem that the softness which had so told against them was their essential characteristic.

> 'We do not yet know with anything approaching precision the value of the wheats indigenous to India, for the simple reason that but few of these have as yet been isolated in pure culture and grown on a sufficient scale for their agricultural and milling qualities to be determined. From the results obtained by us at Pusa and in the Punjab it has been shown that there are wheats now in India very much more valuable both for local use and for export than any of the soft white sorts like Muzaffarnagar and the *Desi Pissi* of the Narbada Valley or Buxar soft white, which have been so much recommended to notice of cultivators.'

The emphasis laid by previous investigators on the introduction of foreign varieties appeared to have been unnecessary and mistaken. There was far more to be gained by concentrating on native types, which, as the Howards realized, had had a history of several thousand years and had become adapted to the conditions of the country. (But see Note by Dr. H. Martin-Leake at the end of this chapter.) There was here material of great promise.

> 'The extension of the cultivation of Indian varieties of wheat and their introduction into new localities have yielded results of some value, which stand out in strong contrast to the failure of the imported kinds. The results in this direction are not only important in themselves but also serve to indicate the direction in which still better results are likely to be obtained in the future.'

At Pusa four varieties were at first isolated, namely, Pusa 20, 21 22, and 23; of these Pusa 22 proved the most useful and subsequently gave rise to superior hybrids, but all four were later discarded for various reasons. At Lyallpur in the Punjab twenty-five agricultural types were isolated. Although none of these were of a really high quality, one, Punjab 11, a white bearded wheat with red chaff, was adopted for distribution on account of its qualities. By 1923 the area under it amounted to 750,000 acres.

The work rapidly proceeded to selection properly so called, namely, to the breeding of new varieties from single chosen plants of outstanding merit (pure lines). This work was at that time comparatively new. The Howards threw themselves into it with ardour, realizing that opportunities were before them which had not been available to previous investigators.

> 'In considering the attempts which have, till recently, been made in India to improve the wheat crop by selection, it must be borne in mind that at the time the work was done, the modern methods of selection were not generally understood even in Europe... In 1906, both at Pusa and Lyallpur, we commenced a system of

> selection from single plants which is being continued. In both cases the separation of forms and of pure lines was successfully accomplished... The use of this method of selection in India has already enabled us to produce several wheats of much greater value than the mixtures now in cultivation.'

The results were, in fact, outstanding and the best series of Pusa wheats were rapidly and permanently established.

> 'Besides these forms (Pusa 20 21, 22, and 23 referred to above as obtained by isolation), a number of new wheats were obtained by selection methods. They were derived from single plants of outstanding merit found in the mass of samples grown at Pusa in 1905. These new wheats, in all probability, arose either by natural cross-fertilization or as admixtures in some of the exotic wheats introduced at various times by government farms. In many cases the original plants selected proved to be crosses and it was from the progeny that the final selections were made. Pusa 4 and Pusa 12 arose in this way.
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> 'One of the first of the wheats obtained by selection was Pusa 6. This variety possesses a small greyish grain of a much higher quality than any of the ordinary Indian types. In spite of this fact and the possession of a high degree of rust resistance it has not been introduced into general cultivation. It has two great weaknesses -- poor standing power and a tendency to drop its grain. Pusa 6, however, has proved to be of the greatest value in hybridization. The good qualities of its grain and its resistance to rust are readily transmitted to the offspring. In countries where the wheat crop does not stand so long in the field after ripening as in India, Pusa 6 has done well and a good deal of seed has been sent to South Africa during the last ten years. In 1923 a request for 2,250 lb. was received from Portuguese Africa, but only a portion could be supplied.
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> 'A large number of other promising wheats were obtained from the cultures of 1906. The best of these from the agricultural standpoint were Pusa 1, Pusa 3, Pusa 6a, Pusa 7, Pusa 8, Pusa 10, Pusa 11, and Pusa 12... As a result of the preliminary trials carried out in Bihar Pusa 7, Pusa 8, and Pusa 12 were tested on a large scale -- Pusa 7 in Bihar and the Central Provinces, Pusa 8 and Pusa 12 all over India. Pusa 7 was distributed for a time in the Central Provinces, but was ultimately discarded in favour of one of the new hybrids. Pusa 8 was eventually given up in favour of Pusa 12.
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> 'Pusa 12 has proved to be the most successful of all the early Pusa selections on account of its great adaptability and high yielding power. It has a large berry of an intermediate texture, while its bright red chaff makes it easy to recognize in the field. Distribution on a large scale is being carried out in the United Provinces, the Simla Hill States, the Eastern Punjab, Sind, and some of the Rajputana States.

> Yields as high as 37.5 maunds to the acre have been obtained. This wheat is also doing well in the Argentine.'

There follows the story of the famous Pusa 4, again best told in the words of the original account. This wheat rivalled and then surpassed even Pusa 12 in popularity.

> 'Pusa 4, obtained by selection from a heterozygote shortly after Pusa 12, is perhaps the best of the Pusa wheats as far as grain characters are concerned. It possesses a strong straw and a large, translucent white grain of very fine appearance. It is a rapidly maturing variety, is immune to yellow rust and is very suitable for tracts where an early wheat is required... Pusa 4 has proved very suitable for certain tracts in India, notably Bihar, Bundelkhund, the North-west Frontier Province and Gujerat. When well grown the grain has a very fine appearance and has been awarded the first prize for hard wheats in Australia. In the report of the judges of the Royal Agricultural Show held at Sydney, Australia, in March 1920 this wheat was referred to as follows: "A sample of the Indian wheat, Pusa 4, exhibited by Mr. W. H. Scholtz of Gilgandra, is worthy of mention. It yielded a percentage of excellent colour flour of 53 quarts to the sack strength, which was the highest water absorption of all the flours tested in the competition. In the exhibit of strong wheats Mr. Scholtz again stood first with an exhibit of Pusa 4, an achievement for Indian wheat, and in the class for five strong flour varieties Mr. Scholtz also stood first, two of the five being Pusa 4 and Pusa 107." Pusa 4 is now well established in Australia and is being regularly distributed by the Queensland Agricultural Department. The Agricultural Department of Rhodesia also reports that this variety is doing well. In India the grain is much appreciated for local consumption and is often used on ceremonial and festive occasions.'

The third method of arriving at an improved variety was to be by cross-fertilization. The Howards were well aware of the difficulties of this task. The start was in any case from a crop already partly cross-fertilized, a process which had been going on for many centuries in India, the result of which was seen in the innumerable varieties growing in the fields of the ryots. While it was very possible that this spontaneous crossing was the natural means of keeping up the vigour of the crop, which without it might have degenerated slowly (*Wheat in India*, pp. 139-40), yet the first necessity was, so to say, to undo all this natural process in order to arrive at pure lines. This was bound to be a complicated business.

> 'In carrying out cross-fertilization work in India the necessity of first growing and studying the parents in pure lines cannot be too strongly emphasized. It is necessary to grow the parents from single plants and to first determine all their characters both botanical, field, and physiological. Crossing botanical varieties is a very dangerous and unscientific proceeding as the botanical variety, in India especially, is complex and often consist of a large number of wheats differing in field characters, rust-resistance and in the quality of the grain.'

Under any circumstances the production of a superior type of wheat by hybridization must be a costly and laborious business; Sir Albert estimated that in India it could not possibly be done under five years as a minimum period. Not only was it necessary to have a large armoury of pure lines, got by careful selection, but it was also necessary to know how these pure lines were likely to behave as parents.

> 'Many of the characters of agricultural importance are not simple unit characters, but are combinations which readily break up on hybridization. This means that an enormous number of plants must be handled before a new hybrid combining all the desirable characters can be obtained. Further, the various types of wheat used as parents disclose very great differences in their power of transmitting their grain characters. Certain wheats can always be relied on to transmit some desirable character unimpaired. With others, the desirable characters break up on hybridization and the chances of recapturing them intact in later generations are small.'

The investigators had to have definite aims. These were what they themselves formulated; throughout this work the standards had to be self-imposed.

> 'In order to select effectively in the F2 and succeeding generations it was found necessary to adopt a definite policy as to which characters are essential and which are desirable. The following standards were therefore maintained: (1) the characters *essential* for an improved wheat are vigour, high-yielding power, strong straw and good rooting power, rust resistance, smooth chaff, white translucent grain equal in quality to that of the better parent employed, ability to hold the grain; (2) the *desirable* characters are: some attribute such as red chaff or the peculiar shape of the ear by which the variety can be readily distinguished in the field.'

There was a temptation to lose oneself in the innumerable possibilities of the work. It was at this point that the field method of sowing in the large became a corrective.

> 'In the third and succeeding generations the seed of the best selected single plants was always sown in small rectangular blocks next to next. These small plots were then periodically compared in the field by eye as regards vigour, standing power, and rust resistance. As a rule, this was repeated three or four times during the growing period and careful records made. The most promising plots were then marked and the single plants for the next generation were selected from these plots only. The rest were rejected.
>
> 'For successful distribution to cultivators it must always be remembered that a

> wheat must be a vigorous grower and yield well, otherwise the cultivator will never adopt it. It is therefore better to select in the field for such agricultural qualities and to examine the plants which survive for finer points in the laboratory afterwards. If the reverse procedure is adopted there is a tendency to forget the need of filling the villager's cart.'

The crossing of wheats was begun in 1906. The first trials were made on a wheat of northern India, Muzaffarnagar, a bearded variety of high yielding power; the grain was, however, soft and weak. Two early crosses in 1906 with Pusa 22 and Pusa 6 gave two successful hybrids, Pusa l00 and 101; these retained the high yielding qualities of the Muzaffarnagar. But the straw of Pusa 101 proved not strong enough to support the heavy-ears and this variety was eventually superseded by the favourite Pusa 4. Pusa 100 was found to suit the conditions in certain parts of the Central Provinces, twenty years later it was reported as still holding pride of place and as averaging nearly 70 per cent more than the native *kathia.*

A second series of crosses from Muzaffarnagar resulted in 'a very fine series of wheats', Pusa 104, 105, 106, 107, 108, 110. Pusa 104 and 107 were some of the best-looking wheats ever bred at Pusa, and when sent to Australia became exhibition wheats, Pusa 107 , as already mentioned, taking first prize at the Royal Agricultural Show at Sydney, being the only wheat to obtain the maximum number of points. In India, however, these wheats proved less useful than some other varieties.

Another successful hybrid was Pusa 80, sometimes known as P80-5, obtained by crossing Pusa 4 with Pusa 6, the object being to get a very strong-strawed white wheat for Bihar. This crossing had the effect of combining the outstanding grain qualities of Pusa 4 with the good growing qualities of Pusa 6, and gave very successful yields in the locality for which it was destined.

In other localities there was a demand for bearded wheats.

> 'In certain parts of the Terai in those tracts where ravines are frequent, wheat suffers much from damage by wild pigs and birds. Further, where labour is scarce the wheat crop has to remain standing for a long time after it is ripe. Under such circumstances there is a tendency for most beardless wheats to lose a certain amount of grain. The cultivators claim that such losses are reduced if bearded wheats are grown. There is no doubt that the beard is a protection against damage by animals, although the prevention of grain shedding through the presence of awns is open to question. The cross Pusa 6 = Punjab type 9 was therefore made, with the definite object of providing such districts with bearded wheats of the same quality and yielding power as Pusa 4 and Pusa 12... Owing to the occurrence of the 15.1 ratio in two of the desired characters and to the fact that nothing less than a very high yield and high grain quality would serve any useful purpose, the time

> taken in working through the cross was above the average. Eventually, however, ten wheats, Pusa 50 to Pusa 59, combining the desired characters were fixed.'

Finally, for all wheats, whether selected or cross-bred, what is described as 'a very rigid selection for grain characters' was carried out in the laboratory. On the results, after cultivation had been tested both on a large and a small scale, the chosen varieties were sent to the Provinces to be tried out under varying conditions. Simultaneously, in order not to lose time, samples were sent to England for milling and baking. Reference to this is made in the last section of this chapter.

The whole work may be reckoned to have taken some ten or twelve years, the most spectacular triumphs arising from some of the early selection work, above all, from the breeding of Pusa 4 and Pusa 12.

The Problem of Rust

Cross-breeding was, however, of great importance in one direction, the finding of varieties resistant to rust. Indian wheat was generally healthy. Perhaps natural cross-fertilization over several thousand years in the ryot's wheat fields had kept it from degeneration; as already stated, Sir Albert Howard had surmised as much, and modern opinion might bear him out.

But Indian wheat was far from immune to rust. It may be a surprise to learn of the extent to which this crop suffered from this particular evil in view of Sir Albert's later statements that Eastern peasant agriculture is an agriculture free of disease. Sir Albert never placed Indian agriculture -- greatly as he admired it -- in the top rank alongside Chinese or Japanese agriculture; there was also that lack of manure. But in the case of wheat there was a special explanation, namely, in the influence of the zonal conditions. Crops, in order to be inherently resistant, must not only be well grown but must be grown in the right place or area. Now wheat is a cold country crop and is on the verge of not being possible in India. The peoples' need for this excellent grain accounts for its wide distribution, but such distribution was inevitably exposed to risks, as proved by the ancient existence of rusts.

> 'Rusts are the most important diseases of wheat in India. Indeed, the damage caused every year by these diseases far exceeds that resulting from all the other wheat pests put together. In this respect India is no exception to the other wheat-growing tracts of the world, and the rust problem is as great a question here as in the United States, Europe, and Australia...
>
> 'In India the ravages of rust vary greatly from year to year, and it is obvious that anything like an accurate estimate of the annual loss is impossible. Further, the damage done in the great wheat-growing tracts of the North-west is generally

> slight, while in Bombay, the Central Provinces, and in parts of the United Provinces and Bengal the crop may be reduced 50 per cent or even more... Rust is by no means a modern occurrence in the wheat fields of India. Sleeman, in 1839, speaking of rust in the Central Provinces, wrote: "I have seen rich sheets of uninterrupted wheat cultivation for twenty miles by ten in the valley of the Narbudda so entirely destroyed by this disease that the people would not go to the cost of gathering one field in four," and further: "I believe that the total amount of the wheat gathered in the harvest of 1827 in the district of Jubbulpore was not equal to the total quantity of seed that had been sown."
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> 'In 1883 the subject received attention from the Government of India. A paper dealing with wheat rust by Carruthers was reprinted and circulated widely in India... The first investigation of rusts in India, including those on wheat, was made by Barclay... a general account of Barclay's work... was published in 1895. A more extended investigation of wheat rust was made by Cunningham and Prain at the instance of the Government of India... The great importance of rust-resistant wheats for Indian conditions was recognized by Prain and referred to... as follows: "Practically the only hope for India in combating rust in wheat is to adopt the method of selecting from among the various kinds of wheat those that show themselves little liable to rust. For, while probably no wheat is absolutely immune, it is a recognized fact that in certain areas particular wheats are relatively proof against rust. By a system of cross-breeding with kinds valuable on other accounts, new kinds can be made that will combine these qualities with the character of resistance to rust." '

The really arresting fact is that this major project of the wheat investigations was started in a locality particularly unfavourable to wheat. Pusa, with its damp climate, was the last place to be chosen for such work. But, as the Howards argued, there was this to be gained: any variety that would stand up to the unfavourable Pusa conditions could be guaranteed to do well elsewhere.

> 'Pusa is not an ideal site for work on wheat, as the Institute is situated in a tract where rice is the most important crop and where the general humidity in the cold season is much higher than in the great wheat-growing areas of North-west India. In the early years particularly the general dampness of the locality interfered with the experiments. Two of the three rusts which occur in India, namely, orange rust (*Puccinia triticina* Eriks.) and black rust (*P. graminis* Pers.), caused an enormous amount of damage and frequently prevented many of the varieties from setting seed. Yellow rust (*P. glumarum* Eriks. and Henn.) also appeared in years when the temperature was below the normal. The handicap imposed by the environment ultimately proved to be not altogether a disadvantage. A large number of rust-liable varieties were automatically eliminated. A detailed study of rust-resistance had to be undertaken and a good deal of time was devoted to the relation between the

incidence of disease and soil management. Besides providing ideal conditions for rust attacks, the high humidity also adversely affected the standing power. Circumstances therefore assisted in carrying out one of the most difficult duties of the plant breeder, namely, the rigorous elimination of unpromising material. Any varieties which did well under the unfavourable conditions of Pusa were almost certain to stand out when transferred to more suitable localities.'

Was rust caused by weather? Everybody thought so, but there was a complete absence of agreement as to what sort of weather would bring on rust.

> 'In reviewing all that is known on this aspect of the rust question [ways in which rust is carried on from season to season] we are struck by the remarkable unanimity expressed among practical men as to the great influence which weather has on the amount of damage done by rust. The most diverse statements are, however, to be found as to the particular kind of weather which is responsible for the spread of the disease. This is true, not only of India, but also of all countries where the rust problem has been discussed. Indeed, on the burning question of the conditions most favourable to the spread of rust, the reports of Australian Conferences (1890-6) may be said to be a mass of contradictions...
>
> 'In general, the most widely accepted view is that long continued rain or cloudy weather in January or February gives rise to those conditions [in India] under which rust spreads with greatest rapidity. The opinion is also met with that rust sometimes follows an excessively wet seed bed in October (in places where the sowing rains have been abnormally great), and is also caused by over-irrigation. Occasionally, however, instances occur where rust appears early in the season on land where there has been no wet and cloudy weather and when the sowing rains have either failed altogether or have been very deficient. Such an example has been observed by us on the Pusa farm during the autumn of 1906. The field in question was sown with various varieties of wheat, including the local kind, on October 15th and 16th. The September rains were scanty and no rain fell during October, November, and December. The seed bed was distinctly dry and the crop very thin and the plants very spindly in appearance. The first ears appeared on the edges of two of the plots during the last weeks in November, and the first signs of rust appeared on the edges of two of the plots during the last week in November. By the end of December it had spread all over the plots, which were at that time very yellow and sickly in appearance. Here we have an example of the spread of rust on thinly sown wheat in the entire absence of rain and of cloudy weather and when the crop was growing in a distinctly dry seed bed. On the other hand, the same varieties were grown by us in another part of the Pusa estate under irrigation where a normal crop was produced. No rust had made its appearance on these plots at the time of writing (December 31st 1906), five weeks after the time when rust was first noticed on the farm.'

What, then, was the explanation of this extraordinary confusion of facts and of opinions? In the following significant passage, which, it must be remembered, dates back to 1909 , the whole later Howard theory of disease-resistance is set out. It is astonishing to find the main points so decisively and clearly expressed and all the apparently contradictory aspects reduced to such simple and convincing explanations.

> 'It has occurred to us that, in considering the effects of the various weather conditions on rust attacks, it is very easy to lose sight of one of the main factors in the case, namely, the plant itself. It is usual to regard the matter as concerning only the fungus and the influence of the weather on the spread of the disease. It is most important, however, that the question should not be regarded from too narrow a standpoint.
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> 'Three main factors have to be borne in mind, namely, the wheat plant, the rust fungus, and the influence of external conditions on both. The chief external conditions are: the amount of moisture in the soil, the humidity of the air, the temperature, the light, and the amount of air movement. We must consider how these external conditions affect the well-being of the wheat crop as well as of the fungus. It is well known that if the sowing and the winter rains are seasonable and the weather up to harvest time is bright and clear but not too cold, we have all those conditions which favour the rapid and healthy growth of the wheat crop, and although a little rust may be noticed here and there, no great damage is done and a bumper harvest results. In such cases external conditions favour the wheat and are against the spread of the fungus. If, on the other hand, we have too moist or too dry a seed bed or if long-continued wet or cloudy weather sets in during any period of the growth of the crop, we have the conditions which check the host plant and bring about unhealthy developments. Wheat sown in a seed bed which is too dry either dies off altogether or else develops into a weak spindly growth almost certain to succumb to the first attack of rust. That this rust attack is wholly moderate in most cases and does not develop into an epidemic is due to the fact that dry weather is not so favourable to the fungus as wet and cloudy weather. In a seed bed which is too wet a good tilth is impossible and healthy root development cannot take place. Either a weak plant results which is incapable of much resistance to the attack of the fungus, or, as sometimes happens, the excessive wetness of the soil rots the young seedlings and the crop fails altogether and resowing is necessary. Long-continued wet and cloudy weather is very unfavourable to the healthy growth of the wheat even when established. Transpiration is lowered and the whole plant tends to become suffused with water. An enhanced wateriness of the crop results and at the same time the other activities in the leaf become abnormal and the protoplasm of the cells lose to a large extent their powers of resistance to a possible fungoid attack. At the same time the moist weather favours the germination of the rust spores and we have a state of things

where the conditions are not only against the host plant but also favour the development of the parasite. Unless the weather changes for the better, a rust epidemic results and the damage will be complete or partial, depending on its duration and on the period in the growth of the crop when the attack occurs.

'High temperatures accompanied by high winds and low humidity have the effect of inducing rust attacks. Thus at Pusa in May 1907, and again in May 1909, we observed that cultures of *Einkorn,* which up to that date had remained immune to rust, became covered with uredo-pustules of black rust. The high temperatures experienced in both years at this time lowered the vitality of this very rust-resistant wheat to such an extent that it became as rusty as any ordinary susceptible Indian wheat. Similar results were observed by us at Lyallpur in April 1907 in the case of the European and North American wheats grown there. These wheats were caught by the hot weather of the Punjab in the flowering stage and the first result of the hot winds was to bring out a copious production of uredo-pustules of black rust, although up to this point they remained practically rust-free. A similar result was observed in March of the same year when these wheats were grown at Pusa...

'In addition to the influence of external conditions on both the wheat plant and the fungus, the inherent rust-resisting capacity of the variety itself has to be considered. While apparently the intercellular spaces of all wheats are invaded by rust mycelium, the resisting power of the protoplasm of the wheat cells varies greatly among the various varieties. Some varieties are easily overcome, others, like some types of *Einkorn* and *Emmer,* are markedly resistant and the invasion of the parasite comes to nothing ...

'If we regard rust attacks from this wider point of view and bear in mind the wheat as well as the fungus and the weather, it will be easy to understand how it is that apparently contradictory causes bring about the same result.'

In order 'to turn the struggle between the wheat and the rust in favour of the cultivator' it seemed desirable to cross-breed from the two primitive wheats, *Einkorn* and *Emmer;* in spite of the experience just related above, these were, as a rule, markedly rust-resistant. Crosses were therefore made with *T. vulgare* Vill. These first experiments proved abortive. It was possible to produce seeds but these either failed to germinate or if germination took place, the seedlings died at once. All attempts to raise even the first generation, whether at Pusa or Lyallpur, failed. With *Einkorn* the failure was particularly pronounced; the plants never flowered.

These set-backs were undoubtedly disappointing, but there were other lines of attack.

'The attainment of the highest possible degree of rust-resistance in Indian wheats was approached in another direction. It was hoped that success might be achieved by crossing Indian wheats with some of the new English varieties. English wheats,

> however, either do not flower at all at Pusa, or form ears so late in the season that crossing is impossible. It was decided therefore to carry out the actual hybridization in England. Through the kindness of the Professor of Agricultural Botany at Cambridge, two Indian wheats, Pusa 4 and Pusa 6, were grown as spring wheats at the University Farm and we made the crosses while on leave in 1910. The resulting seeds were brought back to India and sown in October 1910 and the succeeding generations were grown at Pusa.'

Four crosses were in this way made from Pusa 4 and Pusa 6 with American Club and a new English hybrid. Even these results, though at first sight promising, had eventually to be discarded. Pusa 6 was a variety very apt to shed grain in dry weather; this, which would not have mattered in the damper climate of England, was fatal in India, and, when crossed with the English variety also possessing this defect, the progeny (Pusa 60 to 69), though of excellent quality, had to be rejected as unsuitable for distribution on a large scale. The progeny of Pusa 4 (Pusa 30 to 48) failed to inherit the excellent qualities of their parent, while the progeny of American Club failed to prove rust resistant under Indian conditions.

The work was continued and eventually 'a fair degree of rust resistance' was secured. (*Indian Agriculture,* p. 39.) In summing up results some ten years later Sir Albert states his reasons for being satisfied with this attainment. (See Chapter 1) At an early stage in the work, he points out that the prevention of rust is a problem which involves factors much more comprehensive than the mere breeding of varieties, useful and necessary though such work may be. He himself had tried more than one expedient and it is not without interest when he reports that pickling seed with a copper sulphate solution or spraying the growing crop with a similar solution or iron sulphate proved equally useless. Early sowing, as tried in Australia, was risky in the Indian climate. Another Australian expedient, the sowing of two-year-old seed instead of one-year-old, proved waste of time; not only did such seed germinate very badly, but 'in due course' it was attacked by rust quite as markedly as the crop grown from younger seed. Rotation of crops appeared to be, apart from the breeding of resistant varieties, far and away the wisest preventive, and, as we have seen, this ancient method had always been incorporated in the practice of the East. (*Wheat in India,* pp. 100-1.)

The Results

In dealing with this great staple crop of wheat, so important to the peoples of India, the principles which should govern the work of the plant breeder were perhaps more clearly worked out than in the course of any other piece of work. These prolonged and intensive experiments were a great education to the Howards themselves. A baffling combination of problems was encountered, including unsuspected botanical queries, the difficulties of traditional use and custom, and, lastly, very important economic aspects; these together created a situation so fundamental and so comprehensive that in dealing with it the investigators' faculties were called upon.

The very success of the work put the first question: Would the new wheats retain their characteristics when grown elsewhere than at Pusa? For instance, in the canal-irrigated areas of the Punjab or on the black soils of the Peninsula? It was necessary to prove or to disprove this argument. Sowings were made at a number of stations with the help of the officers there in charge, and more especially with the co-operation of Dr. H. Martin-Leake, later to become Director of Agriculture in the United Provinces. The investigations were continued for six years, from 1907to 1912.

> 'It is unnecessary to discuss the results of these experiments in detail. It will be sufficient to state that they proved conclusively that wheats with good quality can be grown in all the wheat-growing areas, including the canal-irrigated tracts of the Punjab and the black soils of the Peninsula. Environment was found to have little effect on the strength of the flour and on the stamina of the loaves. The weak wheats remained weak, while the wheats of high quality retained their strength.'

It was simultaneously that the milling and baking tests were started, which were to prove so encouraging. In the course of them another point emerged, that high yield and high quality tended to be combined; both large harvests and good grain could be looked for from the same wheat. (The contrary view was prevalent at the time in England; cf. *Journal of the Farmers' Club,* 1912, p. 80.) Of the quality of the Indian grain there could be no doubt. Sample after sample was sent forward to be examined by the principal milling interests of Great Britain and detailed reports obtained; of the thirty-one papers on wheat written by the Howards six deal with these tests, which embraced baking as well as milling. There is not space here to give the points of the verdicts given by the highest authorities in the milling industry of Great Britain. The conventional condemnation of Indian wheats as soft and inferior was completely reversed. Wheats as good as the best of those exported from Canada could be produced, while Pusa 4 was actually declared to be 'as good as any wheat in the world'. (Mr. A. E. Humphries, one time President of the Incorporated National Association of British and Irish Millers, as quoted in Pusa *Bulletin* No. 1 7 1, p. 21. Mr. Humphries various reports are printed verbatim in the Pusa *Bulletins*.) Already in 1909 it could be stated:

> 'Eleven selections made at Pusa in 1906 have so far been tested in England for milling and baking. A large number of others will be ready for testing in 1910 and 1911. While all the Pusa selections already sent in have been favourably reported on, five bread wheats have done remarkably well and shown themselves, both in the mill and bakehouse, to be of the same class as American and Canadian spring wheats, the strongest and best wheats on the English market. These five Pusa selections are far superior to any Indian wheats yet sent to England.'

In view of such favourable verdicts Sir Albert did not hesitate to claim for India a premier position as a wheat-exporting country. (The increase in the population has since made it impossible for India to export grains, making quality of less importance.)

> 'These preliminary investigations showed not only that high-grade wheats were most suitable for the export trade and for the Indian consumer but that wheat of the same class as the best of those exported from North America could be grown in India. There was every reason, therefore, to make a systematic effort to place India on a similar plane to Canada in the wheat markets of the world.'

> 'If... an increase in yield is brought about by changing the variety or by better methods of cultivation, the surplus left over for export will increase and India will then take a larger share in the wheat production of the Empire. There can be little doubt that such a result is easily possible. At present the great plains of India do not produce half of what is possible. With a few simple improvements the alluvial soils of India could be made to grow twice their present crops and the Punjab and the United Provinces would then become the most important bread basket of the Empire. Wheat-growing is at present one of the great neglected and undeveloped natural industries of India. The capital for expansion is lying ready to hand in the shape of a marvellously fertile soil when properly managed, while in the cultivator and in his oxen is the foundation of the labour force necessary for development.'

The European market demanded a strong wheat and it had been an error to ship the soft white varieties.

But in no case was the volume exported more than a fraction of the whole harvest. The problem once more came back to a question of the food of the peoples themselves.

> 'As is well known, wheat is an important food grain in India, and of the 8,000,000 tons produced annually about 90 per cent is consumed in the country, the remainder being exported to Europe. Any improvement in the grain itself, to be of importance, must therefore satisfy both the Indian consumer and also the home miller. It is fortunate that the class of wheat most liked by the people for food is that which is worth the most money on the home markets. This is a most important point and one which cannot be emphasized too strongly. On many occasions, the Pusa wheats along with ordinary samples have been shown to cultivators, and they invariably prefer for their own food the kinds which have done best in the milling and baking tests in England. A number of landholders and educated Indians have eaten these new wheats and are loud in their praises of the superiority of these types over those which can be purchased in the Indian market. Every year at Pusa there is a great demand for any surplus wheat from the Botanical Area, while at the Dholi and Bowarrah estates, where the new varieties are grown for seed on a large scale, a well-marked preference for these wheats was at once shown by the people round about. At Dholi the factory servants asked to be paid in wheat instead of in

money.'

Pusa 4 and Pusa 12 had commanded a premium on their local markets from the moment of their first appearance, in the case of Pusa 12 at the rate of an additional 6 annas (6d.) a maund, in the case of Pusa 4 at the rate of an additional 10 annas a maund.

Eventually, to suit the widely varying soil and climatic conditions of this huge country, five or six main varieties of the new wheats became permanently established. These were Pusa 4 in the North-west Province, Bundelkhund, Gujerat, and parts of Burmah; Pusa 12 in the United Provinces, in Sind, Eastern Bengal, and Bihar; Pusa 52 in North Bihar and the eastern districts of the United Provinces where a bearded wheat was essential; Pusa 100 in the Central Provinces; while Punjab 11covered many hundred acres of the Punjab Canal Colonies.

The areas of the new wheats extended with unprecedented celerity. Estimates could not keep pace with their popularity. In 1919 it could be reported to the Viceroy, on his visit to the Agricultural Research Institute at Pusa, that half a million acres were under Pusa 4 and Pusa 12; by 1921 this had doubled to over a million acres. In 1924 'a conservative estimate' gave an acreage of 2-1/2 million acres, with an additional profit to the growers, at fifteen rupees an acre, of £2,500,000 a year; while in 1925-6 a final estimate, again stated to be conservative, placed the acreage at no less than 7,412,857 acres, and even if the annual profit were reckoned at the lesser figure of ten rupees to the acre, this would mean an enhanced revenue to the peoples of India of seven crores of rupees or £5,500,000 a year. (The figures were arrived at on the basis of the sales of Pusa 12 in the United Provinces in 1916; better quality commanded an immediate pre mium of 3 to 4 annas per maund, which later rose to 8-10 annas, at the local bazaars; increase in yield was at the rate of about 3 maunds to the acre; the two increases combined worked out at 15 rupees extra profit per acre. *Report of the Imperial Economic Botanists the year 1915-16*, p. 3; the same for the year 1916-17, p 7.)

Note

by Mr. H. Martin-Leake, Sc.D.

formerly Director of Agriculture, United Provinces, and sometime Principal of the Imperial College of Tropical Agriculture, Trinidad

Towards the end of the last century, Mr. W. H. Moreland, I.C.S. , then Director of Agriculture in the United Provinces, India, was sent to Australia to study the wheat work of that country which was being conducted by Farrer. He brought back with him a number of Australian wheats including some of Farrer's raising.

These were grown on the Cawnpore Farm under the charge of Mr. J. M. Hayman, then sole Deputy Director of Agriculture. Crossing was attempted, probably with a crude technique, for it was before the days of Mendelism and the basis of these crosses was putting successive 'doses' of the Australian wheats on to local Indian wheats.

When I went to Cawnpore from Saharanpur in the autumn of 1906, the crop had already been sown. The work was transferred to me and I found myself in charge of a very large number of small plots, some of them labelled with the names of the original wheats, both local and Australian -- the Australian names I have forgotten. Others were labelled as crosses; thus 'Australian-x-Zuff', or 'Australian-x-Zuff-x-Zuff' (the first cross recrossed by Zuff) 'Zuff' being the shortened form of one of the standard Indian wheats 'Mozuffarnagar'.

Not one of the plots was pure, so that there had been much mixing; in fact, after close study all plots so nearly approximated to the same complete mixture that I decided that the only thing to do was to scrap the lot, go through the crop as a single mixture and pick out promising single plants for a fresh start.

I had been in touch with Mr. A. Howard (later Sir Albert) since his arrival in India in 1905. He had started his wheat work, so I invited him to Cawnpore and we spent a day or two going through the crops, the various plots being considered as a single unit, each selecting plants that appealed to us. That was in the spring harvest of 1907, and we each sowed our own collections at Pusa and at Cawnpore respectively in the autumn of that year. I did not see the Pusa crop but, in the case of the Cawnpore crop of spring 1908, many of these single plant cultures were pure, suggesting that, where these were not Indian types, they were in fact wheats of the original Australian stock introduced.

It was from these that, I believe, Pusa 4 and Pusa 12, came -- the first wheats widely grown throughout the Provinces. It was from the Cawnpore selection that, without any doubt, Cawnpore 13 came, the third of the new wheats which came to form so large a part of the area under wheat.

My own work on wheats ceased with that selection; I did not attempt actual breeding. The later wheats which came to replace these three were the direct product of Howard's own breeding work on true Mendelian principles as then understood.

The above is written from memory as all my records of this work were left in India. But that this recollection is the true one is suggested by the fact that as early as 1910 and certainly by 1914, the area under these three wheats was very large. There could not have been sufficient time to make crosses, sort out the F1s and obtain purity and multiply pure seed. Even starting with purity in a single plant the multiplication factor was very great.

It is interesting to note that one of these wheats, Pusa 4, I believe, was taken to Australia to become a widely grown commercial wheat. If my interpretation of what happened at Cawnpore is correct, and I can see no other, Australia was merely importing one of the wheats originally imported into India from Australia by Mr. Moreland about 1897;

possibly slightly modified by a selection of minor characters effected by the natural forces of a different climate.

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(See also under (c).)

Next: 3. Soil Aeration and Irrigation

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Sir Albert Howard in India

By Louise E. Howard

Chapter 3
Soil Aeration and Irrigation

A New Subject

Soils in the tropics are successively affected by burning sun and by heavy monsoon rainfall. The seasonal rise and fall of the subsoil water is another factor; the variations of levels greatly exceed the variations in temperate climates. The importance becomes obvious of paying the utmost attention to such factors, and it follows beyond dispute that the relation of the plant, especially of the plant roots, to its environment must be fully studied.

In dealing with these facts Sir Albert Howard had to be a pioneer. The subject was new to scientists. The soil investigator, from the days of Liebig trained almost wholly in soil chemistry, was, it is true, beginning to turn to soil physics. As Sir Albert later took occasion to point out, the most important aspect of the physical condition of the soil is that connected with the air in the soil. (*Agricultural Journal of India*, Vol. XIII, Part III, 1918, pp. 416-17.) It was on the vital question of introducing air into the soil for the use of the plant that his interest was focused. In other words, the physical aspects of soil texture were only a bridge to the biological aspect, i.e. to the needs of the growing plant in its call on the gaseous contents of the soil as material for its life processes. The plant rootlets are in permanent need of the oxygen dissolved in the film of water coating the loose soil particles, and this is lost if there is not plenty of crumb structure giving pore space; without such a supply the rootlets cannot breathe; the plant perishes. The increasing attention which Sir Albert gave year by year to the problem of soil ventilation proved an illuminating first phase in shaping his ultimate views on the requirements of plants. In his imagination the plant's need of air took precedence even over its need of water.

> 'All living plant cells respire just as animals do, and, in the process, use up oxygen

> and produce carbon dioxide as a waste product. Air is therefore necessary for that part of the plant, the root system, which is below ground. This fact is well known, but the importance of continuous gaseous interchange between the soil and the atmosphere during the growth of the crop is not always sufficiently recognized. This is particularly the case in a country like India, where water is so often all important and a frequent limiting factor in crop production. The necessity for irrigation, the attention paid to dry farming methods and to water conservation, all tend to concentrate the attention of the investigator on questions relating to water and, at the same time, to obscure the importance of the air supply of the roots... Much of the want of success in some parts of India is due to deficient soil aeration, and this is particularly the case in North Bihar, where want of air causes much more damage than want of water.'

The years of intense work up to 1913 were the years of the experimental demonstration of the ideas proving the great need of securing soil aeration in India. In these years the Pusa system of the grading and shaping of fields, applied also at Quetta and subsequently with pronounced success at Indore, was perfected; an initial problem of aeration was solved on principles which could scarcely have been bettered. In 1914 appeared some observations on the need for aeration in the application of green-manures, while a full presentation of the conclusions to be drawn from all experiments was first published in the years 1914, 1915, and 1916, culminating in a lecture in 1916 to the Board of Agriculture at Pusa in which some startling suggestions were presented. The facts brought forward rested throughout on a double series of experiments, carried out alternately on the humid plains of Pusa and on the arid desert soils of Quetta, where, however, the work tended rather to illustrate the allied subject of irrigation. The two-fold basis had been widened by notes taken in the course of tours to other parts of India; thus the insight gathered during the nine years since the start of the experiments in 1905 ended in a comprehensive view of the whole problem.

The aims were throughout practical. The Howards realized that there was, indeed, an unexplored scientific problem awaiting investigation in the sorting out of the many intricate and still unknown interchanges in the gaseous contents of the soil. At that time no study had yet been made of these phenomena in India; even such a simple truth as that rain is superior to other waterings because of its dissolved oxygen supply was new. (*Agricultural Journal of India*, loc. cit., p. 424.) Much work would certainly have to be done, but there was no need to wait for it. By making use of field observations it was quite possible to advance in practice. Great improvements could be quickly effected by obvious methods within the reach of all the best cultivators. On this question, as on so many others, work was strictly adjusted both to the needs and to the capacities of the Indian peasant.

The Natural Soil Conditions

Broadly speaking, there are two quite distinct types of soil in India, the alluvium of the Indo-Gangetic plain, stretching right across the peninsula, and the black soils south of this belt. Pusa was situated on the Indo-Gangetic alluvium, and it was here that the problem of soil aeration was first brought home to the Howards.

> 'In the alluvium of the plains of India one of the most difficult things is to manage the soil so that its aeration is not interfered with by rain or by irrigation water. The crumb structure of fine alluvial soils which is so easy to produce, is also readily lost under monsoon and irrigation conditions. In consequence, the soil and the roots of the crops cannot obtain sufficient oxygen and in many cases carbon dioxide accumulates. The crops suffer from lack of aeration in the soil and oxygen becomes a limiting factor. This is the explanation we have suggested for a whole series of phenomena relating to crops on the Indo-Gangetic alluvium. All the facts so far obtained fit into the aeration theory and we have come to regard the surface layer of the alluvium as a vast oxygen filter, separating the atmosphere from the subsoil water which, analysis shows, is particularly poor in dissolved oxygen.' (The word 'separating' is not perhaps very well chosen, the meaning is that the surface soil, when in a proper condition, conducts the atmospheric oxygen downwards to the lower soil layers.)

But this 'vast oxygen filter' could only operate as such if the surface of the soil was kept open. There are innumerable references in the reports on the Pusa work to the crust which was so apt to form on these soils, and which, indeed, was known by a special term, the *papri*.

> 'All silt-like alluvial soils are particularly liable to run together on the surface after rain and to form impervious crusts. The Bihar soil is no exception to the rule and the breaking of the crust (*papri*) is a recognized operation in agriculture. Indeed, the people seem to be born with special *papri*-breaking sense. The formation of these crusts at once interferes with the aeration of the roots and as soon as the air supply in the soil is used up, growth stops. The presence of an excess of carbon dioxide round the roots seems to hasten the first steps of asphyxiation, which can be seen by a slow yellowing of the leaves. This is followed by a gradual wilting of the crop and the plants often die without setting seed. The moment the *papri* is broken and gaseous interchange is renewed, there is an almost instantaneous effect. The leaves turn dark green and the arrested growth recommences.'

How necessary it was at all times not to interfere with aeration from the surface downwards was shown in the course of the experimental work itself.

> 'Numberless other examples of the harm caused by over-consolidation have been observed at Pusa. In the course of the plant breeding work it is often necessary in

> picking off insects, in labelling plants, in removing suckers, and in studying the plants to tread a good deal between the rows. It has been found necessary to limit this as far as possible and to cultivate deeply by means of the *kodar* (a kind of mattock) at least once or twice during the life of the crop. The effect is always instantaneous and, even if a few roots are broken off in the process, the gain resulting from increased aeration is at once seen in the renewed growth and vigour of the plants.'

If the impact of the human foot, but more especially of the heavy rains, on the surface of the soil constituted a problem to be dealt with by continual cultivation, in which the peasants were, as a rule, masters, there was another danger in the rise of the subsoil waters.

> 'Associated with the rainfall are changes in the position of the underground water-level. When the monsoon begins, the level of water in the wells and rivers is at its lowest. As the rains proceed, the rivers fill up and there is a general rise in the water-level, which is shown by the upward movement in the wells... This rise of the ground water must affect the soil atmosphere and must slowly drive much of the soil air past the roots of the growing crops into the free atmosphere. In cases of sudden inundation in the monsoon, caused by the bursting of embankments, the loss of air goes on for some time until the whole of the soil is completely water-logged.'

On the black soils, south of the alluvial plains, the conditions were quite different. There was a natural aeration process which was effective, though the continuation of the monsoon might bring risks.

> 'The Ganges and Jumna mark roughly the line of division between the alluvium and the black soils of the Peninsula. As regards the method of aeration in the two classes of soil, nothing could be more distinct. As mentioned above, the alluvial soils have a great tendency to pack together and there is little or no natural aeration during the hot season. The black soils are quite different in this respect. They expand during the monsoon into a jelly-like mass and begin to crack after drying. This goes on all through the cold season. Further contraction takes place during the hot months and deep, wide cracks are formed in all directions. *Rabi* [cold weather] crops obtain an abundance of air by this process and so great is the cracking that moisture is lost and roots are broken... The cracking of these soils in the hot weather, combined with the hot winds, is a perfect aerating method... The expansion of the black soils during the monsoon, however, if long continued, might easily result in damage due to the air supply being cut off.'

Finally, the Howards had the advantage of being able to compare both sets of conditions with the widely different climate at Quetta, contrasting the moist plains with the dry desert: actually the aeration problem proved the same.

> 'The general agricultural conditions in the Quetta valley resemble to a considerable extent those of large areas of central Asia and are markedly different from those of India. The valley is situated at an elevation of about 5,500 feet above the sea and is surrounded by high mountains... The soil... is a loess deposit, apparently formed by accumulations of wind-blown dust, sometimes mixed with alluvium. With such a geological history and in a climate of great aridity, there have been no opportunities for the accumulation of organic matter... Most of the soil of the cultivated areas does not possess a great range in the size of the particles and behaves on wetting very much like the Gangetic alluvium. Flooding destroys the porosity and the surface runs together easily. Under the dry hot winds which are frequent at Quetta, irrigated land sets on the surface into a cement-like mass, which cracks in all directions and rapidly loses its moisture.'

The Erosion Effects of the Monsoon

Such were the soil conditions. But they could not be understood except in the light of the tremendous effects of natural precipitation taking the form of the recurring monsoon.

> 'The dominating factor in the internal economy of the Indian Empire is the monsoon. The well-being of the people, the commerce of the country, and the revenue collected by Government, all depend on the amount and distribution of the summer rainfall. It is not surprising, therefore, to find that the attention of the agricultural investigator in India tends to be concentrated on questions relating to the supply of water to crops. At the same time, the other factors on which yield depends are apt to be obscured and crop production comes to be regarded almost entirely as a question of water supply.'

The intense cry from the heart of the people for the longed for rains easily led them astray. It was part of Sir Albert Howard's work to point out that water itself could be, indeed, had been for centuries, a menace.

> 'In the basin of the Ganges... the high-lying lands are usually lighter and opener in texture than the heavy soils in the low-lying areas which often grow rice. These differences are largely bound up with the loss of fine soil particles which is going on continually, not only in any one area, but also in the Gangetic system as a whole. Locally, fine soil is being washed from the high-lying lands and deposited in the low rice areas. In this way the rain-washed areas tend to become light in texture while the heavy condition of the rice fields is maintained. Looking at the plains as a whole, a vast amount of fine silt is carried down to Lower Bengal by the Ganges and deposited in the deltaic regions in the form of new land which, after

many years, becomes cultivated and grows uncertain crops of rice. This enormous transfer of fine soil by the Ganges and its tributaries from the area drained by this river represents a great loss of agricultural capital and is a great drain on the natural resources of the country.'

'Soil erosion is, however, by no means confined to Central India. In the great alluvial plains of Northern India, where, at first sight, the country seems quite flat, the amount of damage done by rainwash is enormous... The loss of soil by denudation in the valleys of the Ganges and Jumna is only generally recognized when the erosion has proceeded far enough to cut up the country into deep ravines, which generally run back from the rivers or low-lying areas. While this ravine formation is the most obvious result of the scour, nevertheless it is likely that this form of damage is of far less importance than the slow removal of fine soil from all the high-lying portions of the plains. This form of erosion is not very obvious at first and can only be appreciated after constant observation of the run-off during periods off heavy monsoon rainfall. The muddy water running down to the drainage lines is exceedingly rich in fine particles and this unchecked denudation has, in the course of years, brought about very definite results in the consistency of the soil. The upper lands have become open and sandy through the loss of fine particles, while the low lands have become stiff and heavy by the continued addition of new soil. The consequence is that the high lands have lost to a great extent their power of retaining moisture and only yield crops with the help of manure. The low-lying rice-fields have received more and more silt and the thickness of stiff soil has increased without any corresponding benefit to these areas.'

'A consideration of the above examples of erosion in India leaves no doubt that the natural agricultural capital of the country, the soil, is slowly running to waste. This loss of fertility reacts on crop production and therefore on the well-being of the people. This impoverishment means debt, increased liability to diseases like malaria, and finally rural depopulation. The gradual denudation of the soil of the country is the real "economic drain" on India. A little consideration must show that the first condition of improving crop production in India is to take steps to stop this constant erosion and to keep the cultivated soil in its place. Unless denudation is stopped and the fine soil is retained, it is clear that the provision of improved varieties of crops, of irrigation facilities, of improved credit, of better cattle and implements will not yield their full results.'

The Water-logging of Fields

To forestall these evils the population had from ancient times used systems of embankment.

> 'There are two weak points in the system of embankments in Peninsular India which are of some importance. Although in many places where the soil is deep, where the slope of the ground is comparatively small and where people are energetic, embanking is a common practice and much good results, nevertheless there is hardly any provision for the discharge of the surplus water. The whole of the rain is often held up and the fields become shallow ponds. This is a disadvantage in two ways. In the first place, to hold a large volume of water for a long time, even where the slope is small, the bunds have to be made very strong and one or two breaches in a series might easily lead to very general damage to the whole, and to the escape of a large volume of water, which would take with it much valuable soil. Where the slope is considerable, these difficulties increase and sudden heavy falls would be almost certain to break a whole series of embankments. The serious disadvantage of the existing system is the practical certainty that the flooding of the land for long periods must lead to denitrification and consequently to diminished *rabi* [cold weather] crops. The wheat crop in many parts of the Central Provinces certainly looks as if it is suffering from a lack of available nitrogen and the whole subject seems well worth investigating from this point of view.'

Of the two connected evils, actual soil loss and waterlogging, the more persistent damage was to be attributed to the latter, which thus outweighed even the evil of the washing down of soils.

> 'The degree to which water-logging takes place in India varies greatly. Every gradation is to be seen from slight damage to a crop to the production of saline efflorescence and the formation of permanent, stagnant swamps in which no cultivation at all is possible beyond a little precarious rice-growing near the edge. The occurrence of slight water-logging can only be detected by a trained observer, who has learnt how to read his practice in the plant. The production of swamps, on the other hand, is of course obvious to all, but between these two extremes a vast amount of damage to crop production is being done every year which is only very dimly understood at the present time.'

Waterlogging meant depriving the plant root of air, and that, in the opinion of the Howards, was the ultimate sin. The following short passage may be some explanation of Sir Albert Howard's criticisms in later years of official agricultural research. Certainly the folly of carrying out advanced variety trials without first mastering the elementary lesson of how to manage the soil which was to support the crop would have struck any intelligent observer.

> 'Just as increased aeration means better root development and better growth so diminished aeration leads to a poor yield. Waterlogging during the monsoon and the absence of surface drains are the chief causes of poor soil aeration and poor

root development. Examples are to be seen everywhere and were particularly well marked a few years ago on the old manurial plots and variety trials at the Government farms all over India. I never saw one of these series that was not ruined by obvious want of drainage and by waterlogging. The aeration factor was almost greater than any difference in the yielding power of the varieties or of the manures.'

The Remedy: the Shaping of Fields

What was to be the answer to these evils, which amounted to a kind of endemic disease of the soil, going back for centuries? The first thing which the two research workers had to do, if they did not wish to sink to the unfortunate level of their fellow workers of the old manurial trial plots just referred to, was to use their eyes. There were natural indications, full of significance, which could be noted at Pusa and could lead in the right direction.

> 'The most startling results of natural aeration are, however, to be seen after trees have been felled or when holes (such as the brick-soaking tanks used in building operations) have been filled with new earth. When a tree has been cut down and the roots have died, the white ants become active and proceed to eat out the whole of the cylinder of wood, leaving the bark behind. The result is that there is a perfect network of connecting tubes under the surface, which greatly promotes the aeration of the soil and of the roots of crops. The effect of this becomes very marked about a year after the trees are cut down and the results on the crop are similar to those obtained by heavy dressings of nitrogenous manure. The increased aeration obviously acts in two ways. In the first place, a plentiful supply of air to the roots is supplied. In the second place, the formation of nitrates by the soil bacteria is considerably increased. There is a very good case in the Botanical Area [at Pusa] at the present moment of the effect of old roots on succeeding crops. A line of *sissoo* trees... was cut down in 1910. In 1911 it was observed that the edge of the plot next to the former line of trees was becoming exceedingly fertile. The effect is still more evident during the present year (1914) and the wheat crop on the east side of this plot will have to be cut back to prevent lodging later on. This result is a consequence of the work of the termites in removing the wooden cores of the roots. These insects are always attracted by old wood, which they rapidly devour. In addition to assisting in the transformation of vegetable matter into humus, these insects are most useful as aerating agents and their systematic destruction, as is sometimes advocated, would, if successful, only lead to great loss to India.' (Sir Albert considered that the termites did the same work of soil aeration in tropical climates as is carried out by the now famous earthworm in temperate zones.)

The Indian peasants were not without their own faculty of observation. They had evolved more than one clever device. It has already been stated that they seemed to be born with an inherited '*papri*-breaking sense'. They were ingenious also in taking advantage of the better aeration to be found on the borders of irrigated field, what was called 'the edge effect'. Plants thus located could reach a supply of air through the earth embankment and grew much better than those in the centre of a plot where the soil was waterlogged. It had become habitual practice for the ryots, when requiring *patwa* (*Hibiscus cannabinus* L.) or *sann* (*Crotalaria juncea* L.) for seed, never to sow in field patches, but always to have a few plants on the edges of the field, which were often slightly raised; experience had shown that only in this way would these plants come to maturity. It was interesting that Europeans, growing vegetables on the black soils, had copied this idea of sowing round the edges of plots in order to escape waterlogging.

Perhaps even more important was the widespread knowledge and use of the deep-rooting plant as a natural soil aerator. Many plants could act in this way by the thrusting nature of their root systems, *rahar* (*Cajanus indicus*) being one of the best examples. It was a well-known practice to grow *rahar* before tobacco, a crop requiring especially good aeration, and also usual to breakup soured airless packed soil under rough grass land (*perti*) by means of a first crop of the sweet potato, which managed to thrive in conditions which would choke other crops and whose swelling roots, acting 'like a mild explosive', shattered the soil for the next crop. In the Quetta valley local knowledge dictated the use of *busunduk* (*Sophora alopecuroides*), a common weed, among the peach trees or melons; this was a plant provided with thick underground stems bursting open the subsoil in all directions and with shoots coming to the surface and letting in extra air; where this was found there was seldom yellowing of the peach; it could well be called 'the subsoil plough of the Quetta valley'. Alternatively *shaftal*(Persian clover), a valuable fodder, could be cultivated and ploughed in, the organic matter thus added assisting the excellent aeration effects of the deep taproot and numerous laterals, which broke up the soil in all directions. (It was on a similar experience of the soil shattering work of local deep-rooting crops that Elliot, who had spent many years in the East, based his well-known Clifton Park system of using the deep-rooting crop as a natural aerator and fertilizer.)

Such practices were only palliatives for soil conditions which had slowly degenerated over the centuries. Something more definite was needed. The remedy was found by adopting the very old principle of 'divide and rule'. The rainfall was to be dealt with field by field, and in that way mastered: the monsoon was to be 'put in harness'.

A new system was devised of the separate contouring and shaping of each field, so that it could absorb the maximum amount of water on the spot. This was something quite different from the ordinary practice of terracing. Each field was independently treated, sloped from the centre very gently downwards towards the edges to end in grass-covered drainage ditches. Thus every small area was trained to deal with its own rainfall and was also protected from the run-off from other areas, which is what is meant by the words 'divide and rule'. The idea seems to have been original, but a journey to north and central Italy while on leave in 1913 showed an almost identical system in use, and a few improvements were borrowed from what was seen in that country. (*Report of the Imperial*

Economic Botanist for the Year 1912-13, pp. 17-18.)

'A drainage system, suitable for the Gangetic alluvium, which at the same time prevents soil erosion, has been worked out during the last few years at Pusa... The method consists in dividing up the country into areas of from five to ten acres and surrounding these with trenches, the borders and sides of which are turfed to prevent cutting. The field trenches communicate with larger channels which carry the run-off either to low-lying rice areas or to streams and rivers. The size of the field trenches will vary according to the amount and distribution of the rainfall. In Bihar, it has been found that channels four feet broad at the top, two at the bottom and eighteen inches deep, suffice in most cases. A grass strip, about a foot wide, should be left on the field on each edge of the trench to prevent breaching by the run-off, and it is an advantage to let the grass grow on the sloping sides as well. The roots consolidate the soil and, after the first year, there is little trouble from breaches. A good deal of attention is necessary during the first monsoon in repairing the edges and in checking cutting. It is best to dig the trenches in the hot weather and to plant the sides and edges with *dub* grass in the early rains. During the monsoon the trenches silt up to some extent and it is necessary to clean them out every hot weather, the soil being placed on the down side. A trimming up after the monsoon also adds to the general appearance of the fields... By this method each field deals with its own rainfall only and water-logging is prevented.'

'One precaution is very desirable in grading land in India. As is well known, the surface soil is always richer than the subsoil. Any concentration of surface soil in one place and any corresponding exposure of the lower soil layers in another leads to uneven growth, which does not disappear for some years. It is best therefore before beginning the grading to scrape off the upper three or four inches of the soil and to collect this on one edge of the field, The subsoil is then graded to the extent desired, after which the upper soil is rapidly and evenly spread over the whole with the *ken.* In this manner even crops result.'

'In Baluchistan all grading is done by the *ken,* which is nothing more than a slightly curved board, provided with a handle above and rings at the side for attachment to the yoke. The lower edge, which acts as a scraper, is strengthened with sheet iron. The size is roughly 3 ft. by 2 ft. 4 ins., and one pair of cattle is commonly employed. The local labour is exceedingly expert with this primitive grader and they rapidly and accurately prepare for irrigation the narrow terraces on the slopes of the valley. Earth is collected from the high places and deposited in the low areas by simply altering the slope of the *ken.* In an intermediate position the instrument carries its load of earth without disturbing the level of the ground passed over.

'In the Punjab a very similar instrument drawn by two pairs of cattle, known as the *karah,* is in use... The taking of levels is not necessary as the workmen can prepare

> by eye the desired slope with remarkable accuracy.'

There was no other piece of work done by the Howards in the early years at Pusa of greater usefulness than this device of the draining and shaping of fields. It was a straightforward practical reform which could be brought to the notice of the Board of Agriculture, when addressed at Pusa in 1916, as within the capacity of the peasants, capable of being carried out with existing tools, yet leading to immense benefits of a permanent kind.

The Use of Potsherds in Green-manuring

An entirely different attack on the problem of aeration was made after the fielding system had become well established. The new advance was made in an almost fortuitous way; yet not really so, for it came about, as did so much else, as a result of Sir Albert's acute and penetrating observation. It was in 1915, the year previous to his address to the Board of Agriculture, that in the course of one of his journeys Sir Albert noticed an effect near Jais in Oudh which led to an explanation of the aerating effects of using potsherds or brick to dress the land. This was an Indian practice, not an Experiment Station suggestion. In view of the revival of stone mulching in horticulture, this ancient practice is of interest.

> 'Jais is an old Mohammedan city, standing high above the surrounding plain, and the mounds on which the town is built are composed of the remains of the ancient city of Udianagar. Large stretches of very fine tobacco are grown on the lower land surrounding Jais and the crop is irrigated from wells. In the present year (1916) I again had occasion to pass Jais and took the opportunity of examining the tobacco cultivation. The soil is rich in potsherds, derived no doubt from broken roof tiles and water-pots, and the water used in irrigating the tobacco was said by the cultivators to be unfit for drinking but very good for this crop, in the growth of which they stated very little manure was used. This was remarkable considering the excellent crops and the fact that this plant will not thrive in the absence of abundant nitrogenous food materials.'

A large sample of the irrigation water was sent for analysis to the relevant department at Pusa and was found to be exceedingly rich both in nitrates and in dissolved oxygen. (Potassium nitrate 34.57, sodium nitrate 16.55, dissolved oxygen 0.725, as contrasted with nil to 0.036 for both nitrates and 0.067 to 0. 153 of oxygen in Pusa water.)

It is not quite clear exactly at what point actual experiments in dressing soil with potsherds (*thikra*) were begun at Pusa, but they are referred to in several papers about this time. The rate of application was fifty tons of broken tiles to the acre, mixed with the upper six inches of soil. The results in conjunction with green-manuring are said to be 'exceedingly striking'. It was, in fact, in sorting out the erratic effects of green-manuring that the use of *thikra*was to prove illuminating; the success or failure of green-manuring was found, like so much else connected with the soil, to depend on aeration.

Green-manuring is important in India because animal manure is so insufficient in quantity. But many failures in using green-manures, especially on the alluvium, were registered. It was not realized that the green-crop, while growing, used up the available oxygen supply in the soil and also released a large quantity of carbon dioxide; when subsequently ploughed in any remaining oxygen would be called on to assist decay. The crop thereupon sown, deprived of oxygen and choked by the presence of the carbon dioxide, instead of benefiting from the manurial operation, starved. This was less likely to happen in light porous soils where air could freely enter, such soils as those of North Germany where the original green-manuring experiments of Schultz-Lupitz had been carried out. But on the compacted alluvium of India, the lack of air was fatal for the growing of the succeeding crop.

That extra aeration, or special attention to aeration, was essential in a green-manuring operation had already been established in a special experiment on three tobacco plots green-manured with *sann* at Pusa in 1913. Green-manuring was carried out on successive dates in July and August and across all three plots a strip was subsoiled to a depth of twelve inches two days before the tobacco was transplanted at the end of September. The effect of the extra air supply given by the subsoiling was plain to see on all three plots; the first plot, where the green-manuring had been earliest carried out, gave the best results; the worst results were found where the green-manuring had been done last, thus showing that the decay of the green-manure was a process competitive with that of the growth of the crop.

> 'The simplest explanation of these results appears to be connected with the part played by air in the soil. The soil is usually regarded as a mass of small particles, arranged in various ways according to the degree of consolidation, with free spaces between these bodies known collectively as the pore space. Surrounding the solid particles are films of water of various thicknesses, while the rest of the pore space is taken up by the soil air. The proportion of the pore space filled by air and water naturally varies with the general wetness or dryness of the soil. The closeness of packing of the solid particles varies greatly, after a crop is sown, as a result of consolidation by irrigation water or rain. In the water films round the particles there is intense biological activity. Numerous bacteria are rapidly reproducing themselves, while the root hairs of the crop are competing with these soil organisms for water and inorganic food materials. All the protoplasm of these organisms is actively respiring and, in consequence, there is, in the water films round the particles, a keen struggle for oxygen and a great development of carbon dioxide. Under such circumstances it is easy to understand how it is that analyses of the general soil air often show a high proportion of carbon dioxide and a comparatively low percentage of oxygen.

> 'We must now consider what is likely to happen if this normal struggle for dissolved oxygen in the soil between the roots of the plant and the soil organisms is complicated by the sudden addition of a green crop like *sann.* In the first place, the growth of the green crop itself will naturally lead to a considerable pollution of the soil atmosphere by carbon dioxide. As soon as it is ploughed in, decay begins and an enormous quantity of oxygen is used up in the process, which is by no means complete when the sowing time of a *rabi* [cold weather] crop comes round. The partly decayed organic matter adds a new competitor in the struggle for oxygen. It is easy to understand how the remains of the green crop might easily use up the oxygen in the pore spaces and load the soil atmosphere with carbon dioxide to such an extent as to poison the air dissolved in the water films. Oxygen starvation and carbonic acid poisoning would affect the plant and growth would be checked.'

The only cure was aeration and the Pusa experiments with potsherds were sufficient proof.

> 'Practical planters and cultivators who have seen the preliminary experiments are convinced that the maximum tobacco crop can be grown with green-manure alone on drained land treated with *thikra.* The experiments are most conclusive and there is no doubt that, given sufficient moisture in the soil for decay, the factor on which green-manuring depends in India is abundant soil aeration. Aeration also explains why green-manuring on the open sands of North Germany has been so successful. These soils are of such texture that they aerate themselves. On the plains of India we must overcome poor aeration by drainage and *thikra*.'

Provided, then, that soil aeration could be made 'copious' by surface drainage of the fields on the Pusa system, by subsoiling before sowing, and above all by the potsherd dressing, complete decay, in good time, of the green-manure could be ensured and its nitrification. This was the explanation of why the Jais water was so rich in nitrates. It was also found rich in potash, which Sir Albert attributes to the fact that much wood and cow-dung were burnt for fuel in rural centres. Such potash, together with phosphates, was, in the presence of adequate oxygen, collected by the soil fungi for the use of the higher plants; the cycle was thus complete.

> 'The Jais tobacco fields can be regarded as a natural manure factory in which nitrates, potash, and phosphates are produced in sufficient quantity for crops like tobacco, maize, and poppy, which are all grown on the lands in question. In spite of the fact that maize is followed by tobacco or poppy the same year and that a relatively small amount of manure is used, the tobacco crops are luxuriant and the cultivators are obviously prosperous and well to do. The sources of the nitrogen and minerals used by the crops are evidently the crop residues and the manure supplied for the maize crop. That this organic matter produces such excellent results is, in all probability, a consequence of the copious aeration of the soil

> produced by the great number of potsherds present...
>
> 'It is evident that in the soils of India, the great factor in manuring is aeration and that Jethro Tull's great generalization that "cultivation is manuring" can now be extended and summed up in the phrase: *manuring is aeration.* The potsherd enables us permanently to aerate the soil; and thus make the best use of organic matter including green-manures. The potsherd by itself has only a limited value, but with the help of small quantities of organic matter extraordinary results are possible, as the example of Jais is sufficient to indicate.'

Cheap and simple devices always appealed to Sir Albert. In the Indian potsherd he had something after his own heart.

> 'In future in India the cultivator will go on burying his savings as before, not however as rupees, but in the form of a permanent manure -- *thikra.* In this manner, silver can be transmuted into gold and the dreams of the old alchemists will become a reality. The philosopher's stone is a potsherd.'

The theme of the vital need for allowing air to penetrate into the soil is repeated like a kind of *leitmotif* in almost every paper published about this time, 1910-16. From a very early date the Howards were impressed by the importance of the problem. Their field work was always directed to take it into account, and lysimeter experiments bore out the field work. Every trial told the same story, that the plant root needed air, but that air was not always easy to conduct into the soils of India by reason alike of the violent impact of the monsoon rains and the rise of the subsoil waters; unless prevented there would be the evil of waterlogging, to drown the plant roots, or the other evil of compaction of the surface, to choke off the air. On wheat, for instance, the verdict could not have been more decided: 'After growing wheat in Bihar for nine years, we are convinced of the importance of aeration for this crop and equally convinced that over-consolidation (of the soil) from any cause is very harmful.' A similar verdict was applicable to indigo and tobacco, to lucerne, gram, grass, and vegetables, while in the growing of fruit trees, both at Pusa and at Quetta, the aeration factor had given rise to effects of really startling definiteness. (See Chapter 5.) All results seemed to run together and even slight causes to lead to almost irreparable damage, so that to the general judgment that 'proper relations between air and water in the soil' are a necessary prerequisite for growing the best crops in Indian conditions could be added the stranger dictum that 'water, when it excludes air from the roots, acts as if it were a poison to crops'.

Irrigation: the Furrow System

This pre-occupation with the damage which water can bring was a view unusual in India, where water is valued as one of the most precious of commodities. The benefits conferred on India by the great canal systems built by the British administration, more especially in the Punjab, are a matter of common knowledge; vast new areas of land were opened up for settlement. Sir Albert was interested in the general theory of irrigation systems; as an agricultural botanist, he judged the benefits by the growth of crops and did not always agree that these had been as permanently useful as was supposed. There were risks involved, which were apt to be overlooked.

In local practice at Pusa an error was met with at the outset. This had to be put right, which was not difficult, but he might have argued that with so experienced a population it ought not to have occurred. However, the growing of fruit in India was always rather careless and deficient, possibly because fruit is never an essential subsistence crop. In arranging to water the peaches, loquats, almonds, etc., planted on arrival at Pusa -- these plantings were almost the first of the experiments -- he found a system in use among the local cultivators which might be called a small basin system. Shallow circular holes were excavated round the stems of the trees, connected by means of small trenches, and the water flooded in. Not only did this flooding invite collar-rot and the general waterlogging of young trees, but the water failed to reach far enough to benefit the further growing root-tips of the older trees; meanwhile manuring and drainage were interfered with in the monsoon.

> 'The disadvantages of flooding the surface are well known. Besides the destruction of the tilth and the formation of a surface skin (*papri*), which becomes hard and impervious on drying, this method leads to a great loss of water by evaporation. Moreover, in many cases percolation is slow, as the air in the soil can only escape very slowly laterally. Further, flooding the surface often leads to an infertile condition of the soil, due possibly to the partial destruction of the bacterial flora thereof.'

It was therefore better to replace the basins by shallow rings corresponding to the outer spread of the branches. The water, conducted by a trench parallel to the lines of trees, was sent first into the furthest ring and after that into the nearer ones, one after the other, each inlet to a ring being controlled by a small earthen dam. This simple alteration carried a number of advantages. No more water was used: it reached the growing rootlets of the trees: there was no waterlogging. During the monsoon the rings were filled in to be re-made the following season, but the parallel trenches were left and acted as good drainage canals. This system was being adopted in the United States. (Furrow irrigation was so new in India that when introduced with pruning by Dr. Martin-Leake at Cawnpore for oranges he was challenged by the buyers of the crop in flower to offer compensation for expected loss of harvest; in the event the weight of the crop was so great that it nearly broke the branches.)

> 'In connection with the manuring of trees this system of irrigation has proved most useful. One of the difficulties of applying manure to fruit trees in India is the

> subsequent damage done by white ants (termites), which are attracted by the organic matter of the manure and frequently turn their attention to the tree and destroy it. If the trees are manured just before the rings are made, and if care is taken to apply the manure only to the ring of soil just underneath the outside branches, the first watering not only tends to rot the manure but also to drive off the termites.'

An adaptation of this same device of furrow irrigation was very successful in preventing losses in the transplanting of tobacco.

> 'The great danger in growing a crop like tobacco, especially where the autumn rains fail, is the loss of plants which occurs on transplanting them in the field and also from grasshoppers. The usual method in India is to transplant in the evening, to water the young plants and to cover them with *nim* leaves during the heat of the day. Even when every care is taken, many plants die. In plant-breeding work this loss is of great importance owing to the danger of a dead plant being replaced by one of a wrong variety. In order to minimize this loss, I have devised the following method. After cultivation and manuring are finished, furrows about one foot wide and four inches deep are laid off at the proper distance so that there will be a furrow between alternate rows of tobacco. These furrows are then filled with water several times, and the water is allowed to percolate laterally until the soil is well moistened between the furrows. Transplanting is now carried out in the soil moistened by lateral seepage from the trenches, and the young plants are covered with *nim* leaves during the day which are removed at night. When this method is used, the loss of plants is not more than 1 per cent, and there is practically no danger of destruction by grasshoppers. During the last year, when the failure of the autumn rains almost destroyed the tobacco crop of the cultivators in the district, no difficulty was experienced in growing good tobacco at Pusa.'

It is interesting to see in this example how a mistake in practice had opened the door to insect attack, and how easily such attack was afterwards prevented by attending to the state of the soil.

The Saving of Irrigation Water in Wheat Growing

Armed with these successes at Pusa the Howards proceeded to Quetta for the summers from 1910 onwards. There they found an elaborate system of irrigation applied to the growing of wheat.

> 'The usual method of irrigation is by means of the *karez.* This is an underground ditch on sloping land, which collects the subterranean water near the hills and discharges it on to the surface. It is really an adit with a slight slope, driven into a

> fan talus with a much greater slope of 300 to 600 feet per mile. The land below the opening of the *karez* is watered by gravitation.'
>
> 'The feature of the irrigated wheat-growing area round Quetta is the large amount of fallow land and the concentration of the available irrigation water on a comparatively small area. Land is abundant but water is scarce... When Canopus appears in September, the preliminary watering is given... after forty days the first irrigation is applied, followed by the second at the end of December. Watering is stopped during the months of January and February and the third irrigation is given at the end of February. There is then a cessation while the crop is shooting and the fourth application takes place about the middle of April, followed by at least two more at intervals of about fifteen days till the grain has formed. Including the preliminary irrigation before sowing at least seven waterings are given for irrigated wheat.'

There were, it is true, other methods of growing wheat without irrigation, on dry farming principles, but the crop was always precarious, and the best yields were undoubtedly obtained under irrigation.

One could have supposed that scientific advice would take the direction of encouraging the application of water and of endeavouring to increase the scope and intensity of irrigation practices. This did not commend itself to the Howards. Instead, the problem was viewed from a revolutionary aspect, the previous investigations on soil aeration being the red line guiding their ideas.

> 'The most interesting and significant features of the crop are the slow rate of development about the time the ears appear and the manner in which ripening takes place. The well-known changes in colour of the ears during ripening do not occur at Quetta. The ears dry up slowly from the tips rather than ripen and the full colour of the chaff is not developed. There appears to be a factor which limits the rapid ripening of the crop and there is some evidence for supposing that this is want of air in the soil, caused by the destruction of the tilth by frequent watering.'

These observations convinced Sir Albert that there was much that was wrong. Heavy watering disadvantageously prolonged the period of growth, delaying ripening, induced too great a proportion of straw to grain and a superficial rather than a deep-rooting system; above all, there was a criminal waste of the precious water itself, especially in view of the fact that the cultivators seemed quite ignorant of the uses of a dry mulch in preventing evaporation.

> 'If therefore the methods of growing wheat at Quetta are examined in the light of the best modern practice in arid regions, only one conclusion can be drawn. The local practices are wasteful and unscientific in the extreme. Water is thrown away

> in all directions: there is no effort to conserve the soil moisture and to make the best use of what is, to the wheat crop, a most timely and well-distributed rainfall. All the conditions were therefore exceedingly favourable for the conduct of water-saving experiments and, as soon as the land for the new Experiment Station was acquired, these were set in motion.'

The experiments were conducted from 1912 to 1915. Some fair results were obtained in the first year by the use of the harrow to induce a dry mulch on an unirrigated crop, but this had to be discontinued as the wheat shot up and the late rains of March, April, and May formed a distinct surface crust allowing evaporation, with bad effects on the ripening of the ear, as described above. Some additional moisture was clearly necessary, but it was a triumph to prove that the needed supply could be given by means, not of seven, but of a single irrigation.

> 'A single irrigation, applied before sowing... would enable a thorough cultivation of the land to be carried out before putting in the seed and would reinforce the water in the soil and subsoil to such an extent that there would be ample moisture for germination and for rapid root-development before the winter rains were received. The land was irrigated by surface flooding in the ordinary way and, as soon as the surface was dry enough, it was cultivated by means of the spring-tooth cultivator and immediately levelled with the beam. This operation is of the greatest importance in crop growing in Baluchistan both from the point of view of the saving of water and of the production of a good tilth. Irrigated land dries very quickly and unless it is ploughed up at exactly the right moment, large clods are formed which cannot be broken down by the beam. Where the area watered is several acres and the cattle power is limited, it is impossible to deal with all the land at the proper moment with such a slow-working implement as the country plough. The consequence is a great loss of moisture and a poor tilth.'

This difficulty was overcome by the introduction of a spring-tine cultivator followed by the beam. A pair of cattle could cover at least three acres in a day. Ploughing and sowing would follow, and the young crop was then lever-harrowed with a pair of cheap Canadian lever-harrows drawn by a pair of bullocks. By sloping the tines backwards this could be repeated several times. All this was well within the means of the local inhabitants. In the second year of these experiments (1915) the crop of the Experiment Station, thus treated, ripened about a month before the local crop and was far less affected by yellow rust; the full chaff colour, hardly ever seen in the country crop, was developed. The average yield for this and the preceding season was 17 maunds 29 seers per acre, or 4-1/4 maunds above the average yielded with six or seven irrigations (unmanured land in both cases).

> 'The real difference between the Experiment Station results and those obtained by the people can best be realized, however, by comparing the produce in both cases from the same amount of water. The zamindars water one acre seven times and

> obtain an average of 13-1/2 maunds of grain. The same amount of water spread over seven acres, if used according to the method employed at the Experiment Station, would give seven times 17-3/4 or 124-1/4 maunds of wheat. The difference in favour of the experiments is therefore 110-3/4 maunds of wheat. If the average irrigated acreage of wheat in the Quetta valley is multiplied by 100, the result would indicate, in maunds of wheat per annum, the present annual waste of water on this crop alone. On every 100 acres of irrigated wheat, the water now lost would produce 10, 000 maunds of grain and a large amount of straw of a total value not far short of half a lac of rupees.'

These figures applied only to the desert. But, as had been stated, there was much land lying fallow through sheer lack of water, so that the contention that a saving of waterings would mean distribution of the water thus saved to other land, and therefore much larger harvests, is true. The description ends with a brief statement that the Experiment Station work had been carried out by an Indian staff on written directions only, sent from Pusa, thus proving that the innovations suggested were not only within the financial means of the zamindars, but also within their intelligence and skill.

There was really no need to go further, and the sufficiently dramatic results, when put before the Board of Agriculture at Pusa in 1916 and at Poona in 1917, had already resulted in three resolutions of the Board and even a recommendation proposing a special Experimental Station to enquire into the question. The Howards were clearly justified in speaking with authority when they demanded an overhaul of the systems governing the use of irrigation water and its payment.

> 'The importance of this matter to India needs no argument... It is true that the difficulties involved in overhauling a vast system of perennial irrigation constitute a formidable undertaking. On the other hand, if, as appears to be the case, much more can be made of the present water supplies, it is obviously to the advantage both of the cultivator and of the State that modifications should be introduced into the existing systems. The centre of the subject is the plant and the physiological processes involved in its growth. If perennial irrigation interferes with its growth, it will have to be modified. The difficulty in making an advance in matters such as the improvement of an existing irrigation system is to begin. If the most is to be made of irrigation water, it is obvious that the cultivator must be a willing partner in the undertaking and that the water will have to be charged for according to the amount used. At present the usual method in India is to levy a water-rate according to the area watered, a proceeding often condemned by members of the Irrigation Department itself.'

The arrangements governing the distribution of irrigation waters were, in fact, revised by the Baluchistan Administration in consequence of the representations made. These were subsequently confirmed by three further years' work at Quetta itself, when excellent yields of wheat were obtained with a great saving of water. Similar results were arrived at in the Punjab, in Sind, and the United Provinces, while at Shabjananpur actually over thirty-three maunds were on one occasion reaped (1918-19). Elsewhere, the opposite effect, namely, the deterioration of the harvest by using too much water, was easily established.

The Supreme Importance of the Air Supply to Plants

The risks associated with over-irrigation directed Sir Albert's attention to the world-wide problem of alkali lands. The occurrence of these lands is much dreaded in India. The question was first discussed by him in a book published in 1924 (*Crop Production in India*, pp. 43-50), but as a further long discussion is available to all in *An Agricultural Testament* (*An Agricultural Testament*, pp. 147-55), it is not necessary to go into detail here. Briefly, the excess of sodium salts which kills plant growth is not to be attributed to lack of rainfall but to lack of air and is often brought about by perennial irrigation: once again, the four factors, soil, air, water, plant, are seen to be one problem. But if lack of aeration is the real cause of the degeneration of soils into the alkali condition, then not the washing out of the salts, which in any case is usually impossible in practice, but the opening up of the surface and the subsoil to the air by any and every means will be the only efficient remedy.

Thus in a curious and unexpected way drainage, irrigation, alkali lands, were found to be nothing but illustrations of the aeration problem. The results of surface drainage alone at Pusa had been staggering.

> 'The improvement in fertility and in the ease of cultivation which results from surface drainage are almost past belief. The Botanical Area at Pusa has been transformed by this means. The yields have increased, the plots produce even crops and the tilth of the stiffer areas, which was formerly poor, is now vastly improved... The most convincing proof, however, of the advantages of the adoption of this system on the Bihar estates is to be found in the rents paid by the tenants of drained land... Several areas which previously could not be let to tenants at all and which had to be put under cheap crops like oats, fetched high rents when surface-drained... The improvement in soil aeration which followed the construction of the surface drains thus rendered possible the substitution of money crops for cheap crops.'

If measures for the saving of irrigation water could be added to the field system evolved at Pusa it would seem that 'enormous progress' would be possible, and not merely in India, but in many other countries.

The subject of soil aeration eventually led in a direct way to the subject of disease. The idea that faulty soil aeration invites sickliness and failure in the plant runs through many papers, and is expressly discussed as part of the Presidential Address to the Indian Science

Congress in 1926, by which time the argument had become definite. Aeration again plays its part in a consideration of the final topic, the laws governing decay. It is stressed again and again that the mixed heaps of organic waste must, if they are to break down naturally, be provided with ample air for oxidation. At a later stage, on his return to Europe, renewed aeration, by means of subsoiling, was ardently advocated by Sir Albert for English soils, as a remedy for the subsoil pans, which he strongly suspected to exist far more frequently than either the farmers or the scientists in Great Britain were ready to admit. Indeed, the immense role played by aeration in all Eastern cultivation made him impatient of the Western scientist's slowness to accept the view that plant growth must always be discussed in relation to environment: nothing in the plant could be considered by itself, it must necessarily be related to the surrounding conditions. Of these the first, even more important than water, was the air.

What was the explanation? What were the values derived from the air which made its presence in abundance so indispensable to all growth, so much so that the effects of any interference with the air supply could instantly be seen in the plant? Already in the important lecture delivered before the Board of Agriculture in 1916, when the results of the Quetta aeration experiments were being presented, Sir Albert put his finger on the crucial point. He was arguing on the subject of manuring, and in the light of his later views on artificial manures his words are prophetic. The passage is of great interest.

> 'Once the part played by aeration in crop production is realized, the current ideas underlying manuring will have to be considerably revised. While the application of chemical and other manures has undoubtedly increased production, its very success has worked a considerable amount of mischief and has done much to obscure the real factors on which growth depends. I will confine my remarks to nitrogen and phosphorus, the two substances on which vast sums are now spent or rather wasted.
>
> 'Nitrogen is applied to the earth either as a chemical (sodium nitrate, sulphate of ammonia, or some similar substance) or in the form of organic matter. The best results are obtained by means of the organic nitrogen manures, as these increase the porosity of the soil and help in soil aeration. Indigo *seeth* is the most effective form of organic nitrogen known to me. Now all this expensive nitrogen manuring is largely a mistake. The soil possesses the most efficient nitrogen producers known to science. These are the nitrogen-producing and the nitrogen-fixing bacteria which require for their work organic matter (such as green-manures or farmyard manure), air, and water. Why purchase, at a great price, the fleeting benefits of nitrogenous manures when by draining the land and adding substances like *thikra* (see above, "The Use of Potsherds in Green Manuring"), a crop of green-manure will supply everything that is necessary?
>
> 'Much the same state of affairs exists with regard to phosphates. Phosphates often increase the crop but, in many cases, the results are misleading. It is the fashion to

say, in cases when the effect is beneficial, that the soil contains insufficient phosphates in an available form. Why is this? The answer is to be found in the mycological domain, in the beneficial activity of the soil fungi. These collect phosphates and potash for the higher plants, but they cannot do this adequately unless the soil is well supplied with air. Drainage is perhaps the best and cheapest form of phosphorus just as *thikra* is the best nitrogenous manure...

'The results of the permanent wheat plot at Pusa are simple aeration effects. In this direction we have possibilities of improvement in wheat production which will settle the food supply of the world for generations to come. We need pay no attention to the warnings of the late President of the Royal Society (the reference is to Sir William Crookes' famous address to the British Association for the Advancement of Science in 1898) or to the proposals in a recent issue of *Nature* for a committee to consider the manufacture of nitrates from the air for manuring wheat. Supply air by drainage and other means and the wheat-growing surface of the world becomes of itself a vast nitrate- and phosphate-producing factory... I feel sure that when these ideas bear fruit, a new chapter in the development of agriculture, not only in India but elsewhere, will be opened and the world's production of food and of raw materials will enter on a new phase.' (The new theory of Professor N. R. Dhar of Allahabad University that nitrogen can be fixed abiotically by direct action of the sun on organic matter would explain much in the fertility renewing capacity of Indian soils. This theory is still *sub judice*.)

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Chapter 4
Various Crops and Various Problems

Tobacco

(The work on indigo is discussed in Chapter V on *The Problem of Disease*.)

After wheat, tobacco was the next important assignment during the early years at Pusa. This crop had been introduced by the Portuguese three hundred years earlier. It now constituted the fifth or sixth largest crop in India, covering over a million acres and yielding a harvest of perhaps five million pounds a year. It was especially important in Bihar, the Province in which Pusa was situated.

Two species were cultivated, *Nicotiana tabacum* L., where the climate was warm and moist, and a robust yellow-flowered *Nicotiana rustica* L., in drier, colder parts; only in Bengal and parts of Madras was cigar tobacco grown. While it was an important money crop and very worthwhile, its production was expensive, as it required much nitrogenous manure and frequent weeding and cultivation. It was therefore handled by the best cultivators only and apparently confined to the most suitable soils. This perhaps accounted for its freedom from pests and disease. Only one root parasite (*Orobanche cernua* Loeffl.) was known. (It is particularly interesting that this parasite only appeared when the plant was forced into giving a second harvest.)

While thus ranking as a major crop, the quality of Indian tobaccos was deficient. The product was coarse and suitable for the home market alone; it was smoked in hookahs or made up into snuff. Yet there had been no want of attempts at improvement. Since 1829 the old records abounded in efforts to develop better varieties. Over and over again seed had been introduced from Havana, Virginia, and Sumatra. Expert curers had been engaged. Two Government estates had been leased to a company to stimulate commercial production; one of these had been the Pusa estate itself, and the complete failure of this effort had thrown this estate back into the hands of Government, and accounted for the fortuitous and rather unwise choice as the site of the new All-India Experiment Station.

In spite of the importance of the crop and its money value some rather surprising weaknesses in cultivation methods were prevalent. Careless sowing and above all indifferent transplanting of seedlings entailed heavy losses, so that in some years growers brought no crop at all through the season; there was hardly any rotation, tobacco following tobacco year after year. As usual, all varieties were found mixed in the same field, and, as this plant is capable of cross-fertilization up to about one-fifth of the stand, the confusion of types was inextricable. Above all, there was no attempt whatever to aim at quality. A large harvest was the sole objective and even part of the stalk was illegitimately included in the cured product.

Such was the situation which met the Howards when they undertook this work in 1907. They found some sowings of tobacco on the Pusa farm, made in 1905 and 1906, no doubt continuing the tradition of the old estate. For these seed had been procured from various directions, no selection had been done, and these plants had again been allowed to cross-fertilize.

The usual intensive study of previous literature was made. Not much which was relevant to India had been done. An Italian investigator, Comes, had in 1899 classified and named six varieties. The attempt to assign the many types found in India to these six varieties had soon to be given up. There were far too many intermediates and aberrants. As in the wheat work, the Howards decided that the only thing to do was to start from the beginning and make their own completely comprehensive study of all existing Indian types. It was the second instance in which they committed themselves, perhaps without quite realizing it, to an immense task.

Their aims were, however, quite definite; in later years Sir Albert defined them as modest. All thoughts of competing with the highly organized and heavily capitalized American export market were laid aside; such a project was far too ambitious and could only end in failure. (Later, in 1927, the great success of the cigarette tobacco, Pusa 28, induced Sir Albert to think there might be a possibility of entering the export market.) But at home there was everything to be done. Nevertheless, even to attain the limited aim of improving Indian tobacco for the Indian market, the work would have to be of a fundamental and searching nature.

In commenting on the failure of previous attempts to improve the quality of Indian tobacco by introducing foreign kinds the Howards point out how ill-conceived is such an idea without a complete initial sorting out and classification of existing types, the confusion of which must render variety work nugatory if attempted from so haphazard a basis. Indeed, there should be four stages clearly envisaged: first, to study existing varieties and sort out types; second, to isolate from these varieties pure cultures so as to have the appropriate material for trials and hybridization without which no real work could be accomplished; third, to study the acclimatization of tobaccos from other parts of the world; and, fourthly, by continuous breeding over a number of generations to study the inheritance of characters, a knowledge of which must precede systematic cross-breeding for improvement.

Of these four tasks the Howards embraced the first and second on a great scale. For reasons which will be given below they did not devote a great deal of time to the third. The fourth task led to some prolonged and elaborate work on Mendelian principles. The whole of the work was exceedingly laborious. Every year thousands of flowers were handled, tied into muslin bags, castrated or hand-fertilized as the case might be, the inflorescences counted and labelled, further buds removed, etc., and everything recorded. Mrs. Howard, with her genius for detail, devoted herself to the work; hour after hour was spent in the field, and the excellent health of these years was the reward of an outdoor life unusual in a European woman living in the plains of India.

These delicate operations were actually the final stages of the season's work. An almost equal amount of care had to be expended on sowing and transplanting. The smallness of tobacco seed was found to invite accidental scattering, while its remarkable viability allowed germination anywhere and everywhere even after several years; if stands were not to become mixed no ordinary accuracy was needed. Eventually, in order to forestall mistakes which would ruin the work by inducing cross-fertilization from adventitious plants, the following devices were adopted. The seed was sown in boxes, these being kept moist for six weeks before sowing so as to allow any stray seeds to germinate and be removed; on disuse, the earth was emptied away at a distance and the boxes washed. Between sowing each box and also between thinning each box the boys had to wash their hands. Wire netting and day and night watching prevented damage by animals. By these methods a supply of specified seedlings was obtained without any admixtures.

The next problem was transplanting. The country method was extraordinarily rough and resulted in numerous losses, made good by subsequent insertions of seedlings; this would again have entailed the risk, in experimental work, of taking seedlings from the wrong box. By previous careful watering, and by lifting with a lump of soil attached, then by furrow irrigation, which ensured lateral seepage of moisture but formed no hard lump of soil round the seedlings, so injurious to them, losses were brought down to a minimum. (See previous chapter.)

The result of this detailed work, carried out for three years in the first instance and continued for another three, was the classification of *Nicotiana rustica* L., into twenty, and of *Nicotiana tabacum* L. into fifty-one types. These are minutely described in orthodox botanical terms, with admirable photographs of each type, in the first two of the papers mentioned at the end of this chapter.

In the course of this work the idea was dispelled that variation in type arose with differences in environment, as currently suggested by many American investigators.

Certainly this plant was very sensitive to conditions; changes induced by good or bad cultivation were 'almost incredible'; the same type could produce plants ranging from 1-1/2 to 8 or 10 feet in height; at the same time all variations seemed to be wiped out in poor undeveloped plants, which pointed to the absolute rule for growing normal and well-developed plants for all experimental work. In spite of this sensitivity true morphological change or degeneration was only found as the result of cross-fertilization; the seventy-one types, when isolated and grown from self-fertilized seed under bag, kept extraordinarily uniform, even the smallest morphological details being found constant.

If this were so, a sound basis would be arrived at for improvement of variety by cross-breeding work. This would entail an analysis of inheritable characters. The work was begun and in part completed, but it proved far more complicated than had been anticipated. The study of the extension of Mendelian laws to characters not qualitative but recognized by measurement only was just beginning and the enquiries were carried out on these lines. A prolonged investigation into the inheritance of seven characters in *Nicotiana tabacum* L. and of four in *Nicotiana rustica* L. was made by means of observations on many thousands of flowers, and was placed on record for future workers, the results on *rustica,* however, not until after the lapse of some time. A good many years later one other small piece of academic research was done, but of a negative character, the disproof of the claim that parthenogenesis and parthenocarpy occurred in tobacco. It was to this extent useful, that had parthenogenetic seed occurred, plant breeding work would have been affected.

The scientific work on tobacco must have absorbed an enormous amount of time. More especially was the recording of the facts on the inheritance of characters extremely elaborate. From my own recollection I know that Sir Albert stimulated his somewhat reluctant wife to give herself to these efforts -- one long paper was published under her sole name. He wished her to take her own place in the ranks of science, and certainly these papers must be reckoned to have fulfilled all academic requirements. But I also believe that this work marked a kind of turning-point: that by its very nature and the time it consumed it impressed on both investigators the urgent need for making a choice between the academic and the pioneering principle. They realized the great expenditure of energy which such theoretical investigations must involve, energy which had to be withdrawn from other work, and though, of course, ultimately all plant-breeding work must depend on an understanding of the laws of inheritance, it seemed to them that in the first stages of agricultural investigation -- which, as India was almost uncharted territory, was the position confronting themselves -- the most worth while results could be attained by directing effort to immediate objectives which promised the highest usefulness.

The most attractive aim was perhaps the evolution of a good cigarette tobacco. While after repeated trials, confirming the experience of so many previous investigators, no success was obtained from introduced American varieties, which proved both too liable to windbreak by reason of their height and far too slow in growth to suit the short Indian season, surprisingly enough one indigenous variety was isolated which did not too badly compare in flavour, texture, and colour -- the three important points -- with other good cigarette tobaccos. Later named Pusa 28, this variety largely repaid the immense labour of the selection and cross- fertilization work. It had some most advantageous qualities, proving itself both robust and a rapid grower giving a heavy yield. The product was sent forward for manufacture and stood up to the test. Seed was thereupon propagated and supplied to the growers, who immediately recognized its great superiority. By 1924 enough seed was being distributed to cover one-quarter of the areas devoted to tobacco in India, namely, some 250,000 acres, and thus to maintain a supply of needed material for the cigarette factories which were springing up and catering for the new fashion of cigarette-smoking which was beginning to displace the hookah.

While this rather unlooked for success from a single native variety got by simple selection might be counted as some reward for these prolonged investigations, the emphasis of the work was being completely changed. The very year which marked the publication of the Mendelian researches was also the year which saw the investigators take the situation in hand in quite a different fashion. In the annual address which Sir Albert was for several years pressed to give to the planters of Bihar, a section is included in that of 1913 on tobacco; a longer *Bulletin* was published in 1915. These papers are of a very different character from the previous work. Altogether practical, they are direct, simple, and do not beat about the bush. The local practices are castigated as 'about the worst possible': the local agriculture is, in growing tobacco, 'particularly defective': 'a regular field of tobacco in Bihar is the exception rather than the rule'. Then follows a stream of practical suggestions and advice, covering every point of difficulty, but never such as to go beyond the means of the local planters. And, if proof was needed that tobacco could be grown in Bihar without risk, without losses, and with a 25 per cent increase in cropping over the current average, the planter had only to visit the tobacco beds of the Botanical Section at Pusa, where the well-manured, carefully irrigated, carefully transplanted and cultivated tobacco plants, healthy, vigorous, and of superb growth, were a visible proof of the value of the given advice. (A photograph of a magnificent tobacco field at Pusa is reproduced in the *Agric. Journ. of India*, Vol. VII, Part 1, Jan. 1912.)

The history of the tobacco experiments is interesting from more than one point of view. It drew the attention of the investigators very forcibly to the two critical problems of manuring and irrigation; both the work on green-manuring (see section on green manuring, below) and the perfecting of the system of furrow irrigation had their inception from the growing of this crop. But it also put the investigators into an intimate touch with the Indian planter. The fact that the crop was so badly grown locally was perhaps an accident, which may have had an effect in deferring Sir Albert's general recognition of the skill of the Eastern cultivator; but it must not be forgotten that tobacco, though it had a history of three hundred years in India, was after all an introduced crop. But what clearly impressed itself on his mind was the immediate and grateful response to his teaching. The planters were only too eager to imitate and to buy the improved seed; the innovations at Pusa very quickly became country-wide practice. True, they were always dictated by that peculiar combination of science with common sense which remained the hall-mark of Sir Albert's work, but this readiness on the part of an old community to reform its methods at the given word, simply and plainly uttered but always backed by proved experience, laid the foundation of a most happy lifetime of give-and-take between the trained scientist and the world he was to serve.

Fruit, Including Tomatoes: Sun Drying of Vegetables

The fruit work at Pusa was started even before the work on tobacco, with plantings set in hand on arrival at the Experiment Station, but from the nature of the case only allowed of a slow development. Much the same situation was found as in tobacco, namely, great natural possibilities very indifferently handled by the Indian planters. As long ago as 1863 it had been pointed out what a handsome return would be obtainable, especially in Bihar, by the proper growing of choice fruits.

> 'In India little or no attention seems to have been paid either to the tillage of fruit lands or to the best condition in which the surface should be maintained. Some of the fruit plantations in the country are under grass, others are to a large extent uncultivated, the surface being covered with weeds and grass. In some cases the trees are so closely planted that they form a dense overhead canopy like that of a forest, under which no surface growth is possible. Vegetables or bananas are generally grown between the young trees, the object of the cultivator being to take off the largest crop possible. It is not surprising that under these circumstances the fruit trees have a neglected, stunted, and half-starved appearance. In the older plantations, the thickly planted trees are drawn and spindly and often bear but few fruits. Cultivation is often restricted to one digging in the cold weather, while there is generally little or no cultivation or weeding during the monsoon. The tillage of fruit plantations such as is understood and practiced in Europe and North America is still undreamt of in India. It is not surprising therefore that the produce of the average Indian fruit garden in the plains is so exceedingly poor.'

Not only was cultivation thus deficient, but the adaptation of varieties to different local conditions could hold no comparison with the results achieved in Western countries. The attempt to introduce new varieties had suffered through marriage to the wrong stocks. Nothing had been studied on root systems, and, in general, there had been few experiments of an effective type done by any European scientist. There were, however, a variety of trees to be found in the botanical gardens of the great cities; these gardens Sir Albert made a point of visiting during the first eighteen months of his appointment, thus adding to the extensive knowledge he already had of fruit growing in the West Indies and in Kent. He also used this period to go through all available literature on temperate and tropical fruit experiments in Europe and America.

Meanwhile practical work had been begun in a systematic way. Nineteen acres were selected, on a sloping site, at Pusa for trying out of eleven species of fruit, oranges, citrus, plums, custard apples, loquats, pears, peaches, guava, litchis, mangoes, figs, together with a few odd other fruits ranging from apple to jack fruit. Not everything was easy. Damaging frosts might be expected in January or February and gales could be severe; windbreaks were therefore provided. It is interesting that for the seedlings hedges of Persian rose were grown, with the suggestion that commercial growers could make an extra profit by the sale of roses, thus anticipating the now common practice of our own horticulturists in growing windbreaks of lilac, etc., for cutting.

The difficulties encountered, however, were not so much in this direction as in making a start with insufficient material. It was hard to find enough seedlings, nor were there any records whatever of varieties. To overcome the first hindrance, imports were obtained from France, while with a view to the future a variety plot was started, where a collection was made of 25 peaches, 19 oranges, 4 pumelos, 3 citrons, 5 lemons, 10 limes, 46 mangoes, 9 litchis, 15 plums, and 11 guavas. The question of selecting the right variety for recommendation to growers was of obvious importance, as the late ripening varieties of many fruits would bring them into the monsoon period, which would be hopeless; whereas other varieties which grew well, e.g. loose-skinned oranges, would be unsuitable for packing and transport in a hot country.

More fundamental was the question of stocks for budding. Here some very surprising facts emerged in relation both to cherries and plums. Whereas in a temperate climate almost any stock would be found suitable, in extremes of climate, whether wet, as at Pusa, or dry, as at Quetta, a severe strain would be imposed on the root system of the stock; yet it was on the vigour of the stock that successful fruiting was bound to depend. It was found by budding experiments that, in the case of the cherry and plum, the experience of temperate climates was reversed and that stocks that did less well in Europe were by far the best in India; experiments on budding peaches showed the almond to be the best stock. The results of these experiments were valuable, as much work would have been wasted if carried out on trees budded on unsuitable stocks. The inference is made that all experimental work on fruit in a new country should include preliminary growing of stocks and not merely the growing of trees already budded -- another instance, of course, of the value of going back to fundamentals.

In spite of his labour and attention, and his previous knowledge of fruit culture, Sir Albert records a number of failures in the first few years. The trees had been planted with great care; the windbreaks have already been mentioned; watering was done by pots sunk in the ground, and millet straw shelters were built for each individual seedling to protect it from the fierce sun. Yet green-fly, termites, grasshoppers, and caterpillars all attacked; in the course of 1905, 1906, and 1907 a large number of trees died, while the condition of others was 'pitiable'; the straw shelters attracted rats which damaged the trees.

It was realized that mistakes had been made. Watering by pots was abandoned; it did not give enough water and interfered with symmetrical root growth. In the second year of the experiments, 1906, a revised practice in planting was introduced; the seedlings were planted at the end of the cold weather, in the beginning of February; they made good growth during the ensuing hot months and were firmly established by the time they had to meet the downpour of the monsoon. This proved in practice far better than the orthodox system of planting at the beginning of the cold weather, when the seedlings remained static for many months and easily succumbed to various attacks. But the main point seized was that it was not the sun which was the enemy -- the straw shelters were swept away -- but the water.

Water-logged soil in the damp climate of Bihar was the explanation of much that went wrong. The system of furrow irrigation was introduced (see Chapter III, The Furrow System) and effectually prevented this evil. Here the experiments on fruit ran parallel with what was being learnt from the growing of other crops, proving the supreme importance in tree culture as in all other cultures of paying first attention to soil aeration and drainage. The arrangements were not easy, as trees must be grown on a slope to prevent frost, and this meant an inevitable run-off and danger of erosion with any system of watering or irrigation. Drainage and irrigation experiments had therefore to be supplemented by trying out different systems of tillage, namely, normal cultivation, no cultivation but removal of weeds, and grassing down. Eventually a combination of embanking, good cultivation, and the growing of a cover crop at certain seasons to be turned in for green-manure, proved successful, though some care was needed in the case of the peach not to stimulate the wood too much by manuring; in view of the modern craze for mulching it is interesting to learn that this practice, with a leguminous weed, *busunduk* (*Sophora alopecuroides*), was a pronounced success at Quetta. It is clear that every attention was paid to detail and that an enormous amount of observation was given to watching the growth of the many different species of fruit trees in the experimental plots. Much was once more learnt by trial and error. Thus one attempt to start the budding early in order to be able to deal with a larger number of trees merely ended in disaster -- the seedlings, handled prematurely, died. But in exactly five years, the period always quoted later by Sir Albert as the period of his apprenticeship during which he learnt to grow his crops as well as the peasants around him -- in the case of fruit much better -- he was able to publish an account of very definite results, including the production of peaches 'far superior' to those ordinarily grown in India.

A second set of experiments was started at Quetta, which indeed was named a Fruit Experiment Station. Here from 1912 onwards attention was given to forming a systematic collection of named varieties of suitable fruit trees. All the best local kinds were first secured, comprising 35 peaches, 7 nectarines, 8 apricots, 5 cherries, 8 plums, 5 pears, and 7 apples. To these were added likely kinds from France, England, and America, including 33 apricots, 42 cherries, 45 plums and greengages, 48 peaches, 15 nectarines, and 38 pears. Careful notes and records were made and a very valuable collection of trees was thus established as a permanent Experiment Station asset for future investigators. In doing this work a start had once more to be made from the beginning -- no records of previous work were available.

A rather definite lesson to growers was initiated in the taking over on 1st October 1911 of a derelict fruit garden of fourteen acres. A period of two years was first spent in getting the land into order, fertility being restored by the sowing of *shaftal*, Persian clover. In November 1913 this orchard was planted up with new-budded trees, systematically arranged, an improvement on the completely haphazard plantings of the local growers, which had implied great waste of irrigation, as in order to reach any special tree many others had to be watered. Direct help was also planned for growers in the production of large numbers of young fruit trees, properly budded and pruned, for local distribution. These were never given away, but sold at two to the rupee, so as to ensure that some care would be given to what had cost the purchaser money. The work grew beyond all expectations, and soon reached a quotation of 4,000 to 5,000 trees per annum. By 1918 it became so heavy that Sir Albert encouraged the starting of private commercial nurseries to cope with the demand, so as not to swamp the Experiment Station in routine work.

Some further experimental work was successfully concluded, both on the budding and selection of stocks, but more especially on the relation between green-fly attack and over-irrigation. (See Chapter 5, The Effect of Grass on Trees.) The same principle was also found to govern the occurrence of peach 'yellows', a prevalent local disease; not lack of nitrogenous manures, but simple lack of aeration in the soil, was the cause. This damaging disease was easily cured by a combination of cultivation round the trees and the growing of *shaftal* between the lines.

It was the peach which gave the prize to these efforts. It was peculiarly suited both to Bihar and Quetta. In later years Sir Albert could be heard to declare laughingly that if he could take his listener back to India he would present him with a peach 'as big as a dinner plate'; his test of a good peach was that it should peel in one piece and be perfectly ripe both sides. There is a record of the number of fruits set per tree at Pusa; the average was 3, 500 in 1909 on four-year-old trees; these had to be thinned down to between 750 and 1,000 in order not to break the branches.

The work on tomatoes was as successful as the work on tree fruits, but did not offer the same inherent difficulties, though again the Indian growers made a very poor show of this crop, allowing their plants to trail over the ground with no attempt at training or stopping. The simplest reforms in both these directions produced a harvest in 1912, despite abnormally early frosts in August and September which spoilt at least half the crop, at the rate of twenty-five tons to the acre at Quetta; and similarly good results were obtained at Pusa.

By 1918 the prophecy was justified that 'the uplands of Baluchistan might become the California of India', for it was above all in this blazing desert sun that the fruit could be grown to supply the populations of the plains with their crowded cities.

It was significant of Sir Albert's robust common sense that at the very outset he had recognized that he would have to deal not with one problem, but with two; he would have not only to grow the fruits suitable to India, but would have to find out how to transport them within that country: and this was really the more teasing, though perhaps not the more important, problem. He states that he took it up first, before even embarking on his real experiments, as the expansion of the fruit trade would have to depend entirely on whether the fruit could be properly conveyed. It may be said that he could hardly have inherited a more depressing situation.

> 'In order to withstand the rough handling experienced in all stages of marketing, fruit of all kinds is always picked green and unripe, and at a stage when the full development of flavour is impossible. The want of attention to pruning and the close planting of the trees render the damage in picking much greater than would be the case in modern fruit gardens where dwarf trees are the rule. The crop is often shaken off the branches, either into sheets or else on to the ground. A good deal more bruising takes place when the fruit is heaped up before packing. Padded trays for picking are unknown, and the grading and packing are done on the ground generally under the shade of a tree. There are no packing sheds and no padded packing tables, possibly on account of the national custom of working as far as possible on the ground.
>
> 'The packages used for fruit, even for such delicate produce as grapes and peaches, are for the most part ill adapted for the purpose. Old kerosine oil boxes represent the rigid type of fruit box, while wicker baskets of various sizes and shapes are common. There is a general absence of ventilation in all the packages, a circumstance which probably follows from the necessity of covering in the fruit to prevent theft. The packing material used is often unsuitable -- grass and leaves being commonly employed. These give off water and do not absorb the moisture transpired by the fruit. In consequence, fermentation and decay are hastened. The flavour is often harmed by the want of ventilation, and the fruit sometimes becomes tainted. Other disadvantages arise from the packages used. The upper layers of fruit press on the lower and a good deal of crushing and bruising takes place. The packages are often non-rigid and are pressed out of shape in transit by the weight of others above them.'

The Indian railways which received this fruit at Quetta provided a curious combination of the good and the bad. Excellent ventilated through carriages were available, with specially built shelving, a facility wasted in view of the completely heterogeneous shape and size of the loadings. But when an attempt was made to put good returnable crates on the lines, the resulting charges were not only absurdly high but completely chaotic; nor was there any system of bulk charging by aggregate weight, each package being separately weighed and rated as high as possible; there was also uninterrupted thieving. A very long battle was fought on these questions, into which Sir Albert threw his whole weight and interest, undeterred by the many prophecies that he would achieve nothing. This prophecy seemed to be justified, when in September 1913 these matters were formally debated at the Railway Conference at Simla, with no outcome except to allow that the complaints were entirely correct. However, when three years later, in 1916, the President of the Railway Board, backed by a petition from all the fruit growers of Quetta and endorsed by the Local Government, took the matter up, victory was won; aggregate grouping of consignments was allowed and the return of crates of a specified pattern was to be free. The principal railways in India followed suit. Thus in the middle of a great World War, which was affecting India hardly less than other countries, a notable triumph was won over confusion, inertia, and unwillingness.

The victory would not have been won had not the practical problems been worked out with great care. In no direction was Sir Albert's thoroughness and ability better shown than in the endless details which he devised for the packaging of his fruit; these were throughout considered with an eye to the use of local, or readily available, materials, with an eye to cost, and with a note of prices. He might have been a trader himself, which, indeed, he soon insisted on being and wrung from resistant officials at Headquarters an almost scandalized consent to a trading account at the Quetta Fruit Station -- a good innovation, but outside the tradition of the British Administration in India or of an Experiment Station. It was very successful, ended on the right side of the balance sheet, and taught a great deal to its originator.

In the end, no fewer than seven different types of packaging were invented. Some were elaborate, indeed, we may rather gasp at their elaboration. But they proved their worth, and were, as the facts show, essential. The following passages refer to Pusa and Quetta respectively.

> 'In this tract (Bihar) peaches ripen towards the end of May and the beginning of June, when both the day and night temperatures are high. The air is frequently damp at this time so that the conditions for transporting such delicate produce as peaches are particularly exacting. In 1909 a method of packing was devised and tested by which practically ripe peaches could withstand a journey of seventy-two hours on the railway without deterioration when booked in the ordinary way. Local materials and labour only were used in the work and no artificial cooling was employed at any stage. The packages adopted were round, flat-bottomed bamboo baskets, about 5-1/2 inches high, fitted with flat lids. Into these two tiers of small circular bamboo cells for the single selected peaches were fitted, the two tiers being separated by a flat circular open-work bamboo partition, which could be dropped into the basket to serve as a floor for the second tier of cups. The lid, when wired on, served to secure the upper tier and also to keep the whole basket and its contents rigid. Theft was prevented by sealing the wire with a lead seal... each basket contained about twenty-five bamboo cups and thus served to carry that number of peaches. These baskets were made by the local *domes* for four annas

> each.'
>
> 'Picking (at Quetta) is best done at daybreak as at this time the temperature is near the minimum and the peaches are relatively cool. They are placed, one layer deep, in trays or baskets, padded with *sann.* The wrapping, in thin blue paper, is done on padded tables in the plot. A little *sann* fibre, covered with gunny, provides a good padding on a table for packing purposes. Only the best peaches are selected which after wrapping are placed into the cells with a little *sann* fibre to prevent shaking and bruising during transit. The *sann* should be wrapped round each fruit and the whole should fit well into the cell without any shaking. The paper and *sann* fibre, besides, absorb part of the moisture given off by the peaches during the journey while the open-work nature of the package promotes ventilation. Other materials besides *sann* were tried as packing material, such as peat, cotton wool, and wood wool. None of these proved so cheap or so resilient as *sann.* Sent in this manner, peaches reached Simla in excellent condition and withstood the journey of three days. The transport involved a journey of seven miles in a bullock cart to the railway, the crossing of the Ganges in a ferry steamer, and eight changes between the garden and the destination.'

A first effort with returnable fruit boxes was made at Quetta in 1911. This did not prove successful, partly because the material tried out was found unsuitable (venesta wood and local dwarf palm, *pish,* leaves), partly because the railways made endless mistakes and overcharges. After a visit while on leave in England had been used to study modern fruit packaging arriving at Covent Garden and elsewhere, further experiments were instituted. Five different types of crate were devised, for grapes, for peaches, for the local trade, returnable crates for short journeys and for camel transport, and non-returnable crates for the wholesale trade. The principles were much the same as had been adopted for the bamboo baskets, namely, rigidity of the package, protection from bruising, and ventilation for the fruit. Various changes and improvements were made in the following years, and already in 1912 tomatoes, grapes, and peaches were transported without loss or damage a distance of 1,750 miles on a four days' journey from Quetta to Calcutta. By 1920 seven different types of fruit boxes were on sale at Quetta. The success of the sales exceeded expectations; one type was first placed on the market in 1912, and by 1915, after 4,500 had been disposed of, there was still a demand which it was not possible to satisfy. Even the more expensive returnable crates were in great request when once the Indian railways had been persuaded to handle the traffic properly.

> 'Our experience in... establishing modern methods of fruit packing has brought out two things -- the rate at which time-honoured practices and ideas change in India, and the importance of time and patience in implanting a new idea. When in 1911 we commenced these investigations, we were told on all sides that cheapness was the first condition of success in placing new packages on the market. We were constantly reminded that the grape baskets and old kerosine oil boxes then in use

> were cheap and that they could be purchased for very small sums. When the 24-punnet returnable grape crates were first brought to the notice of the dealers, they were considered too expensive and altogether unsuited to the conditions of the local trade. A few of the more advanced merchants, however, agreed to try them. The grapes were found to travel perfectly even to places as distant as Madras. A change in the attitude of the trade then began to make its appearance. A demand from the more advanced cities like Bombay that Baluchistan grapes should be packed in punnets followed and from that time success has been assured. The difficulty has been to meet the demand rather than to sell the crates. Nothing is now heard about the cost.
>
> 'Time is a factor in India in the introduction of new methods, to which insufficient attention is often paid. This is especially important where trade is concerned. Dealers of all kinds have little leisure and practically all their working hours are spent in details connected with purchase, sale, and finance. Particularly is this the case with the Frontier fruit dealers, whose output of work during the fruit season, considering the means at their disposal, is extraordinary. They have absolutely no time for experiments or for anything else beyond the day's work. To reach such men, patience is essential and they must be given ample time for new ideas to sink into their consciousness.
>
> 'This experience proves that too much attention can be paid to the first ideas of the people of India towards new methods. They are certain to be frankly sceptical at first and to exhibit that conservatism which is so valuable in protecting the race from disaster. The inventor must therefore be prepared for this and when he is fortunate enough to discover a real improvement and the best thing possible under the circumstances, he should resolutely persist in keeping it before his public year after year.'

The First World War, by raising the price of certain imported materials, to some extent interrupted the promising opening secured, but as a survey of methods to overcome trade difficulties it could hardly have been bettered; it was indeed common sense applied to agriculture.

Closely allied to the work on fruit transport was that on the drying and packing of vegetables. The first request came in 1916 from local Army authorities to do something to facilitate a provision of vegetables for men on the march in the arid districts of North-west India. Even in the Quetta cantonment itself vegetables were almost non-existent in the winter, while in the summer they were equally scarce in Karachi and other cities of the plains. Drying by artificial heat was a known European process, but the suggestion now was to take advantage of the heat of the Indian sun.

Merely to slice the vegetables and spread them in the sun, as was done by the country population in some parts with turnips and spinach, was useless. In the work which she now almost exclusively undertook Gabrielle Howard had a project in which her genius for detail found full play. It is necessary to read the two *Bulletins* she soon came to write as a manual of practical advice to commercial producers to appreciate the exactness and thoroughness with which she worked out every stage of the processes required and every item of planning of equipment, cheap and easily procured, but entirely adequate; each vegetable needed slightly different treatment, directions for which were given. Preliminary slicing and paring, in the shade, so as to protect both product and workers from the glare, was followed by a few minutes steaming or scalding. One object was to kill the outer tissues, which accelerates drying; otherwise the effect of quick drying is to cause these to contract, preventing the inside moisture from escaping; such steamed or scalded vegetables also cook better, keep their tenderness and their colour; the first *Bulletin* includes full directions for cooking each vegetable.

The standard set was that the sun-dried vegetables should be almost as appetizing as fresh ones, indeed, scarcely distinguishable from them, and very different from the tough, leathery, brownish product which can be the result of indifferent drying. The drying as carried out at Quetta only took twenty-four hours. After an interval of a week, and careful looking over, the dried vegetables were pressed into bricks, and, as a rule, tinned. The reduction by volume was to one-seventh; by weight 1 lb. of dried product represented from 10 to 21 lb. of fresh vegetables, according to the kind. Thus a week's supply for a battalion on active service would go into twelve kerosine tins, to be carried on two mules. Sir Leonard Rogers, F.R.S., subsequently reported some of these dried vegetables to have antiscorbutic and all to have anti-beriberi properties, which is not the case with vegetables dried artificially.

The first most excellent *Bulletin* was reprinted rapidly and also issued in Urdu. By the summer of 1918 production was in full swing in the Quetta cantonment; in 1919 some machinery was installed, another *Bulletin* giving further directions and all details of costs issued; seven other selling agencies were supplied. The product was exhibited on several occasions and earned a special prize at the All-India Food Products Exhibition at Calcutta in 1918. On his visit to Pusa in 1919, the Viceroy could be informed that, when placed on the market, the orders received were nearly twenty times greater than the available supply.

Grass, Fodders, and Green-manuring

(a) The Making of a Lawn

It is often said that the true farmer does not care for flowers. Sir Albert Howard never devoted himself to the care of flowers. He gave characteristic advice to the horticulturist -- to get a good lawn started and 'to let the flower beds look after themselves'. His judgment that if the lawn were beautiful, the rest of the garden would fit into the general picture without much trouble was a good suggestion, and can be proved by any one who has to start making a garden; the lawn should be the first consideration.

This emphasis on grass was a farmer's emphasis. Certainly in India grass was intensely important and intensely interesting. It was also exceedingly difficult. The only piece of advice on horticultural practice that Sir Albert published in India was on how to get grass to grow so as to make a lawn.

Sir Albert quotes from an old gardening manual to the effect that in a hot country a stretch of lawn is intensely refreshing to the eye and mind. Immediately on arrival at Pusa he decided that he would like a 'park-like lawn' in the Botanical Area. Ten acres of uneven, unsightly, and partly waterlogged ground were taken and converted in nine months into a first-class lawn.

The details of the work are given: repeated ploughing, levelling, grading, picking out of all weeds, bricks, roots; then sowing with *dub* grass on a special method, protection with dried grass cuttings, frequent cutting, weeding, and then watering with a system of improvised iron pipes cut out of sheet iron; top-dressing with well-aerated earth could follow as required; finally, directions are given for the renewal necessary in this climate. Many of the details were copied from work by a previous experimenter.

It would not be worth while to mention this short paper in the present book except that it happens to illustrate a principle which guided Sir Albert throughout his career -- what might be called 'the look of the work'. It was a strong instinct in him to require that all operations should present that kind of attraction which arises out of neatness, order, and symmetry. This is, in truth, an asset in experimental botanical work, that it should look well and be attractive to the eye. The making of the Pusa lawn was clearly conceived as an item which was to tell its story in just this at once obvious and subtle way. A good lawn in India is not an easy thing to achieve, and would of itself convey to the visitor's first glance an impression of good cultivation. It was, like so much that was done by Sir Albert, clever.

(b) The Improvement of Fodder

But it is obvious that the growing of green crops opens up far more important problems than the making of park-like lawns. There are two aspects of a green crop in agriculture, its use as feed for animals and its use as a green-manure for the soil. These two uses run into each other, because the same plant is very commonly first cut for feed and the residue then incorporated in the soil for enrichment. The use of green crops as feed is perhaps the more straightforward topic and may be taken first.

The problem in India was only too glaring. In all tropical countries, where the grass gives out during the hot season, there is for these months a starvation period for the cattle. Where there are also too many cattle on the land the difficulty becomes permanent throughout the year. Add to this that the improvement of pastures is almost excluded by climatic difficulties, while any extension of their area is out of the question as long as there is such pressure of population; the cattle therefore have to depend on cut feed.

> 'The improvement of cattle in India depends largely on a plentiful supply of good fodder. This fact is now being generally recognized and few people are to be found who believe that any real progress can be made in animal production if the food supply remains, as at present, a limiting factor. The first step in the problem is to feed the animals which already exist. The creation of new types and the improvement of the present breeds by selection are matters of secondary importance in so far as the cultivator is concerned.'

Some good work had already been done, such as the introduction of new grasses, or the use of bamboo shoots and the prickly pear for animals. Sir Albert's own start at working on this question was made on receipt of a request at Quetta in 1914 from the Foreign Secretary to the Government of India to find some form of good hay for the Army horses and mules used on the North-west frontier.

> 'The advantage of good hay in the feeding of horses and mules engaged in heavy transport is well known. In India real hay is, however, rare and its place is taken by substances such as *bhusa,* dried grass or dried lucerne, which are exceedingly hard and brittle and which have not undergone the mild fermentation processes involved in the preparation of grass or clover hay... The difficulties of making good hay in an arid climate like that of the Quetta valley are considerable. The extreme dryness of the air, combined with the effects of sun and wind, dry any green fodder with great rapidity and soon render it so brittle that it cannot be handled without breaking it to powder. Such a product cannot be fermented and an operation like baling is out of the question. The people get over this difficulty, in the case of lucerne, by making it into ropes while green. These are afterwards dried in the sun and stored. The product, however, is not lucerne hay but dried lucerne. No fermentation is possible and there is naturally a great loss of leaf involved in the handling of the dried ropes. The product has the further disadvantage that it cannot easily be baled, so that it can only be used locally and is not suitable for an army on active service.'

It was decided to start, not on lucerne, but on a Persian clover known as *shaftal* (*Trifolium resupinatum*). *Shaftal* yielded four crops in the year, three of which could be used as fodder and the last either for seed or as a green-manure. It was free of pests if properly grown, and its growing season was long as it came on early in the spring before lucerne and also went on after the lucerne; another advantage was that it would grow on land not good enough for lucerne, and could prepare the way for that crop by collecting nodule nitrogen. It was thus a particularly useful crop. It could not altogether replace lucerne as, when used fresh, it was apt to cause blowing in some animals. But if it could be made into hay, it would be very valuable.

To overcome the risk of brittleness an elaborate method was devised of carrying out the drying in stages. After cutting it was spread for a day or two, turned, and left another day. When thus half-dry it was heaped, pressed down firmly, and fermentation began; then opened up again from the heaps and carried to the stacks, where further fermentation and drying took place. The sweet smell of clover hay developed and in two months the product was ready to be baled. Everything depended on spreading and heaping at the right moment so as to secure fermentation without overheating, and the process implied experience and judgment.

Arrangements were made for tests by the Army in 1915 and again in 1916. A ration of 3 lb. of *bhusa* and 1 lb. of the *shaftal* hay was found very palatable by the horses, which throve well on it. The second trials in 1916 showed that the mules did better on it than on the usual ration; though they lost a little weight in the second week, by the end of the third week they were 'much finer in appearance than the remainder of the battery mules; coats glossy, less fat, and in every way in perfect condition'. But the most important point for the Army was that there was a saving of 30 per cent in weight in supplies to be carried in these mountain areas; the cost also was less than for the ordinary feed.

Trials on a larger scale were ordered, and in 1917 a successful experiment was conducted to prove that both *shaftal* and lucerne hay could be got into condition for the close baling required by the Army, if the small stacks were watered on the outside with an ordinary watering can, covered with a tarpaulin for twenty-four hours, and then pressed. Sufficient moisture entered, which made the hay compressible. Its good keeping quality was proved when several bales were opened the next year, 1918, and found to be in perfect condition; much later, some bales which happened to have been kept for six years on a veranda at Pusa were found still palatable to animals. The quality of these hays was equal to the very best grades of such fodders made in Europe.

These valuable experiments were brought to the notice of Army headquarters at Simla. But they were of much wider application. They provided the means for solving the terribly difficult question of how to feed the work cattle of the civil populations throughout India.

> 'Anyone who has seen the poor feeding of the thousands of cattle engaged in moving produce over the main trunk roads in the North-west will at once realize how much these fodders would improve the efficiency and reduce the numbers necessary for the work. In urban areas both cattle and horses are underfed and overworked. The numerous dairies springing up in the large towns are producing milk, inferior both in quality and quantity, to that which would be possible if the albuminoid ratio of the fodder could be improved. For famine reserves these baled fodders would be of the greatest use. Such produce is easily stored for long periods, is readily transported and the quantity is easily checked by merely counting the bales. It is highly nutritious and therefore would be a useful reinforcement to such materials as *bhusa* and dried grass, whose function would be the dilution of the leguminous hay.

> 'Once these fodders become general in North-west India, the producing power of the soil is bound to increase. The work cattle will be better fed and the door will be opened for a more intensive cultivation of the land and for the use of heavier and better implements. The country will, at the same time, support a larger population and with the increased production of the soil the prosperity of the people will rapidly improve. Indian agriculture is at present labouring in a vicious circle. The land does not produce enough to admit of the work cattle being properly fed. Without more efficient oxen it is difficult to adopt the simplest cultural improvements. Only the surface of the soil is scratched and only the merest skin of the deep alluvial soils of the plains is made use of by crops. This vicious circle, however, can be broken. Nature in the form of the nitrogen-fixing leguminous fodder crops provides the means. The resources of the State, properly directed, are amply sufficient to utilize the means.'

It was agreed that the drying and baling were not easy. The baling required a press, which was beyond the means of the ordinary cultivator. For the Army three baling stations were set up, and it was suggested that similar stations ought to be started for civil purposes. Meanwhile the very success of the work implied another problem, how to grow the *shaftal*, lucerne, or other fodders for making the hay.

> 'Although there is a great field for botanical work in fodder questions, it must not be forgotten that there are limits to what can be accomplished by plant breeding alone. There is not much hope of producing, either by selection, hybridization, or introduction, the ideal fodder plant, namely, a crop which will give a large out-turn of nutritious, succulent fodder with the minimum; amount of water, which will thrive during that part of the year when all other vegetation ceases to grow and which can be easily preserved without loss or trouble. The evolution of such a type is probably beyond the powers of any botanist. Much, however, can be done by selecting better varieties of existing fodder crops, but the improvement will be one of degree only. A much larger field of investigation lies in the determination of the physiological needs of such crops and the consequent improvements in methods of cultivation... and it is probable that the best solution will be found (where water is available) in the intensive cultivation of fodder crops on a small portion of the holding.'

This ideal of intensive cultivation, with the use of the smallest feasible areas of land, was held in mind. There were two great natural assets -- the intense solar energy of the climate and the quick vegetative growth characteristic of the tropics. Two sets of experiments were carried out, the first set at Quetta in 1915 and 1916, parallel with the drying and baling work, and a subsequent set at Pusa from 1921 onwards. At Quetta *sulla* (*Hedysarum coronarium*) and *berseem* (*Trifolium alexandrianum*) and an annual red clover (*Trifolium pratense*) had been tried as well as the *shaftal*, but rejected for various reasons. While the general trend of the experiments with *shaftal* showed the importance both of soil aeration and of manuring, too much manuring was not resorted to. It would no doubt have been very successful and given very heavy cuts, but the supply of farmyard manure at Quetta among the cultivators was strictly limited, so that there was 'no point in discovering improved methods which cannot possibly be applied'. But by some manuring and intensive cultivation good crops could be secured, in 1915 five cuts were taken off land manured at twenty tons of manure to the acre.

At Pusa the cultivation of lucerne was pursued; these experiments completed those on the *shaftal* at Quetta. Considerable improvements in method were initiated. A system of flat beds instead of the usual ridge cultivation proved most successful. Higher yields were got. These experiments are interesting as they seem to be the first where 'leaf compost on the Chinese system' was applied to any crop. The effect was unprecedented: an increase of 50 per cent of yield in 1921 and of another 70 per cent in 1922. By means of these compost dressings lucerne, which ordinarily behaves like an annual in Bihar, could be made to behave like a perennial and yield the much more luscious fodders which are the result of a second and third year's growth.

Another small piece of work on the substance already mentioned as *bhusa* was carried out at Indore. *Bhusa* consists of the stalks and chaff of wheat, barley, rice and various millets. It is a very dry feed, and while the all-digesting buffalo will consume it freely, it is not the most relished food for draught oxen.

A fifty-year-old paper by a Mr. Jonas in the *Journal of the Royal Agricultural Society of England* (Vol. V, Second Series, 1870, p. 119; commented on by Dr. Voelcker, F.R.S., the great authority on Indian agriculture, in Vol. VII, p. 85 of the same journal) gave the clue to improvement. Experiments were started in May 1926 in fermenting this chaff, as recommended; a small proportion of green maize and some salt were added to start fermentation; further experiments suggested the omission of the salt and the addition of only about 1 cwt. of the green stuff to 1 ton of the dried. The mixture, fermented for thirty-five days, not only proved on chemical analysis (analysis given in the source mentioned at the end of the present chapter) to be much richer than the *bhusa* in albuminoids, sugar, and digestible fibre, but what was in Sir Albert's eyes the most important test -- the test by the animal itself -- it was eaten 'with avidity' by sheep and cattle. The programme of work at Indore did not allow of a continuation of these interesting experiments, but the results were communicated to the Indian Science Congress in 1927 with the expressed hope that they would be followed by further investigations elsewhere.

The way was thus shown, in the making of real hay out of unpromising material, in improved methods of growing lucerne, in improved methods of preparing the dry feed, for a complete solution of the feeding of the animal in India. There was still, no doubt, a great deal to be done. Each fodder plant needed separate study and the optimum conditions of growth had to be established. In summing up this topic some years before he left India, in 1924, Sir Albert declared that the advances he had shown to be possible were 'the merest beginning in the intensive cultivation of fodder crops in India'; but on the face of it there was no inherent reason why this problem should not be solved. Actually one final, very useful piece of work was carried out before leaving the country, in experiments carried on in 1927 and 1928 in making silage out of the *juar* crop; this was done in the first instance in order to feed the Experiment Station animals, and proved so successful that it was introduced to the notice of the Indian public. In later years Sir Albert stated that he saw in the making of silage a solution, indeed, the only complete solution, of the problem of animal feed in the hot weather in tropical countries.

(c) Green-Manuring

The other use of a green crop, as a manure when cut and incorporated into the top layers of the soil to enrich it, is not less important than its use as a feed for animals. As is common knowledge, the first formal experiments on this subject were carried out in the 1880's by Schulz-Lupitz on the sandy soils of North Germany, since when the subject has continued to be a matter for scientific investigation. (There is an interesting discussion of the principles involved in green-manuring in *An Agricultural Testament*, pp. 87-95.) But long before these formal investigations the practice of green-manuring had been known. In Eastern agriculture green-manuring was a very old practice and almost universally applied.

It admitted of considerable extension, and, in fact, was being investigated by a number of European scientists in India.

Very soon after he began to grow the Indian crops Sir Albert came to the conclusion that organic matter in the right condition was the limiting factor in success. It was usual in growing tobacco, which needed heavy manuring, to use *seeth* (the wastes of indigo) or oilcake if cattle manure could not be got. All three manures were very expensive, and this expense was deterrent to the growers. It happened that, for another purpose, early sowings had been made in 1906 of a hemp, *sann* (*Crotalaria juncea* L.), this was for the purpose of investigating fibres suitable for the home and export markets. (See Fibres, below.) But *sann* had also a use as a green-manure, though the possibilities in this direction had been very imperfectly explored. Certain adjustments were desirable. It had been found difficult to get the hemp completely rotted and incorporated into the soil before the cessation of the monsoon led to invasions by white ants, which were only too easily attracted away from the rotting manure to the crop. But 'a little care and forethought' suggested earlier sowing of the *sann* in May or June, ploughing in during the first week in July, and thus complete decomposition before the end of September. This was tried during the next three years.

> 'The effect of a successful green-manuring is extraordinary. The texture and colour of the soil are altered, heavy lands become easily workable and readily yield a good tilth. The effect on the next few crops is wonderful both in luxuriance and also in rapidity of growth. On tobacco, the land for which is left fallow in the

> monsoon, the effect is greater than that of a heavy dressing of farmyard manure... Besides the advantage in rapid growth the *sann* plots of tobacco at Pusa in 1909 gave a much greater yield per acre than the plots manured with cattle dung, rape cake, or old tobacco stems. Further, the green-manure plots ripened off earliest of all.'

Thus the way was shown for a good cheap manure, which had, in fact, always existed, but the advantages of which had been obscured by faults in agricultural practice.

But if it was important not to incorporate the *sann* into the soil too late, it was equally important not to do so too early; too long an interval between the decomposition of the green-manure and the sowing of tobacco produced a very stunted crop. This was realized accidentally as one of those observations in the field which were so often the basis of the Howard ideas. The point was at once seized on, and confirmed by direct experiment in 1910 and again in 1913.

The striking results obtained from the use of *sann* as a green-manure were brought to the notice of the Bihar tobacco planters and widely copied.

Another set of experiments on green-manuring was carried out at Quetta with *shaftal*, mentioned above as the clover which gave a good hay. In fact, the cultivation of this clover had not started with a view to the making of hay for animals, but as a substitute for lucerne in green-manuring the soil. Lucerne, it was pointed out, remained in the ground some five to six years (not at Pusa; see above, [b] *The Improvement of Fodder*); in order to teach the population round Quetta the use of a green-manure, some annually available leguminous crop was needed. *Shaftal* admirably fitted the programme. It had an excellent root system, both a tap root and fine laterals, and was a first-class natural 'plough' for breaking up the soil. It was the best of the four plants tried out for this purpose. Even without being ploughed in, this root action gave elasticity to the sandy soils of Quetta, so liable to pack; when cultivated after the last cut the soil improvement was so marked as to yield heavier crops even than those within the three-mile radius of the Cantonment, where all manure was compulsorily put into the soil, as Army health regulations did not permit of it being stored. The soils green-manured with *shaftal* round Quetta required no more manuring for some years.

In commenting on the use of green-manure to restore soil fertility depleted by continual cropping, Sir Albert notes that this was a century-old practice in India. Whereas Western agriculture had only accepted it towards the end of the nineteenth century after thirty years' controversy, it was part of the fixed routine of the Orient. The scarcity of animal manure forced this method on the Eastern peasant.

Sir Albert was conscious of this problem from the first moment of beginning to cultivate his crops at Pusa. In the course of a few years he saw in it one of the biggest questions he had to handle. Although the local methods he found in use were, on the whole, good, they were not sufficient. Two special difficulties drew his attention, one at the beginning, one towards the end of his career. With the decline of the cultivation of indigo in Bihar the supply of *seeth*, the indigo residues, which was one of the best green-manures used, was getting short; this was one of the reasons for the introduction of *sann* manuring. Meanwhile in quite another part of India, in the newly opened up Canal Colonies of the Punjab, the employment of a green-manure had been neglected. Sir Albert makes a comparison between the agriculture of these Colonies, as first carried on, and the 'soil mining' of the North American continent. As in America, the virgin land opened up by the new canals was rich; the peasant was tempted to take off crop after crop of wheat, cotton, and oil-seeds, which meant money. For a time all went well, but before leaving India Sir Albert issued a warning that with the rapid depletion of these virgin soils production would fall unless the practice of green-manuring were established in these zones as elsewhere in the country. This comparison between the two agricultures, apparently so different, is of great interest.

It is now becoming generally recognized that tropical soils are far more vulnerable than was at first realized. The explanation is quite simple. In tropical climates the intensity of solar energy and the concentration of atmospheric precipitation over short periods stimulates massive vegetative growth, with the consequence that the mineral reserves are present in a high proportion in the growing plants themselves as compared with what is left behind in the soil; in temperate climates, growth is less luxurious, being checked by climatic factors, less reserves are held above the ground in leaf and stem, and more are left in the soil; there is a thicker layer of humus, replete with every kind of reserve, which forms an almost indestructible safety zone. The situation is therefore exactly the reverse, and allows of great elasticity in Western farming. Those accustomed to the coaxing and persuasion which has to be used to get the green crop to come up in the West are apt to be deceived by the easy luxuriant growth of the tropical forest and to deduce from it a vast store of wealth in a tropical soil. The mistake has been universal and has given rise to the legend of the inexhaustible lavishness of Eastern natural resources; it is only lately that we have begun to find out that Africa, for instance, is a poor proposition from the husbandman's point of view.

The scientists who proceeded to India under Lord Curzon's scheme were mostly too well trained to fall into this popular error and were well aware of the problems awaiting them. They had no delusions about the richness of the soils of India. Sir Albert seemed pre-eminently to have been conscious of the delicacy of these soils. He could not but notice how careful were the peasants in carrying out soil conservation practices. The very first crop which he investigated, wheat, he found practically never growing alone, but always accompanied by some plant calculated to restore the nitrogen supply on which wheat makes such heavy inroads, some pulse or even a weed. (See Chapter 2, The Conditions.) A most interesting illustration of this law of compensation between plants was observed in his own work at Pusa. In 1915 a field of wheat was sown, three lines of wheat separated by one line of gram, a pulse; the superior growth of the two outside lines of wheat, which were next to the lines of gram, was so marked that weighings of grain were made when harvest came round; the result was to show that the outer lines of wheat had given a harvest 34 per cent higher than the inner lines. The paper is entitled 'Mixed Crops', and was a signal little confirmation by a scientist of the truth of empiric practices. Then there was the almost universal use of a deep-rooting crop, especially of the pigeon pea, for breaking up the soil; the result was, of course, to induce aeration, the extreme importance of which in the soil could never be sufficiently stressed.

The practice of green-manuring, together with these other allied practices, constituted, in fact, an introduction to the whole wide problem of the nitrogen cycle. Any green-manure, especially if a legume, is an agent for catching the nitrogen out of the atmosphere and donating it to the soil. The significant point is that the Eastern peasant, without scientific awareness of the natural technique of the legume nodule, should have evolved such excellent ways of taking advantage of this natural machinery. In India he had even gone further, and in his cultivation practices had evolved other means of getting hold of the atmospheric nitrogen; thus his rice culture seems to have been a very able adaption of the growth of the nitrogen-fixing algae on the water of the paddy fields to restore the annual nitrogen supply.

This idea that other agents besides the legume can be used to catch atmospheric nitrogen is at the present time somewhat to the fore; it is realized that the nitrogen-fixing soil bacteria can be stimulated to extra activity. Any practice to induce such soil action will be a supplement to green-manuring. Here again the Indian peasant had preceded the Western scientist. Much of the careful cultivation carried on by him had precisely this effect; an interesting instance was the three-year fallow allowed in Sind and Baluchistan between crops of millet; in Sind heavy crops of millet, which is a nitrogen-consuming plant, succeeded each other without any manure beyond the intervening period of rest. The results of this system were 'striking'. Whatever the precise practice may be, the general principle is the same: the soil bacteria are sterilized by some means, but spores survive, and those of the nitrogen-fixing strains seem to have the faculty of very rapid re-multiplication, thus restoring the energy of the soil. Sterilization in Western countries is usually carried out by artificial means, but the Indian sun is so strong that the sterilizing effect is a natural one provided that the soil is cultivated in the hot weather. This empiric practice, which attracted Sir Albert's attention, was confirmed by some early field experiments at Pusa; they were promising and drew the notice of the Indian planters; once again science followed on traditional practice, but explained it and reasserted it. (*Report of the Board of Scientific Advice for India, Economic Botany,* 1909-10, p. 4.) Ten years later, at Quetta, remarkably good results were obtained on three acres continuously grown with wheat for six years from 1912 onwards without manure; the only treatment, in addition to a single irrigation, was to take care to plough up the stubble and expose the soil to the sun and air for the summer months.

> 'The yield in 1919 was just under 20 maunds per acre, the highest so far obtained.

> Results such as those quoted... indicate that alluvial soils, if properly managed, do not require large quantities of organic matter to keep up fertility. That such yields can be obtained at all indicates that nitrogen-fixation in these soils must be much greater than is commonly supposed. The results obtained in the Botanical area at Pusa and on the seed farms in the United Provinces clearly indicate that any fears of soil depletion in the plains of India are groundless. Increased rather than decreased yields are to be expected as surface drainage is improved, as erosion becomes checked, as the texture of the land is improved by the extended use of suitable leguminous rotations and as the conditions necessary for nitrogen-fixation are elucidated and applied.'

A pessimistic view of the soils of India was therefore quite uncalled for, provided that full use were made both of the leguminous crop and of the nitrogen-fixing bacteria -- it will have been noticed that these are coupled together.

Nevertheless, nothing like all the latent fertility of these soils was being put into circulation. There was need for more understanding of soil aeration, of better control of irrigation, and other improvements. If these could be adopted a far greater depth of soil could be brought into use; as it was, 'only a few inches of the surface soil, especially of the great plains, was being used by the cultivator'. It was in such directions that Western science could do much for the Indian peasant.

Fibres

Three species of fibre plants were studied during the early years at Pusa, *Hibiscus cannabinus* L. (Deccan hemp), *Hibiscus sabdariffa* L. and *Crotalaria juncea* L (*sann* hemp). In the course of these studies important contributions were made to botanical knowledge.

Sowings of the hemp, *Hibiscus cannabinus* L., were started at Pusa in 1906 and repeated in 1907. In all, seven samples of seed were obtained from Madras, Bengal, and Lyallpur. A confusion of varieties, quite distinct from each other, emerged. As both self- and cross-pollination occurs with this plant, very careful and tedious hand operations had to be undertaken. By 1910 five varieties comprising eight agricultural types had been isolated. These are described and illustrated in coloured plates in the second of the two papers mentioned at the end of this chapter.

All this was new, and the authors were astonished at their own results. (The claim of the Howards to have been the pioneers in sorting out the botanical confusion of these varieties has lately been accepted by Mr. A. E. Haarer in his book *Jute Substitute Fibres*, 1952, pp. 93 *et seqq.*) They had consulted all possible authorities, had sent to Kew and the Calcutta herbarium and Calcutta India Museum, had, when on leave in 1910, examined the collections of the Linaean Society in London. It appeared 'almost incredible' that the existence of such well-marked distinct varieties should have escaped attention in view of the fact that the value of this fibre and the plant was described in all the books, both recent and older, dealing with Indian economic plants. But so it was.

Besides this important addition to orthodox knowledge another point was established. It would be useless to isolate these new valuable types unless some means could be found to prevent cross-fertilization under Indian conditions: it could not be assumed that inferior varieties might not be grown within range. The problem was one which was bound to be encountered in the cultivation of a number of crops, some of importance, cotton, for instance. The solution, in the case of hemp, was not difficult. The young seedlings presented obvious visual differences, which allowed of roguing out the aberrant types by hand. Indian workers could be trained to do this at two stages of growth. A little common sense and care solved a very considerable problem.

This type of hemp was quite an important crop in India: it was used for making string and rope. In growing it was remarkably sensitive to waterlogging and was therefore usually cultivated along the edges of fields. An export trade did not seem impossible, especially as one of the types isolated in pure line, Type 3, showed great robustness, vigour, and capacity to set seed. Indian methods of retting were not very satisfactory, but a little extra care secured the even retting which was so important in offering products on the export market. A sample thus prepared was sent to Messrs. Wigglesworth, world importers of fibres for the London market, and was welcomed by the senior partner as 'the best specimen of fibre from the *Hibiscus cannabinus* plant which has ever been submitted to me'. Its selling price was estimated at £18 per ton as compared with £8 per ton of another indifferent locally produced Indian sample, and was judged to be capable of sale 'in almost unlimited quantities' (1914).

Similar investigations on other fibres, *Hibiscus sabdariffa* L. and *Crotalaria juncea* L. (*sann* hemp) established the existence in these cases also, of an unsuspected range of varieties. These were named, described, and illustrated. The *sann* hemp proved of great use as a green-manure and is discussed under that heading.

Oil Seeds

The oil-seed-bearing plants of India constituted a valuable group of money crops. There was a considerable export, on the consequences of which there was a great deal of discussion during the period of Sir Albert's career in India. He did not agree with the view that this export was dangerous to India; the amount of fertility sold away from the country was, in his opinion, compensated by that nitrogen-fixing capacity of the soil organisms under a tropical sun noted above in the section on Green-manuring. This opinion was based on the fact that, if this automatic replacement of nitrogen had not taken place, the soils of India would have been exhausted long ago and the cultivation of these crops would have come to an end. To retain more of the harvest in India itself would certainly be an advantage, but there were considerable difficulties in altering the balance of trade. (Discussed in *Crop Production in India*, pp. 147-50.)

In the growing of these crops, the aim would be quantity of harvest; quality, in this instance, mattered little. Of the plants common to India, safflower (*Carthamus tinctorius* L.), mustard (*Brassica juncea* H.f. and T.), and linseed (*Linum usitatissimum* L.) were those that principally engaged the attention of the Howards. Investigations were started early in 1908 and came to be spread over a number of years.

The work was mostly devoted to the isolation and botanical description of types. Two very long illustrated *Memoirs* were published on twenty-four types of safflower, 121 types of linseed; of the 102 types of mustard only a shortened description was given. The labour of description was immense and the plant selection and breeding prolonged.

This work of classification and identification was, like the similar detailed work on wheat, tobacco, etc., pioneering work of importance for the study of Indian botany. Nor was it exclusively systematic, for it led on to further questions of the replacement of inferior by better varieties, which involved a knowledge of the details of cross-fertilization, of vicinism (effect of the growth of two different varieties side by side which accidentally cross-fertilize or 'contaminate' each other), and of the survival of older seeds in an area to be sown with a newer variety. On the question, for instance, of replacing the widely sown safflower by better kinds Sir Albert was pessimistic. The extraordinary viability of the seed permitted of germination for years, as was proved by observation at Pusa. Some seeds were always shed at harvest, so that no field could avoid contamination, which meant that no type could be grown in pure line; there would always be vagrant plants to cross-fertilize, and the new type would speedily be lost. With other crops this problem of contamination could be surmounted by careful roguing or selection of seed, but with this persistent plant it seemed hardly possible.

On the other hand, in the growing of linseed there were prospects of success. Actually three valuable types were isolated at Pusa and the seed distributed to growers. The results on this crop were entirely satisfactory.

In the growing of linseed the adaptation of root systems to different soils was intensively studied, and much light was thrown on the question of the relations of plant type and soil type. Other problems of general bearing were touched on rather than finally pursued, but the point was observed that the castor plant, bearing the castor-oil seed, was vigorous if grown alongside of other crops, in mixed culture, according to the prevailing Indian custom, but became subject to violent caterpillar attack when grown alone. This interesting instance of the saving principle of mixed crops, to which the ancient practice of the East so notably conforms, may be noted. Sir Albert suggested that an explanation would throw light on the mineral requirements of the plant. The question of the mineral interrelations of the roots of plants still, however, awaits solution.

Studies on Pollination and Cross-fertilization

It would not be possible to summarize the whole round of investigations, enquiries, experiments, and observations made by Sir Albert Howard and his wife on the various crops of India. Not every enquiry resulted in a published paper on a named crop. It is not going too far, however, to say that practically all the staple crops of the East (not forestry crops, and not coffee; tea was investigated in a special later journey in 1937-8) came under their notice in one way or another. Thus, though no actual experiments on rice were carried out by the Howards, yet Pusa was situated in a rice-bearing tract and Sir Albert remained extremely observant of the growing of this crop. All the other grains of the East, including gram, on which a long special *Memoir* was published, were grown by him, as also were the pulses, the opium poppy, ground-nuts, pigeon-pea, and jute. On sugar cane he remained in the closest touch with his friend Mr. George Clarke, and had, in fact, grown this crop in the West Indies. Very fundamental experiments on cotton were started at Indore.

All this gave rise to much reflection, and a good deal of writing, on the important subject of pollination and cross-fertilization; many references have been made to this already. Some formal and intricate studies were carried out in reference to hemps, pigeon pea, the indigos, linseed, jute, and also eventually cotton. It is almost impossible to give an idea of this extremely careful and elaborate work, which occupies pages of botanical description, the result of hours of labour in the field, in a number of papers. The work had originally started from the surprising discovery that, whereas in the damper climate of England, natural cross-fertilization of wheat is the very rarest phenomenon, in the drier parts of India it occurs with moderate frequency. Hence the extraordinarily mixed character of the Indian wheatfields.

The facts were of paramount importance because, in the substitution of better varieties, the first necessity would be to avoid future cross-fertilization; otherwise the whole work would be undone. It has already been stated in the previous section that in regard to a crop like safflower, the difficulty was insurmountable. But in wheat, linseed, tobacco, etc., it was merely a question of organizing the seed distribution properly. The principles advocated by Sir Albert were (1) to call on the more progressive farmers to grow the new seed supply on farms which were supervised by the agricultural officers -- in this way enough seed could be made available at any given moment to supply a really large area and so exclude contamination; (2) whatever the size of the area chosen, to concentrate on it and never to disperse seed. These principles were adopted throughout India with the very loyal co-operation of the Provincial services.

The problem of cross-fertilization did not, however, end at this point. There were further issues. It has already been noted that, at a very early stage, Sir Albert guessed, rather than knew, that the prevailing mixture of varieties in the wheat-stands of the ryots kept up the vigour of the wheat crop of India (See Chapter 2, The Breeding of the New Wheats), a crop which had been growing for over two thousand years and yet showed no sign of real degeneration, even if the varieties maintained were not the best.

Quite at the end of his career another important piece of evidence on this vital problem was secured. In starting the work on cotton at the Institute of Plant Industry, Indore, it had been part of the arrangements that fundamental investigations on cotton should be instituted like those which had led to the improvement of wheat; the Institute, as has already been mentioned, was largely supported by funds derived from the Indian Cotton Committee. These investigations were at once put in hand, and gave rise, as was expected, to prolonged work; as usual, the varieties of cotton had to be sorted out from the beginning and pure lines obtained.

Cotton is mostly a self-fertilized plant, and cross-fertilization is limited to 5 to 15 per cent only of the crop. The experimental work proceeded on the basis of selfed cultures; 'very promising' pure lines were obtained. These bred true, matured early, and possessed the desired type of fibre.

It appeared almost as though the cotton work of Indore was going to rival the rapid breeding of the famous Pusa wheats

But Sir Albert was on his guard. He had learnt a good deal from the work on indigo and the break-down there of varieties. Careful observations were kept, and in the fifth year of the breeding programme (1929) the first signs of the falling off of vigour in the selfed plants was observed. The indications of the next year, 1930, left no doubt on the point. When Sir Albert retired in the spring of1931 arrangements were made to carry on the selfed cultures for some five or six years, so as to establish the facts beyond question.

The difficulty, though of importance to plant breeders, can be surmounted. It means that no one pure line can be used alone for breeding where this phenomenon occurs, but that two or more of these will have to be crossed. As Sir Albert put it, 'crossing in cotton in the future will have to be controlled rather than prevented'.

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Sir Albert Howard in India

By Louise E. Howard

Chapter 5
The Problem of Disease

The Theory of Disease Resistance

The theory of disease resistance in plant, animal, and man, which is associated with Sir Albert Howard's name, goes back to his University days, when at Cambridge he first listened to the teaching of Professor Marshall Ward, to whose presentation of the problem of plant disease he always acknowledged himself indebted. The master idea, that freedom from disease is secured by the living organism's natural capacity, if in good health, to repel attack, and its inevitable decline and defeat in the face of the bacterium, virus, fungus, or parasite if any way weakened or out of condition, began to formulate itself in his mind in the course of his first years of work in Barbados and at Wye College. (*Soil and Health Memorial Number*, 1948, pp. 4-5.) During his Indian career, when called on to deal with a number of cases of crop diseases, some causing great economic loss, he surrendered completely to this conception, displaying a startling indifference to the presence of any immediate agent of disaster such as a fungus or parasite; in one case it amused him to prove that a presumed parasite was a mythical creation.

Investigation of the problem of disease has almost always concentrated on a study of the organisms which succumb to, not of those which overcome, attack. This was true when Sir Albert started his work. At that time prolonged attention was being given to the deficiency diseases on which a great deal of information was being accumulated in the field of human health, while the veterinarian was much occupied with the facts of parasitic attack and the botanist began to study viruses; these fields of research seemed very worth while, nor was it realized that they had one common defect -- they dealt with defeat and not with victory.

The development which Sir Albert Howard gave to the tentative idea originally thrown out by Professor Marshall Ward was notable. It is due principally to Sir Albert that the conception of resistance has been substituted for the conception of susceptibility. Sir Albert was pretty firmly in the saddle and had covered a good part of his course when Sir Robert McCarrison's reports on the healthy Hunzakuts of Gilgit in the Himalayas began to be known. These investigations were so immediate and so fundamental a confirmation of the resistance theory, pertaining moreover to the difficult field of human health, that they are rightly regarded as an integral part of the general structure. The names of the two investigators have since then gone forward together.

In addition to turning round the whole subject, to our very great advantage, Sir Albert Howard extended the field of inquiry. By doing so he completed a hitherto incomplete formulation of the problem: he filled a scientific gap. By adding the soil to the factors to be taken into account in sorting out health and disease, he carried the chain of evidence back to its real starting point. Until the life of the soil was included in the general theory of health, that theory was a very lame dog indeed, for the best part of the facts were left out. Sir Albert's standpoint can be stated in a very few words. It is extremely well known but will bear repetition until men are convinced of its truth. Such is the theory very simply stated, founded on a lifetime of the closest observation of crops and stock.

Sir Albert believed the explanation of 'this chain of health' would be found to lie in the passage of the complicated protein molecule from the lower to the higher organism. The bio-chemical elucidation of these processes carries us into quite another department of science, where Sir Albert never dreamt of himself as competent; he pointed once or twice to apparent changes in the plant sap accompanying attacks of plant disease, and once caused some chemical analyses to be made (See below, The Spike Disease of Peach Trees); otherwise he contented himself with indicating what a huge field of enquiry lay in front of the bio-chemist in this direction. But he was convinced that the truth was sufficiently clear in outline from what was already known: that the main points of his statement would hold and were of importance, both as indicating a fresh start for all our nutritional studies, and also as pointing to an era of practical reform in human health which would greatly add to the benefits which science had conferred on mankind.

It was by the favour of Providence that Sir Albert found himself a botanist. In dealing with the vegetable kingdom he enjoyed two advantages. In the first place, the idea of resistance to disease among plants was accepted; it was wholly linked up with the choice of the right variety, and was conceived in a very restricted and limited way as resistance to some specific disease like rust, not in the least as a general plant attribute. It was thus a much narrower conception than that on which Sir Albert came to rely. In the second place, by dealing with crops Sir Albert enjoyed freedom of action. The question was originally posed by Marshall Ward: what would happen if we allowed disease to run its course? What would stop it and where would it stop? But deliberately to allow disease to run its course is not easy where animals are concerned, as, apart from capital loss, too much suffering is involved, and is obviously quite impossible where human populations are affected. The plant is the only live organism on which we can freely try out such watching experiments. Yet to watch the course of an unchecked disease was in Sir Albert's view the only way of understanding it and therefore the shortest road to victory.

It is curious that, in spite of this obvious advantage accruing to the botanist, the study of plant diseases should at this time have been lagging behind the study of animal ailments, a fact commented on at a meeting of the British Association for the Advancement of Science in 1911 by Professor Bateson. The passage was cited by Sir Albert in one of his contributions to the *Agricultural Journal of India*, and indeed is so pertinent that it may be given here.

> 'Nowhere is the need for wide views of our problems more evident than in the study of plant diseases. Hitherto, this side of agriculture and of horticulture, though full of possibilities for the introduction of scientific method, has been examined only in the crudest and most empirical fashion. To name the disease, to burn the affected plants, and to ply the crop with all the sprays and washes in succession ought not to be regarded as the utmost that science can attempt. There is at the present time hardly any comprehensive study of the morbid physiology of plants comparable with that which has been so greatly developed in application to animals. The nature of the resistance to disease characteristic of so many varieties, and the methods by which it may be ensured, offer a most attractive field for research, but it is one in which the advance must be made by the development of pure science, and those who engage in it must be prepared for a long period of labour without ostensible practical results.' (Quoted in the *Agricultural Journal of India, Special Indian Science Congress Number*, 1916, pp. 22-3.)

Resistance or Immunity

The 'long period of labour' foretold by the speaker was indeed to fall to the lot of the man who quoted these prophetic words. This labour was to constitute itself as a series of lessons which forced themselves on his attention. Sir Albert Howard did not start with a theory of disease, he was compelled to acquire it. At point after point Nature challenged him with puzzles, to which he had somehow to find an answer: each puzzle led to another. That was why the theory became so firmly fixed in his mind; it was won slowly and after much consideration, reflection, and work.

The first lesson was to learn that the current ideas of resistant and non-resistant varieties of crops was much too cut and dried. It had been assumed that a resistant variety would retain its accredited degree of resistance whatever the circumstances; on this principle plant breeding could proceed merrily indeed. It was a shock to find that nothing of the sort could be depended on.

> 'The disease-resistant variety... at the present time, is a very fashionable remedy, particularly against wheat rust. As is well known, the unit species of the wheat crop

> differ greatly in rust resistance. By the substitution for the general mixed crop of a rust-resistant variety we can sometimes successfully dodge the disease. If, however, we pursue this matter further we find what at first sight appeared to be a solution of a difficulty is nothing more than an extension of the problem. It was soon found that rust resistance varies according to locality and to the way the crop is grown. It is not a hard and fast character. Thus at Pusa a unit species with a fair degree of resistance, when grown (1) in flower-pots, (2) on heavy land with deep cultivation after the rains, (3) on heavy land without deep cultivation after the monsoon, shows great differences in the amount of rust. In flower-pots (good aeration was secured through the sides of the pots) and after thorough preparation, the rust attack is negligible. When sown in land badly prepared, the same variety is sometimes destroyed by rust. The amount of damage by the fungus appears to increase as the physical texture and aeration of the soil fall off. The amount of rust on wheat therefore depends first on the kind and secondly on the way the kind is grown. Our problem therefore is already ceasing to be a simple one.'

Much more startling was the discovery that a variety universally credited with complete immunity could succumb like any other. The fact has already been mentioned that *Einkorn,* the wheat supposedly immune to rust, fell victim to a severe attack of black rust in the hot weather of 1907. (Chapter 2; cf. *Wheat in India,* p. 99.) This shock to complacency was administered at an early stage and put an end to any automatic faith in the merits of varieties. There was nothing hard and fast, as Sir Albert says, about the capacity to resist rust; it was not a character that triumphed under all conditions. In later years Sir Albert laid much stress on stating that in Nature no such thing as complete immunity to a specific disease exists; what can be secured is a very high degree of disease resistance 'almost amounting to immunity'.

There was one specially interesting aspect in the *Einkorn* episode. The rust appeared after some five weeks of hot weather in the early part of the month of May. Experience had always pointed to damp and cloudy weather favourable to rust, but on this occasion it attacked very suddenly under opposite conditions. Sir Albert was able to point to a fact which later helped him to understand the onset and retreat of a disease or pest; the weather was certainly unfavourable to the rust, *but it was unfavourable also to the wheat,* which, as Sir Albert frequently stresses, is really a cold country crop; though grown in India for over two thousand years, it retains this character. The hot month of May in India can be disastrous. It was thus a thoroughly weakened crop which was sought out by the fungus. (Cf. Chapter 2, The Problem of Rust.)

The point emerged even more clearly in the following account of wheat growing in Bihar. Again, temperature is the factor which disturbs the host; in this case the temperature of the soil, which caused the thoroughly weakened plant to succumb to the attacks of an insect.

> 'One of the difficulties in wheat cultivation in Bihar and the eastern districts of the

United Provinces is to establish the crop. If sown a few days too early, the seed germinates but the seedlings are rapidly destroyed by termites, whole fields disappearing in a few days. The trouble became of some importance a few years ago in Bihar, as it interfered with the raising of seed of the new Pusa wheats on some of the private seed farms. The disease (disease and pests, are referred to at this time under the single term 'disease') was particularly serious in years when the rains ceased early and when the last monsoon showers of early October, known locally as the *Lathia*, were not received. In such seasons the advent of the cold weather is always postponed and the cool westerly breezes which normally set in about the middle of October are delayed till nearly the end of the month. The sowing time for wheat in Bihar in years when there is a good *Lathia* is just after the middle of the month and no trouble with white ants need then be feared. When, however, these sowing rains fail, nearly all the fields are destroyed by termites. More damage occurs on low-lying damp heavy soil than on the higher and dryer areas. Examination of the root system during the attack shows extensive discoloration of the new primary roots and of the first internode. Only in rare cases is there any formation of the secondary system. Before tillering can take place the first internode is devoured by the white ants and the plants wither.

'A possible explanation of the trouble appeared to be a high soil temperature, which subsequent investigation seemed to confirm. In several seasons when the late rains failed, a comparison was made between sowings on October 15th and others twelve days later. In addition to the delay, the furrows in the second case were left open for two or three days so as to cool the soil by evaporation. The early sowings were in every case destroyed by termites, while in the later ones the damage was negligible and normal root development and growth took place. The simplest explanation of these results appeared to be a fall in the soil temperature during the second half of October. That such a fall actually does take place is proved by an examination of a set of soil temperature determinations made by Leake in Bihar in 1903-4. In the year in which Leake's readings were taken the *Lathia* amounted to 3 to 4 inches of rain and the daily soil temperature at 4 inches at 1-2 p.m. fell gradually from 29.5 deg. C. on October 16th to 22 deg. C. at the end of the month.

'This disease of wheat seedlings, which is very common in north-east India, is of some general interest, as the termites, although the apparent cause of the trouble, were in reality engaged in the consumption of a moribund set of seedlings which had been practically destroyed, apparently by a soil temperature above the maximum for growth... There seems to be no doubt that the conditions of the active roots profoundly affect the resistance of the plant to the attacks of parasites.'

Sir Albert denied the capacity of the insect to 'cause' disease and this was perhaps the first of his statements, later made categorically, which repudiated insects and fungi as the real agents of disaster.

The Study of Root Systems

In the above instance the susceptibility of the plant to onslaught from its enemy is attributed to the state of its root system. The prolonged root studies made by Sir Albert were to a large extent the origin of his theory of disease resistance. He had established the rather remarkable fact that in many Indian crops there was a differentiation between deep-rooted and shallow-rooted varieties. These were adapted to their local habitat; but encountered disaster when transferred.

To grow a deep-rooted variety where the ground-water level was high was to drown the roots: to grow a shallow-rooted variety where the ground-water level was low was to dry them up. The result was disease, which, however, was not caused by any outside agency, but was the simple consequence of mistakes in the choice of varieties.

Wilt and green-fly were the two commonest accompaniments to this lack of gearing between root and soil, but any other type of misfortune could overtake an enfeebled crop, the cause being precisely this weakness in the host and not the arrival of the pest or virus. The facts were established for linseed, any attempt to grow the deep-rooting Peninsular varieties on the alluvium ending in attacks of wilt which destroyed the plants. Another example was the onset of, or again resistance to, wilt in fibres (*Hibiscus cannabinus* L., *Hibiscus sabdariffa* L., *Crotalaria juncea* L.), the shallow- rooted varieties escaping, the others succumbing. In the growing of a vetch (*Lathyrus sativus* L.) the proof was irresistible. The experiments were carried out at Pusa in 1921.

> 'In that year deep-rooted varieties [of *Lathyrus sativus* L.] from the black soils, shallow-rooted types from the alluvium, as well as kinds with an intermediate root system from the Allahabad district, were sown in the same plot. All the types from the black soil area were badly attacked by green-fly, all those from the alluvium were immune, while the types with intermediate root-development were only slightly affected. Although the infected and disease-free plots were often side by side, in no case did the *Aphides* leave the deep-rooted cultures and attack those with shallow roots. Really healthy plants seem able to keep insects and fungi at bay, and their juices seem unsuitable for the nourishment of these organisms.'

In the case of wheat the facts were the same.

> 'The influence of soil conditions on disease resistance is seen when the wheats of the Peninsula are grown in the plains. Many of the deep-rooted varieties from the black soils, when grown at Pusa, are practically destroyed by rust. In their own locality, however, rust attacks are rare. Alterations in the environment, therefore, influence the natural resistance of a variety. On the other hand, when the shallow-

> rooted variety, known as Pusa 6, is grown at Pusa next to these black soil types, it always remains free from rust although surrounded by a mass of infection.'

The phenomenon of disease-resistance was thus brought back to the distinction between varieties, but on a much broader basis. It was not just a question of one wheat or another, one linseed or another, one fibre or another, selected by score-card record and accredited with inheritable resistance capacity. The point at issue, the point that mattered, was whether *the variety chosen was suited to the soil chosen*, was geared to the soil. Thus we arrive at the real question, the relation between plant and soil.

The Explanation of Indigo Wilt

Almost every point is illustrated in an intricate set of experiments which the Howards carried out on the indigo crop. This work was done early in their career and must have influenced them in arriving at their general conclusions on the problem of disease. It seems therefore worth while to give a fairly detailed description off these enquiries and experiments.

Indigo was not original to the country, but had been introduced by planters from the East Indies, where it is a wilding. It was much grown in Bihar, where the Pusa Research Institute was situated. It was an old crop and a valuable one, with a famous history. When the Howards arrived at Pusa in 1905 the area devoted to it had greatly shrunk, especially in Lower Bengal and the United Provinces, and it was mostly confined to Bihar.

Following their usual principles the Howards grew some indigo as a matter of course, together with all the other staple crops of the district. (The area of the Pusa Research Station itself was an old indigo and tobacco estate. This had gone bankrupt and had been acquired cheap, which accounts for the unfortunate decision to place the Institute in this spot.) This afterwards proved very useful. There was, however, an independent indigo Research Station at Sursiah, which naturally concentrated its work on the new Java indigo (*I. arrecta*, Hochst), introduced in 1893 as a variety superior to the old Bihar indigo (*I. sumatrana*, Gaertn.), though the latter still maintained its position.

Suddenly between 1910 and 1913 the industry collapsed. Wilt appeared, especially on the valuable Java indigo. The failure was so complete that the Sursiah Research Station was compelled to close down for the simple reason that their crops set no seed -- there was therefore no material with which to continue. The wilt killed the plants entirely -- whole fields.

In these unpromising circumstances the problem was handed to the Howards to hold, and it certainly was a very sickly baby. Everything had been tried. In fifteen years £54,207 had been spent on research, at that time a large sum. Yet the Imperial Entomologist could find no insect, the Imperial Mycologist no fungus, and the Imperial Bacteriologist no virus to account for the plague.

The Howards proceeded differently. Their start was to grow the crop on a field scale and in the best possible way, taking note of local methods. Their observation was directed to the whole plant, above and below ground; they followed the crop throughout its life history; they looked at all the surrounding circumstances, soil, moisture, temperature. But they looked for no virus, no fungus, and no insect.

They noted that beginning in 1910 there had been a succession of wet years following a dry cycle; the appearance of the wilt had coincided with the wet years. Could there be a connection? They were helped by their previous observations on the behaviour of other crops under conditions of excessive moisture, especially of *patwa* (*Hibiscus cannabinus* L.) and *sann* (*Crotalaria juncea* L.); they were familiar with the root systems of these plants, a long tap root and thick laterals mainly concentrated in the first ten inches of soil below the surface. They knew that a distressed condition of these plants under excessive moisture had always been accompanied by a marked dying away of feeding rootlets, sometimes 'the entire destruction of everything besides the main tap root'.

An initial examination of the indigo plant showed the same characteristic root system, and the same absence of feeding rootlets in all wilted plants.

> 'The root system of this plant is very characteristic. There is a long tap root and a great development of long thick laterals, mainly concentrated in the first ten inches below the surface. Below this the number of laterals on the tap root is small. The appearance of the large roots of affected plants is healthy and there are none of the symptoms of definite disease. There are, however, very few feeding rootlets to be found anywhere. The functional root system is extraordinarily limited and almost absent on the laterals near the surface. Little beyond the main root system is alive and the almost entire destruction of the finer roots is most striking. This at once explains the unhealthy appearance of the crop towards the end of the monsoon and the failure of the plants to ripen proper seed afterwards. The fall of the leaves and the wilting of whole branches represent efforts on the part of the plant to adapt itself to the gradual loss of its active root system.'

The first conclusion was that the waterlogging of the Bihar soils towards the end of the monsoon was the cause of the trouble; the pore spaces of the alluvium became flooded with water, no oxygen was available to the rootlets, which therefore died; the plant was then unable to feed itself -- the so-called wilt was simply the last stage of starvation. Many apparently contradictory facts were eventually explained on this basis, everything depending on the plant's ability to grow fresh rootlets or its failure to do so, according to time and season. The first explanation, therefore, proved the final one, though much work was still awaiting the investigators before they could explain the elusive and baffling history of this crop.

Very careful experiments in growing the crop on soil adequately drained and aerated were carried out in 1912 and 1913. Various methods were tried, sowing under cover crop, irrigation, transplanting. A few fields did well for a time, but wilt appeared even on these fields towards the end of the rains, and in general the crops could only be described as poor. The conclusion was that drainage and good cultivation were not in themselves sufficient remedies to prevent the appearance of wilt.

This was a disappointment, for so much success had followed on improvements in drainage and soil aeration in the case of other crops that it might have been hoped to solve the indigo puzzle by the same means. But it was clear that there were further factors involved.

A fresh start was made and consideration given to the above-ground life history of the plant. Here the Howards became aware of the great shortcomings in the local management of this crop. The usual practice was to sow in October and by the middle of the next July to take the first harvest of leaves, cutting the plant right back, and then to repeat this process towards the end of August; seed, if desired, was reaped from a third growth on the same plants starting in September and continuing until the following February or March; the plant stayed in the ground eighteen months. On this system two things were being done by the planters which were bound to inflict a severe strain on the plant. Twice in the course of its growth the indigo plant was cut right down; after this severe treatment it was left to grow again; flower and seed were to be reaped from this weakened plant. Was the indigo capable of withstanding such tremendous shocks?

Suspecting that the fault lay in asking too much from the plant, two innovations were tried. In the first place, one branch was left at each pruning -- the plant was not deprived of the whole of its above-ground mechanism. In the second place, the plants which were to give seed were grown for that purpose only; they were not mutilated for a leaf harvest at any time, but were allowed to live their complete natural life to the end; moreover, when destined as a seed crop, the indigo was sown about the middle of August, to come into flower in October and November and bear seed in February and March, thus avoiding, during the crucial period of reproductive effort, the worst effects of the monsoon.

These improvements, reversing the practice of the planters, proved successful. Fine crops, both of leaf and of seed, could be exhibited to the planters, who were addressed at their Association meetings in 1914 and 1915.

> 'As is well known, the universal method of growing Java indigo in Bihar is to sow it broadcast or by drills in lines close together. The result, in both cases, is a dense crop of unbranched plants, thus leading to loss of indigo. Further, interculture to keep down weeds is impossible after the first cut. When the crop is reaped, the indigo is cut down completely and the plant has to produce new shoots during the monsoon at a time when its roots are in very moist soil. Few plants will survive

uninjured such treatment during the month of July. When an indigo plant is suddenly cut down, the passage of water and food materials from the roots goes on for a time and the stumps bleed. There are no leaves to carry on the transpiration current and the result is that the normal physiological processes in the plant are greatly upset. It is not surprising, therefore, that the new growth is formed so slowly and that it is often unhealthy. Many plants, such as peaches and flowering creepers like *Ipomoea*, usually die outright when cut down to the ground during the rains and hardly ever recover.

'It was decided in 1913 to try the effect of pruning the crop in July at the time of the first cut and to compare the behaviour of plants treated in this way with those cut down completely. To enable the crop to branch freely the indigo was sown in lines, two feet apart, and weeds were kept down so as not to interfere with free branching from the lowest part of the stem. One-half of the plot was cut down in the ordinary way, the rest pruned so that one branch was left at cutting time. The results of the first and second cut are given in the following:

	Plants pruned		*Plants cut down completely*	
	maunds	*seers*	*maunds*	*seers*
First cut	15	23	22	39
Second cut	23	37	6	19
Total	39	8	29	1

'It will be seen that the method of pruning at the first cutting and leaving a branch to carry on the growth has resulted, as was expected, in a material increase in the total crop. There is of course some loss in the pruned plot at the first cut due to the branches left. This is, however, more than made up for in the greatly increased second cut on the pruned plot.'

But what was more important was the reduction in wilt. The August-sown seed, for instance, escaped wilt and carried a fine crop of healthy seed, forming a most marked contrast to the wilted plants which had been sown in June (1912). These results were repeated the next year, and 'fine healthy plants' free from wilt and covered with good pods, were obtained. Thus the seed question was overcome; the disaster which had brought to an end the work of the Sursiah Station could be considered a thing of the past.

In pursuing this question the Howards became interested in the general physiology of the indigo crop and especially in the processes by means of which this plant accumulates in its leaves the substance known as indican, which forms a reserve store of nitrogen essential to the setting of seed. It is common knowledge that plants have an enormous history and have evolved all sorts of ways of looking after themselves. Like other legumes indigo has evolved a double system of getting hold of nitrogen. It can, like non-leguminous plants, absorb nitrates from the soil solution via the root hairs in the usual way. Poor soil will have few nitrates in solution: rich soil will have many. What happens? Indigo grown in poor soil will have to work very hard to get its nitrogen and the supply will be precarious; the plant therefore makes a great effort, producing many nodules, which store an additional reserve of nitrogen obtained not from the soil but from the atmosphere. If grown in rich soil, this mechanism is absent; there appears to be what might be called a lazy dependence on readily available soil nitrates. This is well known, and the Bihar planters had a special name for the indigo grown in poor soil (which from their point of view was the best), namely, *zilla* indigo.

The marked variability of the plant in its capacity for storing nitrogen was a rather clear illustration of intimate gearing between plant and soil; in this instance the one organism, the plant, placed too great a dependence on the other partner in the process, the soil. The test came with the heavy monsoon, when the soil flooded. The plants with nodules found their feeding rootlets drowned; they had omitted to guard themselves against what was literally a rainy day. This state of affairs could thus be summed up in the words: 'What is known as wilt is merely the last stage in starvation.' This amply explains why no parasite, fungus, or virus had been found to account for the disease.

The double nitrogen supplying apparatus also explained why wilt set in when the plant was too severely cut down. If there were no leaves, then the other end of the plant factory could not function. Without foliage the transpiration current could not be carried on and no food could be sent down to the nodules, which therefore perished; plants were found where the nodules were empty shells. Nitrogen was then in insufficient supply, and, as stated, starvation of the whole plant set in. The baffling and contradictory incidence of wilt was thus explained by an examination of the double feeding system and of its relation to soil conditions.

> 'Indigo is a leguminous plant and, like all members of this order, is characterized by a high percentage of nitrogen in the seeds. This nitrogen occurs in the form of proteids and is placed there by the plant for the sole purpose of nourishing the seedling in the first stages of existence and supplying the protoplasm of its growing cells with nitrogenous food until it can lead an independent life. When sown, the indigo seeds at first make no growth above ground beyond the two small seed leaves. All the development is subterranean in the form of roots, and, at a very early stage, and before the first real leaves are produced, swellings, known as nodules, begin to appear on the roots. Soon afterwards indican can be detected in the first real leaves but this substance has not yet been found in the seed. These root nodules are of the first importance in indigo (as in all leguminous crops) and, as will be seen later, everything in indigo cultivation and also in the separation of the indigo from the green plant in the factory, depends on the successful working of these root nodules and of the roots...

'The development and activity of the root nodules of indigo take place best when the plant is grown on somewhat poor land. On such land the soil contains little nitrate, and, accordingly, the nodule factories are working at high pressure to supply the proteids required. Large amounts of the nitrogen and oxygen of the air are used up and the leaves of the indigo become rich in indican. Every planter knows that indigo grown on rather poor land (*zilla* indigo) gives the best yield of finished indigo and often the best colour. Poverty of soil in nitrates is one of the conditions for the numerous nodules on the roots and incidentally of high indican storage in the leaf.

'When indigo is sown on rich land containing a high proportion of organic matter such as *seeth*, the number of nodules formed on the root is small and the bacteria in them do not work at any great pressure. In such soil nitrates are formed in abundance and the indigo plant then behaves like tobacco and takes up its nitrogen by way of the root hairs in the form of nitrates dissolved in the soil water. Under such circumstances the growth is rapid, but little indican is accumulated and, if such plant is steeped, it gives a small proportion of indigo and moreover of poor quality indigo. This fact is also well known to planters, and the inferiority of the crop from highly manured land, compared with *zilla* indigo, is understood by all.

'The activity of the root nodules reaches its maximum about the time the plant is ready to flower. At this period the leaves are also rich in indican. At this time, however, the indican in the leaves begins to be called upon by the plant and to be utilized by the flowers and developing seeds. It is said that if the indigo crop bursts into flower, the yield of finished indigo will fall off and the colour will suffer.

'The activity of the nodules depends on two main factors -- a full, continuous supply of air from the atmosphere and a supply of food from the leaves for the nodule bacteria. If either of these two things is interfered with, the nodule factory does not work. As regards the supply of air round the nodule, this is at first an easy matter in Bihar provided the surface soil is well and deeply cultivated and if crusts, formed by rain, are broken up whenever they occur. When the monsoon sets in, however, difficulties in the air supply of the nodules begin. If the monsoon is short and there are no large falls, the nodules get enough air and, if there is a succession of such years, the air supply in the soil is abundant and Java indigo reaches its maximum development. If, however, there is a heavy rainfall so that the soil is packed by rain and the air spaces destroyed and filled with water for long periods at a time, then the supply of the essential air to the nodules and to the roots generally is cut off and the activity of the whole root system, including the nodules, is stopped. At the same time, no further indican can be produced. When this happens, the whole economy of the plant is upset and it cannot manufacture any more food. A starvation period sets in and the reserves are called up. As at flowering time, there is an immediate run on the reserve indican and this is

> consumed. If the plant in this starving condition is cut, it will give a low yield of indigo of poor colour, just as flowering indigo does. As the starvation process proceeds, the plant begins to look unhealthy, the leaves fall and alter in colour and at last the stage known as the wilt disease appears. This is not a disease but the last phase in starvation.'

The explanation was now plain of why the indigo crop should so suddenly have collapsed in the three years between 1910 and 1913; this was simply the result of several wet seasons bringing disaster to a plant grown on unsuitable methods.

> 'It will be clear that the present practices in Bihar in growing Java indigo are about the worst that could be devised and that, in the past, the indigo plant has never had a proper chance. There has been no attempt at proper cultivation and nothing has been done to increase the air supply by means of surface drainage. The crops obtained have been the result of chance; sometimes the colour has been good, but most frequently it has been poor and only a low price has been realized.'

The argument that wilt was the last phase in starvation was important. It explained the erratic incidence of the disease. Everything depended on keeping intact the working partnership between the foliage of the plant and the bacteria of the nodules. Thus wilt on the ordinary leaf crop during the monsoon, after the first cut in June or July, was due to the water-logging of the soil, which destroyed the nodules and fine roots; wilt on indigo sown in June on particularly well-drained soil, killing practically the whole of this crop by the middle of October, while at the same time leaving untouched the plants which had been re-sown to fill up gaps in the first week of August -- the healthy and wilted plants growing next to next with interlocking root systems -- was another effect from the same cause, the escape of the later-sown plants being quite simply due to the fact that the roots of these had not had time to reach the waterlogged level where the roots of the June-sown crop had been for some time forced to exist; wilt on old branches left at the first cut, which did not spread to the new growth coming along after the cut, was due to the fact that this new vigorous growth, which sprang on the lines of communication nearer the root system, intercepted the nourishment the roots were able to send up; finally, wilt on plants sown in August, previously perfectly healthy and grown after the monsoon when there could be no question of waterlogging of the roots, but cut down to ground-level in mid-October, was due to direct starvation; these plants had been mutilated before they had had time to build up any reserves, and the removal of stem and leaves cut short the usual supply of carbo-hydrates conveyed to the nodules; these then could not do their work and, with the fine rootlets, died in a few days, and were found on examination either empty shells or discoloured; the weak and starved shoots that were sent up soon succumbed to wilt.

An indigo plant is thus capable of starving in the midst of plenty if its working system is put out of order. The main roots have not the power of repair if the nodules are not maintained. But there may be further puzzles arising out of the alternation of the feeding mechanisms of this plant. Cases were known, which baffled the planters, and certainly seemed at first sight to contradict the general explanation, of an indigo crop grown on heavy, badly drained, waterlogged land escaping wilt while another crop grown on light, high-lying land suffered severely. The reason would seem to be that, in certain circumstances, this plant can omit using the nodules and rely on its alternate mechanism for obtaining nitrogen through its roots, in the same way as is done by non-leguminous plants; this is most likely to happen when the plant is growing in rich moist soil where the soil solution holds plenty of nitrates and other salts; actually the indigo was growing in a kind of water culture. But on the light soils there would not be enough nitrates to feed the plant, and the rains would have their usual effect in inducing wilt. This, however, was an exceptional case, and, generally speaking, the resistance of indigo to wilt would depend on a supply, in the soil, of 'the essential air' to the nodules and to the roots; in other words, the state of the soil would be the most important influence governing the health of the plant.

There remained one final mystery. It was noted above that there were two types of indigo, the original Bihar indigo, the Sumatrana, and the new and superior Java indigo introduced in 1893.

> 'When Java indigo was first introduced into Bihar, it did exceedingly well and was noted for its rapid growth and general robustness. After a few years it seemed to slow down in growth and wilt began to appear. The crops kept for seed yielded less and less and soon the seed problem became acute. Between 1910 and 1914 the area under Java indigo in Bihar decreased from 70,000 to about 15,000 bighas largely on account of wilt and the difficulty of obtaining seed.'

Of the two types of indigo the older Bihar indigo was shallow-rooted and flowered early, the new Java indigo varied from being shallow-rooted to being deep-rooted, the deep-rooted varieties flowering late. Unfortunately, in Bihar, early flowering types seldom set seed, owing either to the absence of bees or to the dampness of the air in September and early October. Not until the latter half of October, when the late-flowering types came into bloom, was there fertilization. These late-flowering types, being also the deep-rooted types, tended most easily to get their feeding rootlets drowned in the rising subsoil water of an unusually wet season; in India the soil gets more flooded from this subsoil water than from precipitation falling on the surface. Thus the only indigo likely to flower well in Bihar also met the worst soil conditions. The result was inevitable.

> 'The principal cause of the degeneration of the plant is undoubtedly to be found in the methods in vogue in Bihar in growing seed. It used to be the custom to keep the old leaf crops for seed... Every planter must have noticed that when a Java leaf crop was kept on for seed many pods were formed in September and early October which contained no seed. The early plants gave little or no seed and the main seed

> crop was obtained from the late-flowering types. It requires little imagination to understand the cumulative effect of this unconscious selection. The early, shallow-rooted, quick growing types would slowly become eliminated and the late, deep-rooted, slow growing types, flowering after mid-October, would tend to predominate. In the course of a few years the botanical constitution of the crop would change. The Java crop would become more and more made up of slower growing, deep-rooted types. It is just these deep-rooted forms which in an alluvial soil like that of Bihar would, during the monsoon phase, be apt to be attacked by wilt. Shallow-rooted, quick growing kinds would be much less liable. The main cause of wilt is undoubtedly the unconscious selection exercised by the old method of growing seed.'

The remedy would be, not to keep on importing new seed from Java, which was little help, as the Java crop was also altering its botanical constitution in the same way, but to revise the whole system of seed growing by sowing a separate seed crop in August to be reaped in the following February or March, all late-flowering varieties to be vigorously rogued out at least twice in the course of the season. In this way, combined always with the most careful attention to drainage so as to prevent waterlogged conditions, the Java variety might be brought back to its original strength.

In commenting later on the disappearance of the natural indigo under competition with the chemically produced synthetic dye Sir Albert remarked that years had originally been wasted by launching research from the wrong end. The battle had been lost because attention had been focused on chemical problems connected with the improvement of the dye -- the plant, 'the living machine', had been ignored. His own efforts at salvage had come too late, but even then, had his advice been generally applied, it was not impossible that this interesting and historic crop might have been saved.

The Effect of Grass on Trees

The work on indigo, of which the bearing became clear in the course of 1913, 1914, and 1915, overlapped a little the start of a very comprehensive set of field experiments on fruit trees. This work was carried on at Pusa for ten years, 1914 to 1924. As it has been described in detail in a book available to all (*An Agricultural Testament*, pp. 117-32), only a summary will be given here.

The eight trees chosen were the plum, peach, custard apple, mango, guava, litchi, sour lime, and loquat. A beginning was made by noting the inevitable competition in wild Nature between trees and grass, in which the trees so often win and spread over the pastures to become the ultimate succession. At Pusa itself in the few years between 1918 and 1922 no fewer than 594 young wildings had established themselves on just over half an acre of sown grass and had to be uprooted to save the grass. This was a small illustration of a world-wide process.

Nevertheless there were occasions when grass was able to oust certain kinds of trees. In order to master the facts of the competition the trees chosen were treated in three ways: (a) clean cultivated, (b) completely grassed over, (c) grassed over but subsequently given aeration trenches.

Those that were completely grassed over, if young trees, died, the custard apple within two years of sowing the grass (1916), then, in order, the loquats before the end of 1919, the plums by the end of 1921, and the limes by the end of 1922. Those better established were just able to maintain themselves, the guava being by far the most resistant, though even this species was greatly checked in growth by grass. But under clean cultivation the trees flourished.

> 'Even a temporary removal of the grass leads to a profound effect. Whenever the roots of a tree under grass are exposed (for which purpose the grass has to be removed for a few days}, there is an immediate increase in growth, accompanied by the formation of larger and darker-coloured leaves. The effect is clearly visible on the foliage above the excavation for as long as two years, but the rest of the tree is not affected.'

The examination was pursued with great care and patience, by means of washing away the soil with a sprayer, often to a depth of 11 or 12 feet, and occasionally even to nearly 20 feet. (The technique is explained in *Agric. Journ. of India,* Vol. XIII, 1918, Special Indian Science Congress Number, 'Some Methods suitable for the Study of Root Development'.) Drawings were made of all root systems exposed, while above ground the corresponding foliage and wood growth were measured with exactness. (Details in the paper before the Royal Society cited at the end of this chapter. Leaves and internodes were measured individually.) All trees had a double root system, namely, a surface system and a deep soil system; this was later confirmed for fifteen species of forest trees also. Thus the effect of grass on these trees was to kill them by cutting off the air supply. Only those trees which could successfully force their surface roots upwards to penetrate the grass cover and reach the air survived: these trees flourished. Such trees included among the fruit trees none but the guava, which explains why the pastures of Grenada and St. Vincent in the West Indies are so rapidly invaded and destroyed by the wild guava, a fact observed by Sir Albert at the outset of his research career. All forest trees, on the other hand, had this faculty for conquering grass, which was the eventual explanation of the conquest of trees over grass in so many parts of the world.

The extreme sensibility of the fruit trees to the effects of soil conditions betrayed itself with dramatic clearness. As already stated, the young trees died under grass. The older trees showed smaller, or larger and healthier, foliage according to the way in which they were treated; the two different types of foliage could be seen on the same branch, the change-over to the better foliage being very sudden when soil conditions improved;

where, at one point, burrowing rats had chanced to give air on one side of a tree, a lopsided effect was produced. One tree, the plum, gave the final proof; when grassed down, these trees were attacked by green-fly, but the fly never spread to the healthy trees, free of grass, adjoining (July 1922).

This most interesting observation about the green-fly, as a matter of fact, was no novelty. Already during the eight summers of work at Quetta the facts on green-fly infection had been established; attack was quite obviously the result of a weakening in the host, the tree, brought about by unfavourable soil conditions. Sir Albert was able actually to induce attack on peaches and almonds by over-irrigation, and then to stop it dead by deep cultivation; the young shoots were covered by the pest below, but the upper foliage was completely healthy; the fly never spread from the unhealthy to the healthy leaves. (*An Agricultural Testament,* p. 164.)

Could one ask for a clearer or more convincing proof of the thesis that the health of the plant is to be sought in the condition of the soil?

The Spike Disease of Peach Trees

A short investigation, not systematically planned like the ten years' experiments on grass and trees but arising accidentally, led one step further, to an examination of the metabolism of plants. It confirmed the suspected fact that in disease the sap of the plant deteriorates. It was this deterioration which in Sir Albert's opinion invited insect attack.

He had been preceded in this idea by Mr. R. S. Hole, of the Indian Forestry Service, who had challenged the hypothesis that a parasite was responsible for a disease of the sandalwood tree and had analysed the sap changes. Sir Albert seized on this explanation for something which was affecting his young peach trees at Quetta. The first case -- leaf drop, very stunted growth, often followed by death of the whole tree -- was noticed in 1915. Until 1919 the faulty trees were destroyed, but in that year it occurred to Sir Albert that to allow this disease to take its course would provide the best, if not the only means, towards a true understanding. Thus an interesting turning point was reached in the study of plant diseases, as suggested many years ago by Professor Marshall Ward.

With the help of Mr. Jatindra Nath Sen, M.A., an analysis of leaves of two affected trees as compared with leaves from two normal trees showed far less nitrogen (1.76 as against 3.68 percent), less ash phosphorus (0.25 as against 0.51 per cent), less lime (0.94 as against 1.64 per cent), less potash (0.14 as against 0.64 per cent), but far more starch (5.15 as against 2.02 per cent). (Further figures in the original paper.) The inference was that the leaves of the diseased trees were unable to obtain from the soil a sufficient amount of crude sap and were also suffering from an undue accumulation of carbohydrates. A careful botanical examination showed that faulty budding had left a tiny gap between the ring bud and the bark of the stock; the imperfect junction of stock and scion had led to an interruption of the sap flow. To presume the existence of a parasite was merely a lazy method of evading the need for an explanation of a state of affairs which arose solely out of the condition of the plant itself. The presumed parasite was nothing but a myth; the trees had died because there had been an error in management.

The Solution of the Puzzle of Lathyrism

The investigation into lathyrism is included in the present chapter as having been an episode in research. It did not perhaps contribute to the thesis of disease resistance, but it has a certain interest of its own.

Lathyrism, an incurable disease of a paralytic nature, was associated with the consumption of a pulse, *Lathyrus sativus* L. It was all too common in the central and northern parts of India, where the poorer classes were accustomed to rely on this vegetable, known in the vernacular as *khesari,* for most of their proteins; in times of food shortage it formed a chief item in their diet for months at a time, and as famine conditions approached more and more was consumed and lathyrism increased in incidence.

A good deal of attention had been given to this serious problem. English, Scotch, French, German, Italian, and American scientists had carried out experiments. These had been going on over the last forty-five years with inconclusive results.

In 1921 the Indian Research Fund Association asked two medical authorities to take up the question, and Sir Albert was associated with them for the growing of the crop. He seems almost immediately to have suspected where the trouble lay -- in the admixture of certain weed seeds with the pulse. Four weeds were associated with the lathyrus as commonly grown in India; of these, one, *Vicia sativa* L. var *angustifolia,* known to the peasant as *akta,* had a seed which was almost indistinguishable from the lathyrus seed. Every bazaar example of lathyrus seed included it.

To start the work thirty consignments of lathyrus seed were obtained from twenty different districts where this pulse was grown. Each was then hand-picked to get rid of the *akta.* Then followed three years' botanical work, with classification of types as had been carried out for so many other crops, each seed being separately sown. These careful studies bore their own fruit for the Howards in giving them additional facts on the relation between root development and disease resistance, for the lathyrus, like so many Indian crops, was found to consist of deep, shallow, and intermediate rooted types.

Meanwhile the more immediate object was being attained, a supply of seed unadulterated with *akta.* The chemical and feeding experiments thereupon undertaken by the two medical investigators showed beyond dispute the harmlessness of the lathyrus thus grown in pure culture.

Simultaneously an investigation of the weed known as *akta* was carried out. The Howards isolated this seed, grew a large area in pure culture, and supplied it to the medical authorities, who had no difficulty in proving it to contain an alkaloid poison.

The problem, which had seemed so tiresome, turned out very simple. It appears almost inconceivable that no one had previously taken the trouble to make sure that the basic material for experiment was what it professed to be, that investigators had been content to work on impure samples of seed. Possibly that could not happen to-day, when the minutiae of experimental work are so carefully scrutinized; but it certainly was the case in the 1920's. It is not impossible that the discovery of such ineptitude influenced Sir Albert in his critical view of the science of his day.

The burden of the investigations, however, were not with him but with the doctors. The investigation on lathyrism is here mentioned only in view of providing an instance of his shrewd solution of practical problems. For, with the discovery of the nature of the poisonous *akta*, one problem had only been exchanged for another. What was to be done to get rid of it? It was not an easy question. The pods of this plant ripen a few at a time, explode and scatter their contents, which are very hard and capable of germination after a long interval. This meant that land once contaminated with *akta* would bear self-sown seedlings of this weed for years to come; and the samples of seed originally obtained showed that there was not a field of lathyrus in India which was not infested with this poisonous intruder.

As the seeds were so like the lathyrus seed, it was not possible to separate out at harvesting time. The difficulty could be only overcome during the growing stage. Instead of the usual broadcast sowing, it was suggested that the lathyrus should be sown in lines a foot apart, which would allow of removal of the seedlings of the *akta*, easily distinguishable at this stage, during early growth. By the exercise of this very ordinary precaution the cultivator could protect himself. As always, the remedy was to be within the means of the people.

Explanations and Confirmations

By this time there had come to be an accumulation of experiences justifying the formal setting out of the theory that disease in the vegetable world was a phenomenon resulting from some misadjustment or dislocation of soil conditions. This was done in the form of a contribution to a British scientific journal and also in a lecture delivered at Nagpur in 1921 (*Annals of Applied Biology*, Vol. VII, No. 4, 1921, p. 373: 'The Influence of Soil Factors on Disease Resistance'; *Agric. Journ. of India*, Vol. XVI, Part VI, Nov. 1921: 'Disease in Plants'); in the last-named paper occurs the famous dictum: 'the healthy plant protects itself'.

> 'Why does the natural resistance of the plant to fungi like rust and red rot or to an insect like green-fly break down? We have seen that under certain circumstances at

> Pusa *Einkorn* is unaffected by rust *even when surrounded by plants heavily infected*. Sugar-cane escapes red rot at Chandkhuri on the porous, well aerated *bhata* soils. In a similar manner some of the almond trees at Quetta resisted green-fly when separated by only a few feet from trees badly attacked. When the conditions of growth in these cases are altered, the natural resistance disappears and infection takes place. Why is this? One possible explanation is the following. Normally the protoplasm in the green cells of the leaves of healthy varieties is strong enough to resist the inroads of a fungus or of an insect. The healthy plant protects itself. If, however, soil conditions alter, then root damage is likely to occur and with this it is not difficult for the acid products of decay to enter the sap current and gradually to lower the resistance of the protoplasm of the green cells. A time comes when infection is just possible, then when it is easy, and finally when it is exceedingly rapid.'

Three years later the situation had again altered and in a very unexpected way: with transference to his own Institute at Indore the actual material for study of plant diseases gave out. (See reference in Chapter 1.) Sir Albert has left it on record that during the six years of his directorship of this Institute there were only two instances of disease in crops; they were both more or less accidental. One minor instance was useful as proving more unmistakably than ever the direct connection between soil conditions and health of the plant. By the breaking of a dam a field became flooded; a map was made of the flooded areas. When the field had dried, a crop of gram was sown, and one month after, when the crop was well away, those portions of the field which had been flooded became heavily infested with the gram caterpillar, the correspondence in areas being exact; but the caterpillar made no attempt to attack the gram on the fifty acres which had not been flooded. (*Farming and Gardening for Health or Disease*, p. 145.) The insect was able to demarcate, on behalf of the scientist, the delicate interlocking of the damage to the soil which still lingered, and the effect this had on the plant.

It was at Indore also that the final test came in another direction, on draught animals. Sir Albert was fond of horned stock and prided himself on his familiar knowledge of them. At Pusa he had insisted on keeping his own working oxen instead of borrowing them off the farm attached to the Research Station. These farm animals were suffering from various diseases, including foot and mouth, and there was a routine of inoculation. Against a great deal of official pressure Sir Albert categorically refused to have his own animals inoculated against anything. He then describes how he saw his oxen rubbing noses over the fence with infected animals. The extremely infectious nature of foot and mouth is common knowledge, yet not one of Sir Albert's animals took this or any other disease, thus displaying a degree of resistance which was amazing. Sir Albert did not hesitate to attribute this to the way his oxen were fed, off the area belonging to the Botanical Section which he was bringing to the highest state of fertility. (Cf. the statement that the Botanical Area had been transformed 'past belief' by drainage, etc., Chapter 3, The Supreme Importance of the Air Supply to Plants). The food he was able to provide for them had a quality lacking in that given to the farm stock.

The animals at Quetta also were throughout healthy. The test came at Indore. Here more animals were needed -- twenty pair. But, as was described in Chapter 1, the land when taken over at Indore was in a very bad state. No sufficient supply of good feed could therefore be quickly grown, and when the first hot weather came and there was no green feed, about a dozen succumbed to a slight attack of foot and mouth. They easily recovered, being treated with care and attention, and following years did not see any recurrence of the disease, as special regard was paid to making a provision of silage to carry the animals over the hot weather (which is normally a starvation period for Indian stock). Moreover, these animals, which were rather poor specimens when bought, in two years of good feeding *off fertile soil* were 'transformed'; they became prize exhibits, and their condition a source of the utmost pride and gratification to the Indore staff. (The most detailed account in *Farming and Gardening for Health or Disease*, pp. 153-7.) The history of Sir Albert Howard's draught animals in India is most illuminating.

In the last pronouncement on the problem of disease which Sir Albert made before leaving India the emphasis has changed. The question is put as to whether it is worth while to spend time speculating on the occasions of disease when it would be so much wiser to give one's energy to the pursuit of health. The lesson was drawn from the pioneer work of the Dutch scientists in Java, which Sir Albert greatly admired.

'Twenty-five years ago detailed studies of the insect and fungus disease of the sugar-cane were the chief feature of the work of the sugar Experiment Stations in Java. These are now no longer considered necessary, as experience has shown that the best method of dealing with sugar-cane diseases is by the efficient cultivation of suitable varieties. To grow the right kind in the right way is found in practice to be the most important factor in the control and elimination of the pests of the sugar-cane. This experience is most significant. The Java sugar industry is perhaps the high-water mark of tropical agriculture and owes its present position to various natural advantages which have been developed to the utmost by the efforts of a succession of highly qualified scientific investigators who have explored, in the greatest detail, the various directions in which the production of sugar can be increased. It is most significant that as the investigation of sugar-cane diseases became broadened and included all the factors, direct methods were given up and attention was directed solely to the variety and to its proper cultivation. This is after all only common sense. Disease follows the breakdown of the normal physiological processes in the plant when the protoplasm of the cells loses its power of resistance to the inroads of parasites. Healthy plants, on the other hand, possess a high degree of immunity to insects and fungi. It is obviously more practical to prevent disease altogether by growing the right kind in the right way than to step in at the last moment and attempt to save a moribund crop.'

The Function of Disease

What, then, is the function of disease? In a later amusing passage Sir Albert argued that the function of disease was to keep the investigator in order.

> 'When I left Cambridge, having sat at the feet of the distinguished professors of agriculture there and having saturated myself with the lore of Rothamsted, I was soon placed in a position of some danger when I became a government official in India. Plenty of money and every sort of facility were given to me for the improvement of the agriculture of the country, but it occurred to me one thing was lacking: what was there to keep me in order? What keeps the cultivator of the soil in order is the fact that he has got to make a living; circumstances keep him in order. But what is there to keep the privileged investigator in order, who is in government service and who does not have to make a profit? I found when I took up land in India and learned what the people of the country know, that the diseases of plants and animals were very useful agents for keeping me in order, and for teaching me agriculture. I have learnt more from the diseases of plants and animals than I have from all the professors of Cambridge, Rothamsted and other places who gave me my preliminary training. I argued the matter in this way. If diseases attacked my crops, it was because I was doing something wrong. I therefore used diseases to teach me. In this way I really learnt agriculture -- from my father and from my relatives and from the professors I only obtained a mass of preliminary information. Diseases taught me to understand agriculture. I think if we used diseases more instead of running to sprays and killing off pests, and if we let diseases rip and then found out what is wrong and then tried to put it right, we should get much deeper into agricultural problems than we shall do by calling in all these artificial aids. After all, the destruction of a pest is the evasion of, rather than the solution of, all agricultural problems. I recommend very strongly diseases for keeping investigators in order. They are the post-graduate teachers of the investigators. Although it was a bitter experience for me, nevertheless it did me a great deal of good and I learned much.' (Answer to the discussion on his paper: 'The Restoration of Soil Fertility' at the Farmers' Club, London, 1st February 1937.)

This answer, though given some years after leaving India, may be traced back to a conversation with one of the scientists from the Java Station already mentioned, who had informed Sir Albert that an outbreak of red rot fungus on a sugar estate in that island would involve the dismissal of the manager, as showing he was not doing the right thing *by the plant*. (*Crop Production in India*, p. 178.) The idea appealed to Sir Albert's humour, who later applied it to his own special field by arguing that a single fly on the municipal compost heap should terminate office for the engineer. More seriously he held that in Experiment Station work the first need was to be able to show crops and stock in a perfect state of health; exhibitions and study of disease could follow. He never afterwards modified his firm conviction on this first duty of an agricultural scientist, who must above all be a showman of what is good.

If disease were to be studied, it must be on a far more comprehensive basis than had hitherto been attempted, must take in the whole history of soil conditions preceding some attack, tracing these back possibly for months (a sketch of the ideas which would guide the investigation of disease at the new Station at Indore, in which this condition is mentioned in *The Application of Science to Crop Production*, p. 20), must always pay attention to environment and circumstances, for instance, to the great importance of 'growing the right thing in the right place' (the consequences of this are very important; many 'introduced' crops are by nature susceptible, because out of their habitat; a good instance is wheat in a hot climate, as was pointed out in Chapter 1; but the argument must not be exaggerated: a large number, if not most, of our domestic crops are 'introduced', especially in Europe, yet so wide is the adaptation of Nature that most of them should be capable of being grown in perfect health in the regions where they are now cultivated), must, finally, never be content to stop with the mere identification of the relevant virus, fungus, or parasite, but must find in this only a first step as seeing in these agents 'valuable indicators' ('parasites... very valuable indicators, provided by Nature, for checking the proceedings of the agriculturalist'; *Crop Production in India,* p. 181, 1924) of something much more fundamental which was wrong.

In later life Sir Albert Howard often referred to his good fortune in being sent to a tropical country like India, where the effects of temperature, precipitation, sun, etc., are so much more decisive than in our milder climates, and where phenomena appear on a vaster scale. If anything had been lacking to bring home to him the facts of infection and resistance and their genesis in soil conditions, he had only to look around him and cast his eyes over the Indian landscape. For century after century eelworm had infected wheat unsuitably grown (owing to the pressing need of the populations for food) in the wet tracts of the Harnai valley in the West; yet this eelworm, in spite of a mass of unrestricted foot and wheeled traffic, never spread to the thousands of acres running in an uninterrupted wheat belt across India on drier soil. Or again, there was the area of Ufra-disease infected rice in the undrained part of Bengal, adjacent to the other better drained rice lands to which the infection never spread. (*Farming and Gardening for Health or Disease,* pp. 128-9.) With justice he called India a country where agriculture had had time to impress its pattern on the landscape, a country of endless 'experiments' constantly repeated and plain to the eye.

Challenged once to account for the advance of locust hordes, a plague which seemed to defy the explanations which he had put forward, he states, again out of his Indian experience, that this was not so: that it was a fact that the invasions of locusts in Central and North-west India, starting from the desert where the eggs are laid, always produced their maximum damage on irrigated crops during the hot weather, where they ate everything green in their path; as soon as the rains began and normally grown vegetation was available, the swarms rapidly disappeared: what had been a terrifying visitation was 'soon reduced by Nature to its normal insignificance'. In no case had the locusts in Rajputana, for instance, established themselves permanently on lands alongside the desert when these lands were fed by the natural monsoon. The silkworm, also quoted against him, was disposed of with greater ease, for, as Sir Albert correctly points out, the silkworm industry is a thoroughly artificial one and silkworms are, in fact, delicate creatures and have to be guarded with even more solicitude than is bestowed on the majority of infants. Were silkworms let loose in a grove of well-cultivated mulberry trees their career would be a very different story. (*The Empire Cotton Growing Review*, Vol. XV, No. 3, July 1938, reply to criticisms on his paper in the previous number on 'The Role of Insects and Fungi in Agriculture'. The delicacy of irrigated crops was also argued from the fact that irrigated sugar-cane was invariably attacked by the moth borer in the hot weather, but as soon as the early rains came and the cane grew normally, this insect disappeared.)

Influenced by our knowledge of the incredible rate at which such organisms as bacteria, viruses, fungi, etc., can multiply, we think of infections as something which, once begun, must spread until by some mysterious process they are exhausted. But this is no explanation. We ought to look further. Infection will spread only where it finds suitable food; unless this is offered, it ceases. The fact that an infection does spread is a sure sign that the food is there, that the host is open to attack, in some way weakened, but the phenomena rather easily baffle us, for such weakness in the host is often not apparent to our observation, and its defeat in front of the invading organism is the first sign we have that anything is wrong. It is natural for us to lay stress on the obvious movements of the invader and to forget the 'invitation' which has let such invader in.

During the twenty-six years of his career in India, to which must be added the previous years in the West Indies and at Wye College, Sir Albert had travelled far. Starting with the conventional thesis that resistance to this or that disease must be traced as a Mendelian character and that breeding of specifically resistant varieties by selection or other means would be the only answer to attack, he had even at the outset combined this work with speculations of another kind: What under all circumstances was the secret of resistance when it occurred?

Working in a vast tropical country where for generations the cultivators had grown their food, depending far more on their crops for their subsistence than on their animal products, he was subject to the gradual influence of two permanent factors. On the whole, the crops grown by the peasants were free of disease and pests; on the other hand, the slightest mismanagement of soil conditions brought disaster. It has already been pointed out that under the tropical sun and rainfall soils are vulnerable; peasant practice has attained great experience in conserving and maintaining them; their attention is constantly fixed on this task. Thus the two items, healthy crops and fertile soils, were part of the same lesson, which fortunately Sir Albert had both the wit to learn and the knowledge to reaffirm in the course of his scientific work. Most stress was laid on soil aeration. This was a major problem in the East. It was after leaving India that attention was concentrated on the biological state of the soil, the presence of microflora and microfauna, the mycelia, the earthworm. These were the problems of Europe, where the poor biological life of the soil was startlingly apparent; under peasant systems such biological soil impoverishment is unknown.

Thus not the whole of the problem was mastered in India; there was certainly a further advance in thought after leaving that country. All ideas were, nevertheless, based on the long years of work in the East, which provided him with the conception of the resistant host, of the failure of infections and plagues to overleap this barrier of health, and above all of the supreme importance of tracing health and disease back to the soil.

In the discussion of plant health and plant disease it is worth observing that, while the nutrients which the plant draws from the atmosphere are limitless, constant, and immune to interference, those which it draws from the soil are limited, subject to spoliation, and singularly variable. The soil has a history which alters from hour to hour, and the same area of soil will change rapidly under specific influences, not excluding the influences brought by man, who can intervene so violently as to render a soil 'living' or 'dead'. Is it surprising that so variable a medium should confer variability on its children, the living plants?

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Sir Albert Howard in India

By Louise E. Howard

Chapter 6
The Work on the Indore Process

The Problem

As long ago as 1893 Dr. J. A. Voelcker in a notable Memorandum addressed to the Government of India (reprinted in part in the journal now issued by the Ministry of Agriculture of the Government of India as the *Compost Bulletin,* Vol. II, No. 3, Sept. 1949, Appendix B) laid stress on the misuse by the population of animal manure. Not only was no effort being made to grow timber for fuel to replace the burning of cow-dung, but even the residue that was left after so much had been necessarily used in this way was never properly prepared to go on the land and all the valuable urine was lost. Thirty years later Sir Albert Howard deplored an equal indifference in regard to the preparation of vegetable wastes; assuming that there was no choice but to use most of the animal excrement for domestic purposes, there was no excuse for the neglect of vegetable residues for purposes of soil enrichment.

> 'The statement constantly reiterated that the soil of India cannot be adequately manured, on account of the utilization of so much of the cow-dung for fuel, is only partially true. There is a vast mass of vegetable refuse which, if properly treated, will produce a large proportion of the organic matter and the combined nitrogen which the soils of India require. Most of this vegetable refuse is at present wasted or is misused. It is not uncommon to see dried leaves, stalks and other vegetable refuse burnt by the municipalities to save the expense of removal. Villagers often burn the refuse on the fields or at best put it back into the land in an unfermented condition. It is a distressing sight to see India's potential wealth going up in smoke and moreover in ineffective smoke. The use of cow-dung as fuel for cooking has certain advantages, from the point of view of preparing food, but the misuse of vegetable refuse has none.'

As Sir Albert says, it was a tradition to assume that the soils of India could not be manured with enough animal dung; the problem was an old one. The additional evil of the misuse of vegetable matter which might have been saved was more or less ignored. The result of both forms of neglect appeared glaringly in a scale of food production which spelt year-long hunger and poverty.

Such were the conditions into which the Western scientists at Pusa and in the Provinces intruded with their energetic programmes for raising production. Their suggestions were vigorous; better tools, more irrigation, better agricultural methods, wide seed distribution, but above all improved varieties of crops to give heavier harvests; here was an uncharted field, golden opportunities. There followed a massive output of Experiment Station results in plant breeding, all of which could with advantage be applied to Indian agriculture.

It was some years before the question was asked where this would lead. But the very success of the Pusa wheat experiments, for which he himself had been responsible, as well as those on tobacco and indigo, began to raise doubts in Sir Albert's mind as to whether the Indian soils in their prevailing condition would be able to stand the strain. A great deal more was now being taken out of them: was the corresponding amount being put back? Was not the old manurial problem being intensified, possibly with disastrous results?

The final solution of this ancient problem was only arrived at towards the end of Sir Albert's career in India. There was a gradual development of practice and theory. From the outset stress was laid on the need for organic matter. In default of sufficient animal dung the obvious source was green-manure. Great attention was therefore paid to this question and there are constant references to green-manuring in the early papers; as we have seen, Sir Albert deplored any burning of green wastes. Their use to enrich the soil was constantly advocated and practically no crop was raised without this accompaniment when required. Green-manuring, like proper drainage, became welded into the daily practice at Pusa, and the years of experience gained formed the later basis for an outstanding section in *An Agricultural Testament*, where the principles governing the use and misuse of a green-manure are set forth with great force and clarity. (*An Agricultural Testament*, pp. 87-95.) This work has been referred to in a previous chapter, and need not be further described here.

But while concentrating for a long period on this, the first step in a method for regenerating the soils of India, another and more crucial idea was gradually being absorbed. The numerous journeys which Sir Albert undertook over India, into Baluchistan and Kashmir, Sikhim and Nepal, and into Ceylon, here bore their fruit, for in the course of these one lesson was ever insistent. If agriculture in the broad countryside was only extensive and crops were much as might be expected from soils in an average condition, growth round the villages, where human excrement was daily deposited, was infinitely richer. These belts of vegetation always stood out. As Sir Albert says, India offered a series of 100,000 experimental plots which were plain to the eye.

> 'The urgent need for more nutrifiable organic matter in the black soils is at once evident when we compare the growth of the cotton plant on the rich fields near a village with that on outlying areas which, in Central India and Rajputana, are seldom or never manured. The addition of fermented organic matter leads to rapid growth, to larger plants, to a much higher yield of seed-cotton and to a crop which is able to withstand the heavy rainfall which so often checks the cotton plant on poor soils. No experiments are needed to demonstrate the effectiveness of more organic matter for cotton and other crops. No mathematical formulae and no replication of small plots are required to bring the results home to the people. This work has already been done, the whole countryside demonstrates the results.'

The solution of the manurial problem of India was thus to be found in the combination of animal and vegetable wastes. Yet India herself, in spite of her 100,000 'experiments', could not provide the final formula of success.

The Summing-up of Previous Investigations

In describing the work which he accomplished in solving this great and serious problem Sir Albert Howard used a telling simile; all the materials for dealing with it, he said, were lying about in a builder's yard, but the building was lacking. He was referring to the many investigations, some going back almost a century, on the different aspects which constitute the general problem of soil fertility: the preparation and conservation of animal manure, the preparation of 'artificial' farmyard manures, the use of mineral artificial fertilizers, the enquiry into the yields of soils not manured at all, the role of the leguminous crop, and the principles of green-manuring in general. In these investigations the importance of organic matter and the exact way in which it contributed to soil fertility was as yet but little understood.

The holding of a Symposium on Soil Organic Matter and Green-manuring at Washington in the U.S.A. in November 1928 was a landmark, but Sir Albert noted that even the principal speaker, S. A. Waksman, contributed not one, but three different papers dealing with what were considered to be separate subjects, farmyard manure, green-manure, and artificial farmyard manure. Humus as the general clue to all these matters began to emerge slowly, partly as the result of Waksman's writings, which greatly influenced Sir Albert and which he always considered as forming the basis for future investigation. (Waksman's great book, *Humus,* did not appear until 1936, five years after the publication of *The Waste Products of Agriculture,* but his numerous previous papers gave the results of his extensive experiments.) Waksman's work was founded on lifelong laboratory experiments; he was a pioneer in a new field. Sir Albert's work was of a different nature, also based on experiment, but carried out in the field, though laboratory technique was used as required. It was thus quite appropriate that, in addition to Waksman's writings, Sir Albert should have been simultaneously influenced by a very different writer, F. H. King, who in his classic *Farmers of Forty Centuries,* gave a detailed and extraordinarily interesting description of the methods in use for centuries past in China, Korea and Japan for conserving soil fertility.

In addition, much other literature had been studied on soil problems, including the records of the great Experiment Stations such as Rothamsted. (There was also the work on composting of Dr. Gilbert Fowler at Cawnpore.) When therefore Sir Albert eventually summarized the question in his book, *The Waste Products of Agriculture: their Utilization as Humus* (O.U.P., 1931) he had a great deal to say. At the risk of being a little discursive, I propose to give here the more important points of his summary.

The first source of organic matter in the soil is the root of the crop. When the crop is reaped, the roots are left behind; they decay and form humus. It is possible, with careful cultivation, to continue on this basis for a long time with no other addition of organic matter. This is known from the Broadbalk experiment at Rothamsted, where wheat has been grown on the same land without manure since 1844; over the first eighteen years there was a slow decline, since when the yield has been practically constant at a rather low level. A more striking example, cited by Sir Albert, was the very old system found on the alluvial soils of the United Provinces, where the field records of no less than ten centuries prove that the land produces fair crops year after year without manure and with no falling off in fertility, a perfect balance having been reached between the requirements of the crops harvested and the natural processes which recuperate the soil. (*The Waste Products of Agriculture,* p. 38.) While the Rothamsted work is mentioned by Sir Albert as the recognized European record of the principles involved (the important point that fresh seed was brought in every year to sow the Rothamsted field was not public knowledge until much later), yet Eastern experience provided an example on so much vaster a scale and continued over so much longer a period that it cannot be counted as surprising if once again Sir Albert was led to state that Eastern peasant agriculture could provide him with all the 'experiments' he needed.

If, however, something more is aimed at than this base-line level of soil fertility, some replenishment of the soil is needed; organic matter must be added. The oldest system, and it is very old indeed, we do not know how old, is to add some form of animal excrement, dung or urine. The experience of all nations has endorsed the value of this principle. Yet Sir Albert notes how defective are the methods for preparing and for storing this valuable material. Even under the Western covered-yard system as much as 15 per cent of the nitrogen is lost. Reference is again made to Rothamsted experiments by Russell and Richards and their conclusion is endorsed that the best system would be to store manure in water-tight tanks or pits under anaerobic conditions. (There has lately been some confusion on the subject of anaerobic methods; these are to be advocated for the conservation of manure, not for the making of compost.) Reform in the management of the manure heap was a subject to which Sir Albert returned in later life.

Mention is then made of a new system only ten years old, also the work of Rothamsted, namely, the manufacture of 'artificial farmyard manure' out of straw and other vegetable material by means of the addition of a chemical activator -- the well-known ADCO process. Sir Albert was attracted by this work, to which he attributes importance, and gives full credit to the 'useful' and 'stimulating' quality of the investigation. Yet once again he is able to state that an Eastern nation, the Chinese, had to all intents and purposes done the same thing by mixing clover with rich canal mud, thus anticipating by many hundreds of years the findings of Western science. He justly adds that the Chinese practice would have passed for ever unheeded by us, while the effort of the scientist has made known to many a useful innovation. Synthetic farmyard manure was, in fact, at that time being prepared in India on Rothamsted principles in Madras, the Central Provinces, and Bengal. (*Report of the Royal Commission on Agriculture in India*, 1928, § 83.)

On the subject of actual artificials, i.e. substances of mineral content made in a factory, Sir Albert does not at this stage of his career say a great deal. They are by no means condemned, but there was no demand for them in Eastern agriculture. This question is referred to in more detail elsewhere. (See Chapter 3, The Supreme Importance of Air Supply to Crops, and Chapter 8, The Question of Statistics and Views on Artificial Fertilizers.)

There remained the possibilities of green-manuring. As already stated, Sir Albert had for years incorporated the use of green-manures into his cropping methods. This prolonged experience had taught him one definite lesson, the absolute necessity of not allowing a competition for nitrogen to arise between the decaying green wastes and any growing crop. The neglect to pay attention to this point accounted for the extraordinarily erratic results of much green-manuring practice. But these disappointments could be avoided provided that the green-manure was properly prepared beforehand for the use of the soil micro-organisms and the crop.

> 'Every scrap of vegetable refuse should be utilized as manure, but it is useless to apply it to the soil in a raw state as is so often the case. The pore-spaces of the black soils need a constant supply of finely divided, fermented organic matter, ready for nitrification, so that when the rains break no time is lost by the soil in preparing food materials for the crop. Time is perhaps the most important factor in the growth of monsoon crops on the black soils. Sowing must be carried out the moment there is sufficient moisture for the seed to germinate. The whole energies of the soil must then be used up in growing the crop. There must be no competition between the growth of the plant and the preparation of its food materials. Everything must be ready beforehand if maximum yields are to be obtained. Any delay is paid for by a greatly diminished yield.'

With the recognition of the need for preparing the green organic matter the problem was well on the way to a solution. It needed only the additional lesson of the belts of intensive cultivation round the Indian villages to drive it home, and to lead the investigator to the master principle of combining the use of prepared vegetable and animal wastes. Actual experiments were first begun in a desultory way, but finally very carefully systematized.

The Experiments

It is not on record how far actual experiments go back. Sir Albert Howard was accustomed to say that the Indore Process was the result of nearly thirty years' reflection, had required the services of three highly qualified scientists (Albert and Gabrielle Howard and Mr. Yeshwant Wad, to whom the chemical side of the enquiries were assigned) and had cost roundly £100,000 to perfect. In a paper contributed to the Symposium on the Nitrogen Problem in Indian Agriculture, held at the Indian Science Congress of 1923, there is a reference to experiments which had been in progress 'for some time' at Pusa with a view to working out some easy and practicable system for applying the Chinese-Japanese principles of composting to Indian conditions. (*Proceedings* [in part] *of the Tenth Indian Science Congress*, Lucknow, 1923. Published by the Asiatic Soc. of Bengal, Calcutta, 1924, p. 250.) The work must have been very fairly advanced, for there is already a brief discussion of the process and of the best methods and times of applying the finished product. In this direction success had been registered, for two years previously, in 1921, a first dressing of 'leaf compost on the Chinese system' to a field of lucerne had given an increase of 50 per cent, and a similar dressing in 1922 an increase of 70 per cent. (Cf. Chapter 4, Grass, Fodders, and Green Manuring, and The Improvement of Fodder.) Perhaps these results provided an unlooked-for initial encouragement. At any rate, on taking up the direction of the Indore Institute in 1924 systematic experiments were immediately started in such a way as to show that they must have been mentally planned some time before.

To judge the Process therefore as a mere empiric result, which any capable investigator could have completed, is wholly to underrate what was achieved. The very idea was highly original, for though Sir Albert in his writings makes frequent reference to Chinese principles and though, in any case, the making of leaf-mould in Europe and of some form of humus in indigenous agricultures all over the world has always been known, yet this particular combination of the clever Chinese practice (vastly improved by the skill which has ensured high pathogen-destroying temperatures) with such advanced Western scientific knowledge as has enabled us to apprehend the intricate bio-chemical and biological processes going on in the compost heap, was due to Sir Albert, and he alone can claim the honour of having introduced a practice which is revolutionizing world agriculture.

The work starts with emphasis on the all-important role of humus in the soil. For a description of this complex and difficult conglomeration of substances Sir Albert was accustomed to quote Waksman, whose careful definition seemed to him the best that could be given.

> 'The organic matter found in the soil consists of two very different classes of material: (1) the constituents of plants and animals which have been introduced into the soil and are undergoing decomposition; various unstable intermediate products which have been formed under certain environmental conditions; substances like lignified cellulose which are more resistant to decomposition and which may persist in the soil for some time; and (2) a number of valuable materials which have been *synthesized* by the numerous groups of micro-organisms which form the soil population. The soil organic matter is thus a heterogeneous mass of substances which is constantly undergoing changes in composition. When its composition reaches a certain stage of equilibrium, it becomes more or less homogeneous and is then incorporated into the soil as "humus".'

What is the role of this heterogeneous and variable combination of substances in promoting the growing of crops? In 1931 Sir Albert stressed three aspects and found this analysis so satisfactory that he maintained it in all his future writings.

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

> general work of the soil including crop production. It is not too much to say that this material provides the very basis of successful soil management and of agricultural practice.'

There is a great deal of attention paid to the chemistry of the compost heap throughout *The Waste Products of Agriculture*: at one point the compost maker is actually urged to become 'a chemical manufacturer' (see Chapter 2). Sir Albert could never have ignored the true importance of chemistry in agriculture: the fact that he engaged a first-class chemist to assist him in the compost experiments and associated Mr. Yeshwant Wad's name with his own as author of the resulting book shows how alive he was to the chemical aspects: the various analyses made in the course of the work bear this out, as will be shown hereafter. It is necessary to make this point because in later life Sir Albert had some very hard things to say about the chemist in agriculture, but these diatribes sprang from no contempt for chemical knowledge, but were a protest against the mistaken emphasis which gave exclusive priority to chemical analyses in a field where the principal influences are biological. In course of time Sir Albert came to the conclusion that for all practical purposes the chemistry of the compost heap could more or less be taken for granted. It was, in the first place, so immensely complicated that only a very delicate analysis could ever suffice to establish it; in the second place, it was progressive in that it altered from day to day and even from hour to hour; in the third place, it was quite unrepresentative of the real values inherent in compost, which could only be expressed in biological terms: to ascertain the exact amounts of nitrogen or other elements present in a compost heap at some passing given moment thus seemed singularly unrevealing. He therefore considered himself justified in rejecting judgments on the value of compost which were primarily based on chemical conception. He expressed this in a popular way by saying that 'every compost heap had its own history', by which he meant that every compost heap was a complex and dynamic aggregate of living organisms, the life and death of which was a part of the whole development of the universe and which could never be caught and reduced to static proportions with much approach to the truth. But that a great deal of careful work was done at Indore on the chemistry of compost will be clear from the description which follows.

After defining the three-fold aspect of the values of compost Sir Albert continues by laying down seven conditions for its making. It is remarkable that these seven conditions have needed no major modification, indeed, no modification whatever, from that day to this. They are clear, definite and altogether complete: they are practical and at the same time embrace the fundamental scientific points at stake.

They are here given in a shortened form.

> 'Any successful system of manufacturing compost must fulfil the following conditions:
>
> '1. The labour required must be reduced to a minimum.
>
> '2. *A suitable and also a regular carbon-nitrogen ratio must be produced by well mixing the vegetable residues before going into the compost pits.*
>
> '3. The process must be rapid. To achieve this it must be aerobic throughout (the sentence ignores the point made very clearly elsewhere that the final processes may be anaerobic), and must include arrangements for an adequate supply of water and for inoculation at the right moment with the proper fungi and bacteria. (From old material -- see below -- not from patent inoculants or preparations; these had not been thought of at this stage and were later invariably condemned by Sir Albert.) The general reaction of the mass must be maintained, within the optimum range, by means of earth and wood ashes.
>
> '4. There should be no losses of nitrogen at any stage; if possible, matters should be so arranged that fixation takes place in the compost factory itself and afterwards in the field.

'5. There must be no serious competition between the last stages of the decay of the compost and the work of the soil in growing a crop.

'6. The compost should not only add to the store of organic matter and provide combined nitrogen for the soil solution but should also stimulate the micro-organisms.

'7. *The manufacture must be a cleanly and a sanitary process from the point of view both of man and also of his crops. There must be no smell at any stage; flies must not breed in the compost pits or in the earth under the work cattle.*'

The final words of the above quotation indicate that the experiments at Indore were organized to suit Indian conditions; as always Sir Albert kept in mind the limitations imposed by peasant poverty. The implements used were throughout simple and of types already known to the population or improvised out of accessible materials. The spade, *phawra,* was a kind of scraping or hacking hoe as universally found in the East; measurement was by *tagari,* a sheet-iron bowl with capacity of five-sevenths of a cubic foot; material was carried in a *pal* or stretcher made of gunny-sheet nailed to two seven-foot bamboos; there was a simple wooden rake for charging pits, an ordinary wooden tub for slurry, and the well-known kerosene tin to carry water.

Demonstrations were, however, laid out on a 'factory' scale in thirty-three pits, each 30 ft. by 14 ft. by 2 ft., conveniently sited opposite the cattle shed and carefully arranged so as to allow carts not only to approach each pit but also to pass each other on the way. There was a water supply derived from a raised tank into which a week's supply was pumped, feeding eight stand-pipes so disposed that all pits could be hosed without difficulty; such a piped supply was strongly advocated by Sir Albert for similar large-scale work, though of course he did not dream of suggesting it as needed by the peasant, in whose case proximity to a well was all that was required. Eventually the 300 acres at Indore produced 1,000 cartloads of compost per year. The limiting factor was not animal, but vegetable wastes. The amount of animal wastes from forty draught oxen gave a large surplus, which could be used either directly as manure or as fuel for cooking. Towards this use of some manure for cooking Sir Albert remained sympathetic. He pointed out that the slow heat engendered was very suitable for the preparation of a vegetarian diet and did not advocate the substitution of another fuel. As each cartload of compost was equivalent, as regards nitrogen content, to two cartloads of ordinary farmyard manure, and taking other factors into consideration, had about three times the value of such manure, the fields of India could be supplied as required and yet leave enough material over to allow for the manufacture of the well-known *kundas,* cow-dung cakes for fuel. (The Royal Commission on Agriculture in India, which reported in 1928, was also rather inclined to accept the use of cow-dung for fuel as inevitable and specially suitable in India, at any rate until alternative forms of fuel could be grown. The whole of their Chapter on the Manurial Problem in India is reprinted as Appendix A in *The Waste Products of Agriculture.* The present Government of India has recently started an energetic campaign for the planting of trees to provide fuel so as to conserve the cow-dung for the land.)

Thus the experiments conformed both to traditional needs and to the orderly set-out demanded by science. Sir Albert always laid great stress on siting and arrangement in compost manufacture. Initial planning could save a vast amount of future labour, and the arrangements at Indore were carefully designed for this end; the abundance of labour available in India was thus as shrewdly husbanded as much more expensive labour might have been elsewhere. This led later to the general view that complaints of cost in compost making were usually the result of bad planning and poor management. (The latest figures in England are astonishingly low [1951]; 1s. a ton at Goosegreen Farm, Somerset, without machinery, and 3s. a ton at Chantry, Wiltshire, using special machinery.)

One point which emerges is the very careful preparation of the raw materials. These were not just collected and thrown into the pits. Of the vegetable wastes -- and all were collected (See table below, The

Composition of the Raw Materials; the composting of the water-hyacinth was later carried out separately at Indore, and was also investigated by Dr. Gilbert Fowler and later put into practice in Bengal by Mr. E. Fairlie Watson) -- the woody materials like cotton and pigeon-pea stalks were strewn on the Experiment Station roads to be trampled and broken up by the passing traffic; all green materials were withered for two days; and all material was stacked, layer by layer, near the composting site, when possible under shelter, to be removed in vertical slices so as to ensure an even mixture; refractory materials, such as sawdust or waste paper, were left to moisten under a little earth in an empty compost pit or even steeped in water for two days. Equal care was devoted to the preparation of the animal wastes. Earth from the silage pits, sweepings from the threshing floor, and all silt from drains were stored near the cattle shed; this was spread evenly on the cattle-shed floor, itself earthen, to a depth of six inches and renewed every three to four months: it became heavily impregnated with urine. When removed, one-half was crushed to a fine state by bullock power in a mortar mill, the other half was given over as manure to the fields (in very wet weather all was saved for use in the shed). This urine-earth, together with the wood ashes or ashes from the burning of the cow-dung as fuel, was an essential ingredient of the compost.

Every day one and a half stretcherfuls (*pals*) of the stacked vegetable material were thrown under each pair of bullocks in the shed, together with one-twentieth of this amount of hard or resistant material which had been steeped or damped; uneaten food or damaged silage was used to cover any wet floor patches. The cattle slept on this bedding, which was thus further crushed and broken and impregnated. The next day, a little of the fresh dung was removed to make into slurry, and the remainder (when not otherwise required) carefully distributed; two-fifths of a bowl(*tagari*) of urine-earth was then scattered; the whole mass, being the wastes of two animals, was then spaded (we should consider it rather as raked) to one end and removed by stretcher to the composting site; the process was repeated throughout the shed. When cleared, all wet patches of the floor were scraped out and fresh earth strewn before the next day's distribution of bedding; in this way the shed was kept sweet and free of flies. During the rains, care was taken to make the bedding up in three layers, a bottom and top layer of dry material specially reserved for this purpose, with the remainder of the material in between.

The wastes, thus carefully prepared and manipulated beforehand, were found to be very homogeneous. They were brought on the *pals* to the compost pits, beside each of which were waiting small heaps of fresh dung, of ashes, of urine-earth, and of old inoculated material taken from a pit ten to fifteen days old, also a tub of thin slurry, i.e. of liquid obtained by adding water to small amounts of all four materials mixed together. All quantities were measured with accuracy but quite easily by means of the *tagari* (the quantities are given and also converted into lb. in Table IV and on p. 69 of *The Waste Products of Agriculture*) and the layers of bedding or dung were two inches thick, then sprinkled with urine-earth and finally wetted with the slurry. Another watering in the evening and a third slight watering the next morning completed the charge. Subsequent waterings, again of measured quantities, were given at stated intervals.

During the rains, when the pits were liable to be flooded, composting had to be transferred to heaps, but decomposition did not take place so evenly. There followed processes of turning once, twice or even a third time, at intervals respectively of sixteen days, one month, and two months after charge; these turnings were accompanied by fresh waterings, always in measured quantities; eventually six waterings were given.

It is almost surprising, in view of the elaborate nature of these operations, that the Indore Process caught on in other parts of the world very shortly after publication of the book. A careful reading of the text will, however, make plain that the turnings thus undertaken were not complete turnings as now commonly understood; one-half of a heap was doubled over the other *undisturbed* half; thus, in fact, only one-half of the material was turned on each occasion. Only at the third turn was the material wholly removed from the pit and placed alongside, the contents of several pits being put together to save space. This corresponds with what is usually now done when compost is removed from a heap for ripening.

The extraordinarily careful nature of the operations thus worked out in great detail after innumerable tests needs no emphasis. Nothing was lost by this. It was well to start thus elaborately, perhaps we might even say laboriously. Time was soon to bring confidence. It was found that two turns, if the whole material were moved, were amply sufficient; then only one was used, and this now remains a common practice. Sir Albert himself at the time of his death was experimenting in his small garden at Blackheath in allowing the compost to remain in a New Zealand compost bin until made, relying only on the final turning out for ripening. He had come to the conclusion that provided the wastes were varied, divided, and intimately mixed rather than layered, good compost could result without turning, and many compost makers proceed on this basis with success. (In spite of the elaborate nature of the process at Indore no extra labour beyond the two men and three women ordinarily employed on cattle-shed work was required, except at the third turn, when three men and four women were required at each pit for six hours. The regular staff of five spent half their time on the care of the cattle and half on making compost, the cost working out at 8.5 annas or 9-1/2d. per cart-load of made compost. This was established by exact records kept in 1930, when 840 cart loads were made. Sir Albert attributes the low cost of making to careful planning and arrangement and also to careful training of labour so as to work quickly and without unnecessary fatigue.)

The process as thus worked out with attention to the smallest details was the result of much experimentation into various possibilities. For four years trials were made with different single materials, cotton-stalks, pigeon-pea stalks, cane trash, weeds (green and withered), *sann* hemp (green and withered). In some cases ADCO was employed as the source of nitrogen, in others cattle-dung and urine-earth. The results from single materials were never entirely satisfactory. The cotton-stalks broke down rapidly at first, due to the presence of the green leaves, but then slowed down, and it took 150 days instead of the usual ninety to obtain a usable product; when composted with ADCO, temperature of the heaps was always irregular, the product was coarse and included partially decomposed substance. Results with pigeon-pea stalks and cane trash were still more unsatisfactory; even when passed through the cattle shed these materials were only half-decomposed at the end of six months. Weeds and *sann* hemp, on the other hand, tended to pack; they started with too high a nitrogen content and serious losses took place. Pits which started respectively with 44.2, 42.8, 49.7 lb. of N ended with only 25.7, 28.4, 29.2 lb., proving losses at the rate of 41.8, 33. 8, 41.3 per cent, whereas a control heap of mixed residues, starting with 28.3 lb., gained 1.3 lb. or at the rate of plus 4.4 per cent. (Table VIII, p. 84, of *The Waste Products of Agriculture*.)

It was these experiences which pointed to the rule enforcing the mixing of wastes, in imitation of what is so invariable in Nature. An interesting table gives the exact chemical content of twenty-two raw materials used in making Indore compost.

Composition of the Raw Materials

Material	*Organic matter*	*Ash*	*Proteins*	*Fats*	*Fibre*	*Soluble carbo-hydrates*	*Nitrogen*
Malvi cotton-stalks (with leaves and pericarps)	90.17	9.83	7.35	3.2	36.09	43.53	1.176
Cambodia cotton-stalks	96.91	3.09	4.00	1.11	45.31	46.49	0.64
Cambodia cotton leaves	87.45	12.55	14.06	8.49	8.71	56.19	2.25
Cambodia cotton pericarps	95.26	4.74	11.44	9.81	45.21	29.07	1.83
Mixed weeds	69.48	30.52	10.87	2.05	21.92	34.64	1.74
Sann hemp, 12 weeks old, stems	96.30	3.70	4.00	1.06	53.61	37.64	0.64

Sann hemp, 12 weeks old, leaves	90.64	9.36	14.26	2.90	20.70	52.80	2.29
Sesbania indica, 6 weeks old	89.33	10.67	14.90	3.45	22.33	48.67	2.38
Pigeon-pea stalks	91.08	8.92	4.37	1.90	39.64	45.17	0.70
Sugar-cane trash	94.09	5.91	2.00	1.25	42.16	48.73	0.32
Water hyacinth	75.80	24.20	9.37	-	-	-	2.17
Leaves:							
(Ficus religiosa)	81.37	18.63	3.00	1.33	26.89	58.18	0.48
(Ficus indica)	82.08	17.92	2.18	1.12	28.37	50.39	0.35
Mixed dried grass	83.80	16.20	4.25	1.55	26.20	40.20	0.68
Millet stalks	89.90	10.10	2.24	-	25.42	51.57	0.70
Millet silage	89.20	10.80	4.53	1.55	26.87	51.10	0.79
Rice straw	8.90	19.10	2.25	1.05	35.10	40.40	0.36
Wheat straw	84.70	15.30	3.01	0.98	35.69	37.93	0.58
Pigeon-pea residues	86.80	13.20	11.01	4.40	19.23	44.67	1.99
Gram residues	85.70	14.30	4.68	2.27	26.71	45.86	0.75
Ground-nut residues	86.60	13.40	12.06	2.20	16.60	39.24	1.93
Ground-nut husks	85.80	14.20	7.57	2.80	55.35	13.73	1.21

The chemical composition of the materials, especially the nitrogen content, obviously varied greatly. To begin with a general carbon-nitrogen ratio of about 33:1 and to keep this uniform throughout the year the different materials had therefore to be combined. On completion of the process the carbon-nitrogen ratio is found to be adjusted to the normal 10:1 ratio characteristic of humus.

Losses of nitrogen also occurred when pits were made too deep, 4 ft. instead of 2 ft. Two feet was found to be the maximum distance to which air could penetrate in sufficient volume. Again the figures are interesting. Pits holding just over 4,500 lb. of material, with nitrogen content of 31.25 lb. in the 4-ft. pit and 29.12 lb. in the 2-ft. pit, showed at the end of the process that the 4-ft. pit had lost 1.76 lb., a percentage loss of 6.1, while the 2-ft. pit had gained 3.24lb., a percentage gain as high as 11.1.

Temperature records showed a high temperature established at the outset, namely about 65 deg. C (149 deg. F.) and a regular rise of temperature after each turn. The temperatures in different parts of the pits showed themselves as extraordinarily uniform (figures in Table XVII, p. 97, of *The Waste Products of Agriculture*), proving that fermentation was very even; examinations were made five times in the cold weather, twice in the hot weather, four times in the monsoon, diagonally, vertically, removing a 6-inch layer and at random, for the top, middle and bottom of the pits: temperatures thus ascertained for the different portions of the compost mass varied at most by 2 deg. C., sometimes by 1deg. or half a degree, and on several readings not at all. Thus the internal temperature resulting from fermentation was clearly very stable, but was liable to be affected by wind, which could on occasion lower readings, when in the monsoon heaps had to be used instead of pits, by as much as anything between one and 12 deg. C. as between the leeward and windward side of the mass. This led Sir Albert later to stress the importance of seeking a sheltered site for compost-making. Sudden temporary drops in air temperature, however, had no effect; the intense fermentation could not be checked by a cold spell, but wind was a different matter.

In recent years much attention has been paid to the nitrogen balance sheet of composting; the absurd statement has even been made that nitrogen is lost in the process. The exact contrary is proved by the Indore work; nitrogen was gained by fixation from the atmosphere, in standard heaps, made with one-quarter of the available dung, in amounts from just over 4 to just over 11 per cent. Other heaps showed wider variations.

Nitrogen Balance Sheet in Normal Pits and Heaps					
No.	*Description*	*Total nitrogen (lb.) at the beginning*	*Total nitrogen (lb.) in the finished product*	*Total gain of nitrogen (lb.)*	*Percentage gain of nitrogen*
Pit 14	Standard (quarter dung)	29.12	32.36	3.24	11.1
Pit 15	Full dung	32.70	34.87	2.17	6.6
Pit 16	Dry dung	30.41	32.33	1.92	6.3
Pit 18	Full dung (residues low in nitrogen)	29.10	36.77	7.67	26.3
Pit 19	Dry dung	29.55	30.70	1.15	3.9
Pit 20	Standard (quarter dung)	24.73	25.80	1.07	4.3
Pit 21	Full dung (half period in monsoon)	33.25	33.40	0.15	0.45
Heap 22	Monsoon	22.28	29.52	1.24	4.4

The results showed that much depended on the make-up of the original material. If the nitrogen content of the wastes was too high at the beginning, nitrogen was always lost between charging and the first turn; nitrogen was also lost if the final product was kept too long in storage (figures for these losses, Tables XXII and XXIII, p. 102, *The Waste Products of Agriculture*); it needed to be used on the crop or banked by application to the land, when it became so diluted with such large volumes of dry earth that all further change was checked. This intricate question of nitrogen gain and loss was far from being exhaustively analysed at Indore. It is a very great question and has given rise to an immense amount of investigation, not of course in any way limited to what happens in composting. But even in this limited field Sir Albert notes that further enquiry as to what happens in the heaps will be interesting with a view to determining the exact conditions under which a large amount of nitrogen could be gained from the atmosphere by careful manipulation. In the final product the carbon-nitrogen ratio was found to be not far from the ideal figure of 10:1, which meant that the nitrogen was in a stable form, such as not to permit liberation (i.e. loss) beyond the absorption capacity of the crop. The exact chemical analyses of twelve pits or heaps are recorded.

Composition of the Final Product										
No.of Pit or Heap	*Materials used*	*Organic Matter*	*Total Ash*	*Silicates and Sand*	*Nitrogen*	*P2O5*	*K2O*	*C/N*	*Soluble Humus*	*Fineness*
Heap	Cotton-stalks with reduced (quarter) dung	33.915	66.085	34.97	1.61	0.48	3.38	16.5:1	11.56	68.15

Pit 7	Dry mixed residues	20.135	79.865	46.91	0.90	0.41	1.95	11.2:1	5.56	72.3
Pit 14	Dry mixed residues	19.66	80.34	46.32	0.84	0.68	2.35	11.6:1	6.27	88.5
Pit 8	Dry mixed with full dung	20.185	79.815	46.27	1.004	0.51	3.05	10.8:1	4.83	81.3
Pit 15	Dry mixed with full dung	18.385	81.615	51.33	0.725	--	2.43	12.6:1	3.86	82.5
Pit 5	Dry mixed with full dung	19.76	80.24	50.11	0.841	0.403	2.23	11.7:1	5.29	84.0
Results obtained in the monsoon										
Heap 6	Mixed withered weeds	21.25	78.75	47.55	0.862	09.43	2.33	12.3:1	4.01	76.3
Heap 10	Mixed withered weeds	22.055	77.945	47.77	0.808	0.49	4.99	13.6:1	4.07	78.4
Heap 22	Mixed withered weeds	22.09	77.91	48.45	0.914	0.51	3.59	12.0:1	4.31	75.7
Heap 34	Mixed withered weeds	19.375	80.625	48.70	0.625	0.59	5.31	15.5:1	4.27	79.4
Heap 40	Half-withered weeds, half sann	21.05	79.95	47.61	0.825	0.55	2.85	12.75:1	5.96	78.6
Heap 42	Dry mixed residues	21.685	78.315	46.41	0.806	0.62	3.65	13.5:1	5.36	84.0

Some figures are finally given for the results of compost on the permeability of soils. These effects on the physical condition of soils are now admitted and have been established by innumerable observers. It is generally conceded even by the most hard-bitten opponents of the Organic School that composting has excellent physical influence on soils.

The Results and Significance of the Process

It was one of Sir Albert's hopes that composting would have a direct bearing on general social welfare in India by providing a system for the proper disposal of night soil and thus finally putting an end to the dismal toll of disease and death in the Indian villages arising from the improper disposition of these human wastes anywhere and everywhere. He was much influenced by the pioneer efforts of Colonel F. L. Brayne, I.C.S. , Deputy Commissioner in the Gurgaon district of the Punjab and later of Jhelum, whose work in teaching the Indian peasantry to construct latrines and clean up their villages generally was greatly admired by Sir Albert. It was his belief that composting would carry this ideal a stage further and that 'cleaner and healthier villages will go hand in hand with heavier crops'. (Final words of the Preface to *The Waste Products Of Agriculture*.) Had he lived to see the work now being carried out among peasant communities in such widely separated countries as Nigeria, the territories of East Africa, the Seychelles Islands, etc., he might have declared himself no mean prophet: nothing is of happier augury than to read of the astounding spread of the combined principle of improved sanitation and improved agriculture among communities which so sadly need both, on methods which in all essential respects follow the Indore system, whether or no one wishes to attribute the origin of such methods directly to the work at Indore: let it be enough that the idea has spread, not only among peasant communities but throughout the civilized world. It was the merit of the experiments at Indore that they reintroduced to the world of science, in a way both exact and comprehensive, the Chinese master conception of the restoration of all wastes to the soil by continuous processes of decay. In pointing to the great gap in Western thought which so curiously ignored the significance of these wastes, in drawing for remedy both on contemporary scientific discovery and on age-old Eastern practice, above all, in insisting that the use of these wastes must be systematic and controlled, Sir Albert Howard rendered an immense service at a time when it was peculiarly needed: the Indore Process would not have had its world-wide success -- and it may be added its flood of imitations -- had it not been most urgently required. It is a fact which has now become clear that the soils of the world are liable to run down when cultivated; this deterioration has lately accelerated in an alarming degree.

The Floor of the Forest

Throughout Sir Albert Howard's work one thing stands out, and that is his extraordinary genius for observing and interpreting natural phenomena: there was an inextricable mixture in his mind of what Nature could do and what man could do. His first definition of agriculture was to call it 'an interference with Nature'. He may be said to have spent his life in determining the exact limits to which man could carry that 'interference'.

Those limits can only be determined by measuring them against a standard, which is the end result of the constant interaction of gases, solids and liquids, minerals, organic substances, plants and animals, imposed by Nature on this world of ours after 'experiments' lasting aeons: this final formulation is very old, very delicately adjusted, yet eventually unshakable. It is often called 'the balance of Nature', an expressive phrase capable of some misuse. It was late in life that Sir Albert picked out the floor of the forest as the most perfect illustration of a natural standard of soil fertility.

This phrase does not occur in *The Waste Products of Agriculture*, but I well remember a day, a few years after that book had appeared, when we visited the lovely Lerins Islands off Cannes, where forest had been left untouched for a prolonged period; I did not at that time appreciate the reasons for the excitement which overtook my husband and his friend, the late George Clarke, in finding huge earthworm casts in immense abundance. It is likely that the impression received on that occasion was an insistent one and that it was on that day above all others that came the clear conception not only of the part played by the earthworm in the making of humus, but also of the peculiarly rich and abundant life which the forest shows even on the animal side, a fact so often overlooked in countries where civilization has destroyed the larger wild fauna; this disappearance is compensated by an abundance of smaller and especially of insect life. The lesson of the forest also brought home the important point that ligneous material should be included in the use of wastes, corresponding with the fallen twig, branch or even tree trunk. That diseased material was never eliminated by Nature, but always subjected to the ordinary processes of decay and re-used, was greatly stressed in later years. Finally, this reserve of valuable material is most beautifully protected by the forest canopy and magnificently anchored in place by the forest roots. Thus every detail which had to be taken over by man is to be found in this natural example.

Given this and similar examples, there is almost no limit to what man can do. It is a great mistake to picture Sir Albert Howard's outlook as slavishly subordinate to a kind of Nature worship. He was a very bold and courageous innovator, optimistic and adventurous, and surely a most successful cultivator of the earth's surface. He scorned the idea that men could not feed themselves, or grow what they wanted when they wanted it and as they wanted it. They would have to know what they were about, and to deal with Nature on the terms she imposed: to go against ultimate truths was death. But even a limited amount of manipulation might bring enormous gain.

Thus the transference from one Eastern country to another of a highly beneficial practice and its establishment on a firm scientific basis had already solved the very ancient and disastrous problem of the manuring of the fields of India. It was too soon to foresee the world consequences which so quickly followed on the Indian experience, yet even at that date this optimistic mind could declare that 'the practical results obtained at Indore prove that all that is needed to raise crop production to a much higher level throughout the world is the orderly utilization of the waste products of agriculture itself.' (*The Waste Products of Agriculture*, p. 57.)

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Sir Albert Howard in India

By Louise E. Howard

Chapter 7
Relations with Cultivators and the Treatment of Labour

General Relations with Cultivators

One of Sir Albert Howard's most genial traits was his capacity for human relationships. This was no less important an asset to his work than his scientific attainments and proved of great value during his years in India.

He was launched on a career of research at a time when agricultural science was being started as a comparatively new subject from several university centres and was concerned to prove its position as a branch of learning. The need for contact with the world of practice was rather wilfully ignored, and there was a fairly complete gulf of separation, for which blame was often wrongly put on the farmer. At any rate, it was assumed that in countries where formal education was lacking, the population would be ignorant, obstinate, and averse to knowledge.

Not even as a young man during his first appointment in the West Indies did Sir Albert subscribe to this foolish doctrine. As has been stated in another writing (*Soil and Health*, Sir Albert Howard Memorial Number, Spring 1948, pp. 6-7), he was in friendly and natural relations with the sugar planters among whom he lectured, advocating 'close and cordial co-operation' between scientist and planter, with even some sharing of research tasks. His own descent from a farming family of high reputation locally has already been referred to, as well as his intimacy with the Kentish hop growers, whose great experience and knowledge could not fail to impress even the most advanced investigator.

On arrival in India he met different circumstances. There was certainly here predominantly an illiterate population. Moreover, there were many faulty practices. He notes how very backward, for example, was the cultivation of fruit all over India; an early visit to Kashmir in 1910 to advise on the hop industry showed the cultivation of that crop as 'exceedingly defective'; he was surprised that even a small saleable crop could be produced under the conditions seen. (*Report of the Imperial Economic Botanist for the Year 1910-11*, p. 6.) Again, the utter confusion of the varieties of grains and almost every other crop was certainly baffling to a man accustomed to the orderly agriculture of Europe. The first picture was to confirm the general opinion, which viewed the Eastern cultivator as entirely dependent on the Western scientist for any advances which he might be able to make.

What was Sir Albert Howard's final view on such a question? As will appear in the course of this chapter there is in his writings a great deal of criticism on much that he observed among the Indian cultivators, criticism definite and decided; but there is also from the outset an obvious strain of that profound respect for the accumulated wisdom inherited from generation to generation which eventually convinced him that there was much to learn from the East: does he not call the Indian peasants his 'professors'? As he gradually shook himself free from the influence of the conventional schools of science, he realized what vast treasures of knowledge had been gathered in cultivation under difficult and often desperate conditions by those whose very existence was at stake.

In actual fact his views were directed to each problem as it occurred, and these problems not only differed greatly but were differently handled by the planters and peasants. As it happened, his early examination of fruits, tobacco, and indigo showed up surprisingly faulty methods. But when it came to the great staple crops like the cereals, there was quite a different picture; there might, in wheat growing, be confusion of varieties but, except for plant-breeding purposes, this was not altogether a disadvantage (the robustness of the wheats was possibly kept up by cross-fertilization; see Chapter 2); the cultivation of rice was extraordinarily perfect and even by the time Sir Albert left India the Western scientists could not state how it was done.

The explanation (this explanation is not derived from Sir Albert's writings) of these widely different standards of achievement among the cultivators of the East is surely obvious. In dealing with crops necessary to his existence the peasant is compelled to do his best; economic necessity may, indeed, sometimes push him too hardly and he tries to grow the wrong crop in the wrong place simply because he needs it so badly. (See Chapter 2.) But where the conditions are at all reasonable, he evolves great perfection of method in producing what matters to him so intensely. If, however, he has to deal with a non-essential crop, i e. grown for gain, his practice is much less certain and can be very faulty and careless. Such crops do not sustain life: they merely bring in money: the peasant is content to make a little cash in the easiest possible way, for a little money seems, in some parts of the world, a great reward.

Thus when Sir Albert arrived in the East, he found both good and bad. It is interesting to see how the faulty practices came to be forgotten in the overwhelming impression made by the general excellence of Eastern agricultural practice.

Tools and Implements

Sir Albert was always keenly interested in the tools used by the peasant. At first sight the great expenditure of human labour lavished on all cultivation operations in India with the help of very primitive tools appeared extravagant in the extreme; the introduction of more modern and efficient implements seemed an obvious direction in which Western science could help. In *Wheat in India* (pp. 77-86) there is a detailed review of many attempts made to introduce reaping, threshing, and winnowing machines on European models long before the Pusa Research Institute was created, and the reasons are given why almost every effort had failed, so that the experimental farms had speedily become 'museums of all kinds of European implements which were for the most part quite useless in a country like India'; a few years later he was commenting sardonically on the fact that he found, while on leave, small handy implements exhibited at Bristol for the use of the British smallholder but at Allahabad only large heavy machines shown to the Indian peasant. (*Report of the Imperial Economic Botanist for the Year 1912-13,* p. 16.) The poverty of the cultivator, to say nothing of the availability of abundant human workers, made such suggestions futile.

The existing system could not be radically changed, but it might be developed in useful ways. This must never exceed what the cultivator could afford, and, in a way, also what he was used to. This principle Sir Albert kept in mind to the very end, though he did not always limit himself to what the poorest could manage, but catered very largely for the fairly well-to-do man; his standard seems to have been the possession of a yoke of oxen; when more power was needed, the presumption was that the second yoke would be borrowed from a neighbour. Thus the maximum draught contemplated was four animals. This was sufficient to draw the *kans* eradicator, which has already been referred to in Chapter 1. Better implements would actually increase the efficiency of the animal team; thus the five-tine spring cultivator would increase efficiency threefold, and bring down the great cost of the cultivation of tobacco, though it was not a power machine beyond the planter's purse. (Ibid. *for the Year 1915-16,* p. 8.) When Mrs. Howard introduced some simple machines for slicing and paring in the drying of vegetables, she was careful not to have them driven by electricity or other power, but by an adapted bullock gear. The contouring of fields, again, was an operation entirely within the capacity of any ordinary well-to-do cultivator, and was, in fact, widely copied in many Provinces and Indian States.

At the same time Sir Albert was conscious of the disadvantages which the general backwardness of the population entailed. A passage has already been quoted in which this point is put (see Chapter 1), and the fact deplored that many excellent improvements fail simply through lack of the small amounts of capital needed to launch them; that meant that progress was most regrettably slow and the improvement of Indian agriculture most difficult. His own successes -- and they were startling -- could not blind him to the immensity of the problems to be overcome. Quite at the end of his career he was still stressing the fact that poverty, indifference, and illiteracy were formidable obstacles and that a rise in general standards of education was a crying need, without which little could be done. (*Indian Agriculture,* Chapter V, 'The Human Factor'.)

In the course of his twenty-six years' work in the country, however, some changes occurred. The following passage was written during the First World War, which was affecting the economy of the country.

> 'Speaking generally, there is no question that the time is rapidly approaching when Indian agriculture will be bound to adopt more efficient methods. The cost of labour is rising all over the country and already, in certain tracts like Sind and the Punjab, the supply often falls below the demand. The claims of the urban areas for workers are likely to increase with the spread of factories and with the improvement of communications. Once the supply of labour diminishes sufficiently, agricultural work is bound to become more organized in order that the men available may increase their output. Agriculture will then become more orderly, the small inefficient holding will disappear, labour-saving devices will make their appearance more and more and there will be less waste of effort.'

Possibly Sir Albert was still rather too eager, even at this time (1916) in the cause of innovation. The history of his opinion on the most important of all the instruments of husbandry, the plough, is illuminating.

He starts in 1911 with categorical advice as to the need for replacing the old wooden country ploughs of India by small iron ploughs of a modern kind. The object would be to open up the soil more efficiently in the hot weather in order to get the sterilizing effect of the sun on the harmful soil bacteria, giving scope for the more rapid multiplication of the more beneficent organisms when the rains broke. It was argued that when the cultivators had been taught by example the greater efficiency of the iron instrument, a great market for them would be bound to arise. (*Journal of the Bombay Natural History Society*, 31st October 1911, 'The Improvement in the Yield and Quality of Indian Wheat', p. 198.)

Ten years later he has a far better understanding of the question. The passage has so much bearing on the modern No Ploughing controversy that it is here given at length.

> 'The great contrast between the shallow cultivation of the Orient and the deeper tillage in vogue in Europe has exercised a profound influence on many of the improvers of Indian agriculture. At first sight it seems so certain that the work done by the primitive Indian plough, which only pulverizes the surface, must be inferior to that accomplished by an iron implement which works much deeper and also turns the soil upside down. Hence the persistent efforts which have been made to induce the cultivator to adopt iron ploughs in place of his old-fashioned wooden implement. The general introduction of the new method has been hampered by the limited strength of the work cattle who find soil inversion involves far too much

> work. As horses are not available in India for really deep tillage, the steam engine and the tractor have been introduced. It must be confessed that the response of the people to these innovations has been disappointing. Iron ploughs have not been adopted generally to anything like the same extent as some other devices of the West -- the sewing-machine, the safety bicycle, and the cheap American car, all of which cost much more money than an iron plough. In his attitude of aloofness to the soil-inverting plough and to power cultivation, the cultivator may after all be in the right. The matter needs a very careful and a very critical study. Iron ploughs cost more than country ploughs and moreover often do great harm by disturbing the levels of irrigated land and by interfering with the surface drainage in the monsoon-fed areas. The question naturally arises: Is soil inversion really needed in India? This process has been developed in Europe for two purposes: the destruction of the weeds of stiff land by cutting off the light and the exposure of the soil to the pulverizing effects of the frosts of winter. In India neither of these factors is of any importance. If weeds can be uprooted in this country, the sun kills them at once: soil inversion is not necessary for the purpose. Dryness and heat take the place of frost in improving the tilth. In some cases deep cultivation is needed in India, particularly in connection with the eradication of deep-rooting grasses such as *kans* (*Saccharum spontaneum* L.) and in cleaning the land. It should, however, be carried out by an adjustable subsoiler which does not disturb the surface levels. The power needed for such deep subsoiling must be within the means of the people.

This principle, that whatever the Western scientist offered must fit into the general economy of the country, was also kept to the fore during the last piece of work in India, the experiments connected with the working out of the Indore Process. Throughout these investigations every implement used is an Indian one and Indian vessels of volume are adopted. The work was, of course, designed for India, but not every scientist would have taken the trouble both to work with indigenous tools and to record quantities in that way. It was sensible. Appropriate was also the demonstration, again at Indore during the first of the cultivators' meetings, of a strong and simple new bullock gear, by means of which any good cultivator could use his two pair of oxen to run a fodder cutter, threshing machine, or feed grinder; this, it is stated, would be 'a poor man's engine' if no other could be afforded, thus showing the peasant, by the ordinary working out of a mechanical device, how to make the best out of what he already owned. (*Notes on the First Cultivators' Meeting, 11th-13th November, 1929,* unpublished document.)

Receptive Capacity of the Indian Cultivator

In spite of the Indian cultivator's lack of formal education Sir Albert formed a high opinion of his ability to profit by what was shown to him. He started, after all, from a base line of familiarity with a number of facts. His knowledge of the soil may be described as unique; the Indian vernacular vocabularies for describing the state of the soil are far richer than anything we have evolved in our Western languages. Thus, in *Wheat in India,* in reference to the Punjab:

> 'The occurrence of these terms in the vernacular shows that the cultivators fully realize the existence of many types of soil of varying suitability for the growth of crops. Possibly a modern soil survey would do little more than express in a scientific way what is already understood and applied by the people.
>
> 'Many terms are used to describe the physical character of the soils: thus *nyai* is rich land round the homestead. Heavy clay soils are termed *dakar, chamb,* and the heaviest clays on which rice only can be grown are termed *rakar.* The best soils of the Punjab are well-drained loams known as *rohi.* The lighter loams are called *rausli* and the sandy soils which only grow millets are known as *bhur* or *maira.* *Tibba* is almost pure sand and *reti* is a soil with windblown hillocks of sand.'

The list continues, to give the terms used for the different waterings of land, whether rain moistened, canal moistened, moistened by rise of the rivers, etc. In the succeeding pages a great number of terms are mentioned (some classifying soils by amounts of organic matter they contain) for other parts of India. Clearly the subject interested Sir Albert and convinced him at the outset of his work that the Indian cultivator's knowledge of his craft of husbandry was no superficial knowledge, but detailed, comprehensive, and very exact. (These soil classifications of India go back at least to the time of Akbar and were used by Government for purposes of the district revenue settlements every thirty years.)

Of the cultivator's industry there could be no question. There is mention on one occasion of a practice of ploughing fields fourteen times in a season. What was perhaps more surprising was the accuracy of eye shown in the capacity to level and contour without the aid of instruments. (See Chapter 3.) This was compensation for the absence of literacy.

But was the peasant also shrewd and intelligent? Would he have the wit to adopt any promising innovation? Sir Albert was fond of quoting the popularity of the bicycle and the sewing-machine (see above), which had spread through India 'with the rapidity of a prairie fire', to prove that the Indian peoples might be relied on to accept what was worth while. The condition for success was, however, that any proposition should be launched in the right way. Suggested improvements should be clear cut and definite and not too frequent; the point is made in plant-breeding that a constant stream of new varieties, very similar to each other, only confuse the cultivator and defeat their own object.

> 'Before any scheme of seed distribution is adopted great care is necessary to establish the fact that the game is worth the candle. If the existing variety, indigenous or improved, is to be replaced by a new one, the new type must be a real and definite improvement. It is not worth while disturbing the cultivators unless a marked advance can be made. All new forms at the Experiment Stations should therefore be ruthlessly discarded unless they are at least 20 per cent better

> than the existing types in cultivation. A high standard should be set and maintained. The mistake is sometimes made of sending out variety after variety at short intervals. This not only shakes public confidence but also prevents any variety from ever being established. The importance of the time factor in seed distribution is sometimes not fully appreciated. Time is needed to obtain the confidence of the people, in developing the most suitable organization for seed distribution and in growing and storing the large bulk of seed essential for success.'

A second essential was to bear in mind the real difference between Experiment Station conditions and those in a country at large.

> 'The agricultural conditions at a well-conducted Experiment Station are somewhat different from those which obtain among the ryots in the surrounding districts. The improved cultivation of the soil at an Experiment Station results in a greater supply of soil moisture for the wheat crop than is available in the average ryot's holding. It is likely, therefore, that a variety of wheat grown under the two sets of conditions will behave quite differently. This is found to be the case, particularly if the maximum possible yield is desired at the Experiment Station. To obtain this maximum yield the variety must be a late one so as to utilize to the utmost the available growth period and the ample supply of soil moisture. Under Experiment Station conditions it is easily possible, with due attention to cultivation, moisture conservation, and choice of soil, to grow upwards of thirty maunds of wheat to the acre. If, however, these high-yielding varieties are grown by the cultivators, quite different results are obtained. With defective preliminary cultivation and insufficient soil moisture, these late potentially high-yielding wheats do not reach maturity before the onset of the hot weather has begun to diminish the moisture in the soil. The result is a low yield, often of rather poorly filled grain. The Experiment Station results are thus reversed.'

Thirdly, and the point seems obvious, it was essential to show results in the concrete. The cultivator must see crops in the field, the same sort of crops in the same sort of fields as he himself had to cultivate. This idea was brought forward early in 1910, when Sir Albert took the initiative in proposing a new type of demonstration at Pusa. He suggested that, instead of contributing to a forthcoming agricultural exhibition at Tirhoot, the whole exhibition could be much more effectively brought to Pusa. This was refused for 1911, the year proposed, but in 1912 a renewed suggestion won the day and the grounds of the Botanical Area at the Pusa Institute were lent, Sir Albert acting as secretary to the show. Tobacco and wheat were exhibited in the field, and, together with demonstrations on green-manuring, the value of pure seed, and of hot-weather cultivation, constituted five topics for instruction; plots belonging to two neighbouring ryots were also used for show purposes, the idea of sharing experimental efforts with the farmer, which Sir Albert had desired in the West Indies, thus taking effect. Lectures were given, repeated for late-comers, repeated again in the vernacular, and improved implements shown at work.

Success was immediate. Fifty sets of a new spring-tine harrow were at once ordered by visiting farmers. The experiment was repeated in following years.

> 'These demonstrations were a great success and were followed closely both by planters and by cultivators. There is no doubt that this method of bringing home the results of the work of the Agricultural Department is infinitely more effective than publications or the exhibition of collections of seed and other produce. An acre plot of improved wheat or tobacco, for example, appeals much more strongly to the agricultural mind than results in print or in the shape of collections of seed.' (*Report of the Imperial Economic Botanist for the year 1911-12*, p. 18.)

Invitations to address the Bihar Planters' Association followed and two addresses were given in 1913 and 1914. From this time on relations with the wealthier zamindars and the ruling classes in India became very influential and paved the way for the later arrangements with the Rajput and Central Indian States in setting up the Institute at Indore.

As time went on, the confidence of the growers was given more and more unstintedly. The new wheats, for instance, could not be grown fast enough to supply the seed in demand -- there was 'instant appreciation' of their superiority; the Pusa system of field drainage was eagerly copied; the recommendations on the cultivation of tobacco and indigo widely accepted; the new receptacles for the carriage of fruit bought up in bulk at Quetta; as for the sun-dried vegetables, the demand was twenty times the supply. (*Report of the Imperial Economic Botanists for the Year 1918-19,* p. 64.) It was true that patience was sometimes needed. It has already been noted how much work had been involved in launching the returnable fruit crate in face of the opposition of the Indian railways and its relatively high cost, but by 1919 the supply was being gladly bought up by the dealers at five to eight rupees, though had these crates been offered seven years earlier it was safe to say not one would have been purchased (ibid., p. 65); a gradual education in the possibilities of the fruit trade had had to precede. Such matters are a commonplace in any country, but it is hardly surprising that Sir Albert could never be got to agree, on the basis of his own experience, that the Indian peoples were unreceptive. In looking back on the past in later years he was at pains to contradict so false an impression. Often the time-lag was swept away by their eagerness.

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

'I mention this incident, which was constantly happening in India, because there is a general impression in this country [England] that a well-marked time lag must always occur between the results obtained at an Experiment Station and their adoption in practice. The conventional view is that after a result is obtained it must be repeated on a large number of replicated and randomized plots (see Chapter 8, The Question of Statistics and Views on Artificial Fertilizer) and the figures must then be subjected to a rigid statistical examination. The idea seems to be to protect the farmer from false prophets, forgetting that he is perfectly capable of looking after himself. My experience contradicts this conventional view of the time lag. When results of real practical value have been obtained in India I never observed any delay in their adoption. The response on the part of the cultivators was immediate. There was therefore no opportunity for spending time on the replication and randomization process. The only difficulty met with was illiteracy. Propaganda was impossible by means of print, a circumstance which greatly reduced the rate at which improvements could be taken up over large areas.' (Address delivered as the Distinguished Visitor's Address to the Royal College of Science, 1935; *Scientific Journal of the Royal College of Science*, Vol. VI, 1936.)

The Formulation of a Definite Policy for Propaganda Work and Labour Relations

In spite of the great name gained for the Pusa wheats and the immense influence of the Pusa work generally, neither Sir Albert Howard nor his wife were finally satisfied that the fundamental question of relations with the population was being handled with sufficient vigour and enlightenment. They determined that transfer to their own Institute at Indore should be made into an opportunity for unique developments.

These developments took three directions: the training of students and of agricultural officers, the latter for local work; the holding of Cultivators' Weeks for conveying useful results to neighbouring farmers; and the adoption of the best possible conditions for the labour actually employed at the new Experiment Station, together with the arrangements for training such workers to be sent forth as leaders and teachers in their own communities.

The training of students was embodied in the constitution of the Indore Institute. Such training had also been given at Pusa. As will be set forth in the final chapter of this book, Mrs. Howard was particularly interested in the right way of handling such teaching. In the course of the first four years at Indore nine post-graduate research students completed their course and sought appointments in the various agricultural departments in India. What was more specialized were the grants and student-ships arranged by the various contributing States or by certain Indian benefactors for training staff for work in the States themselves. A number of agricultural officers were thus taught and there was also an interesting scheme for giving a month's course in general rural development to all the thirty-three *tehsildars* of the *amins* of the Indore State, five of these attending at a time. In these and other ways the contributing States were glad to look on the Institute as a great teaching centre in the closest possible liaison with their own officers and agricultural departments. The teaching was most popular and the visitors' quarters provided always occupied. (See Chapter 1.)

The aims were wide and went beyond the problems of cotton, beyond even the principles of agricultural science, to embrace, as already stated, general village welfare. Sir Albert was an enthusiastic advocate of the ideas of the late Lieut.-Colonel Brayne, who wished to see the scattered and divided work of the many authorities looking after the population concentrated in one co-ordinated effort, applied locally to specified areas and thence extending, in fact, the exact principles which have since been applied on a huge scale in the Tennessee valley work and in other parts of the world. (Great success has been achieved by such team work in Africa; see 'Team Work in Africa', by Fergus Wilson, O.B.E. , in *Corona,* Aug. -Sept. 1951.)

A second initiative was the holding of the Cultivators' Meetings. To some extent these had been foreshadowed in the 1912 and other exhibitions at Pusa mentioned above, but the actual model were the famous Cultivators' Weeks of Coke of Norfolk in the late eighteenth century in England. The arrangements were very carefully thought out, and organized groups were brought to the spot to see everything with their own eyes. Groups of visitors, 200 at a time, came for two days from eleven of the contributing States. They were in charge of officers, were housed and transported; none of the bewildering distractions of the large agricultural show were present, and everything was kept business-like, simple, and cheap. There were a series of definite demonstrations, what one might almost call lessons, six each day, on very varied subjects, cultivation methods, well-irrigation, crops, manures including composting, cattle food. The first meeting was held in 1928, and then annually.

> 'The first cultivators' meeting produced other results besides interesting a number of State officers and villagers in agricultural improvements. The general public, for the first time, began to understand the purpose of the Institute and to realize its great possibilities. Since the meeting took place in January 1928 there has been a growing stream of visitors, many of whom are either local notables or well-to-do men who are beginning to take up improvement of their land. Actual cultivators from the villages are now coming in large numbers, many of whom work for a time to learn new methods... It will be necessary before long to appoint a special member of the staff for this work so that this duty [of showing round] can be carried out effectively without any interference with the current work of the Institute... It is now generally recognized that the Institute has become an important research and training centre, which exports ideas and information on rural reconstruction as well as improved varieties of crops and new methods of cultivation. It is already acting as a stimulus in general rural development.'

The meetings were an unqualified success; 'flattery thick as butter' greeted the Director on the conclusion of the second occasion when one was held; they more than fulfilled the purpose for which they had been designed.

In the third place, as Director of the Indore Institute, Sir Albert Howard was an employer of labour. Field and harvesting work was carried out by a regular force of 118 persons, men and women, supplemented by temporary workers. What should be the policy of the Institute towards these workers?

The answer was bold -- an 'experiment', as it is called. Sir Albert's boyhood on his father's farm has already been mentioned; on the relations between employer and employed, he had good recollections. It was his business, as the farmer's son, to carry round the food and drink given in those days to the workers in the field; he described to me once the extraordinary care which was bestowed on carrying out this duty; there was an art in varying what was offered, especially for the hot work of hay-making, and home-brewed cyder, beer, small beer, tea, etc., were all provided in turn, at the farmer's discretion, whose reputation rose and fell with the skill he showed in providing for his workers what was so necessary for their comfort. On this point the standing of his own family was particularly good as excellent, generous employers. I have every reason to say that these fine recollections, gathered from the last years of the best period of nineteenth-century farming in England, were of profound influence throughout Sir Albert's life.

The scene was now very different. The first need was to recruit from the Indian villages 'an efficient and contented body of workers' in spite of the competition of neighbouring mills and factories. The initial attraction was to be regular and above all effective payment of wages. Something had to be done to ensure that there was no cheating of the workers, either by illicit deductions or by the more insidious method of inviting running debts at a canteen or store.

> 'Regularity of payment is a matter of very great importance in dealing with Indian labour. At Indore workers on daily rates received their wages twice a month -- on the 18th and the 3rd, in each case at 2.30 p.m. The permanent labour is paid monthly on the third working day of the following month. To ensure that all payments are actually made according to the attendance registers all disbursements are made in the presence of two responsible members of the staff. Both of these men have to sign a statutory declaration that the payments have actually been made. The signed statements come regularly before the Director for signature, and are in due course placed before the auditors. In making payments the envelope system is used, the payee making a thumb impression in ink in the register or signing his or her name. These arrangements have been found to prevent any illicit deductions on the part of the staff. The payments are made in public; the rate of everybody's pay is known; the signing of a proper declaration in the register makes it possible to institute criminal proceedings at once for any irregularity; the

> Director is always available for enquiring into any complaints. That none have ever been made proves that the labourers actually receive their pay in full at regular intervals. Payment is made in coin; no attempt at payment in kind has ever been made; no shops for the sale of food exist on the estate and nothing whatever is done to influence the workers as to how they should spend their wages.'

An outstanding, indeed, an unprecedented, achievement was the shortening of the working day from the usual ten hours to six in the hot weather and to seven and a half over the rest of the year. This was successful beyond all expectation and indeed so remarkable in the treatment of labour in the East at that period that Sir Albert was well justified in referring to it as 'a miracle' in the paper which he was invited to contribute to the official journal of the International Labour Office at Geneva.

> 'After the regular payment of wages, the hours of labour come next in importance. Indeed, in India rest and wages are to a certain extend interchangeable, as the workers regard any extra rest as equivalent to an increase in pay. At first, the Institute observed the ten-hour day so common in India, but this was soon given up. It was found during the hot months of April, May and June that both the labour and the cattle required more protection from the hot sun. An experiment was therefore made to reduce the hours of labour during the hot months to six daily, beginning work at sunrise and ending the day at sunset. The actual working hours of the three hot months were arranged in two shifts -- four hours in the morning and two in the afternoon with six hours' rest during the heat of the day, i.e. from 10 a.m. to 4 p.m. At the same time the work was speeded up and both labour and supervising staff were given to understand that the six-hour day in the hot months could only be enjoyed if everybody worked continuously and conscientiously.
>
> 'The first result observed was a marked improvement in the health and well-being of the men and animals, probably due to the operation of two factors: the health-giving properties of the early morning air and avoidance of excessive sunlight. With the improvement in general health there was a corresponding reduction in cases requiring medical assistance. To everyone's surprise, it was found possible to speed up the work very considerably. The experiment of shortening the hours of labour was then extended to the rest of the year: working hours were reduced from ten to seven and a half.
>
> 'These working periods, six hours in the hot weather and seven and a half during the rest of the year, refer to the time actually at work; an extra half-hour daily is spent in travelling to and from the place of work. In no case does the working period exceed seven and a half hours, except for about a week at the sowing time of the monsoon crops. During this period, both man and beast do not obtain much more than two hours off duty for food during the hours of daylight. A full ten-hour day at high pressure is then the rule, as all realize that the sowing of cotton and

> other crops is a race against time. As soon, however, as sowing is over, the workers enjoy an extra day's rest on full pay. The sowing of the monsoon crops is the only agricultural operation in Central India for which anything more than a seven and a half hour day is necessary.
>
> 'For three years the agricultural operations of the Institute have been conducted on the short hours system. The result has been successful beyond all expectation. The miracle of speeding up Indian labour has been achieved and shorter working hours have led not only to contentment but also to an increased output of work.'

Further points attended to were good, if simple, housing; really practical arrangements for securing a clean water supply; and medical arrangements, which were given free; for the women a nurse was provided in cases of childbirth.

Finally, a most interesting system of training for efficiency and promotion carrying higher pay was instituted.

> 'An Experimental Station, like any employer of labour, needs some system by which the labour force can automatically renew its youth. The annual export of trained labour to centres at which improvements are being taken up is one of the important functions of the Institute. For these reasons therefore a supply of promising recruits must be arranged. To bring this about some system of promotion for proved efficiency had to be devised. At first this took the form of an annual promotion examination for the ploughmen. As they increased in efficiency and could manage and assemble their implements and also plough a straight furrow, their pay was increased by Rs. 1 per month. This system is now being superseded by the certificate plan. All the permanent workers in the Institute are eligible for special training so that they can earn efficiency certificates for such operations as (1) cultivation, sowing and the care of the work cattle, (2) compost making, (3) improved irrigation methods, including the cultivation of sugar-cane by the Java method, (4) the manufacture of sugar. A certificate of efficiency (with suitable illustrations) signed by the Director can be awarded for proficiency in any of these items. Each certificate which is awarded annually will carry with it an increase of Rs. 1 per month on the basic pay. When a member of the labour force has gained all four certificates, he will become eligible for transfer to other centres on higher pay. In this way the Institute holds out hope and places it within the power of any man to increase his starting pay in four years by about 30 per cent. It also enables an ambitious labourer to save enough money in a few years to purchase a holding and to become a cultivator. This is now taking place. Every year a few of the labourers return to their villages with their savings to take up a holding on their own account. Others are deputed for work in the contributing States on increased pay. The vacancies are automatically taken either by younger members of the same family or by volunteers on the waiting list of temporary

> workers.'

The idea of passing a body of workers recruited from the neighbouring populations through an Experiment Station as trainees, to become on leaving the most appropriate and natural leaders in their own villages and communities, goes a long way back, and was apparently derived from an early trial made of this method at the Raipur Experimental Farm in the Central Provinces under the inspiration of Mr. A. D. Clouston. This had come to Sir Albert's notice while he was at Pusa, and he had even at that time seen the possibilities and had prophesied that the Agricultural Department of India might come to be more efficiently manned by training boys of the cultivating classes rather than by recruiting students from the Agricultural Colleges; detailed proposals had actually been put before the Government of Bihar. (*Report of the Imperial Economic Botanist for the Year 1912-13*, p, 27.) The idea remained and now received its application at Indore.

In summing up this 'experiment' Sir Albert states briefly:

> 'It is possible that the system described... is only fully realizable on a farm working under model conditions. Nevertheless, there are a certain number of elements in this experiment which the writer feels are of universal validity in dealing with primitive labour. From the point of view of the worker it is perhaps most essential that he should feel that he is receiving a square deal. From the point of view of the management the best results are obtained by scrupulous attention to pay, short hours of intensive work, proper housing, and medical care, and by interesting the worker in the undertaking through giving his work an educational value.'

On this question of relations with those whom throughout his life Sir Albert was deputed to serve, his attitude may be called at once original and determined. Both he and his wife gave much thought to it and never assumed it to be a question which would solve itself: they deliberately considered ways and means and applied them. This was largely the secret of the success which attended their work almost from the first moment when they arrived in India. They were, in this field, pioneers.

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Small farms

Sir Albert Howard in India

By Louise E. Howard

Chapter 8
The Position of the Scientist

The Influence of Practice on Science

It is part of our general conception of science to assume that if a new scientific discovery is made it will eventually influence practical life: is there indeed any new scientific advance which does not do so? The effect may be immediate and revolutionary, or gradual and remote, but all new scientific discoveries bring some material changes in course of time.

The opposite idea, that practice enriches scientific discovery, first by revealing problems and then by suggesting solutions, is unusual. It is not commonly agreed that the farmer is capable of pointing the way to the physiologist, botanist or chemist. Yet a little reflection will show that this is bound to happen in a field like agriculture. No doubt Sir Albert Howard's strong predilection to stress the importance of the farmer's role induced him to dwell on this idea. At a time when the gulf between science and practice was a good deal wider than it is now, he was concerned to show the scientist that there was a debt owing to the practical man. (Cf. Chapter 7, Relations with Cultivators and the Treatment of Labour.)

In his Presidential Address to the Indian Science Congress in 1926 he starts with reminding his scientific audience that in the past farmers have sometimes done very well without the scientists.

> 'The great benefits that have flowed from the application of science to practice are not always on the side of agriculture; scientific method itself has sometimes profited from the association. Further, the man of science has had to realize that progress is possible without the aid of science, and that some of the greatest developments in agriculture, even at the present day, have been brought about by

empirical means. Examples of notable advances in agriculture which have taken place without the aid of science are to be found all over the world. In the Orient, perhaps the most remarkable is the cultivation of rice which has been developed by the people in the deltas of the great rivers to a high degree of perfection and carried up the slopes of valleys by means of a system of irrigated terraces. The care and skill which have enabled the cultivator to grow a semi-aquatic crop like rice on the steep hillsides of India and Ceylon cannot fail to command our attention and respect. In this development, science has played no part and even now has not completed the preliminary analysis of the factors involved in the growth of the chief cereal of the Tropics. We can only guess at the sources of the nitrogen made use of by the rice plant. Again in Gujarat in the Bombay Presidency, an indigenous system of agriculture has been evolved to overcome a most difficult set of soil and moisture conditions. In order that the tilth may be maintained and the moisture conserved speed is essential in managing these soils. To get over the fields quickly, the crops are grown in straight lines; simple but effective implements have been designed for sowing and inter-culture and a fast and powerful breed of oxen has been developed. The adaptation of means to end is remarkable and great natural obstacles have been overcome by the peasantry unaided. In the Occident equally striking advances have been made by empirical means. Sub-soil drainage, the modern systems of tillage, the great progress which has been made in the breeding of livestock, the Norfolk four-course system of rotation -- which followed the introduction of the turnip crop into Great Britain in 1730 -- are all improvements which owe nothing to the scientific investigator.'

The example of rice was often cited by Sir Albert as an instance where practice had outstripped science, empiric means for keeping this crop growing on the same paddy fields having been evolved of which no explanation was forthcoming from the scientists. Since then such explanations have in part been arrived at, but it remains a fact, that as regards this immensely important world crop, practice has preceded science in what might be termed invention and adaptation of method: the traditional methods of growing rice are indeed in many parts of the world very wonderful.

Even when the scientist and the farmer did conjoin their efforts it was not always the scientist who led in the choice of problem. As long ago as 1908 Sir Albert had pointed out that the amount of attention being bestowed on cotton investigations was due to the fact that cotton was being increasingly grown within the Empire; the choice of investigation being thus settled by the growers, not by the scientists, since, but for the increased cultivation of this crop, these investigations would not have been begun. (*Report of the Board of Scientific Advice for India,* for 1907-8; 'Economic Botany', p. 1.)

On consideration it will appear obvious that this is what usually happens. The agricultural scientist is almost always confronted by some immediate problem which he is asked to solve. This is true also when he is directed by some administrative authority to devote himself to a specified task, as indeed at the outset of his career Sir Albert was instructed to investigate the Indian wheats. Such directives or instructions are the outcome of an actual situation within an industry, and it is part of the genius of a good administration to know what problems are of importance to its public and to guide the services of the scientists in that direction.

But almost as soon as this is done official guidance ceases and the scientist starts his work as a free agent: it is his business, and his business alone, to 'put the question'. It is just this capacity for putting the crucial question correctly which marks the true researcher; for when it has been once properly put, half the battle is won and the answer is in sight. And here again the scientist joins hands with the practician.

The agricultural scientist, who in some respects has such heavy difficulties to contend with, is specially favoured. He has at his elbow a very experienced set of helpers, men who have farmed all their lives and whose fathers have farmed before them and whose inheritance is a very rich and varied traditional accumulation of knowledge. Not many occupations can offer such outstanding help, and it was part of Sir Albert Howard's chosen role -- himself the son of farmers -- to lay stress on this service rendered by practice to science.

> 'The approach to the problems of farming must be made from the field, not from the laboratory. The discovery of the things that matter is three-quarters of the battle. In this the observant farmer and labourer, who have spent their lives in close contact with Nature, can be of the greatest help to the investigator. The views of the peasantry in all countries are worthy of respect; there is always good reason for their practices; in matters like the cultivation of mixed crops they themselves are still the pioneers. Association with the farmer and the labourer will help research to abandon all false notions of prestige... all engaged on the land must be brother cultivators together.'

In this one respect he criticizes Liebig, whom otherwise he acknowledged as a very great scientist.

> 'He... failed to realize the supreme importance to the investigator of a first-hand knowledge of practical agriculture, and the significance of the past experience of the tillers of the soil. He was only qualified for his task on the scientific side; he was no farmer; as an investigator of the ancient art of agriculture he was only half a man.'

The Role of Science in Agriculture

That Sir Albert was at the same time a firm believer in the capacity of science to improve practice is obvious from his whole life, which could not have been devoted to this end had he not had this faith. He takes considerable trouble to describe the vast benefits which India was receiving from the efforts of the scientists, and goes into the question in detail, giving estimates and figures, in a twenty-page chapter in his small book, *Indian Agriculture,* written some three years before leaving India. He and Mrs. Howard took a leading part in supporting the Indian Science Congress, and he was very gratified to be elected President of this Congress in 1926. That he remained in intimate touch by correspondence and by visit when on leave with scientists at home in his special field, more especially with Professors Wood and Biffen at Cambridge, hardly needs stating.

Nor did he in any way cavil at the position assigned to the Experiment Stations and the claims made on their behalf. On the contrary, he was a convinced believer in their functions, influence and usefulness, and in the book just mentioned, in discussing rural reconstruction, says:

> 'As regards the best agency for devising improvements nothing has been discovered which can supplant the modern Experiment Station, provided with suitable laboratories, in which the investigator takes up a piece of land, copies the methods of the cultivator first of all and then with the aid of science devises improvements in agriculture.'

But even in this very definite statement he lays down his conditions: that, in addition to the usual laboratory work, land must be cultivated and, in fact, cultivated to begin with according to the traditional methods of the indigenous populations to be served. In giving a little later the list of official institutions serving agriculture in India, he gives in each case the exact acreage attached for the use of the various agricultural officers, and not many other details, showing unconsciously the direction his mind invariably took -- work on the land.

But if he declares that the importance of research work, provided it was done on such lines, 'cannot be over-emphasized', that it is the basis of all improvement, so that if research is starved 'the flow of fertile ideas will cease', nevertheless it was while he was in India that he began to express himself as dissatisfied with the way in which such research was being conducted.

The Meaning of Economic Botany

There was more than one kind of research to be considered. The first necessity was to have a clear conception of the aims to be pursued. The universally accepted objectives governing research at a university were not necessarily those which the 'economic botanist' should carry with him to his appointment in the field under some one national government to serve a named community, however vast that community might be. The title 'economic botanist', though perhaps not very attractive, is quite definite and its implications are clear: it presupposes botanical knowledge applied to the economic needs of the country.

This Sir Albert grasped from the outset and never relaxed his firm hold on this essential point. In an early letter conveying the first rough sketch of the lay-out of the precious seventy-five acres he had secured at Pusa there is a scribbled marginal note to the effect that the 'economic' plants, e.g. the fibres, would be grouped together, 'not by natural orders'. This was perfectly correct in view of the aims of the Research Station, but it was an unusual departure from academic convention, and not every scientist would have seen the need for it. From this start there was no going back: the same principle shaped every effort. The methods used were those of the most exact scientific achievement: the aims were to improve the crops of India.

The two investigators were completely at one on this point as on all others. A few weeks before she died Gabrielle Howard was making notes for a textbook specially designed for the training of Indian students in research on agricultural botany. She did not live to complete it and Sir Albert refused to continue the project, which was entirely individual to his wife and based on her own ideas. Some notes survive and a short analysis of part of these is included here. This is the best statement made by either husband or wife of the true difference between the university scientist and the agricultural researcher. The notes were written at a period when Mendelian investigations were engaging the attention of most scientists.

> 'It is very tempting for a student who is set to work in the agricultural field to aim at combining economic and theoretical work especially on Mendelian principles: he will be apt to aim at theory, which is the background from which he has just started, and to assume hopefully that something valuable in the economic field will emerge out of it. It is a common fault of young research workers at a university to think that they will advance knowledge and *incidentally* improve the crop.
>
> 'But the work of the scientist who is investigating the problems of heredity and that of the plant improver, or plant breeder as he is sometimes erroneously called, are fundamentally different and call for quite different attributes and qualities. The improvement of crops is not the same as genetics. Theoretical Mendelian investigations will of course bring out results useful to economic plant breeders, but the actual production of an improved variety must be unhampered by other considerations. If economic work is contemplated, the investigator must concentrate on this; interesting theoretical ideas will arise, but these must be carried on separately as a separate investigation.
>
> 'In fact, to pursue both aims in the same set of investigations is to court failure. There especially is risk of such failure in the economic field. Both the purely scientific and the economic or practical aim are very difficult. To the geneticist the main aim is knowledge and both negative evidence and side issues may contribute to his work. But the plant improver is not paid by the State to seek negative results

> or follow side issues, and his quest should be knowledge, it is true, but knowledge allied with common sense and judgment; the proving to the public that science is of some use is after all very important.
>
> 'Thus in theoretical work the whole range of specimens in any one character ought to be kept, whereas in practical work the secret of success lies in the ability to discard, which needs great courage, decision and judgment. The result is that the varieties retained are quite different: a very large number which the geneticist would keep have to be ruthlessly discarded. The plant breeder has to consider that the issue of a new variety is a very responsible task: it involves the time of many of those in authority, the credit of the Department, and the pocket of the cultivators. A new variety should last for years. Physiological characteristics are very important, as for instance, as to whether a new variety will be inclined to ripen later than usual, will require extra irrigation, or in some other point will make unusual demands. There are also questions of local preference, questions of appearance and recognizability, even questions of trade preferences: there are usually good reasons for the last named, which should not be disturbed without due cause: a new variety should not dislocate trade conditions. None of these questions needs to be considered by the geneticist at the University, but they are of the utmost importance to the plant breeder, whose work will always be a compromise between conflicting advantages and disadvantages. The work of plant breeding is in any case long and laborious, needs to be done in an extremely systematic and orderly way, with the greatest care and much personal attention to detail, especially in pollination work where the plant must be mutilated as little as possible; above all the plant must be studied throughout its whole life-history and the effect of prevailing environment and future cultivation conditions must be taken into account.'

The notes continue into what was to be Part II of the book, *Technical Aids*, with a number of excellent suggestions on the small practical details which the student plant breeder should train himself to master in working in India.

It is clear that these principles are exactly those which had for the past twenty years guided the Howards in their work; the insistence on the extreme necessity of discarding valiantly a great mass of material (which from the theoretical point of view might have been very interesting) is found emphatically stated years before in the book on *Wheat in India.* The notes have been quoted because they show how very definite, precise, and clearly thought out were the aims which the Howards pursued, how determined they were to keep faith with the terms of their appointment, to seek the practical advantage of the peoples of India, and never to yield to the lure -- so tempting to the highly-trained scientist -- of pursuing knowledge into the infinite.

Errors in Organization

The failure of other workers and above all of the directing authorities to accept and be guided by this delimitation of aims led to permanent difficulties. Applied research into the agricultural problems of India was treated as though it were the same as research into pure science -- or rather into the many departments of pure science. The Research Institute at Pusa itself was divided into no fewer than thirteen different sections, the heads of which were not supposed to trench on each other's duties. Again and again Sir Albert tilts against this 'fragmentation'. To the end of his life he never ceased to castigate an organization which set one research worker to look at plant varieties, another at the botanical growth of the crop, another to analyse its chemical constitution, a fourth to investigate the soil in which it grew, and yet others to consider its enemies, one man dealing with fungous attack only and another again with insect or virus onslaught; there might finally be a marketing officer to inquire into the disposal of the harvest. The character of the plant as a living entity could not possibly survive.

> 'The approach by way of the single science is really an inheritance of the Liebig phase when agricultural chemistry and agricultural science were synonymous. As the subject broadened and deepened, first one and then another science became involved, with the consequence that workers in these various branches of knowledge became colleagues of the agricultural chemist. The literature dealing with investigation and the teaching in the colleges and universities naturally followed the separate sciences. When about thirty years ago Departments of Agriculture began to make their appearance in various parts of the Empire, the organization was modelled on the teaching of the colleges and the staff usually included a chemist, a mycologist, an entomologist, a bacteriologist, and a botanist. As research extended, progress has always been marked by the addition of specialists whose business it was to deal with the application of some particular science to agriculture. Meanwhile the real subjects of research have far outgrown the old tradition founded on Liebig's work and the attack by means of the single science is no longer adequate.'

Mrs. Howard was equally emphatic on the point: it may be remembered that the very earliest formulation of the idea that the plant was a natural whole defying the man-made divisions of science had been due to her. She was entirely in accord with her husband in attacking every problem on the broadest basis, not excluding the final preparation of the product for the market, a direction in which some might feel the scientist had no obligations. It was suggested that 'team work' would solve the difficulty. By team work is meant the assignment of a large problem to a group of workers who agree, or who are directed, to work at it simultaneously: the results which each arrives at will, *ex hypothesi*, contribute to a comprehensive solution. Sir Albert argues that team work has a very limited application. It is useful as an apprentice system, when a group of eager students follow the indications of some acknowledged leader in research and work under him; this implies two things, a suitable institution for such an arrangement, e.g. a University, and a leader to direct the team: so that in the end the whole idea comes again to depend on the man and not the organization. Any who have had any experience of team work will agree with Sir Albert that without an outstanding leader in whom all have confidence team work is utterly useless. In other circumstances, states Sir Albert, it breaks down; in no case is it any help to the investigator who can stand on his own feet.

> 'It is, however, in the study of biological problems that team work is most likely to fail. As emphasized above, the growth of a living organism like a plant involves many of the natural sciences and it is difficult to see how team work is to give that insight into vital processes without which all such research remains sterile. A successful biological investigator must be able to visualize the complicated processes taking place in a plant, and to realize that such processes do not take place independently but each influences the other. That this is being recognized is shown by the modern development at the universities of borderline subjects like bio-chemistry, but what is wanted is something more than this; it is an integration of the main facts of the chief sciences which bear on agriculture.'

Though this question of fragmentation remained the basic problem, to solve which, to Sir Albert's dissatisfaction, no attempt was made and which he encountered in even worse form on his return to Europe, a more immediate difficulty occupied the minds of the authorities, this was the division of the work between the central and the provincial services. The difficulty was not only in India but felt throughout the Empire. It was suggested that a proper division could be made by taking note of the nature of work to be done respectively at the two types of institution: while provincial stations handled local results, the central station should devote itself to 'fundamental' or 'long-range' or 'wide-range' problems: all these terms were used. Sir Albert exposes the futility of this argument. The central Experiment Station cannot for ever confine itself to supplying scientific explanations of what is being accomplished at the smaller stations. Unless it wishes to have its grant revoked, it will not be able to escape the call for practical results. But as soon as it begins to enter the practical field it duplicates the work of the provincial stations and renders the whole idea nugatory.

> 'This is not the only drawback. The attempt to divide research into two classes -- fundamental and local -- imposes limitations on both the groups of workers involved, and seeks to maintain a distinction without any real difference. Instead of being allowed to follow the gleam untramelled in whatever direction it may lead, both sets of workers must either conform to the organization or come in conflict with it. In the former case, their work, on account of its limitations, may lead to nothing. In the latter, they may solve their problems at the expense of their own interests. Clearly such an organization does not fit the work. It erects walls where, from the nature of the case, the rule should be -- no walls.'

Errors in Approach

Such might be the errors in overhead organization. An infinitely more important matter was the way in which the scientist set himself to work. Sir Albert had his own very definite ideas on this subject, and they differed widely from what was generally held, and is still held.

> 'One objection may possibly be made to the present presentation of facts, namely, the small number of direct experiments of a laboratory kind, such as are most usual in papers on agricultural science. The conclusions reached have been obtained, for the most part, in another way, namely by long continued and almost daily observations on the growth of crops combined with much reasoning and thought on the phenomena observed. The knowledge which comes from continuous contact with growing plants is of course not of the same order as that which may be called "test-tube evidence", but we venture to think that, rightly used, it is of the greatest value to the investigator and can be employed in advancing crop production. After all, it is on this kind of evidence that the greatest advances in British agriculture have been made, both as regards crop production and in the improvement of stock. It is the method used by the older naturalists... with results which are known to all.'

This topic is stressed again and again. Two further citations are given to show what great importance the Howards laid on their method of closest observation of the crop as it grew. It was the very foundation of their work, and in their opinion, however 'exasperating' and apparently erratic, of infinitely more moment than any preceding laboratory tests. Both citations are from addresses to the Indian Science Congress, in 1916 and 1923.

> 'A knowledge of the reaction of the plant to its environment is essential if the farmer and not the plant is to be the master of the situation. To acquire such knowledge is one of the aims of agricultural investigation. It can be obtained empirically by the method very frequently used, namely, by observing the effect on the out-turn of successive changes in the environment... Such experiments when carried out under agricultural conditions, are known as field experiments and anyone who has experience of field experiments knows how exasperating they are. It is one of the most difficult things in the world to obtain really conclusive and reliable results. Climatic conditions cannot be controlled, some of the soil factors are uncertain and the results in succeeding years have a most annoying habit of being contradictory. The scientific man trained in the exact habits of laboratory investigation, where conditions can be regulated, is apt to be sceptical and to lose patience. Nevertheless, to obtain results which are economically sound and to test the conclusions of the laboratory, field experiments are essential. Here there is great scope for the botanist. In such experiments we are apt to focus attention on the beginning and the end only, that is, on the conditions provided and the yield

> obtained. We tend to ignore the changes and processes which have been taking place in the plant. This is, in reality, a selfish and brutal method of dealing with the subject. If we focus our attention on the plant and instead of regarding it as a machine which grinds out so much food for us we look upon it as a living individual completing its life cycle under certain conditions, we obtain valuable information even from an experiment in which the end result is rendered useless by some climatic circumstance.'
>
> 'The investigator, after having learnt how to grow plants and having mastered agriculture as an art, must proceed to study his crops in the field. It is not sufficient to plant the seed and wait until flowering time and harvest come round for the results. Daily contemplation of the growing crop and observation of the plant through its whole life history will suggest many new ideas and do much to train the observer, and develop the power of accurate deduction and real agricultural insight. In variety trials and field experiments the necessity of constant observation of the growing crop is seldom recognized. An even plot of land is selected, the crop is sown and the harvest weighed. Should the season be abnormal, this circumstance is often recorded. It is somewhat dimly perceived that the quantitative results of any year partake of the nature of an accident, but it is thought that a repetition of the experiment for, say, fifty to one hundred years and the striking of an average result will remove most of the effects of disturbing factors. It is true that this expensive and time-consuming procedure will give the mean result under the conditions of the experiment provided all due care is taken in carrying out the work. On the other hand, a constant observation of the growing crop by a fully qualified observer will lead to the deduction of the factors on which yield depends far more rapidly and accurately than can be done by such a mechanical method. Constant observation of the growing crop is therefore of the first importance. In course of time, the observer learns how to read his practice in the plant and, at the same time, he develops from hardly won experience a sympathy and understanding of the cultivator and of the grower's point of view. The raising of crops is a most useful discipline for a young investigator fresh from the university, and it also serves rapidly to remove any intellectual arrogance he may possess in his attitude towards the farmer or cultivator. First-hand practical experience will thus assist towards producing a proper relationship between the scientist on the one hand and the practical man on the other.'

Finally, the scientist was wrong in his approach to his audience. It was no doubt true that the work to be done was often elaborate; it could only be achieved on the basis of a wealth of data arranged and classified to illustrate some small advance or discovery; the utmost accuracy was essential. But this is the method, not the outcome of research, which should be a very different thing. It was noted in a preceding chapter that Sir Albert set himself against the professional vanity which hastened to publicize a stream of small and often very similar results, thoroughly confusing to the minds of recipients not trained to appreciate the fine differences involved. This was true for all agricultural communities, but when it came to a peasant population like that in India, there was the added difficulty of illiteracy. Only the standing crop, the implement at work, or the harvest as gathered, would convey anything at all to such an audience: only masterpieces should be presented to them.

> 'There is a very natural temptation to bring forward as a new variety anything which shows even a trifling improvement over that already in cultivation. This tendency is especially noticeable among young plant breeders and is easy to understand. Each man wishes to show his employer that he is really accomplishing something. As the work of a plant breeder is laborious and tedious a small success is hailed with delight. From the point of view of general strategy any such premature attempt to supersede an existing variety is, in the long run, disastrous and generally involves a waste of public funds. It also tends to lower the status of plant breeding and to shake the confidence of the public. A small increase in yield or in quality is often wiped out or even reversed in bad years. The cultivator knows this and feels that it is better to stick to his old varieties unless the anticipated profit is great enough to justify the risk of change. It used to be an axiom that the Indian cultivator would adopt nothing new. This is not true. If the profit is great enough, he will adopt anything, but he will not change his seed or his methods unless the increased profit is large. Experiment Station workers do not always realize the amount of trouble and expense involved in changing a variety in general cultivation. Members of the audience who have experience of extension work will hear me out when I say that varieties cannot be changed every two or three years without disturbing the confidence of the cultivators and causing very great expense and trouble. It is better for the plant breeder to wait until he has a really substantial improvement to offer and then to strain every nerve to get it adopted as quickly as possible. The difference between improved varieties is as great as that between the pictures of great artists and those of art students. Only masterpieces should be imposed on the cultivator.'

The Question of Statistics and Views on Artificial Fertilizers

Possibly on no topic was Sir Albert Howard so decided in his objections as on that of the application of statistical method to agricultural research. The extraordinarily vivid conception he had of plants as living things placed in a living, changing environment caused him once and for all to reject the use of statistical method in the biological field. It has already been abundantly made clear what stress he laid on observing the plant grow; the investigator's 'watching brief' should be all in all to him. What he is looking at is constantly changing: no one moment in the existence of any living organism is the same as the preceding or as the following moment. Yet statistical analyses of their nature are records of a momentary condition, and of such an instrument only very limited use can be made in a field like agriculture.

Unfortunately agricultural investigation now began to take the form, advocated by Rothamsted, of the 'randomized' plot and 'replicated' plot. It will be a mystery to future generations that this extraordinary system has attained so great a vogue; to the reader not familiar with these curious terms some explanation may be useful. The basic idea is that of correcting errors due to natural variation by dividing the research project into a number of scattered ('randomized') and repeated ('replicated') areas, and subjecting the collected quantitative results to statistical correction: this can only be done by a trained mathematician, and is a laborious process. Sir Albert refused to see the necessity for thus subjecting agriculture to what he called 'the fastidious approval of the higher mathematics'. An investigator who could not interpret his results correctly without such a prop was not worth his salt: the method was a bolstering up system for the inefficient. But the disadvantages did not end with this. Even the good investigator was being deprived of his greatest asset, the chance to read his practice in the plant: each randomized plot would necessarily differ from the next and a general impression could not exist. Such a method, which under no circumstances could convey its own visual lesson, was hopeless. The determination of good agricultural varieties was quite often a question of viewing a crop in the mass, the small but important variations being only then revealed. By the randomized method the investigator crippled his own efforts. What was even more fatal was the final repudiation of any attempt to show results broadly to the visiting farmer. Here Sir Albert spoke with authority, accustomed as he was to instruct an audience largely composed of the illiterate, who used nothing but their eyes -- and very good eyes too -- to judge results. Applied to India the system was in truth an absurdity and marvellously calculated once more to open the gulf between scientist and peasant which Sir Albert had been at such pains to close. It gave full scope to that pretentious vanity of the research world which he had spent a lifetime in attacking. It was not, however, until his return to Europe that he realized the full force of the intrusion of statistics into agriculture: his most vigorous utterances were made in these later years.

On the question of artificial fertilizers Sir Albert's opinions were at first much like those of his colleagues. He certainly had no objection to them, for a long time taking them more or less for granted, indeed, quite in favour of their use in a general way. There is no reason to attribute to him anything that can be called an initial prejudice against them. He does, however, seem to have made but little use of them in his experiments, and the argument for this abstention cannot be considered open to criticism -- he avoided their use for the simple reason that he knew the peasants of India could not afford them; indeed, they were scarcely to be procured at the bazaars. (According to the *Report of the Royal Commission on Agriculture in India,* issued in 1928, there was a very small production of sulphate of ammonia in India itself as a by-product at the Tate Iron and Steel Company's works, etc. In 1919 of the 4,4336 tons produced only 472 tons were used in the country and in 1925 of 14,771 tons only 6,395 tons, the rest being exported. The Commission notes the prospects of increased imports and use.) However, he made some use of ADCO, the synthetic activator sold by Rothamsted, in his composting experiments, but, as already noted had found this substance a good deal less satisfactory than animal dung; the compost thus made tended to break down unevenly and remain lumpy and finally to lose nitrogen; a number of pot experiments with ADCO compost also gave less good results than those with farmyard manure compost. However, in his final summary, Sir Albert does not depart from the current view of the value of artificials. He does not hesitate to state that 'the full possibilities of humus will only appear when the dressings of compost are supplemented by the addition of suitable artificials. The combination of the two, applied at the right moment and in proper proportions, will open the door to the intensive crop production of the future. Humus and artificials will supplement one another'. (*The Waste Products of Agriculture,* p. 112.) One proviso he does make, and it is an important one, that a fair state of fertility, built up by organic matter, must precede the use of these fertilizers; artificials can 'never be the whole story'.

One passage only, written rather early in 1916, points in an opposite direction. It has been quoted at the end of the chapter on 'Soil Aeration and Irrigation', and the reader is asked to turn back to it. It is a most interesting statement and argues with great clearness against the use of artificials as sheer waste of money. It is pointed out that the soil possesses in its own bacteria and fungi an ample mechanism for providing the plant with necessary nitrogen or phosphate. It ends by repudiating the idea that we need anything more than the natural surface of the earth -- 'a vast nitrate and phosphate-producing factory' -- to enable us to feed the world. (See Chapter 3, Soil Aeration and Irrigation.)

Possibly those ideas remained always in the background of Sir Albert's mind. He was so engaged in thinking in terms of green-manure and compost, organic matter generally, of which there is endless mention in his writings, that he probably scarcely thought about artificials, as something of no importance to what he was doing. Eventually two types of knowledge, the Eastern and the Western, contrasted and compared, provided almost too much food for reflection: what had not been apprehended while so hard at work in the tropics became sudden and final realization on return to the West. (There is a discussion of the question of the relative advantages of artificial manures and natural organic manures *for India* in *Crop Production in India,* pp. 39-41. The question is there put as one which has still to be solved, and it is stated that there was controversy in India itself on the point. Sir Albert does not attempt to deliver a verdict, but argues that 'a good deal of careful experiment' will be needed to determine the matter. He suggests taking up two areas of land and working them on the two types of manure (artificials and compost made on Chinese or Japanese methods), with keeping of costs, results, and records of the nitrogen balance sheet. He remarks that the results will be 'exceedingly interesting'.)

The Ideal Investigator

In spite of the public appreciation of his great services to agricultural science, Sir Albert felt himself somewhat isolated before he left India. There is a strong touch of idealism, idealism mixed with uneasiness, in the utterances of the last years: idealism, in that he knew what colossal advances could be made in India if only the right arrangements would commend themselves in the right quarters, uneasiness because of the realization how slender were the chances that Government or public would have the sense to probe the situation as he had probed it. Here is his own contribution to the decidedly difficult problem of dividing the work between the big Experiment Stations and smaller centres.

> 'Any practical results obtained could be made available to the general public by means of demonstration farms... and a specially selected staff working among the people. Such demonstration farms would require no scientific equipment and would be almost self-supporting. It would be clearly understood that no research work is attempted by the district staff. The art of demonstration and of inducing cultivators to adopt improvements is as important as that of research and every endeavour should be made to develop this branch of the subject as a separate and as an honoured profession. The idea that, to be successful, every officer working in the districts, must attempt something in the way of research must be given up entirely. Two branches -- research and demonstration -- which are both equally important should be developed in every agricultural department.'

He is careful to say that demonstration work should be 'an honoured profession', but that research ranked highest in his mind cannot be doubted. In refusing to the workers at the smaller centres the right to do research, Sir Albert was cutting through a situation full of falseness and pretensions. It was already becoming the policy of governments, perhaps more at home than in India, to recruit an army of inexperienced workers, mostly young, and to tempt them into service by calling their work 'research' and indeed expecting research from them. Sir Albert held very strongly that it is not possible to presume the existence of so many individuals endowed by Nature with the brains and the personality needed for true research in so difficult a field as agriculture. The recruitment of a large cadre could only mean the recruitment of mediocrity, which would have mattered less had there not been that convention that each worker so recruited must produce some tangible evidence of his investigations. A vast mass of unimportant records without synthesis or direction, making no contribution to practical solutions, filled the learned journals -- urgent problems were thrust aside while quality gave way to quantity. On this point Sir Albert was later very bitter.

Who, then, should be the research worker? Sir Albert's requirements are severe.

> 'The knowledge required by the investigator of crop problems must obviously be considerable. On the scientific side he must be well trained in all branches of botanical science, including morphology, anatomy, physiology, pathology, systematic botany, ecology and genetics. In addition he must have a sound knowledge of general science, in which chemistry and physics should be included. Such knowledge is essential because, in crop problems, it is not the plant alone that has to be studied but the plant in relation to its environment. This part of the

> training of the future investigator is the work of the University, and is best obtained in the ordinary science schools.'

There follows one of Sir Albert's many protests against the fragmentation of science, which, while necessary for the teaching of science in a University, should be discarded as soon as the student ventures on a career of research in agriculture, where 'the work of the plant... has no separate existence in terms of botany, chemistry, or physics'. He then continues:

> 'After an adequate scientific training, the future investigator of crop problems must master the art of agriculture as far as it relates to crops, and also pay attention to a number of trade aspects. Here again, anything in the nature of separate compartments must be avoided. The art of agriculture, which is nothing more than the crystallized experience of generations of tillers of the soil, must be simultaneously looked at from the point of view of the cultivator and the student of science. In ancient systems of agriculture, such as that of India, it must never be forgotten that the cultivator is generally sound in his procedure; the difficulty often is to perceive the scientific basis of his practice. Similarly, in studying the trade aspects of crop production, these must be welded into the scheme of things and not regarded as a separate subject...
>
> 'Such is the training and experience needed on the part of the worker. It is obviously considerable. The University phase is the beginning and constitutes the period of acquisition, something like the caterpillar stage in the life history of the butterfly. After this, practical experience is essential, and the future investigator must be at great pains to weld the two stages of his training into a well-balanced whole. Such a training, as has been indicated, must be expensive both as regards money and time, and any State organization which employs such men cannot possibly afford large numbers.'

Two years later, in his Address to the Indian Science Congress in 1926 already mentioned, Sir Albert referred rather more definitely to the two opposing tendencies which must be reconciled in the teaching of science: the integration of several sciences in training recruits for applied work like agricultural research, and the pursuit of the specialized knowledge needed for the advancement of pure science. (Presidential Address, *ad fin.* See also the notes made by Mrs. Gabrielle Howard for her book on the training of students, above.) There is no need to cite the passage here; it is only necessary to refer to it in order to make plain that Sir Albert was quite as well aware of the claims of the single sciences pursued as ends in themselves as any who devote their lives to such a task. All he was at pains to do was to show the distinction between this accepted ideal and another ideal, that of the application of science to practical life, which was too apt to be thrust aside as a secondary objective.

> 'Up to the present, the application of science to agriculture, although successful in many instances, nevertheless has not always led to useful results. If only the training could be broadened and the right type of man with the ideal combination of knowledge and aptitude could be set to work on the problems of to-day, it ought to be possible to accomplish more in the next generation than has been achieved during the last hundred years. The problems have been defined and are before us awaiting solution The scientific knowledge and the ability exist in the great republics of learning. In many cases the means for doing the work have been provided. What is needed is the happy union of all these factors -- the trained investigator, the problem and the means.'

The Investigator's Reward

Although in his discussion of this topic Sir Albert boldly entitles his chapter 'The Ideal Investigator', he had his feet too firmly on the ground not to be well aware that all research workers, however idealistic their ultimate aims, are bound to be affected by the remuneration given to their efforts; more especially is recruitment of clever young men influenced by the future chances of generous rewards. The agricultural research worker would get little academic recognition. Once it is agreed that applied work is different from what is done at a university, this follows logically: for academic distinction must go for academic effort. What comparable reward could the worker in the applied field then look for? The passage in which Sir Albert discusses this is rather interesting, for he shows up a difficulty which has not yet been solved and which is of considerable importance.

> 'A difference of opinion still exists as to the necessity and to the practicability of rewarding work of outstanding merit... Experience shows that professions like law and medicine, which offer outstanding possibilities of advancement and remuneration, and pure science, which is rewarded by academic distinctions, attract the best talent in the Universities. Agricultural research has to be content with a few enthusiasts. From the nature of the work, these men have little time for the kind of research which brings academic recognition. While they have to sacrifice the rewards open to workers in pure science, they often make discoveries from which the country reaps benefits which may run into large sums of money. If some method of reward could be devised for applied work of this character, a great step forward would be made... It is often contended that love of work and joy in discovery are sufficient reward for the investigator of such questions, and that nothing further is required. This method, however, has not been successful in the past, and sufficient workers of outstanding ability have not taken up the work... One reason would seem to be that the rewards now offered for success are not sufficient to attract the best talent in the Universities.'

It was always to the 'best talent' that Sir Albert looked for advancing the cause to which he was devoting his life. Such workers require freedom: and this is the final point to which all discussion must return. It is, of course, necessary to have public control of public funds but in their actual operations scientific workers cannot be guided by official opinion. (Sir Albert favoured the Development Board as the kind of body which could administer such funds without unduly hampering the worker; *Crop Production in India*, p. 193.) In such work 'official views do not exist. At any moment in research, a discovery may be made by the last joined recruit which amounts to a revolution in ideas, in outlook, and in methods of investigation'. The claim thus is for release from the trammels of over-organization, for opportunities to 'follow the gleam' and prove worthy of the task; the corollary to the choosing of ability must be a permitted independence in doing the work.

> 'The ideal system of conducting agricultural research in the Empire seems to lie in the simplification rather than in the elaboration of the organisation... Better men are needed, not more machinery. Any funds that can be provided in the future for agricultural research should be devoted to the payment of competent investigators and to the provision of the means necessary for these men to work out their ideas... Any attempt to overstrain systems of organization in the hope that they may replace competent investigators can only end in failure. In research, the man is everything; the organization is a minor matter.'

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Sir Albert Howard in India

By Louise E. Howard

Final Remarks

When Sir Albert Howard, on his first leave from India in 1910, visited his old College at Wye and again met the Kentish hop growers with whom he had been on terms of such cordial friendship, their welcoming speech described him as 'a man who insisted on knowing all about everything'. There certainly was a wholesome portion of curiosity in Sir Albert's make-up, allied with a thoroughness which, after a strict scientific training, became magnificently organized for useful ends. If his instinct for 'knowing all' led him to a lifetime of massive investigation, he was saved from mental rigidity by that lively alertness which so charmed all who met him. These compensating qualities were combined in a very happy way.

Another distinguishing trait was a great humility of mind. This was hidden. In public his verdicts lacked no sort of decision, were often sharp and condemnatory. He was a born fighter, evoked opposition, and enjoyed it, acquiring towards the end of his life a devastating capacity for turning an argument inside out to confound an opponent. He was determined, exceedingly shrewd, and sometimes extremely obstinate.

It was the shrewdness of his insight, allied with his inherited sympathy for the farmer's point of view, which led to those criticisms of contemporary scientific research which earned him the reputation of being a very difficult colleague. But it is to be remembered what he met in India. Possibly he was unfortunate that in starting on the sorting out of varieties he found in crop after crop preceding work in India which was practically worthless or at best non-existent; that in accommodating his classifications to European systems he could never find anything that fitted the tropics; that he came across the 'quite incredible' omission on the part of Kew, the Linnaean Society, and the curators of Indian herbariums to list more than a single Indian hemp when quite obviously five different varieties and eight types were easily identifiable; that when he came to look at practice he visited no official farm but where the ground was so waterlogged as to make variety trials of crops a farce; that he had the problem of the indigo wilt thrust upon him after every scientist in the place had failed to solve it because no one had started by trying to make the plant grow; that he was actually the first, after nearly fifty years of research in a number of countries, to put his finger on the unpardonable carelessness of using unsorted material for the study of an injurious and serious disease like lathyrism. These instances of ineptitude were startling, but they may have been accidental; the real grounds of criticism were much wider -- that unfortunate lapse into 'fragmentation' of effort between a number of competing departments which could only stifle initiative and limit judgment; this departmentalism was supported by authority to such an extent that in course of time the organization of agricultural research in India, and indeed in other countries, became in Sir Albert Howard's view 'obsolete'.

Contrasted with the pretensions of science -- the word is not too severe for what Sir Albert encountered -- were the very ancient practices of the Eastern cultivators. It was here that what I have called Sir Albert Howard's humility guided him. Without it he would not have been willing, almost from the first moment of arrival, to pay such close attention to the day-to-day performance of the peasant world. Though confronted with some ignorance and a good many shortcomings, he allowed himself to be convinced of the permanent validity of the peasant achievement. As he himself says, he met a people who were so experienced that, when it came to dealing with cultivation problems, they 'seemed born with a special *papri*-breaking sense', and, in general, an agriculture on which time had impressed the appropriate characters over a period of more than two thousand years. To introduce a stream of trivial improvements to such a people might be reckoned an impertinence and it was to Sir Albert Howard's credit that, though a scientist from the Western world, he was able to respect a conservatism 'which had saved the race from disaster'. He was himself fortunate in being able to offer to India results worthy of her notice, but he could not have done so had he not first been receptive to her teaching. He never departed from the principle laid down early in his career that to impose Western methods on Indian agriculture was a fundamental error and that the only thing to do was 'to improve Indian agriculture on its own lines'.

Like every good worker he was prepared to learn from his own failures. The fruit trees at Pusa, sinking into a 'pitiable' condition, were landmarks leading him forward to an understanding of diseased conditions of plants; the tobacco plants which varied from eighteen inches to ten feet in height taught him the necessity of first dealing with soil conditions before embarking on the refinements of variety trials; the Quetta fruit merchants who were too busy to look at his new fruit crates evoked his human capacity for understanding the ordinary difficulties of life. Common sense and above all a most penetrating observation were everywhere applied, an observation which rivalled that so uniquely displayed by the great Darwin, much of whose general attitude of mind towards the phenomena of science was repeated in Sir Albert Howard.

This was why Sir Albert Howard's work was later found to have a universal validity. What he learnt in India were the facts: the deductions he drew from them were true and were exact, so that they came to be easily and speedily applied to Western agriculture; every further experience confirmed them. The man who stood for them became the natural champion of our own lowly earthworm because he had been impelled to say a good work for the abused termite of the East.

I will not call him a genius, but I present him as the forerunner and introducer of a revolution in agriculture which may be of the utmost use and consequence to the world at large.

Albert Howard, C.I.E. , M.A., F.L.S.

Born 8th December 1873, at Bishop's Castle, Shropshire, son of Richard Howard, farmer, and Ann Howard, neé Kilvert; died 20th October1947 at Blackheath, London, S.E. Educated Wrekin College, Royal College of Science, South Kensington, and as Foundation Scholar, St. John's College, Cambridge.

Married, 1905, Gabrielle Louise Caroline Matthaei; 1931, Louise Ernestine Matthaei.

1896, 1897, First Class Natural Sciences Tripos, Cambridge, first in England, Cambridge Diploma of Agriculture, second in England, National Diploma of Agriculture; 1899, Lecturer in Agricultural Science, Harrison College, Barbados; 1899, 1902, Mycologist and Agricultural Lecturer, Imperial Department of Agriculture for the West Indies; 1903-5, Botanist to the South-Eastern Agricultural College, Wye; 1905-24, Imperial Economic Botanist to the Government of India; 1914, created Companion of the Indian Empire (C.I.E.); 1920, Silver Medal of the Royal Society of Arts; 1924-31, Director of the Institute of Plant Industry, Indore, and Agricultural Adviser to States in Central India and Rajputana; 1928, Fellow of the Royal Asiatic Society of Bengal; 1930, Barclay Memorial Medal of that Society; 1934, knighted; 1935, Hon. Fellow of the Imperial College of Science.

Gabrielle Louise Caroline Howard, M.A., F.L.S.

Born 3rd October 1876, in London, daughter of E. C. H. Matthaei, merchant, and of Louise Henriette Matthaei, neé Sueur, musician; died 18th August 1930, at Geneva.

Educated South Hampstead High School and North London Collegiate School for Girls; scholar, Newnham College, Cambridge; First Class, Natural Sciences Tripos, Cambridge; Bathurst Research Student, Fellow, and Demonstrator in Chemistry at that College, later Associate; researched under Prof. F. F. Blackman, F.R.S., on transpiration and respiration of plants (Trans. of the Roy. Soc.); 1905, married Albert Howard; 1910, Personal Assistant to her husband; 1913, Second Imperial Economic Botanist to the Government of India and Kaiser-i-Hind Gold Medal.

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Sir Albert Howard in India

By Louise E. Howard

Introduction

Sir Albert Howard's career falls into two distinct periods, the period of scientific investigation in India and the period, following his return from India to England, when the last fifteen years of his life were devoted to the fight for restoring fertility to the depleted soils of the world. His own tireless industry during these years in speaking up and down the country, his many letters to the press, his readiness in debate, his instant success in personal interview, made a deep impression on the public; out of what might have been a leisurely official retirement he emerged as a reformer in the cause of a new conception of agriculture.

The principles for which he stood have become a matter of public knowledge and debate. The world has been rendered conscious of its sins in exploiting and misusing the natural riches of the soil; these matters have become history.

If my husband's influence had ended with his death there would have been nothing more to say. It might have been a tribute of affection to present him as a scientist, and some few would have been glad to examine with me the past and find him such. But his work did not end with helping to expose the character of modern husbandry, which in its ill-advised chase after profit alone from the fruits of the earth has originated evils, perhaps less dramatically described but not less disastrous than any which have accompanied the notorious rise of the industrial system and which so justly evoked their Shaftesburys. It is true Sir Albert was by no means the first critic of this late nineteenth-century decay and degeneration in farming outlook and practice, which is far more important than we have realized, but he was able to add something which not many could offer. His mind was essentially constructive and he never saw a problem but he knew or envisaged a remedy. In making further wide deductions from the facts, in bold suggestions for reform, in his challenge to vested interests, to accepted systems of teaching, to conventional results of previous research, he inevitably met bitter criticism and hostility. Some of the most important ideas which he stood for are discussed but doubted. It has not as yet, for instance, become a matter of agreement that quality in food production is as important as quantity and that the fear of not having enough to eat does not end the matter; it is not believed that the arid methods of statistics are usually an absurd approach to the living problems of agriculture; it is not admitted that the expenditure of public moneys on agricultural research needs a thorough overhaul; above all, it is denied that our health derives from the state of the soil on which we tread and which we cultivate and that our best chance of breeding and maintaining a healthy and happy human race is to breed and maintain the millions of unpaid workers, the invisible, silent and minute soil inhabitants, which Nature has chosen to dispose within the first few inches of decaying wastes strewn over the surface of our globe.

It is true that a great deal of progress has been made; indeed, the spread of ideas has been astonishing, which shows how greatly they were needed; our detractors are being pushed from one position to another in no uncertain manner. But one favourite argument still persists, that there is no adequate evidence for the claims advanced -- the word used is 'scientific'. In these circumstances it is important to show that what Sir Albert Howard himself said was based on what he himself did.

Nearly thirty years of the most exacting investigation, conducted on strict scientific lines, the results of which had to convince, and in fact did convince, the world of scientific opinion in the East, at that time in its heyday of keenness and success, were in themselves an achievement of great distinction, but their true importance emerges when it is realized that it was this slow building up of fact which made possible the later evolution of opinion. That complete assurance of view which so characterized Sir Albert Howard's speeches, that challenging certainty and biting criticism, that supreme contempt for the second-rate result, were essentially the outcome of years of intensive study and experiment. Because that study and experiment were carried on seven thousand miles away on a series of tropical problems not of obvious practical interest to the British public, because their results were embodied in a mass of papers contributed as official reports or printed in Indian technical journals difficult of access, it could not be expected that those who heard him speak in this country should be familiar with, or perhaps even be aware of, what had preceded those appearances on platform or in the press. To his audiences and readers he was the great champion and campaigner: as a scientist they took him for granted rather than knew what he had done.

The investigations thus carried out, which it is my purpose in this book to summarize and explain, are interesting in that they illuminate modern practice under tropical conditions; they will take the reader a little away from the routine round of British farm, field and garden. They have other claims to attention. Throughout the years passed by Sir Albert Howard in India an early and sustained interest was displayed in putting agricultural research into its right relation with the needs of the people; not for one moment, even in considering, for instance, the intricate genetics of the wheats, was this fundamental requirement forgotten. The social setting of husbandry, taking those words in their largest meaning, was always to the fore; only those results were useful which could be translated into terms of peasant or of zamindar practice, and only these were pursued. There was abnegation in this point of view. In refusing to spend time on the completion of elaborate results not of obvious practical bearing Sir Albert was perfectly clear-sighted; such final research needs to be done, and when called for can and must be handled by any investigator worthy of the name, and some periods during his own early years were spent on this type of enquiry. But as time went on such work fell into place as only part of a larger whole. To pursue primarily academic questions would not, in the view of the investigator, have been true to the terms of his appointment. He had been chosen to assist the peoples of India in their day-to-day agriculture on which their whole existence depended; to confront them with items of remote Mendelian or other theory would have been no use at all. Such topics are properly pursued at a university or other suitable centre of higher learning: an Experiment Station has quite different functions.

The nature of research and the way it is approached will depend on the aim pursued. The word 'scientific' is truly applied where correct and accurate methods are in use throughout, where previous knowledge is wide and abundant, where facts are never disguised but accepted and ranged as they emerge, where there is the ability at once to master detail and to read principle from the detail. To all these requirements the Howard researches conform generously; the work done was outstandingly fundamental, but, as time went on, less and less narrowly academic.

Rejoicing in his somewhat unusual title of *Economic Botanist* Sir Albert aimed at improving the crops grown and sold throughout the sub-continent of India. This practical aim was taken in no narrow spirit; even the, as yet, scarcely explored problems of monsoon cultivation, or the untouched sphere of improvement of tropical plant species, did not suffice for the whole programme. Were the grains, cotton, indigo, tobacco, fruits, nuts, fodders, when reaped to be eaten or consumed by the producer or were they to be stored, to be transported, to be sold at home or abroad? To pursue all produce to its ultimate destination and to see that it was so brought into existence as to satisfy whatever might be the further conditions of its handling or sale was as much the duty of the Economic Botanist as the obvious task of making things grow. This voluntary extension of his own duties was quite original in Sir Albert Howard. It drove him to curious initiatives -- intervention in the confused Indian railway system for the transport of fruit, technical devices for packing, drying of vegetables for army use, examination of peasant storage bins, prolonged contact with the British millers and final pursuit of his own wheats down to the form of the baked loaf on the breakfast table.

Such trade and technical aspects were actually only a part of his conception of the whole social setting of agricultural research in India. Among those western scientists who were brought to India to fulfil Lord Curzon's ideal of serving the Indian communities, Sir Albert Howard was one who deliberately and consciously started with this aim in front of him and stressed it more emphatically year by year. He never ceased to put to himself the question: were the final fruits of his work suitable for those to whom they were being offered? Was it within the scope and ability of the Indian cultivator to copy them? Had he the necessary tools? Were his oxen strong enough to draw the new implements? Could he afford the new seeds? Could he, illiterate as he was, be trusted to see with his naked eye in the field, without being expected to read a fly-sheet, that one wheat was better than another? Given the right answers Sir Albert had faith that any worthwhile suggestion would earn an immediate and lasting success and was adamant in opposing the fashionable complaint that the peasant must be 'educated' or even bullied into acceptance of Experiment Station results. He believed fundamentally in peasant shrewdness or perhaps he would have called it peasant wisdom, but was almost equally determined that from the other side only very clear improvements should be popularized for adoption, and entirely opposed to the stupidity of launching a stream of small Experiment Station successes, following rapidly on each other, all very much of the same kind, and thoroughly confusing to the average recipient. In this, as always, he showed great common sense and above all stood for a genuine and sincere relationship between experimenter and cultivator; nothing irritated him so much as the professional vanity which sacrificed this essential position to the temptation of publishing small temporary research triumphs.

It was from much the same point of view that towards the end of his career in India he adopted the unusual principle of recommending the discharge of well-trained and experienced manual and field workers from an Experiment Station staff. Most Stations would make a point of retaining such workers as indispensable. In Sir Albert Howard's view it was a duty to send them out as a constant stream, especially in a country like India where they would be the most natural and successful agents for the popularizing of knowledge. This idea was systematized at the Indore Institute of Plant Industry, where the giving of certificates was arranged, and where also 'cultivators' weeks' were started, to bring the neighbouring public into contact with the work accomplished.

Is it surprising that with these wide views in his mind, having tested and proved their worth, having been proclaimed as a pioneer in model Experiment Station management, Sir Albert Howard on his return to this country was horrified to find agricultural research elaborate, finicky, 'fragmented', and very much out of touch with the farming world (a condition which has since improved), in fact, to use one of his favourite phrases, devoted to 'learning more and more about less and less'? Add to this that it had become less concerned with the improvement of crops than with the salvage of what there was from disease and pest; that it was being recruited *en masse* by an army of workers who, from the nature of the case, could have but scant idea of the real problems to be solved. He launched out into frank criticism, which became more decided as he found to his astonishment that the world of Western agricultural science was a closed world to itself arrogating a superior position, very confident of its authority, and not at all willing to listen to any of the new ideas which experience abroad might suggest. This could have been called the battle of the frogs and mice had the results -- British agriculture -- been what they ought: the returned traveller found a falling-off so terrible as to cause him to recall with bitter contrast the old agriculture of his youth.

What would have been Sir Albert Howard's position had fate caused him to remain at home there to carry out his work? It is impossible to say. He might have fitted better into his surroundings and, assuming that he had acquired a leadership comparable to that he earned in India, might have done much to keep British agricultural research more on a level with practical needs. But much would have been lost. It was precisely because he worked away from Western agriculture that Sir Albert gained that enormously wide understanding, so much so that there was seldom a distant agricultural puzzle referred to him in later life on which he could not, in a letter from London, give some useful suggestion, often ideas both fundamental and ingenious. He himself never ceased to acknowledge the inestimable advantage he had gained by watching the operations of agriculture in tropical climates, where results are far more certain, usually more rapid, and where the sanctions of Nature on faulty practices are infinitely more devastating and therefore more instructive than anything that can be observed in temperate zones. This severe apprenticeship was, in Sir Albert's view, the making of a scientist, and to the end of his life he considered that fortune had apportioned to him an exceptional favour in putting him to work among the peasants of the East.

At first I had hoped that the best picture of my husband's work could be given by verbatim extracts from the scientific papers referred to. But examination showed this to be impossible. Papers were poured out at a rapid rate, as research went on, each new paper bringing something but also involving much repetition. Work was so intense that there seldom seemed time to pause and sum up, and although three books were written in India and another on leaving the country, two were short books mostly for students and two on quite special subjects. I have therefore made it my duty to go through all papers as carefully as possible in order to extract a general picture, incorporating as many verbatim passages in Sir Albert's own words as seemed possible. It is a disadvantage of which I am quite conscious not to have had a scientific training; at the same time it is not altogether absurd to see some value in being in exactly the same position as a number of my readers, namely, without special knowledge but profoundly interested in the subject. One thing has helped me, the fact that Sir Albert, even in his earliest days, wrote plain lucid English; his matter frequently lacks arrangement, due probably to pressure of work, but his meaning is always clear, and I am therefore able to offer my services, as was said on one famous occasion, in the spirit of 'the honest broker', towards the interpretation of his great work.

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