THE IMPERIAL STUDIES SERIES

THE EXPLOITATION OF PLANTS

BY VARIOUS WRITERS

EDITED BY

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MCMXVII

LONDON AND TORONTO

J. M. DENT & SONS, L'

PARIS: J. M. DENT & FILS

THE EXPLOITATION OF PLANTS

PREFACE

DURING the first term of the present year the subject matter of this volume was delivered in the form of Public Lectures at University College, London, by the several authors. The object of the course was particularly to bring before young botanists, and also such members of the general public as cared to attend, some account of prevailing methods of plant exploitation, and of the field awaiting development in the matter of our great and varied resources of plants from the botanist's point of view. It is of course evident that the chapters in this book touch but a very small part of the field of plant exploitation. At a time like the present, when so many of our experts are serving their country in various ways, this is just what was to be expected; nevertheless, the subjects dealt with are sufficiently representative of the whole to make the lectures worth publishing in book form, so that a wider public may be reached. Signs are not wanting that our neglect in the past adequately to develop our resources is now beginning to be generally recognised, and if this book can help, in however slight a degree, in the new "push," it will have served its purpose. It is at the desire of the contributors that I have undertaken the pleasant duty of seeing this volume through the press.

F. W. O.

June, 1917.

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THE EXPLOITATION OF PLANTS

CHAPTER I

INTRODUCTION

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It is not possible to say offhand what proportion commodities of vegetable origin bear to the total of all merchantable goods. The volume of trade in plant products may be guessed to be not less than one-half, and, if coal be included, may well exceed 60 per cent. of the whole. Moreover, animal products derived from the herds which we tend depend largely on a proper utilisation of the plants which form their food, so that the exploitation of animals is closely related to our present subject matter.

The reason for this pre-eminence of plants is, of course, the fact that the plant is the universal agency by which inorganic matter is worked up into organic. It is true that chemical research has been able to build up synthetically not a few organic substances, including many that are not known to be produced by plants in

Nature, and it is evident that this number will go on increasing indefinitely. Nevertheless, until the secret of the universal function of green plants, the chlorophyll mechanism, has been discovered, we shall be well advised to hold fast by the plant as the giver of nearly all good things. Even if we suppose that one day cellulose will be made synthetically, it is hard to believe that it will ever be possible to manufacture it in a form to compete with timber and vegetable fibres as they are given us by plants.

Actually the triumphs of synthetic chemistry often serve to stimulate a threatened plant industry to redoubled efforts. Thus synthetic indigo has not yet driven the natural product from the field. The effect of competition is to eliminate waste on the one hand, and on the other to call forth a more economic production, an increase of the output of indigo per plant, partly by cultural means, partly by improving the strain. As a consequence of the relaxation of competition with synthetic indigo, due to the war, it is interesting to see that the natural product has received a new lease of life. For we read that the acreage of the current crop in India has been doubled, and that the output is expected to be increased in 1917 by something like 75 per cent. as compared with 1916.

The products which we derive from the vegetable kingdom are without number, and it is possible in a little book like this to attempt to deal with only a very small selection indeed.

These products vary in the complexity of the manufacturing processes required to make them available, from the relatively simple case of timber, which is felled, dried, cut up and distributed, to fats and volatile oils, glucosides and alkaloids, which require elaborate processes of chemical manufacture for their production and extraction.

Sometimes the source is a wild plant available in quantity. Such are the timber trees of primeval forests, Pará rubber as it grows in Brazil, esparto grass for paper making, and a host of others. Nevertheless, there remain a very great number of wild plants, growing socially in immense stands and easy to get, for which no remunerative use has been found. For instance, the bracken fern, an almost cosmopolitan plant, is useless except for litter, whilst the Zostera of the sea shore, available in unlimited quantities, makes a stuffing for inferior mattresses, and has a limited use as packing material for venetian glass. On the whole, wild plants are exploited much less than might be expected. Their exploitation requires fertility in ideas and courage in their development; for the product to be a success must either displace some staple, or it must satisfy some taste or fulfil some requirement not yet created. In the one case the exploiter is up against a vested interest, in the other against inertia. On the whole, there is a great tendency to introduce and cultivate established plants rather than to improve and make valuable the indigenous plants of a territory. The empire affords many examples of this.

Moreover, in the exploitation of wild plants there is always a liability to overcropping and destruction without replacement, so that in the absence of regulation the source gets more and more inaccessible. It then becomes profitable for the planter to step in and give us, *e.g.* plantation rubber.

In the case of crops raised under control, it is of the greatest importance for the cultivator to realise at the outset for what precise purpose his output is destined. With this knowledge he may at every stage in cultivation —by selection of variety, by manuring, thinning, pruning, and so on, promote a close approximation to the specification. The forester should consider the requirements of the carpenter; the tea planter the taste of those he desires to pay for the privilege of sipping his beverage; and equally in other cases.

Exploitation without consumption.—This is a branch of the subject which, not being dealt with elsewhere in this book, may receive passing reference here. It is, briefly, the department of economic botany wherein plants are employed as a substitute for the constructions of the engineer, more especially the rendering of ground which is mobile, from whatever cause, secure. Hitherto it has been practised only in occasional instances, and its possibilities are not realised as fully as they should be.

The best-known example and the most highly elaborated is the planting of sand dunes with marram grass (*Psamma*) and other sand-binding plants. The technique of dune protection by planting, though developed into a fine art in Gascony and the Baltic, is not well enough known in quarters where it might be of service.

Other cases to which planting is applicable are those of travelling beaches, eroding cliffs, the banks of rivers, and steep sloping ground liable to crumble or develop slip, as in the case of the banks of railway cuttings. The most troublesome case is that of slip, of which the cause is easy to formulate. When the banks dry in summer the surface cracks; and later on, by these cracks, water gets access, rendering a deep-seated zone plastic so that the superficial layer tends to slide down the incline. As a consequence, railway companies are put to great expense in remedial measures, especially drainage, cutting away material so as to reduce the angle of slope, constructing brickwork and masonry, etc.

Probably this particular sort of trouble could be met by appropriate afforestation, and it is remarkable that the companies should not possess in common an experimental department of forestry to advise them on these and analogous problems. Perhaps something of the kind may be established in the future should our railways remain permanently under unified control after the war.

THE BOTANICAL EXPLORATION OF THE EMPIRE

A matter of the first importance, if our vast resources are to be properly and systematically utilised, is the botanical exploration of the empire.

In his interesting Address as President of the Botanical Section of the British Association at Newcastle-on-Tyne, Dr. A. B. Rendle alluded to the way in which in the past our possessions have been explored, and expressed the hope that it might be possible to arrange an Imperial Botanical Conference after the war, at which matters of this kind could be discussed. This proposal is likely to meet with general approval, and it is to be hoped it may bear fruit.

The first definite step in the botanical survey of the empire was taken sixty years ago at the instance of Sir William Hooker, the then Director of Kew. According to the plan arranged, twelve floras corresponding to the various possessions and colonies were to be worked out at Kew by the staff in what leisure time was available.

Though subject to much interruption, the greater part of this scheme has been completed, two of the series of projected floras alone awaiting completion. Canada, for some reason, was not included, but the omission is likely to be repaired by local effort.

The materials on which these floras have been based are collections made by occasional travellers, officers accompanying boundary commissions, missionaries, and medical men attached to punitive expeditions. The whole thing has been characteristically haphazard, and it does great credit to the writers of the floras, largely men fully occupied with administrative and routine duties, that the enterprise should have been as successful as it undoubtedly has been.

A flora, of course, is a mere starting-point, a bare inventory of the plants of the area dealt with, and much remains to be done. Detailed physical descriptions of the countries are now required, giving a picture of their resources, stating to what extent, if at all, these are at present utilised, the existing lines of communication, available labour, and everything pertaining to the development of their resources.

Meanwhile in most of the British possessions botanic gardens have been founded, and each Government possesses a department of Agriculture, all in their several ways doing a good deal to promote the local exploitation. It is hardly necessary to emphasise the importance of having attached to every district an expert systematic botanist. Very slight specific or varietal differences between allied plants are often of critical significance in matters of exploitation, and it is of fundamental importance, when a given plant is found to be adapted to a particular purpose, that we should know how to recognise it with certainty. Thus some years ago a certain species of timber was exported to the West Indies from British Guiana, and was found to have the rare and valuable property of resisting the attacks of boring molluscs when used for piles, jetties and similar maritime constructions. Apparently no record of the species of tree was kept at the time, and it is stated that its identity has been lost, and that further consignments are unobtainable in consequence. Cases of this kind could be multiplied indefinitely, but with proper organisation their occurrence should be impossible.

It seems eminently desirable at the present juncture that the whole empire should march together in this matter of the development of its resources, and that this resolve should find expression in centralised action. So far as the subject matter of this book is concerned, we seem to need a great " Imperial Department for the development of the resources of the Empire, Section A, Vegetable Products." Such a department would require a great service, and London should play an important part in connection with the recruiting and early training of the cadets. London has a great advantage for the purposes of a training ground, because it alone is constantly visited by men on leave from the distant parts of the empire. These men would be temporarily attached to the central school, and they could work up their results and give lectures and demonstrations upon matters in which they had been intimately engaged. As the cadets were passed out and drafted to their jobs they would be liable to come in contact with these same individuals, who would keep an eye on them.

Such a self-feeding mechanism should promote a close solidarity between all ranks, a fundamental condition if such a service is to prove equal to the large opportunities awaiting it. The dominions, of course, are wholly self-governing, and it is to be expected that they will be eager to play a leading part in their own development. At the same time, there is a good deal to be said for an imperial corps with interchange between the different parts of the empire; there must be many problems in common, *e.g.* between South Africa and Australia, and it would be a pity if the organisation provided was isolated in separate compartments.

In this connection we might perhaps adapt the American system to meet our requirements. There is first the system of State Experimental Stations, where the local problems are dealt with. Then there is the great Department of Agriculture at Washington, with its innumerable Bureaus. The personnel of this department is analogous in its working to the staff officers of an army, whilst that of the stations may be compared to the regimental officers in the field.

Applied to our case, the latter correspond to the existing staffs of the botanic gardens and agricultural departments of the various dominions and other possessions, whilst the equivalent of Washington would have to be created in the form of the new Imperial Service.

Were such a trained corps asked for with a guarantee of work for cadets reaching an adequate proficiency, there is little doubt it would be possible to provide them (speaking for botany alone) at a rate of twenty or even twenty-five a year. It is remarkable how quickly good men and women of the best type begin to render services of the highest value when put to work of this kind.

When one recalls how much little countries like Denmark do for their possessions, one is filled with shame at our own backwardness. Botanists will be familiar, for instance, with the *Botany of the Faroë Islands*—a model of a complete monograph on the flora, vegetation, economics and vegetable resources of those islands.

Then take the case of Germany. Whatever the defects of the German scheme of colonial development, it was right in two respects. Germany did not hesitate to take long views, and was content year after year to go on spending large sums of money on her acquisitions; in the second place, their exploration was put in the hands of qualified experts, and not left to the chance visits of travellers and amateurs.

Probably no country in the world is more alive to its responsibilities in these matters than the United States, and the provision made for the development of their resources under the Department of Agriculture, to which reference has already been made, merits the most careful study at our hands. A feature which might certainly be adopted by us with advantage is the issue of a *Year Book* for general information; thus bringing under the covers of one volume a record in not too technical language of progress in particular fields of development in different parts of the empire.

We have seen how the first inspiration towards a systematised botanical exploration of the empire originated at Kew. Throughout its history no Government establishment has served the empire more loyally and impartially than has Kew, whilst men trained under it are to be found in all the British dominions and possessions. With an organisation having such traditions as one of our assets, the great task ahead should be materially lightened so far, at any rate, as the development of our botanical resources is concerned.

CHAPTER II

PLANT FOOD AND SOIL PROBLEMS

By W. B. BOTTOMLEY, M.A., Ph.D.
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THE importance of a knowledge of the conditions and factors influencing plant growth is evident when one considers the intimate connection between the profitable exploitation of plants and maximum crop production.

The living plant is a synthetic machine absorbing as raw materials such substances as water, carbon dioxide, nitrates, phosphates, etc., and manufacturing them into various commercial products—foods (sugars, starches, proteins), timber, fibres (cotton, linen), colouring matters (dyes) and alkaloids (drugs)—and the value of any knowledge which enables the owner to run the machine more economically or to increase its output cannot be denied.

The soil is the source of all the raw materials, excepting carbon, and at first sight the problem of maintaining or increasing the crop-producing power of any soil would appear to be a simple one. Analyses of the ashes of plants have shown that a certain few mineral substances are always present in plants, and are essential to them as nutrients. The importance of these has been amply confirmed by water and sand cultures. Obviously these mineral nutrients have been derived from the soil and must be replaced when deficient.

The prevailing idea, until recently, regarding the maintenance of soil fertility, was that each crop requires certain mineral elements from the soil, and these must be supplied by means of chemical fertilisers when they are lacking or are present in insufficient quantities.

Recent research, however, has shown that this "mineral" theory, which assumes that the fertility of a soil or its crop-producing power is dependent only, or even mainly, upon the mineral constituents which it may contain, is far from complete.

The soil is not merely a reservoir for the mineral nutrients of plants, but is the seat of complex physical, chemical and biological actions which directly and indirectly influence soil fertility. These actions are intimately associated with the organic matter of the soil and its bacterial inhabitants. Mineralogy and inorganic chemistry, though helpful, are no longer capable of solving soil problems. Biochemistry and bacteriology, with their modern conceptions of colloids, absorption phenomena, enzymes, oxidising, reducing and catalytic actions, etc., are now rapidly extending our knowledge of the soil as a medium for plant growth.

Organic matter in the form of manure has been used from earliest times for promoting plant growth, but nothing definite was known as to its specific effect upon plants. It was believed that it acted in some mysterious way. Certain "spirits" were supposed to leave the decaying manure, enter the plant and produce more vigorous growth, leaving behind a leached substance of a worthless nature. The trend of early ideas respecting the composition of organic matter is indicated by the use of such terms as "spirits of nitre" and "spirits of hartshorn."

During the seventeenth century, when the so-called "nature philosophers" were endeavouring to trace the origin of living things to a "first principle," the search for a principle of vegetation to account for the then known facts about soil fertility and plant growth led Van Helmont, about 1630, to state that he had found this principle in water. From his experiments with willow plants he concluded that water is transmuted in some mysterious manner directly into plant tissue.

In 1650 Glauber suggested that saltpetre is the principle of vegetation. Some years later Külbel stated that a *magma unguinosum* which is obtained from soil humus must be regarded as the principle sought for. Then in 1726 appeared the celebrated textbook of chemistry by Boerhaave, in which he says that plants absorb certain juices of the soil—the humus—and work them up into food. The raw material, the prime radical juice of vegetables, is a compound of fossil bodies and putrefied parts of animals and vegetables. "This," he says, "we look upon as the chyle of the plant, being found chiefly in the first order of vessels, viz. in the roots and the body of the plant, which answers to the stomach and intestines of an animal."

Thus arose the old humus theory that plants derive all their nourishment from the humus of the soil, and this when exhausted was replenished by manuring with dung and other organic matter.

This theory held the field for the next 150 years, and it was not until the middle of last century that it was replaced by Liebig's famous mineral plant-food theory. Liebig held that plants obtain their carbon from the carbonic acid of the air, and their necessary ash constituents from inorganic salts in the soil, and soil fertility could be maintained solely by the addition of mineral fertilisers.

This was a complete swing of the pendulum; from organic food to solely inorganic. We are now learning that neither theory was wholly right or wholly wrong. There are certain fundamental truths in each of them.

Just at the period when Liebig's researches were thought to have finally solved the problem of plant nutrition, there was arising a new science—bacteriology—which was destined to play an important rôle in all questions relating to soil fertility. Studied at first chiefly in connection with infectious diseases, the new knowledge was first applied to plant nutrition problems by Schloesing and Muntz in 1877.

In the old humus days it had been held that "corruption is the mother of vegetation," and even Liebig taught that nitrogenous organic matter decayed in the soil by a chemical process known as "eremacausis," with formation of ammonia, which was further converted into a plant nutrient—nitrate. In 1877 Schloesing and Muntz showed that nitrification was due to the action of bacteria, and in 1879 they claimed to have isolated the specific organism. This last claim proved to be erroneous, for Warrington in 1884 demonstrated that nitrification consists of two processes—first the production of nitrites, then their conversion into nitrates—but it was not until 1899 that Winogradsky succeeded in isolating the two kinds of bacteria concerned.

The work of Schloesing and Muntz attracted a great deal of attention, and soon there were a number of workers in the field of soil bacteriology. Most striking results were obtained in relation to the nitrogen cycle. In 1886 Hellriegel and Wilfarth demonstrated the presence of nitrogen-fixing bacteria in the root-nodules of leguminous plants, and thus solved the problem of the nitrogen nutrition of these plants. Another most important discovery was the isolation by Beyerinck in 1901 of a special group of nitrogen-fixing bacteria, known as Azotobacter, which live free in the soil. From the standpoint of crop production these organisms possess great significance, for they are constantly adding to the stock of available nitrogen in the soil by converting the atmospheric nitrogen into nitrogenous organic matter.

The science of soil bacteriology has grown so rapidly that the most recent textbook on the subject contains 900 pages. Over 300 species of the bacillus group, and some 200 species of the bacterium group have been isolated from soil.

In some quarters it is now held that the real makers of plant food in the soil are bacteria, and they are essential to the growth of all plants. At any rate, the close connection between bacterial activity and the nutrition of plants has been amply demonstrated by numerous experiments, and forms the basis of our modern conception of the soil as a producer of crops.

How different now is our conception of soil from what it was even thirty years ago. The term "living soil" is literally true. No longer is soil regarded as a heterogeneous mixture of rock particles, clay and organic matter serving simply as a trough for mineral plant nutrients. We now think of it as a porous mass made up of a skeleton of sand coated with a colloidal mixture of clay and organic matter, which serves as a nutrient medium for myriads of bacteria whose necessary supplies of air and water are contained in its pores. To quote Dr. E. J. Russell, "Into the pores of this mass we have no means of penetrating; no microscope has been devised that enables us to look into it and see what is going on. . . . We shall find the study of the soil very unsatisfying and uninspiring if we become too much absorbed in its utilitarian aspects and forget to stop and reflect on the infinite wonder of its honeycombed structure and its dark recesses, inhabited by a teeming population so near to us and yet so hopelessly beyond our ken that we can only form the dimmest picture of what the inhabitants are like and how they live."

But what is the work they do? Knowledge as to this has been slowly accumulating during the last few years, and we are learning that the all-important work of the decay of animal and vegetable matter in the soil is carried out through the agency of these bacteria. This process is effected in several stages, and distinct groups of bacteria are responsible for each stage. One thing is certain, they are absolutely dependent for their life and activities on the organic matter of the soil. No soil can be truly fertile unless it contains organic matter—humus material—as food for the bacteria which bring about decomposition.

Hitherto attention has been directed chiefly towards the organisms concerned in the nitrogen cycle in the soil. These fall into four chief groups—decomposers, nitrifiers, denitrifiers, and nitrogen-fixers, and they have been investigated mainly from the point of view of the total balance of nitrogen which they maintain in the soil. Recent research, however, has shown that at least equal importance attaches to certain intermediate products formed by the decomposition bacteria which not only influence the activities of other soil bacteria, but also act directly upon plants growing in the soil.

For some years past an investigation into the nature and composition of the organic matter of the soil from the standpoint of biochemistry has been in progress by the scientific staff of the Bureau of Soils department of the United States Department of Agriculture. The results already obtained have thrown considerable additional light upon the question of soil fertility. For example, Schreiner and Skinner have shown that certain decomposition products of nucleo-proteins and proteins, such as xanthine, guanine, creatinine, histidine and auginine, which they have isolated from fertile soils, can replace nitrates in a water culture solution and are directly used in building up plant protein. This discovery that beneficial organic decomposition compounds exist in soils and play a prominent part in the life processes of growing plants is of fundamental importance in soil fertility.

The significance of the organic constituents of the soil has not received the attention it deserves in this country, and it is unfortunate that this promising field of research has not attracted more workers.

For the last few years research has been in progress in the Botanical Department of King's College, London, respecting the influence of certain decomposition products of organic matter upon the activities of soil bacteria, and Professor Oliver has asked me to give a short summary of the results obtained.

Krzemieniewski and others demonstrated some ten years ago that soluble soil humates exercise a remarkable stimulating action on the fixation of nitrogen by azotobacter. As a result of a search made in 1912 to find a material rich in soluble humates to serve as a medium for the growth and distribution of these organisms, it was discovered that when peat is incubated with certain aerobic decomposition bacteria at a temperature of 26° C. for a fortnight, a large proportion of the humic acid present is converted into soluble humates, and this material after sterilisation forms an excellent nutrient medium for nitrogen-fixing bacteria. Tests as to the manurial value of this "bacterised peat" made at Kew Gardens and other places during 1913 showed that it contained a substance or substances which stimulated plant growth to an extent which could not be accounted for by the mineral nutrients present. This suggested that the growth-stimulating properties of bacterised peat might be due to the presence of organic substances similar in nature to the accessory food bodies or "vitamines" concerned in animal nutrition.

As these accessory food substances are soluble in water and in alcohol, and are further precipitated by means of phosphotungstic acid, both aqueous and alcoholic extracts and also a phosphotungstic acid fraction were obtained from bacterised peat and were found to have a stimulating effect both on nitrogen-fixing bacteria and on plant seedlings grown in water cultures.

The results obtained with the plant seedlings were so striking as to suggest the possibility that a certain amount of organic matter in addition to mineral nutrients is essential for the maximum growth of plants. As in the usual water culture experiments with ordinary plant seedlings a fairly large quantity of organic matter is supplied to the young plant from the organic food reserve of the seed, it was necessary to experiment with a plant free from this objection. *Lemna minor* was eventually selected as being suitable. Its normal habitat is water, it multiplies rapidly by vegetative methods, and a reliable estimate of variations of growth in different culture solutions can be readily obtained by counting the plants at regular intervals of time.

Preliminary experiments at King's College during 1915 showed that *Lemna minor* plants fail to grow for any length of time in a pure mineral culture solution, but if certain extracts from bacterised peat be added to the solution growth is normal and vigorous for an indefinite period. These experiments were repeated and extended last summer in the greenhouse laboratory of the Imperial College of Science and Technology, South Kensington.

Fifty culture dishes, each containing 250 c.c. of the required solution, were prepared and arranged in five series of ten dishes each. The solutions employed were: Series I, Detmer's standard culture solution; Series II, Detmer's solution together with a water extract of bacterised peat; Series III, Detmer's solution with a similar extract freed from humic acid; Series IV, Detmer's solution plus an alcoholic extract of bacterised peat; Series V, Detmer's solution with the addition of the phosphotungstic acid fraction of bacterised peat. The proportions of organic matter thus added in Series II, III, IV and V were respectively only 368, 97, 32 and 13 parts per million of culture solution.

Twenty plants of *Lemna minor*, as nearly uniform as possible in size, general healthiness and root development, were counted out into each of the fifty dishes. The solutions were changed twice each week, and the plants in each dish were counted once every week.

The plants in all the series multiplied fairly uniformly for the first week, then the effect of the added organic matter became very marked, until at the end of three weeks the plants in Series II and III completely filled their dishes. At this stage the plants in all fifty dishes were halved, one-half being retained in the dish to continue the experiment, and the dry weight of the other half estimated. This was repeated each week during the continuation of the experiment.

The average figures obtained for the total number of plants derived from the original twenty in each series, and their total dry weight at the end of six weeks, are as follows—

	Series I.	Series II.	Series III.	Series IV.	Series V.
Number from original 20	326	6723	3124	1100	483
Dry Weight (in mg.) from original 20 .	17·6	1103	516	129	46

The fact that successive fractionation of the extracts obtained from bacterised peat resulted in a diminution of the effective growth-promoting substances present is evident from the following comparison—

	Series I.	Series II.	Series III.	Series IV.	Series V.
Organic matter added	—	368	97	32	13
Ratio of total number	1	20·6	9·6	3·4	1·5
Ratio of total weight	1	62·6	29·3	7·3	2·6

The effect of the reduction in amount of organic matter with successive fractionation of the bacterised peat was also manifest from the general appearance of the plants. Those in mineral nutrients only decreased in size week by week and became very unhealthy looking, whilst there was a progressive improvement in the appearance of the plants supplied with increasing amounts of organic matter.

In view of these striking differences in general appearance an examination was made of the internal structure of representative plants from each set at the conclusion of the experiment. It was found that in all the plants receiving organic matter the tissues were more dense and the proportion of air spaces to cellular tissue was much less than in the control plants. The difference was also very marked in the individual cells of the respective plants. Those supplied with organic nutrients were larger and more densely filled with protoplasm, and also contained larger nuclei and more numerous chloroplastids. This difference was especially noticeable in young newly-formed plants.

As it is well known that the ordinary distilled water used in the laboratory often contains traces of toxic substances, it was suggested that the beneficial effects of the added organic matter might be due to a neutralisation of the toxicity of the distilled water used. Accordingly a parallel series of experiments, using glass distilled or "conductivity" water instead of ordinary distilled water, was carried out. The figures obtained showed that whilst the toxic substances in the ordinary distilled water had a certain injurious effect upon the growth of the plants, the use of pure non-toxic water will not suffice for continued normal and healthy growth.

The necessity for the presence of certain organic substances in a mineral culture solution in order to ensure healthy growth is not peculiar to *Lemna minor*. Experiments with *Lemna major, Salvinia natans, Azolla filiculoides* and *Limnobium stoloniferum*, growing in both Detmer's and Knop's culture solution, are equally sensitive to the presence or absence of organic matter.

As the organic substances employed in the above experiments were evidently decomposition products of vegetable matter (peat), experiments were made to test to what extent similar growth-promoting substances are present in other sources of decomposing vegetable matter used for cultural purposes. Extracts of stable manure, leaf-mould, and even a well-manured garden soil were found to supply the beneficial growth-promoting substances, although they are present in relatively much smaller proportions than in bacterised peat.

The results thus obtained appear to justify the following conclusions: (1) That bacterised peat contains certain organic substances which, when supplied even in small quantities to water plants growing in a complete culture solution, have a remarkable effect upon their growth; (2) That in these plants normal growth and multiplication cannot be sustained for any length of time in the absence of these organic growth-promoting substances; (3) That these substances are essential for the effective utilisation and assimilation of the mineral nutrient supplied to the plants.

These conclusions are contrary to the generally accepted botanical theory that green plants can build up complex protein compounds from mineral salts and mineral salts alone. Must we then consider these water plants as exceptions to this theory, or must we modify our present conceptions of plant nutrition? Further experiments alone can decide this. The well-known fact that the seedlings of land plants can be grown to maturity in water culture solutions of mineral salts is not a fatal objection to the suggestion that *all* green plants may require traces of certain organic substances for their development, since it has been shown that such substances are produced during the germination of seeds, and the seedlings used in water culture experiments may already contain the necessary minimal quantities required for ordinary growth.

It is impossible as yet to state definitely how these substances function. Some of them may be absorbed and utilised directly as plant nutrients, whilst others may have a similar effect to that of the accessory food substances or growth vitamines concerned in animal nutrition. Whatever may be the specific nature of these organic decomposition products, they all have the effect of promoting plant growth, and the term "auximone" (*αὔξιμος*, promoting growth) has been suggested as a general descriptive name for them.

No apology is needed, I think, for describing these results in a lecture dealing with soil problems. Modern research has shown the intimate relationship between soil fertility and soil organic matter. For successful crop production the soil must be supplied with humus-forming material. Unfortunately, owing to the advent of motor traction, one important source of such material—stable manure—is rapidly diminishing. It has been stated that during the last few years the omnibus companies of London have dispensed with the use of 50,000 horses. This represents a loss to suburban growers of 250,000 to 500,000 tons of organic manure annually from this source alone. All over the country there is increasing difficulty in obtaining supplies of stable manure, and some substitute will have to be found. The experiments I have described point to the possibility of utilising peat as an organic fertiliser. Raw peat, owing to its acid nature and the toxic substances it contains, is not only useless, but actually injurious to plants. It has been shown above, however, that when peat is "bacterised" its condition is altered, and it then contains substances which have a remarkably beneficial effect upon plant growth. There are unlimited supplies of waste peat available in the United Kingdom, and if only a portion of these could be treated and rendered available as a cheap and effective plant food, it would greatly assist the successful exploitation of plants and benefit the whole community.

CHAPTER III

WASTE LANDS

By PROF. F. W. OLIVER

THE term *Waste Lands* is used here to designate ground not exploited in an economic sense, or, at any rate utilised only to a very slight degree. In the British Isles the term may properly be applied to the following terrains: sandy heaths, peat moors, sand dunes and other maritime lands, including salt marshes and shingle beaches, mountain talus, fen and artificial aggregates, such as pit-heaps.

Before considering how some of these may be profitably utilised or reclaimed, it may be well to state that in the event of the adoption of a settled state policy of reclamation, it would be necessary in some way to safeguard what is a great national asset, viz. the characteristic and unparalleled beauty of English scenery. Suppose, for instance, that the administering of such a scheme were entrusted to a Waste Lands Commission with statutory powers, it might be an instruction to the Commission to leave untouched a large number of reservations—analogous to the "national parks" of the United States. These would vary in size and form, and also in the purpose for which they were intended. Some would be quite extensive, like the Lake District, others smaller and representative of the various categories. Sometimes the latter might with advantage take the form of long belts left so as to screen and diversify the exploited areas of the landscape.

Some proportion should be laid down between the area to be reclaimed and that which should remain inviolate, *e. g.* some such proportion as three to one or four to one. In a matter of this kind expert advice could no doubt be obtained from the Nature Reserves Society and from the National Trust, both of which bodies have accumulated experience; they might even be asked to take over the guardianship of the reservations. By analogous machinery the rights of commoners might be guarded, and when interfered with, compensation found.

The argument for reclaiming land on any considerable scale depends on the economic position. The war has shown the peril of depending on overseas trade for essential commodities to the great extent that has obtained in the past. After the war we shall be burdened with a vast debt, the bulk of the interest on which will have to be raised internally. Money, therefore, must be retained in the country and productivity increased. This should be possible partly by the adoption of higher standards of cultivation, partly by the exploitation of areas hitherto neglected. Thus in some measure we may hope to see imports relatively restricted, money kept at home, and additional rural occupations provided.

Lands remain waste, *i. e.* unproductive, from some inherent physical or chemical defect, such as dryness, mobility, lack of some ingredient essential to plant growth, or from toxicity; they are also often neglected through want of knowledge, inertia or deliberate intent.

Though much has been learnt in the last thirty or forty years as to methods of ameliorating these obstinate soils, especially in making good deficiencies by the application of chemical fertilisers, this increase in knowledge has coincided with a down-grade movement in agriculture in this country. Instead of being a question as to what land should be taken in and reclaimed, it has been much more a matter of what should be abandoned or laid down to grass. Largely as a consequence of this adverse economic trend the problem of reclamation of waste lands, under the climatic and other conditions prevailing in the British Isles, is sadly in arrears. Hence at its beginnings any scheme of reclamation must be experimental, and only as experience accumulates should the rate be accelerated.

In practice two methods have been applied in reclamation, viz. the bit by bit and the drastic. According to the one the ground is cleared and broken up, drained if necessary, perhaps limed, and then cropped in the ordinary way. The process is long and tedious, and the produce small: with perseverance, however, the soil gradually acquires some fertility, and the reclamation counts as a hard-won success.

The second and more modern method of reclamation is characterised by supplementing the mechanical operations by the addition of very large amounts of chemical fertilisers with a view to making good deficiencies in lime, potash, phosphoric acid and nitrogen. Such treatment of the land involves an expenditure of

Farrow, by means of a very simple experiment, has shown in striking manner how the dryness of the soil sets a limit to the vegetation. By allowing water to drip continuously from the tap of a cask throughout the growing season, it was found that the otherwise dwarf grasses of the grass-heath association grew up with the greatest luxuriance, in marked contrast with the stunted vegetation round about. In order, therefore, to neutralize the normal aridity of the soil, it is evident that the water problem will require serious attention if crops are to be raised profitably. Now there are three ways in which more water can be put at the service of plants; (1) by increasing the rainfall; (2) by irrigation; (3) by rendering the soil more water-holding, and so conserving its moisture. No. (1) is out of the question; irrigation is not applicable in the present case, hence the soil must be so treated as to increase its water content. This is provided for in Dr. Edwards's reclaiming experiments by growing first a crop of lupins on the cleaned and broken-up ground. This crop is turned into the soil as a green manure, which not only adds to the nitrogen content, but, by the humus it provides, improves the water-holding powers of the soil. By such means as these, combined with continuous tillage, the water problem finds its solution. Dr. Edwards is also an advocate of the practice of sowing thinly, by which means the individual plants which constitute the crop are more sturdy and deeper rooted than is the case with denser sowing, whilst an equal or greater output is obtained.

The preliminaries to cultivating Breckland include in addition to clearing and breaking up the surface the addition of large amounts of manures in the form of chalk, basic slag or crushed bones and kainit with nitrate of soda or sulphate of ammonia, according to the crop. These preliminary operations, representing charges of about £5 an acre, were more than met by the returns from the crops produced, that is to say, the value of the produce not only paid for its cultivation, but was sufficient to meet the higher rental corresponding to the larger capital expenditure. For details of the experiment, see P. Anderson Graham's *Reclaiming the Waste*, chap. ii–vi.

Though Dr. Edwards's reclamation has been limited to a comparatively small area (150–160 acres), there is no inherent reason why similar methods should not be pursued on a much larger scale, both here and on other sterile sandy heaths.

Whilst the arable cultivation of Breckland and other sandy heaths would thus appear to be remunerative propositions, there is another way in which this class of ground can be utilised. Breckland produces pines and so do the Bagshot sands and other areas of the kind. Mr. Farrow, indeed, holds the view that Breckland was formerly forest land, and that its primary economic use is to be once more afforested.

Any scheme of national security must include not only the home production of food stuffs, and especially cereals, but also of timber. As I understand Mr. Farrow's view, sandy heaths like Breckland should only be ploughed up in the event of the minimum requirements of forestry being satisfied by rough ground which cannot be cultivated in any other way. If the safety-line in cereals can be reached by ploughing up grass land alone, then Breckland should carry trees. A decision without full data is very difficult, and ought not to be made hastily.

A further alternative is also possible, viz. that these areas should be partly afforested and partly converted into tillage. This method has two advantages. The woodlands would give shelter to the ploughed-up land, and they would also guarantee work in winter for the farm labourers, thus providing the countryside with another useful bulwark. If the view repeatedly expressed in recent discussions be well founded, viz. that a closer entente between forestry and agriculture is necessary for the success of both, there would seem to be a reasonable probability that a division of Breckland on these lines might prove to be the best economic policy to pursue.

So far as sandy heaths are concerned, there can be no doubt whatever of their amenability to profitable reclamation alike for tillage and forestry. This has been firmly established on the continent of Europe, and nowhere more convincingly than in the Netherlands. The peoples of the Low Countries are the world's pioneers in reclamation work. In England, and especially in East Anglia, we have in the past been much beholden to the Dutch in showing us how to drain and utilise our fen lands and salt marshes; whilst in times still more remote, the Prussians received instruction from the same source. When Albert the Bear overcame the Wends about the year 1170, he peopled Brandenburg with refugees from Holland whom the overrunning of the Zuider Zee had rendered homeless. These were " men thrown out of work who knew how to deal with bog and sand, by mixing and delving, a who first taught Brandenburg what greenness and cc pasture was."[1] Full details of the various types reclamation practised by the Dutch are to be foun in J. W. Robertson-Scott's *War-time and Peace i Holland*, Heinemann, 1914.

The Afforestation of Pit-heaps

Before passing on to consider the utilisation of other types of waste land, reference must be made to a very successful scheme for the afforestation of the waste heaps of pits in the Midlands. The area exploited is the Black Country which coincides with the South Staffordshire Coalfield. It has the peculiarity, owing to its shallow surface workings, that the pit-heaps are widely spread and cover much ground, thus contrasting with deep level coalfields where the waste is concentrated in much higher mounds near the shafts by which the coal is won.

The area of these heaps in the Black Country has been estimated at 14,000 acres, but it may exceed this figure considerably. A beginning was made in 1904, when an organisation known as the Midland Re-afforesting Association, founded for the purpose, began planting xperimental and demonstration areas. In some cases he planting was done for private owners, in others n ground leased by the Association. The work has one steadily forward, thirty-five experimental areas ave been established, together with one large one of irty to forty acres at Bilston.

[1] Carlyle's *Frederick the Great*, 1st edition, vol. i. p. 94.

The soils afforested are principally of two types, viz. shale or "clunch," and carbonaceous shale, which, as it contains much coal slack, is apt to fire and burn into a friable red soil. The cultivation is of the simplest. Pits are dug one spit deep, the surface vegetation is placed at the bottom and the young tree filled in. The labour has been of the casual type, and has proved quite satisfactory. The cost of planting averages £6 per acre, with about 1*s.* per linear yard for fencing (1742 trees per acre, *i. e.* five feet apart).

The most successful of the trees planted include the alders (*Alnus glutinosa* and *A. incana*), black poplar, sycamore, willows, wych elm, birch and robinia. Plantations dating from 1904–1908 are now eighteen to twenty-four feet in height, whilst black poplars which surround some of the plantations have reached a height of thirty feet. The impression created on the mind by a visit to these afforested pit-mounds is a very agreeable one indeed, the dirt and desolation everywhere throwing into strong relief these bosky woodlands, which in fulness of time will doubtless extend through the length and breadth of the Black Country. A very great merit of this scheme is its conception on genuine forester's principles. The enterprise is no mere plan for tidying up and beautifying the district—laudable though such would be—but a definite and successful effort to grow trees for profit. The district round about is hungry for small timber. Thus birch and alder fetch good prices for making handles for the innumerable objects produced in the locality, whilst poplar is in demand for brake-blocks.

The moving spirit in the affairs of the Association is Mr. P. E. Martineau. His principal criticism of the earlier plantings is that they would have been better with the trees at four feet instead of five feet intervals (*i. e.* 2722 in place of 1742 per acre), especially on windswept areas. Future developments will doubtless conform to experience in this matter. It is to be hoped and expected that other coalfields may follow the lead of the Midlands Association in the period of reconstruction after the war.

Maritime Wastes

By the sea shore products of erosion accumulate in the form of sand dunes, shingle beaches and salt marshes, terrains the possibilities of which have been too long neglected in this country.

1. *Sand dunes.*—These attain their fullest development in Gascony, along the Bay of Biscay, in North Holland, and in Baltic Prussia. Owing to their extent and to their great capacity to "wander" before the prevalent winds, the dunes of these regions have been very fully studied for more than a century, and the technique of their fixation by means of vegetation has reached a high degree of perfection. They are fixed partly by planting *Psamma* (marram grass), partly by afforestation, especially with coniferous trees. In Gascony productive forests of *Pinus Pinaster* have arisen, whilst on the Baltic a variety of coniferous and broad-leaved trees are employed. In Gascony the pinasters are exploited for their turpentine, and when they have run dry they are felled to provide pit timber, largely for the South Wales Coalfield.

Experiments at Holkham in Norfolk, and later at Formby on the great dune area near Southport, have shown that English sand dunes can be afforested with pine trees in a perfectly satisfactory manner.

The Holkham plantations, which cover 500–600 acres of sand hills parallel to the shore, date more than forty years back, and consist of Austrian (*P. nigra*) and Corsican (*P. Laricio*) pines, together with some amount of Scots pine (*P. sylvestris*). From a forester's point of view these woods were not planted quite close enough—being intended rather for shelter and to improve the amenities of the estate than for profit. Nevertheless, by natural regeneration the Holkham plantations are becoming denser, and should if required provide saleable timber.

It is to be hoped in any scheme of afforestation the utilisation of our sand dunes may be seriously considered. Rabbits are the bane of dune planting, and for success these must be exterminated or held in check.

Another possibility in the way of dune exploitation is the improved cultivation of *Psamma* (marram grass). Paper experts have reported very favourably on the prospects of marram as a raw material for the manufacture of paper,[1] though it does not appear to have been exploited commercially in this sense hitherto. The fibre obtained belongs to the same class as that of esparto grass, and can be dealt with in the mills where esparto is treated. Before the war we imported some 200,000 tons of esparto grass from Southern Spain and

[1] *Kew Bulletin of Miscellaneous Information*, 1912, p. 396; 1913, p. 363.

2. *Shingle beaches.*—England is rich in shingle beaches. For the most part these are narrow strips of pebbles protecting low-lying ground from the sea. The principal use of these is defensive, and to ensure them from being breached or overrun by high tides they should be fixed by suitable planting.

In certain cases, as at Orfordness, Rye, and notably at Dungeness, enormous areas of shingle are deposited, often covering many square miles. Such aggregates are termed apposition beaches from the successive strips or unit beaches lying side by side that compose them. Cut off from the sea, the inner beaches are apt to remain sterile for long periods, largely because the sea no longer gaining access, they are deprived of sea-borne seeds to colonise them and of the vegetable drift to form a humus soil.

It has often occurred to the writer that these areas might be turned to some account by afforestation. For that purpose it would be necessary in the first instance to sow nurse plants, such as gorse and white alders (*Alnus incana*), which, possessing nitrogen fixing root tubercles, would at the same time enrich the soil. These would be followed by the planting of trees—the most suitable species for the purpose would have to be ascertained by experiment, as there exists no experience to guide us.

3. *Salt marshes.*—The value of these for reclaiming by banking out the sea is well known and requires no emphasis here. On the East Coast especially much ground was won formerly in this way, though since the fall in agricultural prices there has been no inducement to risk the large investment of capital which these

intakes demand. With higher prices the position is altered, and, should there be a reasonable probability of their continuance, no doubt the reclaiming of salt marshes will once more receive attention.

In the past not a few of the reclamations, especially in estuaries and harbours, have been imprudently made with serious results to the navigation. The decayed ports of the north coast of Norfolk are outstanding examples. No operation is more tempting than to bank off the head of an estuary and to convert it into rich pasture or tillage. But in so doing the fact is too often lost sight of that the capacity of the estuary for storing tidal water is seriously impaired, and in particular it is robbed of just that storage space which holds the water that flows away relatively late in the ebb, and has the greatest effect in scouring the channel at the outlet. Deprived of this natural means of clearing the mouth, silt gradually works up channel and raises the level of the bottom, with the inevitable consequence that navigation is seriously compromised. For the sake of a few hundreds or even thousands of acres of new land it is hardly worth while to destroy a port, for, after all, our maritime facilities must remain one of our greatest assets.

Much less risk of silting up is incurred when the sides of an estuary are banked off by longitudinal works, whilst the scour of the ebb can be concentrated at the effective place by means of training walls. These operations, however, belong to the province of the maritime engineer rather than to that of the botanist. Ecological investigations show that the botanist has a field of usefulness in such operations in speeding up the vegetation phases on the mud flats before the proposed intake is sufficiently advanced for banking. On mud flats, as elsewhere, the vegetation shows "successions" which are subject to delays, owing sometimes to lack of seed of the plants of the next phase, sometimes to mobility of ground or other cause. By close study of these successions it is easy to recognise when a given phase is overdue, and its appearance could doubtless be accelerated by sowing seeds or by treating the ground in some appropriate way.

On the other hand, we deepen navigable rivers by dredging, and the sludge is commonly taken out to sea in barges and dumped. Thus at the mouth of the Thames we dispose in this way of enough mud in a single year to raise the level of 1000 acres of the low-lying shore by as much as three feet. On the tidal reaches of the Seine such materials are carried over the banks and used to level up low marshy ground, rendering it suitable for agriculture and tillage. Is there any reason for this divergence in procedure?

Utilisation of Natural Products of Salt Marshes

Before leaving the subject of the salt marsh, there is the possibility of direct *utilisation* in contradistinction to reclamation. The species of plants that flourish on tidal marshes are, as is well known, limited in number; not more than 1½ per cent. of all British plants are halophytes, and this, of course, circumscribes the possibilities of utilisation.

There is, however, on the South Coast a plant which has latterly appeared in enormous quantities on the mud flats of Southampton Water and Poole Harbour, and which is certain to penetrate into other areas. Public attention was first directed to the spread of *Spartina Townsendii* ("rice grass") some ten years ago by Lord Montagu of Beaulieu, and a good deal of precise information as to the plant has been made available by Dr. O. Stapf. *Spartina* now occupies thousands of acres of mud flats in the areas named, and is still rapidly spreading—particularly in Poole Harbour, where it was first detected in 1899. Its original appearance in the waters of Southampton dates back about fifty years, and it is presumed to be a natural hybrid between the indigenous species *Spartina stricta* and a supposed introduction from America, *Spartina alterniflora*, recorded early last century.

At first *Spartina Townsendii* was an isolated botanical curiosity. A shy seeder, it penetrated slowly to new centres. Its vegetative power is remarkable, however, and the seedlings by spread of rhizomes deep in the mud, grow into clumps, and in time the neighbouring clumps unite into pure, continuous meadows. By occasional seeding and water carriage new areas are systematically invaded, and then as the grass gets a hold it rapidly covers the higher mud flats to the practical exclusion of other vegetation.

Hitherto this miracle of Nature, which is transforming the waters it occupies, has been put to no definite use, that is to say it has not been exploited.

It has been tried, in a small way, at various places as an agent in promoting reclamation in virtue of its powers of holding silt. And no doubt on suitable ground, under a congenial climate, it will make its mark in this capacity.

On certain parts of Poole Harbour, where the ground has been sufficiently consolidated, cattle go down on to the marshes to feed on it, but so far as we know its feeding value still awaits investigation by critical trials.

Since the war a sample has been submitted to a paper expert who reported favourably on the qualities of its fibre, and at the present time *Spartina* is undergoing trials at the hands of paper manufacturers. *Spartina* undoubtedly possesses good qualities from this point of view, but the difficulty of its habitat will have to be overcome before commercial success can be attained.

These difficulties are probably novel in the exploitation of any plant. *Spartina* grows on very soft, sticky mud, and is covered by the high tide twice a day. The problem is to cut the grass, to keep it from being sullied by the mud, and to get it ashore and spread out to dry before the next tide rises. If these operations are to be done by hand, the reapers will have to be very highly trained, as mud on the leaves and stalks is most difficult to remove, and makes black specks in the paper. Hitherto cutting by machinery has not been tried, nor will it be till the conclusion of the war, for the paper industry is hardly to be reckoned an "essential trade."

The above examples may serve to illustrate the possibilities of utilisation of waste lands by the sea. They indicate the existence of a considerable field well deserving a closer investigation than it has yet received.

The time is probably ripe for the preparation of a much fuller survey and report of this type of ground than has hitherto been considered necessary. And what is true of maritime wastes applies with equal force to other types. Towards the realisation of these objects there seems room for a "Waste Lands Commission" provided with very considerable powers of initiative; to such a body would also fall the task of guarding public rights, especially those of commonage. Into the details of organisation, however, space does not permit us to embark.

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CHAPTER IV

TIMBER PRODUCTION IN BRITAIN

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THE national importance of an adequate supply of home-grown timber has been very cogently brought before us during the present war. It can scarcely be gainsaid that for the future it is extremely desirable that in times of stress we should be independent of sea-borne supplies for our minimal requirements. But apart from the utilisation of timber in its unconverted form, the maintenance of sufficient home provision would both encourage and create the numerous associated industries which depend upon forests for their raw material. Not only would these produce an increase of employment, but, what is perhaps even more to be desired, would tend to retain permanently the rural population in country districts, and thus maintain a more equable distribution of labour.

The value of forests in regulating water supply has long been recognised, and the planting of water catchment areas might profitably be undertaken on a much larger scale than heretofore. The example of Birmingham, Leeds and Liverpool in this direction is one which might well be followed by other municipalities.

For purposes of protection against erosion and denudation, forests are also of the greatest utility.

Without labouring the theme, it will be realised that apart from the value to the nation of sufficient home-grown timber, the forests that produced that timber would subserve national interests of the first importance.

In spite, however, of the undoubted value of forests to this country, it cannot be said that in the past they have, generally speaking, been a success, either from the financial aspect or from the point of view of the timber produced.

I propose, therefore, even at the risk of recapitulating much that has already been said or written elsewhere, briefly to review what are probably the chief causes which have led to failure in so many cases.

There are certain factors which materially affect the financial aspect of timber production, and which are more or less external though none the less fundamental. Such are cost of labour, cost of transport, and foreign competition.

These are matters with which I have no special qualification for dealing, but in reference to foreign competition it cannot be too often urged that timber producers in this country undoubtedly labour under a great disadvantage. Evidence brought before the Royal Commission in 1908 showed that in effect there is a preferential tariff for the carriage of imported timber. The extent of this has sometimes been exaggerated, but it undoubtedly operates very adversely against the home production of unconverted timber such as pitwood, scaffold poles, etc.

A still more serious consideration is that in effect imported timber, paradoxical as it may sound, is placed upon our markets at under cost price. This is due to the fact that the imported timber is nearly all the produce of virgin forests on which, of course, there is no accumulated debt representing compound interest on the cost of establishment and maintenance. The low price of foreign timber is thus largely maintained at the expense of the national capital of the exporting country.

Now the major part of the expenses of establishment of a timber crop are paid in wages, so that most of what is gained by the low price we pay for imported wood we lose in home labour. It is therefore a matter for careful consideration whether it is not in the national interests to place an import duty of equivalent value on all timber which conditions of soil and climate admit of being produced at home. I am fully aware of the controversial character of such suggestions, associated as they unfortunately are with certain political creeds, but those most competent to judge warn us that the virgin forests are rapidly becoming depleted. If, therefore, no steps be taken to encourage home production, we shall be faced in the near future with the necessity of paying a higher price for foreign timber than would at the present time show a profit on home produce, without the commensurate advantage of forests of our own to meet the growing demand, and to provide labour for our own countrymen.

Apart from the foregoing fundamental adverse conditions, there are many internal and remediable factors, a reform in respect to which would materially affect the financial aspect.

Understocking.—Probably one of the most adverse factors tending towards the failure of economic forestry in this country is the inferior quality of the timber produced. This is due in a very large degree to the fact that most of our forests are too open in character. This feature is probably largely a result of the fact that in past generations the English oakwoods were the source of supply for the oak used in shipbuilding. For this purpose the crooked branches were highly valued for the making of the ribs and knees. Open canopy favoured the production of large, strong, and numerous branches such as the shipwrights required.

Many of our woods of common oak were planted shortly after the Parliamentary Commission report early in the nineteenth century, when a famine in wood for naval construction was anticipated. With the introduction of iron for shipbuilding about 1836, the demand for bent oak rapidly decreased, so that at the present day we have in this country a considerable quantity of common oak in a mature condition which was grown for a specific demand that no longer exists. Unfortunately the very method of growth which was most advantageous for the purposes of the shipwright is least suited to modern requirements.

The demand at the present day is for clean, straight poles, with straight grain and uniform annual rings.

The defects which result from understocking may be summarised as follows—

The growth is too rapid, and results in an unevenness of grain which renders the wood less durable and of variable strength.

The open canopy permits each tree to produce a large mass of foliage, and to meet the demands of transpiration a large number of vessels are consequently formed each spring. In a well-stocked wood the canopy of each tree is much reduced, and the proportion of vessels to fibres in the spring wood is much smaller. Consequently the timber produced is of greater strength.

The boles in open canopy tend to be short and taper rapidly, so that not only is the gross amount of timber in the trunk small, but also in order to obtain planks of adequate length there is far more wastage than in a long trunk which tapers slowly.

By far the most serious defect, however, is the early production of numerous strong branches, so that the trunk is knotty and largely consists of faulty wood.

Since the practice is for the landowner to sell the trees standing to some timber merchant, it will be evident that the latter, even in the case of well-grown trees, accepts a certain risk in respect to the quality of the timber. It is scarcely surprising, therefore, that much of the oak growing in this country at the present day is practically unsaleable.

In view of the many adverse conditions, we are certainly not justified in forming an estimate of the economic soundness of British forestry on the basis of the financial results which the average present-day woodland yields. This is emphasised when we remember that the understocking itself, apart from the correlated effects, considerably reduces the increment value of the forest.

The extent of the understocking can best be illustrated by a few figures. We may take it that a properly stocked oakwood between 100 and 120 years old should have not less than 100 trees to the acre. In actual fact a large majority of the oakwoods in the southern part of England have less than 30 trees to the acre at maturity.

Open Canopy and Game Preservation.—We have seen that the historical factor has played a large part in determining the open character of our woodlands, but another practice, and one far more difficult to remedy, is the influence of sport.

A high forest properly stocked usually exhibits a very sparse shrub layer and scarcely any herbaceous flora. Such woods, therefore, present very poor cover for ground game and pheasants, so that financial success is all too frequently sacrificed to the demands of pleasure. The widespread character of coppice with standards is probably due to the fact that it constituted a compromise between the dictates of forestry and those of sport.

Under modern conditions, however, this system rarely produces satisfactory financial results. An exception to this generalisation must be made where the coppice supplies the demands of some local industry, as, for example, around Haselmere, where the chestnut coppice is utilised for fencing, and realises from £6 to £18 per acre in a fifteen years' rotation.

Much might be done towards reconciliation of the forester and gamekeeper by suitable underplanting with covert shrubs, such as yew, box, laurel, etc. The use of *Rhododendron* for this purpose in the past has, perhaps, brought the system into disrepute. For where the soil is suited to this plant it often exhibits such luxuriant growth and seeds so freely as to constitute an impassable barrier to the beaters.

One great defect of the coppice with standards is the enormous increase in the ground flora after coppicing, with consequent impoverishment of soil, particularly by breakdown of the humus.

Rabbits.—In quite a number of woods upon the lighter soils rabbits flourish and multiply to an inordinate degree, and there can be little doubt that the paucity of self-sown seedlings of our forest trees can in most cases be laid to their charge. It cannot be too strongly emphasised that rabbits and good forestry cannot go together. This fundamental fact must be realised if our British woodlands are to be improved.

No one who has carefully examined any large area of coppice can fail to have noticed the common tendency toward degeneration, even where the stools are hornbeam with its proverbial longevity. There are in the oak-hornbeam woods of Hertfordshire many hundreds of acres where there is scarcely a living stool, and the soil is being exhausted by a rank growth of brambles. This condition, there is good reason to believe, has been brought about almost entirely by the depredations of rabbits, which nibble off the sprouting shoots that appear after coppicing. A systematic destruction of these animals would not only result in a much smaller accumulated debt consequent upon the saving in wire netting, but in all probability the large number of seedlings surviving would make it possible to regenerate disafforested areas by natural means. If rabbit fences could be dispensed with, the saving effected would represent between £1 10*s*. and £2 per acre, or an accumulated debt, reckoned at 4 per cent. on a hundred years' rotation, of from £76 to £101. Viewed from another aspect, it would represent an increased annual rental of from 1s. 2d. to 1s. 7½d. per acre.

Reform in policy.—We can summarise the necessary reforms in policy as follows—

1. Much denser planting.
2. Subordination of the gamekeeper to the forester.
3. Extermination of rabbits in afforested areas.

To these may be added increase in size of the afforested areas. The tendency to form numerous small woods has been largely owing to the dictates of sport. By increasing the area of contiguous woodland many advantages would accrue.

Firstly, it would render possible the construction of good forest roads, thereby reducing the cost of transport; moreover, the utilisation of motor lorries would under these conditions become feasible. Large areas produce a constant supply of timber, so that the erection of plant for dependent industries becomes economically possible, and where considerable supplies are available, the cost of local conversion is more than compensated for by the diminution in the cost of transit.

I now come to that part of my subject with which I propose to deal more fully, viz. the importance of ecological research to practical forestry. It may be said of forestry that much of the present practice is purely empirical and not based on sound scientific principles.

One only has to glance through any textbook on forestry and read the conditions given as suitable for the growth of different forest trees, to realise how vague is the information regarding the requirements of the various species.

Recent ecological research on the distribution of natural woodland types has done much towards placing our information on this subject on a sounder basis. For it may be fairly argued that if a particular species of tree forms pure woods on a particular type of soil under the stress of natural competition, that same tree will grow, at all events, no less vigorously when the struggle with other species is eliminated by artificial protection.

To illustrate the value that ecological work may have in this direction, I cannot do better than quote an example that has come prominently under my notice during the last ten years. There are in this country two native species of oak, viz. the common oak (*Quercus robur*) and the durmast oak (*Q. sessiliflora*). In many of the older works on forestry the distinction between these two was either ignored, or if recognised was not made the basis for any distinction of treatment. In the more modern and better works the two are usually stated to require the same cultural conditions.

One is indeed led to assume that in general it is of no consequence which species is planted either on account of the soil conditions or the timber produced.

The study of plant communities has led to the realisation that marked preferences as to soil and situation are often far more pronounced between closely allied species than in those which are wholly unrelated. And perhaps in no case is this more striking than in the natural distribution of the two native oaks as brought to light by the ecological work of recent years.

Thus Moss found that in the Peak District there was a sharp distinction between the areas occupied by the common and durmast oaks. There the common oak is met with growing on deep, non-calcareous, fluvio-glacial sands, whilst the durmast oak is restricted to the *shallow* soils overlying the siliceous rocks. The same investigator found the common oak forming woodlands in Somerset on the deep sands of the greensand series, and on the deep calcareous marls. Adamson in Cambridgeshire found the common oak both on calcareous marl and loam.

In Hertfordshire the common oak is entirely confined to the stiff clays and heavier loams, whilst the durmast oak is restricted to the lighter loams and sands or soils deficient in lime.

In upland districts the durmast oak forms extensive *woods on the shallow soils overlying the non-calcareous* and sometimes calcareous rocks of the steep valley sides.

Thus we find woods of *Q. sessiliflora* on the lower estuarine sandstones of the superior oolite of Yorkshire, on the Devonian sandstones of Somerset, and on the Cambrian and Silurian rocks of Wales, such woods often extending to an altitude of 1000 feet.

Although we are far from having entirely solved the problem of the respective habitats of the two species, it is clear that the vague statements of foresters in the past have not merely been misleading, but often positively erroneous.

Thus it is evident that except in districts where the rainfall is exceptionally high, the durmast oak does not naturally occur on calcareous soils, whilst the common oak flourishes in heavy soils of this character when of sufficient depth. On non-calcareous soils the common oak is restricted to the heavier and the durmast oak to the lighter soils. But the outstanding feature elicited by a study of the distribution is that deep soils are only necessary for the common oak, whilst the other species flourishes on relatively shallow soils where, moreover, it produces quite good timber.

From an investigation upon which the writer is engaged at the present time, I believe it will also prove to be a fact that whereas *Quercus robur* requires a soil relatively rich in mineral salts, *Quercus sessiliflora* grows well in soils which are relatively deficient in this respect.

It is by no means infrequent to find plantations of *Quercus robur* on light soils to which it is quite unsuited, as also on shallow soils where it grows for a time but afterwards becomes stunted.

The question naturally arises as to whether there is any difference in the quality and properties of the timber produced.

The sp. gr. of the wood of *Q. sessiliflora* is slightly higher than that of *Q. robur*, and, though the available data are somewhat conflicting (doubtless owing to confusion of the species), it seems evident that for durability and strength the wood of *Q. sessiliflora* is preferable to that of *Q. robur*. Moreover, the grain of the common oak is not so even and consequently harder to work than that of the durmast oak.

A very important difference is that whereas *Q. robur* tends to produce a short bole with numerous strong branches, the durmast oak usually, even when grown in open canopy, forms a long straight bole with weak lateral branches. This natural tendency renders the durmast oak particularly suited for planting as high forest with coppice. Moreover, as it is not necessary to plant it so close as the common oak in order to produce good quality wood, the amenities of the game covert can be preserved without diminishing the value of the timber.

It is significant in this connection that the timber from a certain wood in Hertfordshire in which the oak is almost exclusively *Q. sessiliflora*, realises nearly twice the price of that from the surrounding woods where *Q. robur* is the predominant tree.

Owing to the long period that must elapse between the seedling stage and the mature tree, the experimental method so largely adopted in agriculture is only to a very limited extent applicable to forestry. As a consequence the ecological method of investigating the natural conditions as they occur in the field, and correlating them with the quality of timber produced, offers the best avenue for an increase in our exact knowledge of the factors governing timber formation.

Data of inestimable value to the forester are being slowly accumulated by the ecologist. As, for example, accurate determinations of the acidity, water content, and mineral salts present in the soils of different types of woodlands.

But apart from information of this character, there is another line of research which the ecologist has opened up, and which in co-operation with the practical forester should yield fruitful results. I refer to the association of species. There is little doubt that in the past we have been too much influenced by the German tradition in this country, as a result of which large areas have been planted with a single species which would have yielded much more profitable results planted as a mixed wood.

It must not be thought that in criticising the methods of forestry in this country that the blame lies entirely at the door of the forester. The wonder is that he has accomplished so much against the numberless disadvantages with which he has had to contend. It is the duty of the ecologist to supply those accurate data in need of which the forester stands, and my plea is for co-operation between the practical man who has his hands full enough already looking after his nursery, his plantations, and his timber, and the scientist whose function is the provision of exact information and advice.

In no respect is such accurate information more scanty than with regard to association of species. The data as to those which occur together naturally on the different soils cannot fail to aid in the choice of trees for mixed planting, such as will not interfere with each other's development and yet contribute to the increment yield. And still more will such information supply a warning as to what species should *not be planted together.* Mixtures indicated by our present knowledge are—

Calcareous soils: (ash and wych elm) and (beech and yew).

Non-calcareous soils: (*Q. sessiliflora* and Spanish chestnut), (*Q. sess.* and *Fagus*), (*Q. robur* and *Populus tremula*).

The phases of succession which occur naturally on different types of soil might well serve as a guide towards the choice of nurse trees. Such would indicate the almost universal employment of birch, preferably *Betula pubescens*, on all non-calcareous soils, and the use of ash on those which are calcareous. The freedom with which these species colonise ground indicates that they might be utilised for natural regeneration, and later underplanted with shade-enduring species.

One of the great decisions which a forester is often called upon to make is the choice of species for a newly afforested area. In making this decision the soil conditions are of the greatest importance, but unless he has had the forethought to take soil samples for a year previous he may be quite in the dark as to the extremes of drought and moisture to which the area is subject. Moreover, in addition he should know the chemical constitution of the soil and its physical structure, each involving a laborious determination. Yet the ecologist could often tell at a glance, from the vegetation already present, what were the prevailing conditions and what trees would be most likely to succeed. In this connection I would strongly urge that more attention should be paid to the cryptogamic flora, which is often a very delicate index of the soil conditions. For example, the abundance of liverworts appears to bear a very close relationship to the relative proportion of coarse and fine particles, being very scanty both in individuals and species where clay and silt predominate, and becoming more numerous as the proportion of sand increases.

Again, the proximity of the water table may often be gauged by the character of the mosses present. Thus the presence of *Brachythecium rutabulum* on a light sandy loam indicates at once the unsuitability of the area for beech, owing to the proximity of the permanent water table.

Probably a careful study of the fungi and humicolous lichens in this connection would yield results of equal value, and we may perhaps look forward to the time when cryptogams will provide indicators as valuable to the forester and agriculturist as are vegetable dyes to the analytical chemist.

Afforestation.—We now turn to the very debatable question of afforestation. There can, I think, be little doubt that if afforestation be undertaken, it should be by the State or by municipalities.

Firstly, the State is able to borrow money at a lower rate of interest than the private individual; secondly, the private individual is seldom in a position to provide the necessary capital for afforesting a large area such as is necessary for financial success; thirdly, the return from timber is so long delayed that for some years the capital yields no return, a matter of serious consideration for the landowner.

Moreover, afforestation for the State is to be regarded not merely as a national investment, but also as a national insurance against timber famine. And since it is for the benefit of the community in general, the community as a whole, and not the individual, should bear the burden.

In view of the current state of the money market and the probability of the high value of money being maintained for some time after the war, it is extremely doubtful if the most paying species would yield a return sufficiently large to attract the landowner, especially having regard to the speculative character of the investment.

But although one cannot go so far as some optimists have done, and predict that State forests would yield a high rate of interest, yet there is reason for believing that it would prove at least as profitable as many of the municipal ventures which are undertaken for the benefit of local communities.

In this connection it must be borne in mind that probably when this war is over we shall pass through a period in which unemployment will be even more acute than in the corresponding years succeeding the Boer War.

Afforestation has been looked to as a palliative for the unemployed problem, and though many objections can be raised on the grounds of the unskilled character of such labour, it will probably prove the best means of retaining and increasing our rural population.

But by far the most weighty argument, to my mind, for the establishment of State forests is their value in bringing about the establishment of attendant industries. We see this in the flourishing chair industry of High Wycombe, which had its origin in relation to the regular local supply of beechwood, but which now requires large quantities of imported wood for its upkeep. In the days after the war, when we shall have to strain every sinew to re-establish our former wealth, will it be too much to sacrifice a high rate of interest if we can supply our home markets with converted timber or even perhaps wrest this trade from the hands of foreign competitors?

Our supineness in respect to this aspect has lost us industries in the past which the foreigner has been quick to acquire. Where is the industry in crude naphtha and oven charcoal which formerly flourished in the North? Or again, what are we doing to protect the industry in split chestnut fencing against unscrupulous foreign competition? I venture to think that in the future, we shall not deem it sufficient that the foreign substitute be cheaper unless that lower price is an expression of real ability in production, that more than compensates for the transference of labour and wealth to a foreign land.

The subject of afforestation naturally leads to the question: What trees is it profitable to plant at the present time? Generally speaking, we may take it that the cost of planting, of fencing, and of the young trees themselves, ranges from about £5 to £8 per acre, according to the method of planting which the soil and situation admit of. Now if we content ourselves with requiring a return of 4 per cent. on the capital expenditure, this will at the end of 120 years, the normal rotation period for oak, amount at 4 per cent. compound interest to about £890. In addition, there will be an expenditure of some 2*s.* per acre a year over and above the rental value of the sporting rights. This, together with the cost of planting, will represent a debt at the end of the 120 years of about £1160.

On a moderate soil a properly planted crop should yield about £260, together with a sum of about £500 for the capitalised value of the thinnings at the end of the 120 years. So that there would be a net loss at the end of the period of about £400. If the trees planted had been beech, the loss would be even higher, about £620. On the same basis of computation, ash on a 70 years' rotation would, however, yield a profit, after paying compound interest at 4 per cent., of about £170. This discounted into annual payments is equivalent to a rental of 9*s*. 2*d*. per annum per acre for the land.

On the chalk downs of the Chilterns we can find extensive stretches covered with high forest consisting of beech. In many parts, wherever clearings occur, we almost invariably find ash appearing from self-sown seed. These ash thickets are cut down and planted with beech and sometimes larch. Were they retained and properly maintained, they would show a handsome profit in place of the present considerable loss.

It cannot be asserted that any other of our native trees will show a profit if the debt be calculated at 4 per cent. interest. Larch, however, will yield a rental value of about 5*s*. to 10*s*. per annum, and Douglas fir, the most paying of all our trees, whether native or introduced, will yield a rental value of as much as £2 per acre.

Even then, looked at as a purely financial investment, afforestation on proper lines is not so unprofitable as some have led us to believe. But if we compute the return in terms not only of money but of employment, decentralisation of population, establishment of rural industries, and independence of sea-borne supplies, then surely the undertaking is not merely justified, but becomes a duty of national importance.

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CHAPTER V

TROPICAL EXPLOITATION, WITH SPECIAL REFERENCE TO RUBBER

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To deal fully with tropical exploitation in an hour is an obvious impossibility. I shall endeavour to indicate the general principles which underlie its practice, and illustrate my remarks especially by the case of rubber, which has come into such prominence in recent years, and with which I have had much to do, both in tropical Asia and in South America.

Agriculture does not proceed by haphazard ; we talk about things as determined by chance, but that simply means by causes which as yet we do not fully, if at all, *understand. But we are gradually coming to com*prehend with reasonable clearness the chief causes which are responsible for agricultural progress, and so it becomes possible for those concerned with the government of a country to act so as best to encourage it.

At first agricultural progress, if progress it can be called, was dependent only upon one or two factors, but as time went on it became dependent upon the action of more and more. The incoming of the new factors does not throw out the action of the old, so that the problem becomes more and more complex. Any one factor, if it cannot act properly, may limit the rate of progress until it is put right.

Agriculture in its earliest stages may be largely summed up in the words, " Grow what you want and consume what you grow." It was essentially what would now be termed a peasant industry, but one must remember that in early times there was but little differentiation among the people. If for no other reason, there could not be further progress because means of transport were not yet developed, and so if a man grew what he himself could not consume, he could not get rid of it if his actual next-door neighbour did not happen to want it.

For this earliest agriculture, then, land available for use—that is clear of forest or grass, drainable, and supplied with sufficient water—and crops suitable to growth upon that land, were the only absolute requisites. The crops cultivated in those early days would of course be those which experience of the produce of the wild flora of the country had shown to be suitable. Thus in a forest-covered country the great struggle of the agriculturist, as it is to this day for the peasant in districts where the population is thin, was to prevent the crops being swallowed up by the continual impressing of the forest.

As the country became cleared, paths began to be opened up, and gradually it became possible to grow a crop in one place and dispose of it in another, so that differentiation in labour, whether within agriculture itself or between agriculture and other occupations, became possible. A class devoting itself to fishing, for instance, could arise, and the fishermen exchange their fish for the products of agriculture which they needed; this would react on the agriculturists, who would now devote themselves to growing more of certain crops, and would gradually find that they got a better return per square yard than by growing every kind of crop; this would gradually bring about a certain specialisation among themselves, one man growing one thing, another another, and exchanging by means of the markets that would gradually spring up. In this way, provision of means of transportation acts as the *third differentiating factor in* agricultural progress.

A later stage was that the land was owned by large owners, who had come into possession of it in various ways. To possess a large area is obviously of no particular use if it cannot be cultivated, and this difficulty was got over in different ways, perhaps most often by a system of cultivation on shares, the land being leased out to different cultivators, who pay to the landowner, say, 50 per cent. of the resulting crop as his rent. Sometimes forced labour was employed, but the share system was more usual; hired labour only appeared at a later time.

The next stages in agricultural progress, therefore, after the provision of land and crops, are the provision of means of transport and of capital—which enables the purchase of land, tools, etc., to be carried on, and allows of waiting for the return to come in after the sale of the produce.

In Europe there is now comparatively little of the old style of peasant cultivation, though it is tending to revive of late in modified forms. But in the tropics progress was less rapid, and there had, previous to the arrival of the white man, been but little progress beyond the stage of " grow what you want and consume what you grow," except in Peru, in India, and a few other spots.

To a large extent this continues to the present day, and the bulk of the land employed in the tropics is in the hands of peasant cultivators, or of large landowners, who cultivate to a great extent upon the share system. But with the coming of the white man all the conditions of agriculture in the tropics were altered, and a capitalist agriculture was more or less violently superimposed upon the other.

The incoming European brought capital (as money) with him, and with the proper provision of this factor, agricultural progress became possible far beyond the point hitherto attained. At first he had little or nothing to do with agriculture proper, but settled as a merchant where he could procure the products of agriculture and transport them easily to Europe for sale. This determined the kind of locality in which he settled—usually either at the mouths of the great rivers, which afforded transport from the interior, like the Ganges, or upon islands, like Ceylon or Java. These early settlers collected and sold in Europe the products gathered by the natives from the forests, like cinnamon in Ceylon, or produce which certain districts produced in excess of their own requirements, like rice in Bengal.

Before long the Europeans became themselves interested in agriculture. Land was easy to obtain in most countries, and native experience pointed out the possible crops. Means of transport were usually bad, but where there was a great river, or the country was a small island, were generally sufficient. Capital was available, and the only obstacle to progress was the provision of the necessary labour (the fifth requisite for progress) to grow the crops, and so for a long time the labour employed upon plantations owned by Europeans was forced labour in the form of unadulterated slavery.

With this, real exploitation of the tropics by Europeans began. The first great agricultural enterprise was the sugar industry of the West Indies, where all the necessary conditions were fulfilled in a very perfect manner. Transport was easy from these small islands, and in the islands themselves presented but small difficulties; sugar was known to grow well, and had a good market in Europe; land was easy to obtain; capital was provided from Europe; and the labour problem was easily and simply solved by importing African slaves. Rapidly there grew up a great and prosperous industry. But with the abolition of slavery all this was thrown out of gear, and the West Indies sank into a state of great agricultural depression, out of which they are now slowly rising.

The next great industry to rise was based upon hired labour, and was the coffee industry of Ceylon. Land, transport, and capital presented no difficulty, and labour was obtained from the densely populated Presidency of Madras, close by. The duty on coffee in England had just been reduced, and its consumption was increasing. By 1838 the success of the industry was assured, and in that year 10,000 acres of crown land were sold to planters, while in 1841, when the boom was at its height, no less than 78,000 were disposed of. To quote Emerson Tennent, "The Governor and the Council, the Military, the Judges, the Clergy, and one-half the Civil Servants penetrated the hills and became purchasers of Crown lands . . . capitalists from England arrived by every packet . . . so dazzling was the prospect that expenditure was unlimited; and its profusion was only equalled by the ignorance and inexperience of those to whom it was entrusted. The rush for land was only paralleled by the movement towards the mines of California and Australia, but with this painful difference, that the enthusiasts in Ceylon, instead of thronging to disinter, were hurrying to bury their gold."

Soon after this there was the inevitable collapse, but by 1855 the industry had recovered, and was conducted on practical lines, forming the staple industry of Ceylon until the eighties. Almost a million hundredweights of coffee were exported in 1875. But the writing was already upon the wall; a fungus disease was beginning to spread, was disregarded until too late, and had as a result the complete collapse of the industry, hastened and made more complete by the competition of Java and Brazil.

Cinchona illustrates several other features in the general study of tropical exploitation. The tree is a native of the Andes, especially of Peru. The febrifugal properties of its astringent bark, due to the fact that it contains the alkaloid quinine, were known to the natives before the arrival of Europeans, and became familiar to the Jesuit missionaries, one of whom cured the Countess of Chinchon of a fever by its use. The bark was for a long time obtained by felling the trees, and as extermination appeared probable, Sir Clements Markham was sent on an expedition to Peru to obtain seed, with a view to the cultivation of the tree in the British tropical colonies. He was successful in this, and as the climate of India appeared unsuitable, it was sent to Ceylon, where in the early eighties, when coffee was failing, some planters were induced to give it a trial, it having been shown to grow well in the Government Botanic Gardens. Thanks to the then very high price of quinine, the venture was extraordinarily successful, with the result of a boom in cinchona cultivation. The effect was to lower the price of quinine upon the market from 12*s*. an ounce, at which it once stood, to 1*s*. 1*d*., which considerably reduced the profits and reduced the industry to a state of comparative collapse, which was hastened by the competition of better barks from Java, where more scientific methods were adopted, better species used, and care taken to improve the yield by the selection of the best seed from each generation.

Cinchona thus illustrates all the phases of European exploitation of a tropical industry—the discovery of the value of the product, its collection from the wild plants by the cheapest methods, usually the most destructive, its transfer to another country by means of seed, its preliminary study by the aid of a botanic garden, its first taking up by one or two planters, the boom which followed their success, the resulting fall in price, its more scientific treatment in another country, and its collapse in the first owing to the competition.

Finally, let us turn to the tropical product whose exploitation has aroused the greatest interest in recent times, viz. rubber. Rubber is obtained from many different species, but the one that first came into notice, the one that as a wild tree produces the greatest amount, and the one that is by far the most commonly cultivated, is the rubber tree of the Amazon valley, the tree now usually known as the Pará rubber, *Hevea brasiliensis*. Other rubber trees of importance occur in Africa, in Central America and Mexico, and elsewhere, but though exploited commercially for all they are worth, they are but little cultivated.

The Pará rubber, growing in the valley of the largest river upon earth, a river up which liners of 10,000 tons can go for more than 1000 miles, and which has innumerable navigable tributaries, was fortunate in the matter of transport. Capital was forthcoming, the crop being profitable, and labour in the early days was obtained by slavery. A merchant industry thus sprang up, with its headquarters at Pará.

This was all that was necessary for a very long period. The Indians had known of the properties of rubber for a long time, but it was little used in England or elsewhere in the colder zones. The real advance in its use came with the discovery of vulcanisation, in which by the combination of sulphur with the rubber, its nature was changed, and it became much more durable, and suited for the manufacture of many different sorts of things. From that period onwards, the consumption of rubber has increased without any serious break, until at the present date it may be looked upon as one of the indispensable products for modern civilisation, like cotton.

About 1875 an expedition was despatched to the Amazon by the Indian Government, under Mr. Wickham, at the advice of Kew. At about the same time the seeds of other rubber trees were also collected in different parts of the world. A few score of plants were raised at Kew, and sent to the East in charge of a special gardener. The bulk were sent to Ceylon, and the rest to Singapore, although the cost was met by the Indian Government, for experience of the climate in which the tree was native showed that it could hardly be matched in India. The seedling plants were established in the botanic gardens in both countries, and public interest in them ceased for about twenty years.

In the interim, rubber cultivation went off along what has proved to be a side line. The seeds of the rubber tree of North-east Brazil, *Manihot Glaziovii*, whose produce is largely exported from the state of Ceará, and which is known in trade as Ceará rubber, had been brought to Ceylon about the same time, and proved to grow like weeds. In the early eighties, when coffee was failing, this tree, which seeded freely, was taken up by a good many planters, and for some time there was a small export of the rubber from Ceylon. What was chiefly against the Ceará tree was the fact that its yield was disappointingly small, while at the period the price of rubber on the market was but low—two conditions which, as we shall see, were almost exactly reversed at the period of the incoming of the Pará rubber. The cultivation, therefore, never spread to any great extent, and gradually fell away to almost nothing.

To return to the Pará rubber; about twelve years after its establishment in the East, rough experiments on yield began to be made in the botanic gardens there, but had not very satisfactory results. Thus Dr. Trimen in Ceylon showed that a yield of about 1½ lb. a tree a year might be expected at ten years old, provided that every tree yielded as well as did the one that he tapped, which was the largest of the forty-five existing. To wait ten years for a return meant a large outlay of capital, and this amount of rubber, valued as it was considerably below 2*s*. 6*d*. a lb., did not offer any very glowing prospects. It was a long time before any planting estates were induced to plant the tree seriously, and indeed it was also long before any large quantity of seed was available.

However, in the nineties, especially as the result of further experiments, which were carried out on larger numbers of trees, and gave more encouraging results, the tree began to be taken up to a greater extent, and at the same time a rise in the price made the prospect of profit more alluring. In the later nineties some of the earlier trees in Ceylon were tapped, and produced better results than was anticipated, and the planting of rubber was suddenly taken up with a rush. Seed, for example, which was available in the botanic gardens, had to be sold by auction, and at one period as much as ½*d*. was realised for each seed. In a year or two afterwards the price went down, as large quantities began to be available on the estates which had first taken up the tree.

At the same time that seed began to be plentiful, the results of the sale of the rubber first exported began to be known. Soon it was clearly seen that the older estimates had erred altogether upon the conservative side. Not only could more than 1½ lb. be obtained from a tree in a year, but the trees were found to be in bearing at six years old; and the price obtained was decidedly better than some years previously. The result was to cause the pushing on of rubber planting in Ceylon and Malaya to an extent that put even the tea boom quite into the shade, and which is second only, as far as tropical crops are concerned, to the coffee industry of Brazil. We talk of the wonderful British industry of rubber, but it is worth while to notice that the value of the entire export, though rubber is worth so much more per pound than coffee, is barely one-third of that of the export of coffee from Southern Brazil.

From this time onward, the export of rubber from Ceylon and Malaya went steadily and rapidly forward, and we may quote the Ceylon figures to illustrate this—

1901	3 tons 6 cwt.
1904	34 tons.
1907	354 tons.
1912	4,506 tons.
1916	24,000 tons approximately.

The Brazilian export, it may be noted, is about 40,000 tons.

In 1907 there occurred the Ceylon boom, a precursor of the great boom of three years later in London, but the Ceylon people knew better what they were doing, and did not throw money away. Ceylon raised every penny that was possible, and started many companies, chiefly in the Malay States, where suitable land was more readily available, and at the present time these companies are doing well. But the historic boom in rubber cultivation was that which sprang up in London in 1910, and during which many fortunes were made or lost.

The plantation rubber of the East is now the chief rubber upon the market, for the export of the wild Brazilian rubber has stood practically steady at about 40,000 tons, and that of the African and other wild rubbers is much less. What has perhaps most of all surprised the planters of rubber is that they have been unable to kill off the Brazilian trade. To close our consideration of tropical exploitation, it may be of interest to go into this question.

It would be very unscientific to prophesy that the cultivated rubber will never kill out the wild, but the time is not yet. One great difficulty in the way is the fact that, though it is often denied, the Brazilian upriver hard cure, as the finest rubber is called, is superior in quality to any of the plantation rubber. No one who has seen them side by side in quantity could have much doubt on the subject.

The cultivated rubber is all marketed in a form that contains practically no water at all, whilst the wild rubber has about 15 per cent. This fact is usually lost sight of in comparing the market prices. At to-day's rates, for example, 85 lb. of dry Brazilian rubber is worth 335*s*. against 278*s*. for the same quantity of plantation. This fact struck Mr. Bamber and myself at the Ceylon Exhibition, and we made a rubber which contained water, and was of better quality; but by sending to market rubbers with different percentages of water, people soon spoiled any chance of success which this method might have had. And this difference is not the only one, there are others. For certain fine qualities of goods the fine Brazilian rubber must continue to be used, if the best results are to be obtained, for example for inner tubes, for surgical instruments, and the like; but, as the plantation rubber now controls the market by being present in much greater quantity, it forms an industry *per se*.

But to complete our study of tropical exploitation, it may be of interest to deal briefly with the steps which are being taken in Brazil to meet the competition of the plantation rubber, which is admittedly very formidable. The cost of placing the Brazilian rubber on the market is ahead of that of placing plantation there, though the increased price almost equalises it, and the problem is how to reduce it. Export duties, at present almost 20 per cent. *ad valorem*, are being reduced, and would be more rapidly reduced were it easy to get the enormous cultivable areas of the Amazon valley, the richest tropical land on earth, taken up for other kinds of agriculture. Rubber is the only taxable value in the Amazon states, and therefore provides their revenue. Here, one may perceive, is one of the problems of the kind that confront the man who is occupied with tropical exploitation, and which one is apt to think, when one is young, and fresh from the study of science at school and university, are purely scientific problems, whereas in reality they are much more complex, and are rather problems of finance and political economy. Given the Amazon valley, one knows that land is available; one knows that cacao, rice, rubber, and almost innumerable crops will grow well there. *Why*, then, cannot agriculture be made to succeed? To begin with, most of the land is covered with high forest, and the small cultivator will spend most of his time and work in fighting the continual inroads of the forest upon his crops. The only chance for any kind of rapid opening up is that people with sufficient capital to open up large areas should commence there. But if capital come in, then transport is also necessary, to get the crops away for sale in large markets. Now in the Amazon valley there is an absolutely unrivalled water transport available, and this is the cheapest form of all, generally speaking. But even here great difficulties spring up. At many places there are great rapids in the big tributaries running from the south, and to escape these railroads are needed. A beginning of such lines has been made with the Madeira-Mamoré railroad, but many more are needed, and in the present state of the country they have nothing to depend upon but the carriage of rubber. A second great difficulty is the fact that transport is easy enough down stream, but unfortunately the boats have to come back against the current, and so unless they can get freight back, they must charge high rates for going down. This reacts in a way which we shall understand better in a moment. For the present it will suffice to say that one of the chief factors against the opening up of the Amazon valley is the comparatively high cost of transport.

The cultivation of small areas by small cultivators is being pushed on by the Brazilian Government as much as possible, for one of the chief causes of the high cost of getting rubber is the fact that practically all food supplies have to be carried up stream—none can be obtained locally. But against progress in this direction must be set the fact that if the river steamers do not carry food, they have almost nothing to carry up stream, and so must charge higher freights for bringing the rubber down, so that the one thing works against the other.

But transport is not the only factor whose proper working is not as yet ensured in the valley of the Amazon. For the cultivation of large areas of land labour is necessary. Now the population of Brazil is as yet small, and the country is larger than the whole continent of Australia, while the coastal lands are by far the most healthy in the tropics. It is from these healthy north-eastern states that the labour of the Amazon valley has hitherto come, and especially in the years when the cotton crop, upon which they chiefly depend, has been bad. But now the Brazilian Government is taking the wise step of pushing cotton cultivation in the north-east, under charge of one of the first American specialists, and as Brazil is the native land of most of the cottons, and has about a million square miles of magnificent cotton land, the result will inevitably be to diminish the supply of labour for the Amazon. The obvious remedy, many capitalists will say, is to import Chinese or Japanese, who can stand the climate. No doubt this would in a way solve the problem, as slavery would solve it, but the Brazilian stands out for a Brazilian Brazil, and does not desire to be flooded with Orientals any more than does Australia. For the present, therefore, labour supply is even a greater difficulty in the path of those who wish to open up the valley of the Amazon than is transport. After all, the latter can be largely avoided by opening up at first only the land near to the mouth of the river, an enormous area. But the labour problem is the great difficulty.

This digression upon the economic conditions of the Amazon valley has been introduced to show the kind of problem which is involved in dealing with tropical exploitation. But the same kind of problem turns up when we come to deal with the opening up of any of the British tropical colonies. Take, for example, Guiana, contiguous to Brazil, and just as rich by nature; is it to be slowly populated by British Indian coolies growing rice, as is at present happening, or is it to be exploited more rapidly and completely in some other way? The question is political, as is also the question as to whether we should use the African colonies for growing large quantities of cotton, though Brazil is better suited to that crop, and has a much larger area available. But if we did not possess a large area yielding cotton, we might as an empire be at any time at the mercy of outsiders, and so it seems advisable to sacrifice some agricultural efficiency to political considerations. All these things, one may perceive, are at present much more questions of finance, labour, or politics, than of scientific agriculture properly so-called.

To return to rubber and the measures being taken in Brazil to meet the competition of tropical Asia. One of the most obvious would seem to be to introduce the use of the tapping knife employed in the East, instead of the machadinho (little hatchet) at present employed, and which gradually covers the tree with awkward scars. This seemed so obvious that it was tried on one or two places with bad results. In the damp air of the Amazon valley, the cuts became perfect hotbeds of fungus disease, and many trees were lost. Here, you might almost say, was the first application of science to the Brazilian rubber industry, and as has often happened in the East, the results were disastrous. We are slowly learning that while the native methods of any given place may be very bad and very inefficient, they are in general the best for the local conditions as they existed at the time when these methods were employed; they are open to improvement, but the improvement must go hand in hand with that of the other conditions, and must be very gradual and cautious. Before the tapping knife was employed in Brazil, there should have been a series of experiments carried out to determine the best way in which to use, and if needful to modify, the new tool. As it is, the tappers in the Pará district have acquired a prejudice against the knife, whereas there is little doubt that by its careful and judicious use a large number of trees could be tapped which are at present left idle as being too small.

Another problem is the sernambý, or scrap rubber, produced in great quantity and of but poor quality; the collector most often gets the scrap as his pay, and so does not make any more fine hard than he must.

Yet another great difficulty is the supply of necessaries to the collectors; little is cultivated up the valley, and food and necessaries are supplied by the merchants in Pará and Manaos, in exchange for the rubber. We have already been into this question from the transport point of view; it is merely brought up here to show the way in which all parts of the problem hang together.

The whole problem, so far as Brazil was concerned, was much complicated by the high prices obtained for rubber a few years ago, which caused the great boom in planting rubber in Asia, and made the merchants of Pará and Manaos think that the millennium had arrived. Extravagant ways of dealing grew up, and now that the pinch has come it is, as usual, found that it is a good deal easier to increase expenditure than to reduce it. There is no reason to doubt, however, that reduction is steadily going on.

We have now surveyed in a very brief and superficial way some of the enormous field of tropical exploitation, the object being not so much to give actual facts as to illustrate the underlying principles that are operative in tropical, as in other, agricultural progress. The same principles rule everywhere, and it will be well, before going any further, to recapitulate them. In the first place, we must have *land* available—that is to say, it must not be merely land, it must be clear of forest or other growth, it must be drained enough for the purpose, and if needful it must be irrigable, or have water available. We must also have *crops* which will grow upon that land, and whose produce can be used by the cultivator. The next stage begins with the provision of means of *transport*, by which the cultivator, instead of using all that he grows, may sell some of it elsewhere (or barter it), and obtain other things with the proceeds. This in itself does not mean any great advance till the next factor—*capital*—comes into operation, and enables a man to have a larger area, to cultivate with hired labour, and to wait for his return till the crop can be sent to a distant market for sale. Capital without *labour* can of itself lead to nothing. We thus have, as the conditions for successful exploitation, as petition begins to be involved to a very serious degree, and each country wants to equip its agriculturists to the best advantage. New varieties, suited to the local conditions, can be produced by breeders trained in the principles of Mendelism. Mycologists and entomologists can aid in the suppression or extermination of the many diseases to which agriculturists owe such great losses. Bacteriologists can investigate soil problems, chemists the same, and both can work at the numerous problems which turn up in finding out the best methods of preparing such crops as rubber or tea. Engineers can work at the improvement of machinery, whether the larger machinery of the capitalist or the small tools of the small cultivator. All these improvements apply chiefly to the capitalist agriculturist, but the small man can also be helped, especially by the provision and encouragement of co-operative credit societies, which may help him to get free of the incubus of debt, and ultimately bring him into what we term the capitalist class of agriculturist. The day of science as applied to tropical agriculture is dawning, and we may hope to see great results. The tropics provide an immense area of rich and unused land, and their proper exploitation will not only provide for an enormous native population, but will supply the wants of the colder zones in a way that has never hitherto been dreamed of.

CHAPTER VI

THE COTTON PLANT, ITS DEPENDENT INDUSTRIES, AND NATURAL SCIENCE

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THOSE subjects of the State who are scientists by training, and still more those younger scientists who are seeking a useful career, can only be very thankful that a national conviction with regard to scientific method and result has at last been awakened. But since this conviction is hasty, largely Press-made, and is not based on real acquaintance with experimental methods, it will not easily be transformed into working practice.

Such transformation will be hardest in the domain of pure science—which, fortunately, is less expensive than industrial research—because the economic application of its incidental discoveries must of necessity be unconventional. This, too, is the happy hunting-ground of the charlatan.

The transformation is easiest on the fringe of working practice, where minor difficulties, which arise day by day, are demonstrably most easily solved by trained men. Here the immediate practical utility of the scientist is as obvious as that of a telephone or of a typist, and the returns are quick. On the other hand, the exercise of the Craft of Research is so restricted, and its potentialities are so cramped, that the word Investigation is now being employed to indicate the purely utilitarian and detective function of such work, as distinct from the limitless scope of Research proper.

Between these two there is an enormous field for work, which has scarcely been exploited as yet, where any results achieved are inevitably of some value to the State, and where there is also a very large chance for the open mind to discover lines of inquiry which may lead up to scientific conclusions of the first order. This field corresponds to the strict definition (now much abused) of Applied Science, and its scope may be defined as the conduct of strictly scientific research, with all its professional criteria of precision and exhaustiveness, but limited in its central subject to material of economic importance.

This field of work is even more fascinating to some minds than pure science, being in the closest relation with the intellectual problems of science, on the one hand, and with the State-service aspects of industry on the other. Research in this field has a direct educational value for the student, in that it brings him to realise the intimate dependence of all research upon the unlimited labours of the laboratory, and it throws up in vivid relief the enormous lacunæ which exist in the web of our present knowledge. An example may illustrate these points—

The writer studied the effect of sowing Egyptian cotton in successive weeks for nine weeks around the usual sowing-date, using every known experimental precaution, such as chequerboard plots, differential irrigation, plant-development records, and statistical treatment. The result had three main aspects: first, the State aspect, by showing that the conventional practice of the Egyptian native in not planting very early was the correct practice under the existing climatic and agricultural conditions; secondly, the utilitarian aspect, by systematising the routine of propagating valuable pure-strain seed so as to involve the minimum risk of damage or loss, either to the seed put into the ground, or of the expected harvest. Lastly, and most important, it showed up a gap in our knowledge of the relation between temperature and the permeability of protoplasm, because the observed facts were only explicable on an hypothesis that the permeability of root-hairs as well as the growth of the root was a logarithmic function of the soil temperature; the only existing scientific data (Von Rysselbergh) showed no such simple relation. Subsequently and independently this relation was actually found (Delf) in purely laboratory work directed solely to the study of protoplasmic permeability, using for convenience the hollow flower-stalks of dandelion and leaves of onion; the gap in our knowledge was thus filled up, and the new knowledge is of importance, not only to cotton and to all agriculture, but to all our knowledge of Life; as a current example, it may be applicable to the technique of asepsis during irrigation treatment of wounds.

The field of science in relation to the cotton industries has two main divisions, the study of the Plant as a producer of cotton hairs, and the study of the cotton hairs as raw material for industrial purposes; but it must be understood that these divisions are convenient mental abstractions, not water-tight compartments, and that they break down and intercommunicate in sound research practice; obviously, cotton should be grown to meet the needs of the consumer, and the consumer is limited by the capabilities of the plant.

For all practical purposes we may regard the second division as an untouched field for serious modern research, while the first has only been pioneered sufficiently to indicate its possibilities. The various subjects available for study, and their general interrelation, are indicated in the following table, which, in its present form, needs a little amplification.

The task before the Grower is to grow the right thing; firstly, in sufficient quantity to pay him adequately for the land and labour employed; thus his concern is primarily with Yield. Since the financial return is not dependent on yield alone, but on the product of yield by price, he is also concerned with Quality; whether such quality be due to inherited properties of the variety grown, or to the effects of cultivation, or to both causes. The conduct of the Grower's work in regard to the yield obtained from a given variety is a form of Applied Plant Physiology; so also in the matter of the quality of cotton obtained from the same variety; in the choice of the variety grown he is implicated at more or less distance in researches on the isolation of pure strains, and the working of Mendel's Law in hybrids.

The job before the Spinner—allowing him to typify the consumers of cotton—is to arrange the tangled cotton hairs gently in the most regular way possible, so as to form the strongest and longest threads from a given weight of raw material under limitations of output and cost. His concern is mainly with Quality. The actual growing of the crop does not appear at first sight to affect him, but closer consideration is now showing this to have been short-sight; except by accident he cannot obtain the quality of cotton he wants, unless he knows what he wants, and why he wants it. The interests of the Grower and the Spinner are therefore intimately linked together; they are not merely antagonistic; the former, chiefly interested in yield, loses something if he grows poor stuff which the spinner does not want; the latter, chiefly concerned with quality, has to pay for it unduly if the grower's yield is low.

GROWER AND SPINNER

(Yield) (Quality)

Plant Physiology — Gametic Composition of Crop
Fluctuation
Crop Physiology — Mendelism

Crop Records — Agriculture — Pure Strains
Crop Reports — Variety Testing
Crop Forecasts — Seed Supply

Merchanting
(Economics, Transport, etc.)

Spinning Technique, etc.
(Physics, Colloids, Chemistry, Engineering, etc.).

The total cotton crop of the world before the war amounted to a weight of some 12,000,000,000 lb. per annum of cotton lint. The crop is usually spoken of in terms of "bales," and since these bales vary somewhat in weight according to their country of origin, the nominal unit bale is one of 500 lb. It will be easiest for the general reader to deal with pounds, or rather with thousands of millions of pounds; the distribution of the world's production and consumption of cotton then appears as follows, grouping the countries according to their political relations.

THE WORLD'S COTTON CROPS. After J. A. TODD.
(Expressed in thousands of millions of pounds weight.)

Production, 1912-13.		Consumption, 1913-14.	
U.S.A.	7·30	U.S.A.	2·90
India	2·60	Great Britain	2·10
Egypt	·75	India	1·10
Russia	·50	Russia	1·25
Other Allies	·10	Japan	·80
Neutrals	·50	France	·50
Turkey	·10	Italy	·40
China	?	Belgium	·10
		Portugal	·05
		Canada	·05
		Neutrals	·35
		Germany	·85
		Austria	·40
		China	?
Total Crop (Excluding China)	11·85	Total Consumption (Excluding China)	10·85

It will be clear from this table that the U.S.A. dominates the world's supply of cotton, and is, moreover, a great cotton manufacturing country. The remainder of the supply is largely British, including the Egyptian crop, and a small but valuable crop from the West Indies, which will now be almost the sole source for very long fine cotton (the "boll-weevil" having made its way into the Sea Island districts of the U.S.A.) excepting the Islands themselves. It should be understood that different species of cotton are grown, which vary greatly in value and in capabilities; these variations depend partly on the length of the hair, which ranges from a quarter of an inch to somewhat more than two inches. The bulk of the Indian crop is about half-inch, that of the U.S.A. one inch, that of Egypt under one and a half inches, and that of the West Indies over one and a half inches. Concurrently with these and other differences there are differences in the fineness of the material, yarn, and fabric made from the cotton, and the finer the yarn the more time and work is spent on making it. These peculiarities show up in statistics of consumption per spinning spindle, which range from nearly 350 lb. of cotton per annum per spindle in Japan, where the mills run all night, or 170 lb. in India, down to 38½ lb. in England, and 35 in Switzerland. England being the original home of the cotton-spinning machines, it is only natural that we should have tended to monopolise the finer spinning, though our initial lead in even this matter, and still more in ordinary spinning, is steadily decreasing.

It may be asked why the great sub-tropical areas of the British Empire do not provide enough cotton to restore some sort of balance to the world's supply, instead of leaving it dependent on the chance of good or bad weather in the United States; or again, why India should not grow better cotton? There are many reasons, some valid, some invalid, but the primary one and the central fact of the situation is simply, that we do not know enough about cotton. The real scientific exploitation of the cotton plant has not yet begun, because exploitation cannot begin without exact knowledge of the plant exploited. Further, such study and exploitation must be effected in close inter-relation with the consumer, if the results are to have practical significance. There are scientific workers in various countries studying the cotton plant, and the British ones have shown the way in more than one case to their American colleagues, who had a very long start, but from the nature of the case their nominal official work consists rather of Investigation as we have defined it, than of deep-digging Research. There could be no more convincing example of the vagueness of our present knowledge than the fact—almost incredible—that only during the present decade have the U.S.A. growers discovered how to increase their yield per acre by *30 per cent.* at no cost; the method is simply to leave twice to three times as many seedlings standing on the area as had previously been the custom. Incidentally it may be added that the Egyptian fellah many years ago discovered the equilibrium-point in this system of diminishing returns, on his own account, by the accumulated experimental evidence involved in growing and selling his crop, and he has steadily resisted the well-intentioned efforts of would-be reformers with smatterings of biology, who wished him to adopt wider spacings of his plants. The present writer studied the principles involved, and America has now copied the practice.

If another example were needed, it might be found in Mr. Leake's assertion that the whole of the work on the introduction of exotic cottons into India during more than a century needs to be repeated *ab initio.* The cotton flower was always assumed to be self-fertilised, or only very occasionally cross-fertilised, until the writer showed in 1905 that from 5 to 10 per cent. of the ovules were habitually crossed under actual field conditions. Then it was easy to see why new cottons deteriorated or acclimatised themselves, why no new variety ever reached the market in a truly pure state, and why uniform cotton was unobtainable. Leake demonstrated independently that the same conclusions applied to Indian cottons, and drew the logical, but daring, deduction which we have just quoted.

Without the assistance of photographs, sketches and graphs, it is hardly worth while to attempt any account of the life-story of a cotton plant, and the reader who is desirous of further information may perhaps be referred to the writer's *Development and Properties of Raw Cotton*, but it might be of use to draw attention to a *method* of study which the writer has worked out to some degree of refinement for the study of Egyptian cotton, and by means of which some permanent results have been obtained, together with a fairly adequate comprehension of the manner in which any result was reached. This method is simply the obtaining of a continuous statistical record of the life-history, which can be plotted in graphic Curves of Plant-development, studying the crop—whether of a plot or of a country—as an Average Plant. Cardinal points are chosen for observation, the chief of these in the case of cotton being the number of flowers opening per plant per day, together with the height of the main stem and the ripening of the capsules or "bolls." The records can be carried to an incredible degree of precision by suitable scatter of the observed groups of plants, each group numbering about 200 plants; equally, they can constitute a very serious waste of time and energy if the observed groups are not scattered so as to be comparable, as a recent publication has shown. They can be utilised in a number of ways; in the first place, they abolish that bug-bear of agricultural experiment, the Probable Error of a Single Plot, since by showing exactly how the final yield was built up, they show how plot-to-plot differences arose, and so convert the probable error into a recognisable error due to definite physiological causes. They serve as seasonal or site-records of crop behaviour, and, if obtained at a sufficient number of observing stations, they could depict the crop of a whole country in a form which appeals to the eye, and is further of exactly definable precision. Moreover, such records, as they grow day by day along the squared paper on the laboratory wall, very soon begin to foretell their own form; the rates of stem-growth indicate what will be the flowering-rates three weeks later, and these again determine the rates of fruiting two months afterwards, so that a system of cold-blooded Forecasts for any country can be developed at small cost of organisation to replace the present subjective expressions of more or less disinterested expert opinion. They not only show the effect of weather conditions on the crop, but even in our present state of knowledge they can occasionally be used as records of the environment. Lastly, variety-testing can be conducted with absurdly small quantities of seed, thus enabling real agricultural trials of new strains or varieties to be made at a very early stage of the breeding work; for this purpose the observed groups are planted here and there through an ordinary field of a variety which is roughly similar in size and habit of growth; they obtain no special treatment whatever, but are carefully observed day by day.

Having mentioned the subject of plant-breeding, we should make a serious omission from this article if we neglected to mention the possibilities of Mendelism. The work which has already been carried out in this direction on cotton, under the limitations already mentioned, shows promise of useful results in the future, but any serious investigation of heredity, as such, in the cotton plant, is beyond the powers of ordinary agricultural experiment stations, for the following technical reasons. The plants are large, and even a small "family" occupies a great deal of ground; they are subject to sufficient natural crossing to obliterate entirely the demonstration of the more subtle Mendelian ratios unless the flowers are artificially protected at considerable expense from such contamination; the work of the writer in particular has shown that such ratios, indicating complex inheritance, are far from uncommon; further, many or most of the characters which have economic importance are not matters of colour or form, but of dimension, and before these can be studied adequately in their inheritance, the student must have intimate knowledge of the possible fluctuation which such dimensions may undergo as the result of mere environmental changes. Lastly, the practical application of such results as have been obtained has been hindered because the grower has been working in the dark, on account of the absence of detailed knowledge on the consumers' side of the trade; there has been no common language in which the spinner could explain to the grower the exact kind of cotton he required to meet his need.

One practical conclusion seems to be definitely established, which is this: that a gametically pure cotton spins stronger yarn than an ordinary impure commercial variety of similar type, *alii æquando*, even though the latter is of much more pleasing appearance. This last remark carries with it the implication that the highly skilled judgment of the cotton-grader should not be trusted entirely in approving or condemning new kinds of cotton, as regards their spinning qualities; means should be developed whereby the testing of such cotton may be conducted by actual spinning-tests, for, after all, cotton is grown to be spun, and to judge it by its mere appearance is an unscientific conclusion to scientific labours.

Our space will not permit of any attempt to describe the various processes of manufacture through which raw cotton may pass; they may be summarised as Spinning, with doubling; Fabric construction, by weaving, knitting or lace-making; Bleaching; Dyeing; Calico printing; Finishing.

The end product may be any of the well-known cotton fabrics—sheetings, nainsooks, cambric, muslin, sewing-cotton, lace, or hosiery; it may be a blanket, motor-tyre fabric, suède-finish gloves, or a useful and satisfactory imitation of almost anything commonly made from silk, wool, or flax. With such a range of possibilities for industrial research it is useless to deal here, and we will confine ourselves to a few figures indicating the delicacy of the initial process on which all this production depends, namely, spinning, and remembering that there are nearly 60,000,000 spindles spinning cotton in Great Britain alone, that the produce of a single plant of Egyptian cotton is worth less than a farthing, and that the weight of a cotton hair is of the order of 0.004 milligrams.

We have mentioned that this country specialises on fine spinning, averaging about 40s counts, at the rate of $38\frac{1}{2}$ lb. per spindle per annum. In effecting this production the spindle in question would put about 1100 million twists into the length of yarn produced, and this length would exceed 700 miles. Ordinary 40s sewing cotton consists of six such strands of yarn. But spinning is carried on commercially to counts as fine as 300s and over, for special purposes; one mile of such yarn weighs three grams, and has received about four million twists.

These mechanical processes whereby the tangled epidermal hairs of the cotton-seed are finally arranged in regular sequence, all straight and parallel, with as few as twenty hairs in the cross section, date back in their conception to more than a century ago. Although many improvements and refinements have been introduced into the machinery, and although the speed of production has been enormously increased, there have been no further inventions of primary importance for over sixty years.

The basis-mechanism of the whole machinery is the "drafting-roller" patented by Lewis Paul and John Wyatt in 1738. The cotton is fed into the nip of one pair of rollers, and shortly after emerging from this nip does not merely connote the spinning and manufacture, but the growing of cotton as well.

The first of these attempts was directed to the formation of a department in the University of Manchester, at the time of the British Association's visit in 1915, but it was a little too far in advance of public opinion. Subsequently the Department of Scientific and Industrial Research took the initiative, and a Provisional Cotton Research Committee has undertaken to formulate a suitable project for the purpose.

In any attempt to evaluate the potential importance of such research to the Empire, it should be remembered that the inventive genius of Wyatt, Paul, Hargreaves, Crompton, and Arkwright made England the original home of mechanical cotton-spinning. That some of the adventitious results of their genius are not entirely commendable is beside the point; the brains of these men contributed largely to create our modern prosperity. Subsequently we lost much of this initial supremacy as other countries learned how to spin for themselves, but we naturally retained a superiority, in the form of finer spinning than our pupils and competitors. Nevertheless, though Lancashire possesses certain natural advantages, some of these are less important than they were in the past, and after a certain time it is inevitable that the product of our rivals will approach or even surpass our own if we do not exert ourselves to regain our initial lead, by scientific study of our industry from the cotton-field to the factory, and by a renewed deep-seated inventiveness.

It will be seen from the preceding account that there is no lack of material for study, and we may hope that a few years of good mental team-work will begin to re-establish the threatened security of this amazing industry upon a sure foundation of knowledge.

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CHAPTER VII

VEGETABLE DYES[1]

By the late SARAH M. BAKER, D.Sc.
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THE art of extracting colouring matters from plants and impregnating with them animal or vegetable fabrics, has been practised from the earliest dawn of civilisation. All trace of the pioneer workers has disappeared, and within historic time, until the advent of synthetic dyes in the last generation, no fundamental change was introduced into the technique of dyeing. Modern methods are essentially modifications of the primitive processes still employed in the East, and, although they reduce time and labour, the quality of the work generally suffers from such departures.

In the Egyptian wall paintings, garments coloured scarlet, bright blue, yellow and green, are represented very early; but the custom of using fine white linen for mummy cloths has prevented the preservation of much coloured material. One mummy cloth of about 1000 B.C. has been shown to contain two yellow dyes

[1] The lecture on which this chapter is based was delivered on March 12, 1917, and a few days later the manuscript here printed was handed in by Dr. Sarah Baker with final corrections for the press. This gifted botanist died on May 29, in her 30th year.

of vegetable origin. Pliny mentions Tyrian purple (an animal dye), scarlet (probably madder), and yellow as highly esteemed dyes and very ancient.

The best collection of coloured materials, both of silk and linen, found by Prof. Flinders Petrie, date from the relatively modern Roman occupation of Egypt, A.D. 300–500. The colours used were the soluble yellow from safflower, several madder colours and indigo, and, in spite of being over 1500 years old, they are still quite bright and clear (see Schunk, 1892).

In each of the European countries the dyeing industry was at first dependent upon indigenous plants, which were often extensively cultivated to supply it. An interesting list of indigenous English dye plants, comprising some ninety species, is given in Mairet, 1916 (p. 38–44), but most of them give such a poor yield, or are so difficult of collection in quantity, that they have now no economic importance.

In the sixteenth century several tropical dye plants were introduced, giving a larger and purer yield of the same colouring matters. In spite of stringent prohibitions and heavy penalties against dyers using these "pernicious drugs," logwood from South America and indigo from India quickly supplanted home-grown products, and were followed by numerous other dye plants, especially from the tropics.

This influx of new foreign dye plants continued until the middle of last century. Then in 1858 Perkin prepared mauveine, the first of a long series of synthetic dyes produced from coal tar. Not only were many hundreds of new colours evolved, but two of the most important vegetable dyes were successfully synthesised, viz. Alizarin (the dyeing principle of madder), about 1870, and Indigo blue in 1870.

The triumph of the chemists brought with it the usual penalties of progress. The madder industry of Southern France quickly succumbed before its formidable competitor, and whole districts were ruined. The indigo planters of Natal and Bengal answered the challenge in a different way. They studied their plant more intensively, undertook breeding and hybridisation experiments, and succeeded in materially increasing the efficiency of production.

At the present time the whole trade in vegetable dyes is faced with a similar problem. Even where, as in the case of logwood and the red woods, the natural dye principle has not actually been synthesised, numerous substitutes of practically equivalent value may be prepared; so that the most pressing object for inquiry is whether there is now any justification for the survival of the natural dye industries, or whether the land bearing dye plants could not be more usefully employed in other ways.

Before the question can be intelligently considered, a survey must be made of the most important natural dyes and their sources.

It is easy to approach the subject under a misapprehension. The wonderful brilliance and diversity of colour shown by flowers and foliage would naturally lead us to hope that we could borrow some of their magnificence. But the pigments elaborated by plants for their own decoration are fugitive and elusive substances, closely knit with the life of the organism, and all these are quite useless as dyes.

The colouring matters which serve the dyer are generally present in the plant in the form of soluble colourless compounds with various sugars, called glucosides. The conditions governing their production are only vaguely understood; but it seems probable that they are waste products, which the plant has no means of excreting. They are found, as a rule, in the bark of stems or tubers, or in the leaves. The number of different plant dyes is surprisingly small, but each of the principal elementary compounds has a wide range in the vegetable world. Tropical plants, on the whole, produce larger quantities of the same dye than the plants of temperate regions. Beyond this, and the fact that the *Leguminosæ* provide a large proportion of the world's dye plants, it is impossible to generalise.

The object of the dyer is to impart a permanent colour to his fabrics. For this purpose the colouring matter must be firmly united to the fibres. It is a disputed point whether, in dyeing, this is due to an actual chemical combination between the molecules of dye and fabric, or whether it is a physical property of the large colloidal particles of the material, known as "adsorption." Probably, in most cases, the two effects are combined and, when the processes of dyeing are slowly performed, a purely physical adsorption is gradually followed by chemical combination.

The fabrics may be sharply divided into two classes, according to their origin from animal or vegetable sources (mineral fibres, like spun glass or asbestos, cannot be dyed).

The animal fabrics, wool, silk, leather, feathers, etc., are all built upon a basis of proteins. That is, their chemical constituents, while very complex, are yet relatively reactive. They contain groups, analogous to ammonia and carbonic acid, arranged alternately on immense chains, many hundreds of atoms long. Each group in the chain still retains some of its original qualities; so that the proteins are capable of acting either as weak bases or as weak acids, as occasion requires. This is very important from the dyer's point of view, for it means that either acid or basic dyes (from neutral or slightly acid solution) will be absorbed and held by animal fibres.

The vegetable fabrics, cotton, artificial silk, linen, jute, hemp, etc., are all composed of cellulose, an extremely inert carbohydrate which is insoluble in almost everything and has practically no chemical affinities. Dyeing upon vegetable fibres is consequently a far more difficult process, and there are very few dyes which can be applied to them direct. The most general special treatment for rendering vegetable fibres amenable to dyeing is to cause them first to absorb tannic acid (found in galls, sumach bark, tea leaves, etc.), and then, upon the tannic acid groundwork, basic dyes may be applied from a solution made faintly alkaline by soap, lime, or soda. Acid dyes cannot be used for vegetable fibres.

The dyes themselves may be roughly classified as: (*a*) Direct or substantive, when they are applied without further treatment; (*b*) Pigment, or vat dyes, when the colour is developed upon the fibre; and (*c*) Mordant, or adjective, dyes when they are fixed by means of metallic bases.

Among natural dyes there are only three which will dye vegetable fabrics directly, namely, turmeric, safflower and annatto.

Turmeric is a bright yellow dye, which may be used for cotton, silk, or wool dyeing. It is made from the ground-up rhizome of *Curcuma tinctoria*.

Safflower is obtained from the flower-heads of the Egyptian thistle, *Carthamus tinctoria*. These contain two dyes, a fugitive yellow, which is one of the most ancient vegetable dyes, and also small quantities of a bright pink, which was formerly used in all the countries of Europe to dye red tape.

Annatto comes from the pulpy seed-coat (aril) of the shrub *Bixa Orellana*, and gives a bright orange colour.

Since the discovery of Congo Red in 1884, a number of direct cotton dyes have been prepared from coal tar with a wide range of colours. They are all fugitive, and are not fast to hot water; but they are extensively used for cheap calico printing. The natural dyes, being equally fugitive, possess no essential advantages over them and cannot, with their limited colour range, hope to compete successfully with the synthetic dyes.

Several direct dyes for silk or wool only were formerly used; but as they have now been superseded by artificial substitutes, they need not be considered here. There is, however, one interesting group of direct wool dyes, which might be capable of more extensive exploitation. These are the lichen dyes.

Lichen dyes.—In general the dye-producing lichens are drab-coloured species growing on rocks or trees in the most exposed places, especially in bleak mountainous districts, or near the sea coast. They occupy habitats where no other vegetation could be supported, and the chief cost of production is the labour involved in collecting them. It is generally supposed that lichens grow too slowly to form a satisfactory crop; but planting experiments have never been systematically tried. At any rate, a study in the field of the successions, in which these economic lichens form a conspicuous part, would be most interesting and might even prove profitable.

Two series of dyes have been obtained from lichens. The beautiful purples and reds, sold as Orchil, Cudbear, and Litmus, are obtained from various species of *Roccella* imported from the Canary Islands. The colour is developed by oxidation of the powdered lichen in ammoniacal liquor (obtained by the peasantry from stale wine, etc.). The fermentation takes some weeks, and the mass must be frequently stirred and kept at a moderate heat. After the oxidation the colour may be extracted by alkalis, and the insoluble dye can then be precipitated as a reddish powder by any acid (acetic or hydrochloric acids are the ones generally used). The process can quite easily be carried out on test-tube scale with a lichen suspected of having tinctorial properties; allowing a week in 0·880 ammonia for the oxidation stage.

Although the colours, orchil, cudbear, etc., are not very permanent, they are of peculiarly beautiful quality, and are still used by dyers to impart bloom to compound shades. Similar dyes can be extracted from several of our native lichens, by analogous treatment. In Scotland and the Shetland Islands *Lecanora tartarea* and *Urceolaria calcarea* were at one time collected in large quantities for this purpose. The collectors obtained from 1*d*. to 2*d*. per lb. for the lichen, and could gather from 20–30 lb. in a day. As the cost of transport of the bulky lichens from remote districts is heavy, it would be more efficient for the collectors themselves to develop and extract the dyes and export them in the more convenient powder form.

The other lichen dyes can be extracted with boiling water. They give shades of brown and yellow of great permanence. They are still used in the Highlands, where they are known as "crottles," or crotal, and in the West of Ireland. *Parmelia saxatalis* and *P. omphaloides*, collected and dried in July and August, are used to dye woollens for tweeds; the peculiar smell of Harris tweed is partly due to the use of these lichens. *Ramalina scopulorum* also gives a fine yellow brown, and several other *Parmelia* species give similar colours.

The dyeing process is very simple. The dried "crottle" and cloth are laid in alternate layers until the bath is full, cold water is added, the whole is brought to the boil, and boiled till the colour is strong enough. Alum is sometimes used to mordant the cloth, but it does not seem to be necessary (see Mairet, 1916, chap. on "Lichen Dyes," also Lindsay, 1855). If the dyeing principle of crotal could be extracted and put up in portable form it might prove a useful commercial product, as the demand for fast brown shades for cloth is likely to be permanent.

Indigo.—Although direct dyes are simple in application, they are usually (with the striking exception of crotal) rather fugitive, and consequently of limited applicability. The most permanent kind of dye is one in which the colour is not applied to the fibre from solution, but is developed within the fabric.

The type from which this method of dyeing, known as "vat dyeing," was derived is the famous vegetable dye indigo blue. Indigo occurs in the form of a glucoside, "indican," in the leaves and berries of a number of different plants. Sometimes it is associated with a yellow dye, and the plant yields a compound green.

In England up to the sixteenth century the source of indigo was the woad plant *Isatis tinctoria*. The plant was cultivated, and gave two crops of leaves in the year. The dye was developed by a long and tedious process, involving, first, a slow drying of the pulped-up leaves rolled into balls, then a damp fermentation lasting several weeks, and, finally, a second drying. Woad as a dye plant was superseded by imported indigo extracted from various *Indigofera* species cultivated in the tropics. But the woad industry still survived, on a small scale, up to the end of last century; because the addition of small quantities of woad to the indigo vat was found to improve the fastness and penetrating power of the dye, and also to assist in the fermentation process used in its reduction. An interesting account of a woad mill at Parson Grove near Wisbech, where the primitive machinery and methods were still used in 1896, was given by Darwin and Meldola in *Nature* (1896).

The cultivation of *Indigofera* in the tropics is, however, a valuable industry and, as India is the chief producer, the maintenance of the natural dye is of direct imperial interest.

In Bengal indigo land is ploughed in October, and the seed sown in drills the following February or March.

By June the plants are three to five feet high, with a stem $\frac{1}{4}$ inch in diameter. The maximum colour is developed by the end of August, and the young leaves are the richest. Generally two crops are taken from the plants, one in the middle of June, the other two to three months later.

To extract the dye the plants are cut early in the morning and closely stacked together upright in a large vat. Bamboo rods are laid across the vat and fixed down by heavy timber. Water is then run into the vat till it nearly reaches the bamboos. The whole is left nine to twelve hours at a temperature of 30°–35° C., while an active fermentation takes place. The whole mass expands, and high pressures are developed in the vat, so that the beams are sometimes broken. Meanwhile several gases are evolved, carbonic acid, marsh gas, and hydrogen; the latter often catch fire and form a blue flame playing about over the surface of the vat. The course of this fermentation must be closely watched, as it is important to stop it at exactly the right point. After a time the liquid subsides; then a valve is opened at the bottom of the vat and the liquid is run out. It should now be orange yellow or olive in colour, and contains reduced indigo in solution. It is run into a beating vat, where a rotating wheel mixes the liquid with air. Atmospheric oxygen quickly converts the reduced indigo in solution into insoluble indigo blue, which comes down as a blue precipitate, until the liquid is clear. It is collected, dried, and exported in powder form. The refuse plant or "seet" is valuable as a manure; but, curiously enough, it cannot be used direct for indigo lands, or the resulting crop is poor in the dye.

The usual plan is to grow some other crop on "seet" manure, and return to indigo the next year.

The competition of synthetic indigo caused an outburst of scientific inquiry on behalf of the indigo planters. Several investigators tackled the complex fermentation process with the idea of improving its efficiency; while the experiment of transferring the Natal species *Indigofera erecta* into Bengal, where *Indigofera sumatrana* had been exclusively used for 150 years, proved very successful. The new colonist gave much heavier yields of the dye up to even double that of the old species. Evidently the indigo planters are fighting their competitors along the right lines, and further work may result in still greater yield.

In spite of all this activity, synthetic indigo has steadily encroached upon the plant product, and in 1914, 90 per cent. of the world's supply was made from coal tar, and made in Germany (see Morgan, 1914). Plant indigo, although it is faster than the synthetic compound, gives a slightly less brilliant colour. The synthesis of indigo blue led also to other important results. By slightly altering the radicles composing it, a number of other vat dyes were produced. The thioindigos gave fine scarlets, while one of the dibromindigos turned out to be the famous Tyrian purple of the ancients, once extracted at great expense from sea shells, such as Buccinum and Purpura, and used as the symbol of regal state.

The process of dyeing with indigo, or any of the eighty to ninety vat dyes now known, is fairly simple. The dye itself is quite insoluble in water. There are two methods of making it soluble. One is to treat with concentrated sulphuric acid, which converts it into a soluble blue derivative, capable of dyeing directly. But this procedure is not satisfactory, as it yields a fugitive colour.

The most usual method is to reduce the blue dye to the soluble colourless leuco-compound. This reduction used to be carried out by means of a complex fermentation lasting over several days, or even weeks. The preparation of the reducing vat required great skill and judgment; the materials used were stale wine, dock roots, bran, madder, woad, etc., whilst an even, moderate temperature had to be maintained. Nowadays chemical reducing agents are generally used. The chief of these are: (*a*) for vegetable fibres, hydrosulphite of soda made by the reduction of sodium bisulphite with zinc dust and lime water, tannic acid is also added to the vat; (*b*) for woollens, etc., either ferrous sulphate, quicklime and water, or zinc dust, quicklime and water. These vats can be prepared in from four to six hours; the indigo is then added, and dissolves in the solution with a yellowish brown colour.

The cloth is boiled or warmed in the vat for some time, which may be anything up to a month for navy blue. Then it is oxidised in the air by various mechanical devices. As the oxygen penetrates the fibres the insoluble blue colour gradually develops there, and in about twenty-four hours the process is complete; then no amount of washing or milling will remove the colour.

Mordant dyes.—The majority of plant dyes belong to the third class and require some metallic base or mordant, to fix them to either animal or vegetable fibres. The mordants usually employed are salts of aluminium, iron and chromium; copper and tin salts are also sometimes used, while salts of arsenic or antimony may be added in small quantities to modify the colour, but are too poisonous to be used in bulk. There has been a good deal of controversy about the nature of the action of mordants, but a few general principles can be safely formulated.

The dye itself is feebly acidic, and forms soluble salts with the alkali metals, sodium, potassium, etc., but insoluble coloured "lakes" with the alkaline earths, calcium, barium, etc., and also with the mordant metals. To be a successful mordant a metal must first form an insoluble "lake" with the dye and, secondly, it must be what is called an "amphoteric electrolytic," *i. e.* it must be capable of making either weak acids or weak bases. This second property enables the mordant to form a linkage, partly acidic and partly basic, between the material on the one hand and the dye on the other.

The mordant is usually applied in a separate operation either before or after the dye bath, though very occasionally the two may be applied in the same bath. With vegetable fibres, impregnation with tannic acid must precede the absorption of the mordant, so that the whole process of adjective dyeing is rather tedious.

One important property of all mordant dyes is that, by changing the metallic radicle, considerable modification in the colour of the dye may be introduced so that, from a single dye radicle, several distinct colours may be produced.

The most important vegetable mordant dyes fall into three groups of closely allied chemical substances—the hæmatoxylin group, the flavone group, and the alizarin group.

The hæmatoxylin group of dyes come from a series of South American woods used for dyeing under the names of logwood and the red woods. Logwood is produced from the hæmatoxylin tree (*Hæmatoxylon campechianum*). The wood must be matured by ageing. To do this chips and raspings are stacked in heaps 20 feet long, 10–12 feet broad, and 3–4 feet high; water is added and a fermentation probably goes on. The process is very touchy, and depends largely upon the state of the weather; on a warm, dull, foggy day the whole of the wood may be destroyed, for dyeing purposes, in a few hours.

The matured chips are exported, and the colouring principle hæmatein dissolves out in the dye bath. Logwood is still used a good deal for dyeing black on iron or chromium mordants for silk or wool; it also gives a dull blue with alum mordant and a dingy purple with tin.

The soluble red woods (Brazil wood, peach wood, etc.) from various species of *Cæsalpinia* give, in a similar manner, a closely allied colouring principle "Brazilin," which gives shades of pinks and purples with the different mordants.

The insoluble red woods (barwood, camwood and saunderswood) contain the principle Santalin, of unknown composition, which gives very fast shades of dull red and rich claret brown, which are used for wool dyeing in compound browns.

The second group of adjective dyes, the "flavone" group, include by far the largest number of vegetable dyes. All these dyes are built upon the same skeleton "flavone" with slight modifications in the number and position of the hydroxyl groups in the molecule. They produce a range of shades of yellows and browns, and are very widely distributed in the vegetable kingdom.

For yellows the plants generally used were: 1. Weld from *Reseda luteola,* once cultivated in France, Germany and Italy. 2. Old fustic, the wood of a Central American tree *Morus tinctoria.* 3. Young fustic from the *Rhus Cotinus* of Southern Europe and the West Indies. 4. Quercitron from the inner bark of *Quercus nigra* and *Q. tinctoria* of the United States and Central America; while the ling, *Calluna vulgaris,* is still used by the Highlanders on an alum mordant. The tips are gathered just before flowering, boiled in water, and the liquor used for dyeing.

Although these plants all give fast good yellows, there are so many cheap yellow synthetic dyes that they are hardly likely to survive. Fustic wood can still be bought, and is used for compound shades.

The closely allied brown dyes are more likely to hold their own because in many cases they give fine permanent colours. Catechu gives a brown on cotton, mordanted with copper sulphate and later "saddened" in potassium dichromate; which is fast to light, soap, and even bleaching. It is used also for compound shades and weighting black silks and woollens. The dye is obtained from the heartwood of *Acacia Catechu* or *Areca Catechu* from Bengal, and also from the leaves of the mangrove *Ceriops Candolleana.* The leaves are extracted in hot water till the liquor is syrupy, the insoluble matter is strained off, and on cooling, the pasty mass is cut into cubes and dried. This is known as "mangrove cutch."

Other brown dyes, once much in favour, walnut, alder bark, and sumach from *Rhus Coriaria*, have now practically disappeared from use.

The third group of mordant dyes, "the alizarine group," were formerly the most important of all cotton dyes. The two associated colouring matters, alizarin and purpurin, are found in the tubers of several plants. In Europe the chief source of the dye was *Rubia tinctoria*, which was largely cultivated in Southern France. The colour is present in the cortex of the tubers; these were gathered up in their third year, and the plant was propagated by shoots. The ground tubers were exported and used in alkaline solution for cotton dyeing, in neutral solution for wools.

Madder gives a whole series of brilliant and very fast colours with the different mordants. With alum it gives the famous turkey red—the fastest known cotton dye. This red was used by the ancient Egyptians, and in Turkey and Persia madder is still cultivated for dyeing hand-made carpets. With chromium madder gives a rich red brown, with copper a brown, with tin an orange yellow, and with iron dull purples and a dingy approach to black.

When the dye is to be used for cotton printing the patterns are stamped upon the material with different proportions of the various mordants mixed with tannic acid. Afterwards the whole piece is passed through the dyeing bath, when the colours are developed upon the mordanted parts only. With well-chosen combinations quite pleasing effects can be obtained in this way.

Artificial alizarin has now entirely superseded madder for Manchester cotton printing; the colours it gives are brighter though not quite so fast as those from natural madder. Also a number of derived alizarins have been prepared with similar properties, and some of these complete the colour range by providing colours from the blue end of the spectrum.

Besides these three groups, which include the chief textile dyes of the past, there are a few plant dyes of limited applicability which, like the insect dye, cochineal, have held their own and will probably continue to do so, because of their harmlessness. One of the chief of these is alkanet, much used for colouring medicines, pomades, sweets, etc. The real alkanet of the East is obtained from the roots of *Lawsonia alba*; in this country "false" alkanet only is used, made from the roots of *Anchusa tinctoria*, a plant cultivated on a small scale for the purpose. Alkanet gives violet or grey shades with iron or alum mordants.

These, then, are the most important vegetable dyes. Every one of them has played a worthy part in the history of industrial development, and two at least, indigo and alizarin, have pointed the way to science in the development of new colour principles. But it is more important, for present-day practice, to know how they stand in relation to modern synthetic dyes. There are always enthusiasts to be found who will uphold anything ancient, and who would have us believe that the road to the millennium leads through the past.

So there are voices even now which advocate a return to the austerity of vegetable colours and bewail the garish profusion of the coal-tar products. But they forget that time can only move forwards; the shadow may return on the dial perhaps, but it never moves backwards. If vegetable dyes have really a part to play in the future, those who exploit them must go ahead and keep abreast of the chemical activity of the times.

Certainly vegetable dyes can never hope to compete in variety of colour and tone with the hundreds of synthetic dyes, whose numbers increase every year. Why, even a simple colour like green had to be obtained by compounding yellow and blue, before the coal-tar greens were invented. But it is possible that, for certain standard colours for which there is a steady demand, and especially where fastness is important, a vegetable crop may be the most effective source of supply. This would apply most to the colours possessing heavier radicles—dark browns, blues, purples and blacks, whose synthesis is always a complex process.

To compete successfully with coal-tar colours the highest efficiency must be maintained. If possible the dye principle should be extracted and sold in convenient form; the bulky dyeing woods, etc., are at a disadvantage in every stage of packing and transport, and ultimately in the dyeing trough itself. Further, if plant dyes are to be the standard fast colours in certain shades, the public should know their names so that, as in the case of indigo blue, any one can obtain a dye of proved quality by asking for, *e.g.*, logwood black or cutch brown.

Another and far more fundamental necessity is an intimate study of the dye plant itself—its physiology; the production and maintenance of good, pure strain seed; the best methods of dye development and extraction, etc. The importance of this kind of work is amply illustrated by recent work on indigo. If only the processes leading to dye production in the plant were really understood, there is very little doubt that the yield of dye could be greatly increased by suitably modifying the conditions of cultivation.

There is still another side of the dyeing process, which is of general application, but affects plant dyes most especially, and this is the potentialities of new mordants. The periodic table positively bristles with elements, closely allied to iron and chromium, amphoteric electrolytes, having the chemical properties appropriate to a mordant, e. g. nickel, cobalt, molybdenum, tungsten, uranium, titanium, bismuth, gold, platinum, and all the rare earths.

Now it is of the first importance, if a plant dye is to be the standard thing for a given colour or colours, that exactly the right mordant should be used to bring out its best qualities. Further, the modification in tone introduced by a change in mordant often increases the colour range of a given dye quite appreciably. This can easily be illustrated by dyeing with alizarin on some of these theoretical mordants. Most of the colours produced fall within the usual range, but nickel gives old gold, cobalt bright yellow, bismuth crimson, while uranium gives a good heavy black; these are, in different directions, outside its usual range. Some of these mordants, especially the heavier metals in the chromium group—molybdenum and uranium—have the desirable qualities of dyeing evenly and very exhaustively, and imparting weight to the material. The rare earths are now commercial commodities, and it is a question which can only be worked out in connection with technical experts whether the use of some of them as special mordants for certain adjective dyes may not enhance the value of the colours produced sufficiently to justify the extra expense of the mordant.

In general, however, it seems poor economy, while we are still wholly dependent upon living plants for the fundamental necessities of food and clothing, to employ ground for cultivating dyes which we could substitute quite well from the vast deposits of fossil plants.

Where dye plants occupy terrain otherwise unproductive, as in the case of the lichens, mangrove swamps, trees cleared from tropical forests, and the heather of our own moors, it is to our obvious advantage to exploit them where practicable. In other cases, *e. g.* in the indigo industry, much costly machinery would be out of action by the suppression of a long-established plant industry. The policy, which seems to be indicated, is intense specialisation and efficiency in a few superfine dye crops, and the exploitation of new dye plants only from terrain which is otherwise of no economic value.

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CHAPTER VIII

TEA MAKING

chemists, however, the manufacturing processes have quite special attractions, and in the present lecture it is proposed to deal with tea making. In reviewing this oft-told story it is perhaps natural to begin with the tea plant in the field, and to follow the leaf until it reaches the cup. But with some profit this procedure may be reversed: it is instructive to examine first the finished product, and the infusion obtained from it, and then consider what has been done in the way of scientific inquiry as to the meaning of the processes which have converted the green leaf into the finished tea—objects which could hardly be more dissimilar. At the outset it should be said that modern methods of tea manufacture cannot be claimed as the direct outcome of such scientific inquiry; but research has explained, in considerable measure, their significance, and thereby furnished fuller possibilities of intelligent control.

The Tea Infusion

It is noteworthy that, whereas the market value of many commodities is based upon the results of chemical examination, no tea merchant ever dreams of analysing his teas with a view to their relative valuation. Hitherto, chemical methods have not proved sufficiently "fine" to discriminate readily, and with certainty, between those subtle characteristics which separate one tea from another; and it has been claimed by the tea man, and conceded by the chemist, that while chemical analysis will indicate the strength and astringency of a tea, it tells us little or nothing of practical value as to the flavour and aroma upon which so much depends. The methods of the expert tea taster are well known: full attention is paid to the appearance and condition of the leaf, but the critical features are the strength ("body"), astringency, colour and, above all, the flavour and aroma of a standard infusion which, by simple methods, he makes for himself. However, within recent years, some very interesting and suggestive work tends to show that, provided the chemist pays attention to the relative proportions of the chemical constituents of the tea infusion rather than to their percentage amounts, the views of the analyst and of the tea taster have a relationship which is of considerable scientific interest to the one, and gratifying to the commercial instincts of the other.

The following table, adapted from Kozai (1), gives an analysis of the dried *green leaf* of unmanufactured (Japanese) tea—

Crude protein	37·3%
Crude "fibre"	10.4
Total "extract"	34·2
Ash	4·9
TANNIN	12·9
CAFFEINE	3·3
ESSENTIAL OIL	small quantity
Soluble in hot water	50·9

There is nothing of especial interest in this leaf composition apart from the three constituents to which tea leaf owes its market value, viz. the essential oil, the "tannin" and the caffeine. The essential oil is probably characteristic; "tannin" is a widely distributed plant constituent; while, as is well known, the alkaloid caffeine is of restricted but very interesting occurrence in the vegetable kingdom. In a single genus this latter substance may be present in one species, and absent in another; present in one organ of a plant, and absent in another; and occur in varying amounts in the same organs of different ages. The genus *Camellia* to which the tea-plant belongs well illustrates these points: caffeine is present in *C. Thea* (tea), but absent in *C. japonica;* while its occurrence in the organs of the tea plant and in tea leaves of different ages is well shown by the following figures—

CAFFEINE IN *CAMELLIA THEA*

1. Leaf (Youngest leaves)	4·92%	(Du Pasquier)
(2nd „ „)	3·27	
(3rd „ „)	2·64	
(4th „ „)	2·47	
2. Hairs of young leaves	2·2	Various authorities
3. Calyx	1·5	
4. Bark	1·2	
5. Petals	0·8	
6. Twigs	0·5	
7. Seeds	Nil	

The essential oil occurs in exceedingly small quantities (·006 per cent. in manufactured tea), and, broadly speaking, the two most striking constituents are the caffeine and the tannin. We call down blessings on the former as a stimulant, but look askance at the latter as an unavoidable evil with abundant powers of gastric derangement. By happy instinct those who can afford to do so eschew cheap teas and drink the "best" (*i. e.* highest priced) teas, claiming satisfactory results especially in regard to tannin effects. We are therefore the more surprised to find that chemical analysis shows that, in any one class of tea, the expensive teas commonly contain in the cup more tannin than cheap teas! *e. g.*

a cheap Ceylon tea contained 5·46 per cent. of tannin, while an expensive Ceylon tea gave 7·56 per cent.

Now, the probable explanation of such figures appears to be forthcoming as a result of investigations carried out in 1911 in the laboratories of the *Lancet* (2). Ordinary infusion of tea is a slightly alkaline liquid; if just acidified, it becomes lighter in colour, and as it cools a flocculent precipitate is formed, which can be brought down more completely by appropriate means. It is not unreasonable to suppose that these happenings take place when the beverage reaches the acid contents of the stomach. An analysis of the precipitate gave the following results—

CAFFEINE AND TANNIN IN TEA INFUSIONS

(5 gr. of tea infused for 5 minutes in 400 c.c. boiling water)

Variety of Tea.	Amount of precipitate.	Caffeine in precipitate.	Tannin in precipitate.	Approx. ratio of Caffeine to Tannin.
China . . .	6·8 %	1·72 %	5·08 %	1 : 3
Ceylon . . .	10·12	2·53	7·59	1 : 3
Indian (Assam)	12·88	3·22	9·66	1 : 3

The table gives the total amount of the precipitate (estimated on the dry tea); and suggests that, as a rule, China teas yield it in least amount, and Assam teas in greatest. Further, the precipitate is composed of caffeine and tannin in the proportions of 1 : 3. These facts led to the view that the precipitate is a definite compound which may be described as caffeine tannate, so that we arrive at the inspiring conclusion that a cup of tea is, broadly speaking, a slightly alkaline aqueous solution of caffeine tannate. This latter substance is bland and smooth to the taste, possessing neither the bitterness of free caffeine, nor the astringency of free tannin; and, in all probability, in this combination the physiological effects of the two constituents are greatly modified. This leads, then, to a new position: in a tea infusion we may not be dealing with "free" tannin and "free" caffeine, but with a more or less completely balanced compound of the two. How far does this prove to be the case? A comparison of the chemical composition of three pairs of teas—Indian, Ceylon and China respectively—each pair comprising a cheap tea and an expensive tea, gave the following results (*Lancet*, loc. cit.)—

TANNIN AND CAFFEINE IN VARIOUSLY PRICED TEAS

Variety of Tea.	Tannin combined with Caffeine.	Caffeine combined with Tannin.	Total Tannin.	Total Caffeine.	Free Caffeine.	Free Tannin.	Broker's Price.
	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per lb.
Indian .	9·40	3·10	9·50	4·00	0·90	0·10	1/10½*d.*
Indian .	7·20	2·40	8·73	3·20	0·80	1·53	11½d.
Ceylon .	9·00	3·00	8·40	3·60	0·60	—	1/4*d.*
Ceylon .	6·84	2·28	7·14	3·04	0·76	0·30	10½*d.*
China .	4·86	1·62	4·60	2·8	1·18	—	1/5*d.*
China .	4·02	1·34	3·02	1·92	0·58	—	6½*d.*

The figures indicate that—

1. Indian teas may be expected to contain more caffeine tannate than Ceylon and China teas (first two columns).

2. In any one class of tea, the higher priced sorts contain more caffeine and tannin than the cheaper sorts.

3. Taking two teas of a single class, one smooth and pleasant to the taste, and expensive; the other harsh and astringent, and cheap: then the former tea has its tannin and caffeine in balanced combination with little or no surplus of free tannin; while the cheaper tea has a relatively much larger surplus of uncombined tannin, resulting in the harsh astringency characteristic of its class. This is well seen in the Indian and Ceylon teas; with China teas it is noticeable that, so far as the above analyses indicate, they seldom give any free tannin; but, *per contra*, usually possess a relatively *higher percentage of uncombined caffeine, which fact* probably accounts for the pleasant bitterness of many China sorts. There would appear to be evidence for supposing that in China teas the caffeine has relationship with some constituent other than tannin.

Summing up: as regards Indian and Ceylon teas, at any rate, it seems that in good quality, high-priced sorts, there is comparatively little uncombined tannin; in low priced sorts, a notable surplus. On the other hand, most good teas contain caffeine in some excess. Further, teas of higher value contain more total caffeine and tannin (*i. e.* beverage making material) than cheap teas, and in practice actually may prove to be more economical, as well as more wholesome than cheap teas.

Tea Manufacture

We may now refer to the processes of manufacture which result in these interesting complications. The most important tea in the world's markets to-day is *black tea*, and the manufacture of this variety will be first described. As is well known, the modern manufacturing process obtaining in India, Ceylon and Java are ultimately based upon the Chinese practice, but the genius of the engineer has virtually eliminated hand methods and produced a cleanly efficient system of tea making. There are four chief manufacturing processes between the plucking of the green leaf and the final appearance of the finished tea. They are—

1. *Withering.*—The freshly plucked leaf is brought into the withering house, and spread in a thin layer on clean floors ; or, more commonly, on light shallow trays (made of hessian cloth, wire netting or bamboo) arranged on racks. The process is complete when the leaf is soft and wilted—" withered "—and at a temperature of 80° F. it occupies eighteen to twenty hours, though in the cooler hill districts of India a longer period is necessary. Since withering must in large measure depend upon uncertain conditions of weather, it is not surprising that special withering machinery affording regular conditions of temperature by means of currents of warm air is also in use. The next step is—

2. *Rolling*, in which the flaccid leaf is partially bruised and crushed, becoming twisted in the process. Carried out by hand (and foot) methods, this process gave offence to the æsthetic sense of the European, but in the modern rolling machine the leaf is untouched by hand. Fed from a hopper into the cylindrical metal " jacket," which travels eccentrically over the surface of the " rolling-plate," the leaf is rolled on the latter under adjustable pressure. The plate may be fixed, or itself

have a differential motion in regard to the jacket. In due course the leaf is discharged from the machine, the process occupying from fifteen to sixty minutes, according to type of machine employed, character of leaf, and size of charge. Short periods of rolling constitute "light" rolling; longer periods, "heavy" rolling. After a sifting, and a re-rolling of older leaves, the next stage is the—

3. *Fermentation.*—When small quantities of leaf are dealt with, the leaf is placed on shelves, or in trays arranged in racks; but in large factories special fermenting floors, made of cement, tiles or even plate-glass are employed, the twisted ruptured leaf being spread out in thin layers one or two inches deep to give full access to the air, which should be freely admitted. The optimum temperature is about 80° F., and the atmosphere is kept moist by means of suspended wet cloths. Similar cloths are also arranged over but just clear of the leaf. The floors, cloths and everything connected with the fermenting house (which is kept relatively cool and darkened) should be maintained scrupulously clean by frequent steaming and scouring, to prevent the growth of putrefactive bacteria, which are very detrimental to the production of good-class tea. During the fermentation, which lasts a few hours (but may be much shorter), the leaf changes colour, and gives evidence of becoming tea as distinct from leaf. When the fermentation is complete, the final major operation takes place, the so-called—

4. *Firing.*—This process, originally effected over open charcoal fires, is now carried out entirely by automatic machinery. The tea is fired or dried by means of hot

air. The " drier " consists essentially of an air-heater, and a drying-chamber through which hot air is drawn over the tea by means of an exhaust fan. The tea is carried slowly through the chamber on a series of moving perforated metal tables arranged one over another and so constructed as to resemble endless roller shutters. The motion of the individual tables is such that the tea travels from the top of the chamber to the bottom, where it is discharged. The temperature of the air entering the drying chamber is usually between 220° F. and 240° F., but when the firing is about three-quarters completed, the temperature is lowered to 180° F. or 200° F. The time required for the drying is usually about twenty-five minutes.

With the completion of the firing the tea is made. Subsequent processes of grading, " equalising," packing, etc., need not be considered here, except to mention that previous to packing, the tea is subjected to a final firing to complete the drying.

Theory of Tea Manufacture

It will be obvious that the key-phase of black tea manufacture is the *fermentation process*. Indeed, it is recognised that virtually everything prior to fermentation is tributary to that process, and adapted to give it full scope; while the subsequent stages of manufacture are to control the fermentation and take full advantage of its results. The scientific work which has established this position is due chiefly to the following British and Dutch chemists, viz. Bamber, working in Ceylon ; Mann and Hope (3) of the Scientific Department of the Indian Tea Association; and Naaninga, Welter and Bernard (4), working in Java at the Government Proefstation voor Thee. To these should be added Kozai, a Japanese investigator, whose work has been already quoted.

The work of these chemists (and notably the British representatives) has shown that the most important change taking place in the fermentation process is in regard to the tannin. This substance becomes slightly oxidised, forming brown-coloured products which unite with the caffeine present; the significance of spreading the leaf in thin layers on the fermenting floor, and arranging for free access of air, is therefore at once clear. Further, it has been demonstrated that the colour and body of an infusion of tea depend upon the proportion of tannin oxidised; the more complete the oxidation ("fermentation") the more colour and body. But the consumer demands a certain pungency in addition to these qualities, and pungency depends upon the relative amount of tannin left *un*oxidised. Here it is that the skill and experience of the practical planter comes in to decide how far the fermentation is to be allowed to go. During the process the leaf assumes a fine copper tint, and the characteristic odour of tea is developed; these are the criteria upon which the planter's judgment is based.

The main object of the fermentation would thus appear to be the oxidation of the tannin. Another change of much practical significance, and already hinted at, also takes place, and will be referred to below.

The actual mechanism of the oxidation process has given rise to much discussion, and there have been the three inevitable theories. Bamber, in 1893, put forward the *chemical theory*, ascribing the fermentation changes to direct union of the tannin of the cell-contents with the oxygen of the air. In 1900, however, he described the presence, in the cell-juices, of an (oxidising) enzyme through whose agency the union of the tannin and atmospheric oxygen is effected. This *enzyme theory* was later confirmed by Mann, Naaninga, and Newton (the last-mentioned giving the name "thease" to the enzyme), and has since found widespread acceptance. It occasioned much interest and surprise, therefore, when Bernard, in 1911, revived the *micro-organism theory*. As far back as 1891 Kozai had attributed the fermentation changes to the action of bacteria, but his views had given way in the face of Bamber's work. The special attraction of a micro-organism theory is readily understood; there is the question of the distinctive qualities of a tea being due to specific races of organisms, with all the possibilities of inoculating inferior grades of leaf with artificially-obtained pure cultures of the organism found associated with good tea. Bernard's organisms are not the bacteria of Kozai, but yeasts which he finds invariably present on the surface of the living tea leaf. Some very arresting observations are made by Bernard, but the case would not appear to be yet fully established; so far as the writer is aware, no practical application of the theory, on a commercial scale, has yet been attempted.

In the light of the fermentation process, the object of *rolling* the leaf, apart from the production of a satisfactory "twist," becomes clear. We have outside the leaf the atmospheric oxygen, and within the leaf-cells the oxidisable substance (tannin), together with the enzyme through whose agency the oxidation can be brought about. The partial crushing of the leaf brings these three elements into contact; the cell-juices are brought to the surface of the leaf tissue, which acts as a sort of sponge, allowing of penetration by the air. Further, there can be no surprise that "fermentation" actually commences during rolling. We see, too, the meaning of discrimination in rolling. In light rolling, less juice will be expressed and relatively less fermentation probable, with the resulting tea infusion light in colour, lacking in body, but comparatively pungent owing to the proportion of unfermented tannin; with hard rolling, more juice is expressed and oxidised, and the infusion is relatively less pungent, but possesses greater colour and body.

Then as to the *withering*. If fresh, turgid leaf were jammed into the roller, the leaf would become disintegrated with the production of a leaf-mash rather than a "leaf-roll." With a velvety, flaccid leaf, however, a "twist" is obtained that will appeal to the purchaser, and an evenly distributed rupture of the leaf-cells, which should promote an even fermentation. These were once considered to be the only objects in withering, but Mann and others have shown that, so long as the conditions of temperature and moisture remain satisfactory, the oxidising enzyme greatly increases in amount during the withering. Not only this, but the essential oil, to which the tea owes its aroma, increases during withering by about 15 per cent.; and this increase rises still further during rolling, and reaches its maximum during fermentation, constituting the second of the important changes accomplished in that stage of manufacture.

It will be readily understood that the chemical maturation involved in the processes described will demand a certain period of time ; and in abnormally dry weather the leaf may be ready, physically, for the roller before it is chemically mature ; in wet weather the reverse may be the case. It is mainly these difficulties which have resulted in the use of the withering machinery referred to above.

The withering and rolling, therefore, are preparatory to, and culminate in the fermentation. There remains to be considered the object of the post-fermentation process, the *firing*. It is known that if the fermentation is allowed to proceed too far the pungency of the tea is unduly diminished owing to the reduction of the residuum of unoxidised tannin, to which pungency is due. The object of the firing, therefore, is to arrest the action of the enzyme in time. At the right moment the fermenting leaf is transferred to the dryer and its temperature raised to a point sufficient to destroy the enzyme and arrest the chemical action resulting from its activity. Incidentally, the tea is dried. The process must be carried out rapidly and stewing of the leaf at relatively low temperatures avoided, otherwise the leaf loses quantities of " soluble matter " by the decomposition of the tannin, and pungency suffers for the same reason ; further, the flavour is reduced owing to the volatilisation of the essential oil.

Other Teas

The above remarks have reference to the manufacture of black tea, the standard tea in the markets of this country. In other countries, however, an important place is held by other varieties of tea, the chief being green teas, oolongs, brick teas, and the unique Leppet tea. In the space available the manufacture of these teas can be referred to but briefly.

Green teas.—Black and green teas were known in this country long before any attempt was made to establish the relationship between them. Misled by information supplied with botanical specimens from China, the botanist Hill, in 1759, explained the two products as being derived from different varieties of the tea plant,[1] viz. *Thea Bohea*, yielding black ("Bohea") tea; and *T. viridis*, yielding green tea (5). Hill's explanation held place for nearly a century, until it was finally disposed of by another botanist, Fortune, who in 1847 described the manufacture of the two teas, as witnessed by him in China, as from one and the same variety of plant. Curiously enough, the true explanation had been previously published by Bontius (1631) and Lettsom (1799), but their accounts had been overlooked.

As is well known, the differences between black and green teas result solely from differences in methods of manufacture. Whereas in the case of black tea, everything is done to promote enzyme action (fermentation) up to a certain point, in the manufacture of green tea the essential feature is the prevention of fermentation by the destruction of the enzyme as soon as possible after plucking the leaf. In China and Japan (where most of the green tea is made) the method employed is

[1] The tea plant was originally described by Linnæus in 1737 under the name of *Thea sinensis*.

that of heating the leaf in metal pans over fires in simple furnaces ; in India and Ceylon, where a little green tea has been made for the Russian and American markets, the agent used is steam under pressure. In green teas, therefore, the tannin constituents remain practically unoxidised, and the liquor possesses less colour and body, but greater pungency, the latter feature being characteristic of this class of tea.

Green tea is subjected to a light rolling after firing, not with the object of rupturing the leaf-cells, but to impart a " twist." The tea has a soft, silky feel, quite distinct from that of black tea. During manufacture it becomes sticky, especially in the case of the youngest leaves which adhere in small balls to form " gunpowder."

Oolongs.—North America absorbs practically the whole of a remarkable tea exported from Formosa, viz. the famous Formosa oolongs, which in recent years have made considerable but not very successful efforts to enter the English market. The chief characters of oolongs are a distinctive delicacy of flavour, and lightness of body and colour suggesting green teas, but an absence of marked pungency. So considerable is the value of the American market for this class of tea that in 1904 a special mission on behalf of Indian and Ceylon planters was despatched to Formosa to investigate the industry with a view to the production of British-grown oolongs. The information gained was of much interest, but no practical results followed. It was found that much of the character of the tea is due to a special feature of its manufacture, viz. a partial fermentation, effected during a prolonged withering, previous to rolling; but that the chief factor is the special jat (variety) of plant cultivated—a jat unknown in India or Ceylon, and calling for such cultural treatment as renders its cultivation in those countries impossible. That the natives themselves are fully aware of the importance of the jat, and of the necessity for keeping it true to type, is evidenced by the fact that, while in every other tea-growing country the bushes are normally propagated by seed (with the attendant possibilities of variation, hybridisation, etc.), in Formosa all but the inferior oolong plants are propagated vegetatively, by layering.

The importance of the jat as a factor affecting the quality of the Formosan teas is a reminder that it would be misleading to suppose that the processes of manufacture alone influence the character of the resulting tea. The case has been stated thus: "A correctly grown tea plant provides the possibilities of a good tea; it is the aim of good methods of manufacture to realise these possibilities to the fullest extent." Apart from their effect upon yield of leaf per acre, it is well known that differences of jat, rainfall, elevation; differences of soil, manuring, and even type of pruning have their effect on the quality of the final product, and are taken into the fullest consideration by the practical planter.

Brick teas.—These famous teas form an important item in the Chinese trade, and are of two distinct kinds, differing in methods of manufacture, physical characters, and manner of domestic use. The first class comprises the brick (and tablet) teas destined for the Russian markets. These teas are no more than the dust and siftings of ordinary black and green teas compressed into slabs, originally with the intention of economising bulk in the prolonged and difficult overland transport between China and Russia. The material used in the process is obtained chiefly from China, but considerable quantities of tea dust are now exported from India, Ceylon, and Java to Hankow, where the factories (under Russian control) are situated. In making the bricks the sifted tea dust is steamed and then poured into wooden moulds in which it is subjected to hydraulic pressure. The bricks weigh from $1\frac{1}{2}$ lb. to 2 lb. each, and are remarkably hard, smooth and tough; they are marketed under the trade-mark of the exporter, stamped upon them while in the press. Tablet teas are essentially brick teas put up in smaller sizes weighing each a few ounces.

The second type of brick tea is that manufactured by the Chinese for Tibet. This remarkable product (which is made in Szechwan) was investigated by Hutchison in 1905 on behalf of the Indian Tea Association. Tea leaf, and not dust, is used. Very rough material, however, is employed for the average qualities, leaf-stalks, small twigs, and even clippings of the bush being utilised. This coarse "pluck" is heated in iron pans for a short period, then subjected to a light hand-rolling and subsequently allowed to ferment for the long period of three or four days, when the leaf is dried in the sun.

No chemical investigation of this process has been made, but it is evident that such should prove of considerable interest. In making the bricks the fermented "leaf" is steamed, and while moist rammed lightly into wooden moulds, its adhesion being assisted, in the coarser qualities, by the addition of rice paste. The bricks are finally wrapped in paper and packed in hide-covered bales. They differ much from the hard, black Russian bricks, being readily broken up into a loose mass of twigs and leaves. Their domestic application is also different; the Russian brick is used for ordinary infusions, but the Tibetan article is boiled with butter, salt and other materials to form a soup.

Leppet (*Letpet*) *tea*.—Probably the most interesting of the applications of the tea leaf is in the manufacture of the leppet tea of the Shan States and neighbouring districts of Burma. The product does not enter into external commerce. Two methods of preparation are described. West of the Irrawaddy the leaf is softened in boiling water and then rolled and allowed to cool. It is then rammed into a length of bamboo retaining one of the natural diaphragms, and the end plugged. The bamboos are then inverted to drain away moisture, and finally buried in the soil for the leaf to mature. Eastwards of the river a different process is employed, though the principle remains the same. The softened and rolled leaf is tightly packed into a pit in the ground, lined with boards or matting, and pressure applied by piling heavy weights on a cover placed over the leaf. In due course the leaf assumes a yellow colour, when it is ready for sale.

As in the case of Tibet brick teas, leppet is not used for making a beverage. The cured leaf is eaten direct as a vegetable, or mixed with garlic, oil and salt to form a kind of salad.

It will be evident that the process of manufacture has little or nothing in common with that of ordinary black or green teas. In both methods employed one is reminded of the ensilage of green fodder so largely carried out in certain countries, and it is not improbable that the chemistry of the fodder silo and the leppet pit and bamboo tube would have features in common.

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CHAPTER IX

THE PLANT AS HEALER

By ETHEL N. THOMAS, D.Sc.

NOTWITHSTANDING that the supreme importance of the plant's contribution to human sustenance overshadows even its rôle as healer, the consideration of the medical virtue of the plant needs no apology. The nation, still less an army, could hardly continue to exist if unarmed against the depredation of disease. Of the South African War it has been said that the fly killed more than the sword, the disease carrier was more effective than the bullet carrier.

Though, indeed, prevention is better than cure, as Peace is better than War, yet peace is not always possible, and health is not always possible, so that we dare not yet, in either case, despise the weapons of defence.

Every one is familiar with the wonderful cures effected recently in the most devastating form of tropical dysentery, by means of special preparations of the drug emetin obtained from the root of ipecacuanha. The effects of quinine, a preparation of cinchona bark, are of such importance in the tropics that the Government long since arranged that it should be available in small quantities at every post office throughout India. Its use is so general, that after the failure of coffee in Ceylon quinine became for the time the great export. The use of morphia, in the last resource, for the relief of human pain renders the poppy a plant of price, while through all ages mankind has looked to plants for the alleviation of suffering.

It is a matter of great interest and of no little importance to ascertain the means whereby man has become acquainted with the existence and properties of drugs. Many are the strange legends of miraculous and semi-divine instruction. We cannot doubt that from all time knowledge has been built up as the result of experience gained through the exercise of that "divine" curiosity which results in the knowledge of good and evil, of life and death.

Like all knowledge it gave power, and hence was not lightly parted from, so that we find the subject from earliest times deliberately surrounded with that mystery which has not wholly departed from it. The combination of the healing art with priestcraft in ancient Eygpt and other countries is, therefore, not surprising, and Hermes, the companion of Osiris and Isis, is credited with the production of a vast series of medical works. This legend was repudiated later by Galen in the second century.

Among the Greeks the fame of Æsculapius was traditional, and the names of his daughters, Hygeia and Panacea, stand for Prevention and Alleviation to the present day. He perished, like many others, through too great a manifestation of power.

Eight hundred years later (466 B.C.) we come to Hippocrates, the first authentic written source of medical lore, with some four hundred "simples," or herbs, of healing value, and Materia Medica may be said to be established with Dioscorides in the first century A.D.

By this time physicians are distinct from herbalists, who, however, frequently took upon themselves curative work, and who, in any case, were much respected botanologoi. The botanologoi, alas, hedged round their trade with darkest superstition, and we read of the scream of the mandrake as it is drawn from the ground, the inoffensive rhizome being deceptively trimmed to resemble the human form before it is allowed to be seen of the people.

It was the botanologoi who established the foundations for the science of botany, for the philosophical speculations of Aristotle and Plato proved less productive of knowledge than the observations, simple though they were, of the herbalists, who were ultimately driven through the exigencies of their trade to note and faithfully describe the characteristics of their stock.

The great herbals of the fifteenth and sixteenth centuries gave rise to the pharmacopœias, on the one hand, and the floras on the other.

Both the knowledge of plants and of their uses seems to have needed improvement, for Bacon writes, "Medicine is a science which has been more professed than laboured, more laboured than advanced, the labour having been, in my judgment, rather in circle than in progression. I find much iteration, but small addition"; and Turner, who has been called the Father of British Botany, dedicates his herbal to Elizabeth with the words, "Such was the ignorance in simples that I could get no information on the subject, even from the Physicians."

So much for the Art, what of the actual vegetable medicines used?

I have chosen a few from the list attributed to Hippocrates, and it is most interesting to find that these are still in great request—

Plant		Natural Order.	General action.
Marsh Mallow	*Althæa officinalis*	Malvaceæ	Demulcent, emollient
Hemlock	*Conium maculatum*	Umbelliferæ	Sedative, anodyne
Henbane	*Hyoscyamus niger*	Solanaceæ	Narcotic, anodyne
Hyssop	*Hyssopus officinalis*	Labiatæ	Stimulant, pectoral
Mandrake	*Mandragora officinalis*	Solanaceæ	Sedative narcotic
Mandrake (American)	*Podophyllum peltatum*	Berberidaceæ	Hepatic and intestinal stimulant
Mints	*Mentha*	Labiatæ	Expectorant, emetic
Mugwort	*Artemisia vulgaris*	Compositæ	Diaphoretic
Pennyroyal	*Mentha*	Labiatæ	Carminative, diaphoretic
Poppy	*Papaver somniferum*	Papaveraceæ	
Castor Oil	*Ricinus communis*	Euphorbiaceæ	Purgative
Spurge	*Euphorbia*	Euphorbiaceæ	Anti-asthmatic
Tarragon	*Artemesia dracunculus*	Compositæ	Stimulant
Willow	*Salix*	Salicaceæ	

Judging from instructions on ancient papyri, etc., it seems to have been the fashion to administer compounds of as many "simples" as possible, and this is still the custom in the herbalist prescriptions of the present day, though the more recognised medical practice is in the contrary direction.

The *poppy*, the source of opium, was undoubtedly cultivated in Mediterranean regions at a very early date, and although it is doubtful whether Hippocrates really used the poppy as we know it, Dioscorides most certainly did. Galen states that he only used it for very urgent cases, but it seems certain that much of the fame of Paracelsus at a later date was due to his bold use of opium. In the seventeenth century it was much recommended, but Hoffman thought that later it was abused.

At the present day it is grown largely in Turkey, Persia and India, and the inspissated juice from the unripe capsules exported as "ball" opium, from which the more liquid part has drained away.

The plant is an annual whose seed is sown in October, preferably in rich, dark, sandy loam, or heavily manured light clay, and the harvest culled some seventy-five to eighty days later. That grown in India has only recently been used in London for medical purposes, and undoubtedly the Turkish and Persian product is superior.

Castor oil, a native of India, has been found in Egyptian tombs, and was known to the Greeks. Like so many medicines of the time, it was chiefly used externally. It fell into disuse at one time because of a drastic element which, however, is not present in the properly extracted drug, which then constitutes an excellent mild purgative.

The *henbane* of the ancients was probably *Hyoscyamus alba,* which is particularly recommended by Dioscorides. It was very much used as a narcotic in the Middle Ages, but fell into disuse at the end of the eighteenth century, and was only revived through the experiments and recommendations of the famous Viennese, Störck.

Several members of the Solanaceæ have similar properties, thus *Datura Stramonium* may have been known to the ancients as a poison, but Dioscorides undoubtedly confused it with henbane, and *Atropa Belladonna* cannot be identified with certainty in the writings of the ancients. *Datura Tatula* serves the same purpose, and quite recently an ethnological report on certain Indian tribes comments on their use of *Datura Metel*.

Aloe, familiar in the Bible, was known to the Greeks 400 B.C., and there are many interesting legends as to its value and trading in the time of Alexander, who caused it to be improved by cultivation in the island of Sokotra, from which supplies are still obtained, though many of the old plantations are now in disuse, since the introduction of the plant to the West Indies, etc. The quality of the bitter purgative juice depends largely upon care in the process of inspissation, and carelessness accounts largely for the inferior quality of South African aloes.

The very important plant *Digitalis* (foxglove) seems not to have been introduced into medicine until the Middle Ages, perhaps partly because it is a native over the greater part of Europe, including Great Britain, flourishing on siliceous soils, and knowledge up to that time was derived from the East. The Welsh physicians of 1200 seem to have used it, though it was not named until 1542 by Fuchs.

It was regarded at this period as a violent drug, and it was not until after the investigations in 1785 of Dr. Withering, a botanist and physician of repute, that it became established as a heart sedative of great value.

The history of the cultivation of *Ipecacuanha* constitutes an interesting page in therapeutical and botanical lore. A native of Brazil, it was in common use in that country, but did not get a trial in Europe until towards the end of the seventeenth century. At first, as so often happens, it was brought into disrepute by ignorant use. Helvetius, however, established its fame for the treatment of dysentery by employing it as a secret medicine, and ultimately secured the sole right of vending it.

Its widespread use was followed by an astonishing drop in the death-rate from dysentery in India. The consequent high price made it desirable in the middle of the nineteenth century to attempt to cultivate it. This met with poor success, until vegetative propagation from the rhizome and even from the petiole, was established in the Botanic Gardens in Edinburgh, and seeds obtained by suitable cross fertilisation.

Of late years progress has been made in the manufacture of suitable preparations of the most active principle emetin for injection, and quite recently the intensified study of dysentery necessitated by the war has resulted in the production of a non-emetic double salt which can be taken *per os*.

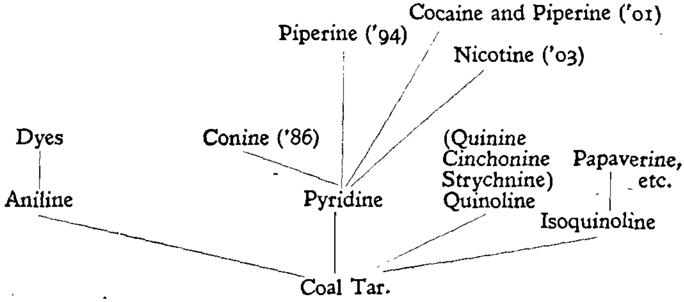
Quinine, although indigenous to South America, like ipecacuanha, is in marked contrast to it in that it is found on the west of the continent, is a denizen of mountainous, not swampy, regions, and seems to be quite unused by the natives. The travelling doctors, descended directly from those at the time of the Incas, never carry it in their wallets, and there is great dislike to its use apart from dyeing. Nevertheless, it was through an Indian cure by means of red bark that it was introduced into Europe by the Countess Cinchon, whose name was later given to the plant.

The subsequent depredation of the South American forests necessitated the cultivation of cinchona, which was ultimately established, with some difficulty, in India and Ceylon. Its introduction in the latter place proved an immense boon to planters ruined by the spread of coffee disease, but over-production has reduced the price to such a point that it can scarcely now be grown at a profit in Ceylon. The more scientific methods of the Dutch have, moreover, given Java a practical monopoly.

The pharmacists of the sixteenth and seventeenth centuries were very naturally constantly attempting to extract the "quintessences" of the medicinal plants, but it was not until the early part of the nineteenth century that much progress was made.

In 1816 Serturner isolated an alkaline base *morphium*, "a remarkable substance, which shows much analogy with ammonia." Vaquelin had already in 1812 extractracted daphnine. In 1820 Pelletier and Caventou cleared up the question of quinine, and in 1821 Robiquet, while looking for quinine in coffee, discovered caffeine. The isolation of strychnine, codeine, emetin and atropine soon followed.

The synthesis of urea in 1828 and the consequent breakdown of the artificial line between inorganic and organic compounds, together with the isolation of aniline from indigo, on the one hand, by a pharmacist in 1826, and from coal tar, on the other, in 1834, led to the *synthesis of certain of the alkaloids*, beginning in the eighties with conine (active principle of hemlock) by Madenberg. They constitute, from a chemical point of view, a parallel series to the aniline dyes built up on other bases derived from coal tar, and hence from fossilised plants.



The accompanying table shows the coal tar bases of several familiar alkaloids. Those from the pyridine base have already been synthesised at the dates given.

The quinoline derivatives have not yet been synthesised. They are more complex even than the pyridine alkaloids, and include quinine, strychnine, etc.

These results are of the first importance, both theoretically and practically, as they pave the way for the better understanding of the action of the drug. We are still very far, however, from being able to correlate chemical constitution and physiological action. The tentative suggestion that the presence of OH groups is associated with antiseptic properties, and of NH_2 with narcotic properties, is not always supported by clinical experience—notably in the sulphonal series, in which narcotism does not increase according to expectation with the number of ethyl groups present in the substances.

Synthesised drugs are sometimes cheaper than the natural product, but, on the other hand, even the chemically isolated principle, still less the synthesised product, may be much less successful in the hands of the clinician. Thus aloin is much more uncertain in its action than the crude drug aloes, and the synthesised salicin compounds are very difficult, practically impossible, to purify from phenolic associates.

It seems as though in many cases the total action of a drug is due to the interaction of several components, some known and some, it may be, unknown. This is paralleled by the reinforcement which seems to take place in mixtures from several plants having practically the same properties. Such mixtures have been proved to be more effective than a corresponding strength of any one, and they form a justification for old-fashioned multiple compounds, now fallen into disrepute in orthodox medicine. The explanation of phenomena of this kind will, no doubt, ultimately be found in the realm of *Physical Chemistry*, as it is very probably a question of solubility.

It is as well, therefore, perhaps, that most vegetable drugs are still manufactured from the plant, and consequently there is a vast industry in medicinal plants. Both medical men and herbalists use large quantities of—

Balm	Penny Royal
Comfrey	Rue
Feverfew	Southernwood
Celandine	Tansy
Woodsage	Wormwood
Marsh Mallow	Yarrow, etc.

It must be remembered that while the tendency of orthodox modern medicine is to limit more and more the use of drugs to a few of the better known, there is loss as well as gain in this system, and the distinct revival of interest in herb lore may well be productive of the discovery of new and important drugs if associated with wider knowledge and more scientific investigation.

In addition to the *British Pharmacopœia* and the *British Pharmaceutical Codex*, there exists an important compendium of plants of established medicinal value in the *National Botanic Pharmacopœia*, published by the National Association of Medical Herbalists of Great Britain.

The curious use of *Drosera rotundifolia*, the insectivorous sundew, which is official in homœopathy for pulmonary consumption, needs scientific investigation. Unfortunately in this country the people's knowledge has been allowed to lapse more than on the Continent, where "simples" are still culled and administered by the housewife. This gives the more possibility, however, of interesting results accruing from studies in relative folk-lore.

As the ancients are said to have watched animals, so it behoves us to observe closely the habits of the primitive peoples still left in the remote corners of the earth. Exploratory and experimental research is still more necessary where, as in Australia, there are few natives, and those rapidly disappearing. We are unfortunately unable to believe, with certain herbalists of the sixteenth century, that "God has imprinted upon the plants the very signature of their virtues," by some cabalistic likeness to the part of the human body affected thereby, but everything goes to show that Nature usually gives us the hint, if we do but sufficiently closely observe her doings.

In view of the series of alkaloids known to exist in the Solanaceæ, it is not surprising to find in a recent American publication an account of the use of *Datura Metel* as a narcotic by certain primitive Indian tribes.

It would be of immense interest if evidence were obtained of native use of the abundant droseras of Australia, and in view of the application of *Drosera rotundifolia* in Great Britain might well point to the existence of unexplored medicinal principles in this group destined to be of value in tuberculous disease.

In the meantime there is waiting at our door the improvement and development of the important drug plants known to us, and the even more limited, but very practical, and urgent question of the production in England of the necessary herbs to make good the interruption of the supply occasioned by the war. Though more medicinal plants are grown in this country than is usually realised, Mr. Evans (1) affirms that many more could be introduced, as, for instance, *Cascara Sagrada* as a hedge plant, while *Podophyllum peltatum* could be reared in Norfolk or the New Forest. English henbane, lavender and mint stand untouched by any rivalry. It is a recognised fact that English henbane is the only really satisfactory kind, and this is a plant of great importance, as its use is not attended by the deleterious gastric effects of opium. On the other hand, the open tracts of country and well-organised system of gathering and export gave the Central Powers a practical monopoly of the herb trade prior to the war.

These matters should be considered together if the industry is to be established, and Mr. A. D. Hall

(Development Commissioner and now Secretary of the Board of Agriculture) classes (2) drug growing and manufacture as a subsidiary agricultural industry, which it behoves us to try. As in other agricultural matters, probable *post bellum* conditions must be considered, since the comparative slowness of agricultural returns, the moment of inertia, so to speak, in the operations involved precludes a sudden *volte face* to meet new conditions. I place on one side the political aspects of the situation, to dwell only upon the responsibility of the grower, who must not rely on the special conditions obtaining at the moment, but be prepared not only by organisation, but by scientific development to face renewed competition in the near future.

On the debit side of all accounts appears annually the sum set aside for depreciation. I should like to see also in such an industry as we are contemplating an annual sum set on one side for appreciation, if I may so term it; not only a sum "to make good," as we say, loss, but a sum "to make better," bread upon the waters which, maybe, will return a hundredfold. Now, it is obvious that methods of improvement are so slow and expensive, that one grower, or group of growers, can effect little; but if small sums are pooled to support experiment, as is done by the Cotton Spinners' Association, much might be effected.

What are the directions in which experiment might work?

We have it on the authority of Mr. Holmes of the Pharmaceutical Society of Great Britain that the cultivation of medicinal plants is capable of improvement under more systematic and scientific control, and, as a matter of fact, some experiments are now in progress at Cambridge on the effect of different manures.

In America Bailey (3) records the increase of glucosides in Phaseolus, Zea and Sorghum following upon the increase of nitrate manure. Tannin is also affected by manuring, none being found in Phaseolus, when chlorine is absent, while it is well known that the highest tannin yield is obtained from oaks grown on silicious soils. Bailey remarks also on the influence of climate on flavours—due to essential oils—as on other ingredients of plants.

An extreme instance of climatic control is furnished by the hemp plant, *Cannabis sativa.* The Indian grown plant alone is narcotic, with the result that it was at one time regarded as a separate species, but there is no doubt that the surprising difference between the supposed distinct species *C. Indica* and the European *Cannabis sativa* is climatic. The modern development in ecological aspects of field work bids fair to help considerably in the elucidation of problems of this kind, and the analysis of climatic and edaphic factors paves the way to that partial control of plant products to be desired in the service of man. But there is also another means to this end emerging as the result of modern experiments on heredity. Thus Bailey's account of the breeding experiments with pumpkin and gourd, showing association of the size of the former and bitter principle of the latter, suggests that a similar but useful combination of robustness and medicinal content might be effected by the interbreeding of certain medicinal plants, and in fact some progress along these lines has been effected in connection with cinchona trees.

Little has been done, however, as yet in the light of the more exact possibilities of Mendelian breeding. It is affirmed, however, that the biennial varieties of *Hyoscyamus niger* are Mendelian in their behaviour, so that pure strains can be isolated—a fact of great importance to the drug trade.

Prof. Bayley Balfour writes: "There is undoubtedly room for heaps of work in the matter of drug plants," and Mr. Bateson informs me that there is some reason to suppose that scent-bearing and non-scent-bearing characters behave in a truly Mendelian manner.

These indications justify, nay, demand an output of capital and labour commensurate with their significance, in the sure hope of an ultimate reward, both scientific and humanitarian.

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CHAPTER X

PLANTS AS A SOURCE OF NATIONAL POWER—COAL [1]

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MAN is not only a restless centre of energy himself, he demands increasingly the dispersal and rearrangement of the energy of the material world around him. Units of energy, leashed, give man his power to build, to grow and to destroy; and of all stores of dormant energy, coal is the most useful to him.

In the words of the Royal Commission on Coal (1905), "We are convinced that Coal is our only reliable source of power, and that there is no real substitute" for coal. It is true that we were a powerful nation in Elizabeth's reign, and yet it is said that she prohibited the use of coal in London when Parliament was sitting, lest the health of the Knights of the Shires might suffer during their residence in town. But that was before the days of the hatching out of James Watt's brood of steam engines, which, like fiery dragons, demand more and ever more energy to feed them. Yet we dare not slay these dragons, as Samuel Butler told us to do in his inimitable *Erewhon*, for in the world to-day other

[1] Public Lecture delivered at University College, London, March 26, 1917.

nations have harnessed them, and before these nations we should be helpless without our own energy-transformers.

In a normal year, the forty millions or so of the population of the United Kingdom use, or waste, something over 5,000,000,000,000,000 British thermal units in coal alone. But of this array of units of energy in coal which we destroy we have actually used but a fraction, for we waste ten at least for every unit put to useful work.

From mighty waterfalls (if we had them) we might get this number of units of mere energy, but that would not be the equivalent of the wasted coal, for from a waterfall could be got none of the myriad other products which make coal the most essential of raw materials. Recent events have made us all realise how dependent we are for our home comfort on the coal supply; but some, perhaps, who were without coal, cherished themselves with gas, coke or electricity, without realising that all three are the products of the manipulation of coal. Without exaggeration, one may say that coal is the very basis of our civilisation, because not only our home-life depends on it, but its use is essential for the production of nearly every manufactured article: warships, ploughs, or babies' feeding-bottles, the cloth we wear, the high explosives we use against the Germans, all are either the direct products of coal or the result of coal-stoked furnaces which drive machinery. Not only is coal the foundation upon which the edifice of our present civilisation is built, it is part of the superstructure. Several hundred thousand organic compounds are obtained directly or indirectly from coal, the names of many of which, like carbolic acid, for instance, are "household words"; but most of them are known by name only to the specialists who deal with them. Coal products in some form or other are used in innumerable trades and manufactures. We swallow coal products, wear coal products, scent ourselves with coal products, nourish our flowers and crops with coal products, destroy our enemies with coal products.

How much coal does it take to do these things, and more, for us? As these last years have been abnormal, I will go back some distance for actual figures: in 1903 in the United Kingdom we used approximately—

For our Railways	13,000,000 tons of coal.
" " Factories	53,000,000 " " "
" " Mines	18,000,000 " " "
" " Iron and Steel Industries	28,000,000 " " "
" " Gas Works	15,000,000 " " "
" " Domestic uses	32,000,000 " " "

and, as we are a coal-producing nation, we exported very much more than all that was used in our houses. I need not remind you that our financial position as a nation is largely influenced by our export trade, hence, indirectly, coal is thus another source of power to us.

To illustrate how greatly our use of coal increases with the years, a few comparative figures may be of interest; and these tables will also indicate the relative changes of precedence held by the leading coal-producing countries in these short periods of time.

In 1845 *Production was—*		*In* 1865 *Production was—*	
Great Britain	31,500,000 tons	Great Britain	99,760,000 tons
Belgium	4,960,077 "	Germany	28,330,000 "
U.S.A.	4,400,000 "	U.S.A.	24,790,000 "
France	4,141,617 "	France	11,840,000 "
		Belgium	11,840,000 "

In 1914 *Production was—*

U.S.A.	513,525,477 tons
Great Britain	297,698,617 ,,
Germany	270,594,952 ,,
France (1913)	45,108,544 ,,
Belgium (1913)	25,196,869 ,,

Germany is rapidly catching up, as can be seen from these three tables, and she has huge reserves, the United States already immensely exceeds us in the quantity she produces; but neither of these countries are part of a widely scattered empire as we are. For the sake of a truer comparison between the coal production of the British Empire and these two countries, I give below that of the various parts of our empire and of Germany and the States for 1910. In that year production was—

By U.S.A.	445,810,000 tons
,, Great Britain	264,500,000 ,,
,, Germany	221,980,000 ,,
,, Canada	13,010,000 ,,
,, India	12,090,000 ,,
,, Australia	10,000,000 ,,
,, S. Africa	5,500,000 ,,
,, New Zealand	2,230,000 ,,

Having thus reminded you of what coal means to us in a practical sense, let us consider: What is Coal? A great variety of incomplete or inaccurate statements about it are to be found in dictionaries, encyclopædias, and textbooks, but I do not know of any published definition which is entirely satisfactory. Hence, recently, at the Society of Chemical Industries, I had the temerity to define coal provisionally, and for want of a better definition for the moment I will offer that. "Ordinary coal is a compact, *stratified mass of dismembered 'mummified' plants* (which have decayed to varying degrees of completeness) *free from all other matter*, save for the mineral veins, partings, etc., which are local impurities," as are the quartz veins in a nugget of gold. It is to be noted that unless the plant substance is sufficiently free from other matter to be substantially a deposit of plants alone, it is not a coal; but impure coals may grade into oil shales and a variety of other deposits. There are many varieties of coal which really merit separate consideration, but though cannels, anthracites and the others have their commercial importance and scientific interest, for the purpose of this lecture I shall generally mean by "coal" the most important and most widely used "bituminous" coal of the household and factory.

I do not wish to mislead you into thinking that my definition represents a universally accepted view of coal, but I believe it will be the generally accepted view when sufficient time shall have elapsed after the completion of certain researches now in progress. At present there is in the air a vague idea that coal is in some way due to plants, but they are widely supposed to be mineralised plants. Prof. Lebour in the recent British Association discussion on coal said: "Geologists regard coal as a rock"; and it is widely called a "mineral," a "rock," a "stratified rock," or other term, which conveys to ordinary people the suggestion that it is a stone of some sort. In the older books black coal, such as we use in this country, is always spoken of as "stone coal." On the other hand, some experts, influenced still by Frémy, tend to look on coal as he did, as a structureless, hardened jelly. Shakespeare asked: "What's in a name?" and I would answer, that it is the very mould of human thought, and in its name lies the conception of a race about the thing it names. Hence, I regret that coal is so universally called a "mineral."

When I was a child of about eight or nine years old, I first heard my parents speaking of a curious incident of their honeymoon. They had gone into the Egyptian desert, and at one place the little railway train had been stoked with animal mummies for want of ordinary fuel. My childish imagination had never been stirred by the thought that *coal* could make an engine move, but the idea that *mummies* could do so seemed like some fairy tale of old Baghdad, and impressed me not only with its faint aroma of horror, but with a vivid revelation of the magic power of the steam within the boilers.

And now my research into the structure of coal is bringing me back this sense of magic, for it is becoming clear to me that *coal is mummies*—the mummies of dismembered plants.

In general the remnants of extinct creatures of former periods of the world's history are spoken of as "fossils," or "petrified remains"; indeed, the terms "fossil," and "petrifaction" are almost synonymous, for most of the fossils are petrified, and the plant or animal is represented by a simulacrum in stone. But in some instances the very substance of the creature is preserved from decay by natural chances, as were mummies by man's design. This is what happened when coal was formed—the dismembered fragments of plants of all sorts were preserved together, neither petrified nor mineral-infiltered, but shut away from the air to form a stronghold against bacterial attack before it had made too devastating a progress.

The coal which looks so black a lump in your hand, is not black if it is cut in thin enough sections; but it is extremely difficult to cut such sections, because, as the slice is being rubbed down to be made thin, it tends to crack and split up. Without doubt many of the older, and still prevalent, mistaken notions about coal are due to the difficulties of section cutting. This art has been greatly improved in the last few years by Lomax, in this country, and Jeffrey and Thiessen in America, so that the way is prepared for more satisfactory researches into coal structure.

When a thin section is obtained it appears under the microscope as a mottled mass, grading from opaque to transparent regions of deep coppery red to yellow. The untrained eye finds it difficult to see any structure in coal, save the most conspicuous and well preserved; and the most conspicuous things in most coal sections are the spores, particularly the macrospores. These originally spherical or egg-shaped bodies are generally flattened, but often they appear to be not otherwise affected, and their thick, uniform walls show up as brilliant yellow or orange bands in the more opaque or granular masses of the coal. The conspicuous appearance of these spores, even in sections not otherwise very good for microscopic examination, early attracted attention to them, and probably partly accounts for the extreme view of their importance in coal formation taken by Huxley in his famous essay in the *Contemporary Review* for 1870. Dawson, who knew infinitely more about coal than did Huxley, answered him in the following year, and maintained his (Dawson's) original thesis, that in the coals of Nova Scotia and New Brunswick, at least, spores were relatively unimportant, but that the barks of Sigillarias, and Calamites, and other great forest trees of the Coal Measures were the principal source of the bright layers. Since those days many researches on coal have been published in many countries, yet it still remains woefully true, as Parkinson said in 1804, that "Among the humiliating proofs of our limited powers of inquiry, there are few which are more striking than that which is manifested by the inefficiency of our investigations relative to coal." Though to Huxley's question, "Why does not our English coal consist of stems and leaves to a much greater extent than it does?" we can answer to-day that it does consist of stems and leaves to a much greater extent than he knew.

The vegetable origin of coal is indubitably true, and whether you accept Frémy's theory that coal is a structureless plant jelly, Huxley's view that it is chiefly made of spores, or White and Thiessen's view that it "is chiefly composed of residue, consisting of the most resistant components of plants, of which resins, resin waxes, waxes, and higher fats, or the derivatives of the compounds composing these are the most important," or my view that ordinary coal is preponderatingly composed of variously preserved plant mummies—you will all be agreed as to its vegetable origin.

Hence, recalling the vast practical uses of coal, we see that for all these wonders we are indebted to *plants*. We use, or waste, every year the energy and the products which were stored in the plant bodies of long ago. So astonishing is the quantity of their substance in our Coal Measures, that the idea has got about that the plants or the atmosphere, or both, of those times, must have been unique in their coal-forming power. And this view has been fostered by the natural configuration of Western Europe. In this country our important commercial coals are of Coal Measure (palæozoic) age, and in Germany, Belgium and Northern France also this is true. In Germany, where more recent coals are also valuable, they are all "lignites," or "brown coals," and hence appear to support the view of the exceptional black-coal forming conditions of the Coal Measures.

Without going beyond our own empire we can discover how fallacious is this view; and true black coals are to be found in almost every geological period in some part of the world or other. For instance, the assumption that Tertiary or Cretaceous coals are all lignites or brown coal (and therefore of little value) is disproved by the great coalfields of true bituminous coal, and even anthracites in Western Canada. While in Eastern Asia, one of the greatest storehouses of coals in the world, vast deposits of true black coal are of this geologically recent age.

Even where the Tertiary coals are still in the brown-coal stage, they are of great commercial value if intelligently utilised, and this the Germans, who have such large stocks of brown coal, have been wise enough to do. The brown coals also are mummified plant masses, in most instances entirely comparable with black coals, save that they contain more moisture and are less compressed and consolidated. As wise old Goeppert realised in 1861, the boundary made between black coal and brown coal is often artificial and unscientific, and the distinction is far clearer in textbooks than it is in Nature.

Important coals are to be found in each geological horizon in some part of the world; until we get right back to the Upper Devonian, which is the oldest epoch in which true coals occur.

If the leading divisions of geological time are arranged vertically, a few of the more important coalfields of corresponding age may be indicated beside them to illustrate the above remarks.

Geological Epoch.	*A few of the areas with commercially useful coal of corresponding age.*
Tertiary	Germany, Canada, U.S.A., Japan, Spitzbergen, New Zealand, etc.
Upper Cretaceous	France, Servia, Canada, U.S.A., etc.
Lower Cretaceous	Spain, Balkans, etc.
Jurassic	Sweden, Caucasus, Portugal, China, etc.
Triassic	Virginia, U.S.A., Japan, Sweden, etc.
Permo-Carboniferous	India, New South Wales, etc.
Coal Measures	England, Scotland, France, Belgium, Germany, Russia, U.S.A., Canada, China, etc.
L. Carboniferous	Scotland, Russia, etc.
Upper Devonian	[Bear Island (Arctic): true coal, but of more scientific than commercial value.]

This indicates that each of these geological epochs is, in some part of the world, represented by local "Coal Measures." Now we know from the palæontological record, as well as from our theories of evolution, that the organic life of the epochs was ever changing, trending toward genera and species liker and liker to those around us to-day. Hence, as coals are found throughout all these periods of time, we must either postulate the special survival of "coal-forming" plants, or accept the view that the plants of any geological age can make coal. In my opinion there is potential coal in every plant, in an oak tree as in a *Lepidodendron*, in a goose-grass as in a *Sphenophyllum*. In one of the greatest coalfields of Japan, of Tertiary age, I have seen much evidence that the woody trees of genera still living contributed to the thick beds of true black coal; and, to come nearer home, in Canada the great coalfields of the West are rich in evidence that they were produced from a mixed flora of "modern" type, mainly Gymnosperms and Dicotyledons.

Coal, in truth, is not the product of a particular kind of plant, nor is it the product of particular parts of plants; it may be produced by any parts of any kind of plant. But we are still ignorant of the extent to which differences in quality and in contents may depend on the differences in the parts of the plants producing it. This carries us into a realm of work too technical for present discussion.

To plants, then, we owe our coal, to coal our power, to coal innumerable substances wrought into our comforts and our luxuries. Our demands for power and for luxuries grow daily: does our source of these, our coal? The answer, as is probably well known, is in the negative. As a result of the recent searchings of heart caused by the war, it is also probably well known that we have certainly a few hundreds, possibly a thousand or two, years' supply of coal. But long before we have reached the limits of our reserves, coal will have become so expensive and difficult to get that we shall have to face the handicap of restriction of all those things coal provides. It may be of interest to some to have before them the estimated total reserves of coal of all kinds in the world. They are—

Asia	1,279,586,000,000	tons
America	5,105,528,000,000	„
Europe	784,190,000,000	„
Africa	57,839,000,000	„
Oceania	170,410,000,000	„

Many suggestions for reform and economy of our use of coal are before the public; and I will not repeat them. But it is of interest to know that the demands for Government intervention in our handling of coal are neither so novel nor so recent in origin as most believe. In the course of my efforts to read all that has been published on the aspects of coal research which interest me, I came upon the work of J. Williams, published in 1789. The book is in the British Museum, and the title page immaculate, else I should have thought I was reading extracts from the current newspapers. In 1789 this prophetic man proclaimed: "If our coals are really not inexhaustible, the rapid and lavish consumption of them calls aloud for the attention of the Legislature, because the very existence of the metropolis depends upon the continued abundance of this precious fossil . . . and not only the metropolis . . . but the most fertile countries in the three kingdoms. . . . It is high time to look into the real state of our collieries." He continues: "The present rage for exporting coals to other nations may aptly be compared to a careless spendthrift, who wastes all in his youth, and then heavily drags on a wretched life to a miserable old age, and leaves nothing for his heirs." If this was said in 1789, what can be said to-day?

Williams recognised the difficulties and economic dangers of restricting exports, and suggested that Government encouragement should be given for the development of coal resources in other parts, Cape Breton, for instance.

But to-day it will not help the world as a whole to waste coal outside as well as inside the United Kingdom; other counsels must prevail. I will not repeat the general suggestions for coal economy, much as I have some of them—the use of powdered fuel, for instance—at heart; rather let me present an aspect of the subject generally neglected.

The "analyses" of coal given by the chemist denote merely the proportions of carbon, hydrogen, oxygen, nitrogen and ash in the sample. Sometimes the amount of sulphur is determined. Thus a typical coal analysis is as follows—

C.	H.	O.	N.	S.	Ash.	
74·81 %	4·98 %	4·99 %	1·22 %	0·96 %	3·04 %	of 100 parts of coal.

What indication is there here of the molecular complexity of the mummied plants of which it is composed? What indication of the complexity which, out of 100 lb. of coal, yielded $2\frac{3}{4}$ oz. of benzol, less of toluol, and $\frac{1}{4}$ oz. of Perkin's mauve? There is obviously no indication in such analyses of the true combinations of the elements into chemical compounds, nor of the type of compounds into which they may be converted. Mauve and toluol and countless other products obtained from coal are valuable and costly, but I know of no rational efforts to attempt to discover what it is in the coal which is their source. Yet, were the source of each such substance discovered, there would open up a vista of potential economies, and we might then use coal only to get from it the things not obtainable in other ways. To-day Americans are finding it pays to grow sissal (*Agave rigida*) for the production of alcohol from its leaves, and the necessary machinery is run by the dried and caked fragments of the same leaves used as fuel. Both in German East Africa and British East Africa sissal covers hundreds of thousands of acres, and, it is said, the profit in exploiting it thus amounts to 20 per cent. at least. But this is merely one illustration of illimitable possibilities. The French, sadly out of coal by the war, have formed a committee to look into practical gas manufacture from substitutes for coal. To what do they turn to supplement the power they owe to coal? Again to plants. In a recently published report they found that even the squeezed pulp residues from olives gave not only a gas with a high illuminating power, but a charcoal which, with tar, makes good briquets for fuel. From a peculiarly resinous material, the strainings of the resin tapped from pine trees, they got a gas of specially high illuminating power.

Though at present there is no attempt to correlate these products with the details of botanical structure of the plants thus used or usable, such research cries out to be done; some day it will be done.

When we thoroughly know our coals, their contents and the sources of their contents, we shall have gone a long way toward overcoming the dangers of lack or restriction of coal. I see, as no impossible dream, not only the wise utilisation of the fuel we have, but the artificial production of particular kinds of coal from particular types of plants to supply special substances we may from time to time require as our civilisation advances.

In 1833 our countrymen led the way in microscopic examination of coal. For long we led in the production of coal; we have lost that lead. Ever since coal was a marketable commodity we have led the world's export trade in it—now, owing to the disposal of the stores of coal by Nature, we see that we cannot for ever maintain that lead. Hence, now, let our inspiration be to lead in real understanding of coal and the plants which formed it, and by our understanding master the coal problem.

But that means Scientific Research, and yet again Research.

A Few References to the Literature on Coal

The general reader will probably find most interest in "The British Coal Trade," by H. S. Jevons, 1915. Pp. xii, 876, 23 text figs. and maps. London.

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PRINTED IN GREAT BRITAIN BY RICHARD CLAY & SONS, LIMITED, BRUNSWICK ST., STAMFORD ST., S.E. 1, AND BUNGAY, SUFFOLK.

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