THE SPIRIT OF
THE SOIL

GORDON D. KNOX

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FIG. I

The Grevilleas shown above were treated, the plant on the left with complete chemical manure and the plant on the right with humogen and ordinary soil. The freedom of the side growths, apart from the general improved growth of the humogen-treated plant, is remarkable.

(The Royal Gardens, Kew.)

THE SPIRIT OF THE SOIL

OR

AN ACCOUNT OF NITROGEN FIXATION
IN THE SOIL BY BACTERIA AND OF
THE PRODUCTION OF AUXIMONES IN
BACTERIZED PEAT

BY

GORDON D. KNOX

AUTHOR OF

"ALL ABOUT ENGINEERING," "ALL ABOUT ELECTRICITY," AND "ENGINEERING"

WITH A FOREWORD

BY

PROFESSOR W. B. BOTTOMLEY

"Semina vidi equidem multos medicare serentes
Et nitro prius et nigra perfundere amurca
Grandior ut fetus siliquis fallacibus esset."

VIRGIL: *Georgics*, I. 193-195

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FOREWORD

THE interest aroused in bacterized peat during the last two years is sufficient reason for the publication of a popular book dealing with the recent researches on humus formation, nitrogen-fixation, and accessory plant-food bodies (auximones). Owing to pressure of other duties I had neither time nor opportunity to undertake the work myself, but in leaving this task to my friend Mr. Knox I had every confidence that the subject would neither lose in accuracy of fact nor in the interest of its presentation.

Mr. Knox's literary ability, combined with his scientific training, render him peculiarly well fitted to write a book popular in style, yet without sacrificing the scientific side of the subject. Mr. Knox has submitted to me the manuscripts of the various chapters, and it is a pleasure for me to be able to say, at his request, that I can take full responsibility for all the results which he has described.

I can confidently recommend Mr. Knox's book as an accurate and popular exposition of a new development in agriculture and horticulture which may have an important bearing on the national food-supply.

W. B. BOTTOMLEY.

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PREFACE

THE present volume is the outcome of the keen personal interest that I have taken for some eight years in the work on nitrogen-fixing organisms that has been in progress in Professor Bottomley's Laboratory at King's College. It would have been difficult for me to write of the subject without enthusiasm. To many botanists the beauty of plant life to some extent masks the supreme mysteries of the vegetable world. Few conceptions are grander than the wonderful storage system which from the beginning of biological time has enabled plant life to seize and hold in the tissues some of the steady stream of energy that flows continually from sun to earth, avoiding waste, steadily purifying the air, and rendering its composition constant. That is an old conception well established and commonly known. To-day, however, we are watching the growth of a new conception. Just as the plants have been steadily storing the energy that is required for the support of animal life, and making existence possible for them, so the bacteria in the soil have been supplying the plants with the essential substances that they require for their more limited activities. Nitrogen as such is valueless to plants. Were it not for the work of the bacteria in the soil no plant could

win a livelihood, for it is only when the abundant nitrogen in the air and in decaying organisms has been combined into suitable chemical compounds that it becomes available as a plant food. The work of Professor Bottomley has been concerned exclusively with the activities of these organisms, and his object has been to find a means for giving them an environment in which they can freely develop. His aim has been in fact to do for the bacteria the same service that the gardener and farmer perform for the plants that they cultivate. Husbandry is the oldest of the arts and sciences, bacteriology the youngest. In this book I have attempted to indicate some of the results that will certainly follow from soil inoculation. I am not suggesting that Professor Bottomley has found the whole truth, that later workers will not achieve the results that he can claim by more suitable methods. I think, however, that the evidence collected in the following pages will convince the reader that a notable advance has been made in horticulture, and that a new discovery of momentous consequence has been made in the accessory food bodies or auximones, a discovery that will complete and round off the corresponding discovery of vitamins and their relation to the health and growth of animals. Lastly, I have prepared the book in the hope that farmers and gardeners will, as they alone are able to do, carry these experiments into the wider field of everyday life. Farming and gardening are arts requiring expert knowledge. It is only reasonable to suppose that laws and conditions, comparable with those governing

the growth of plants, maintain for bacteria. The work of Professor Bottomley opens up an opportunity for every gardener and for every farmer to undertake important scientific work, and at the same time almost certainly to increase very considerably the yield from his land. Such work is of the very first national importance and of world-wide interest. It is certain that one of the most important factors in the fertility of all land is the nature of the bacteria in the soil. In every department of life man, by assisting Nature, has been generously rewarded. The science of bacteriology both in medicine and in the arts has very richly repaid the labour spent on it. It is inconceivable that horticulture and agriculture should prove exceptions to the general rule.

In the preparation of this book I have to acknowledge much assistance. To Professor Bottomley and his writings I am indebted exclusively for my knowledge of his work and for the major part of what I know about the subject in general. During the years that I have known him he has at all times given me access to his laboratory and to the reports that have been sent in to him. Throughout he has inspired, read, and criticized the manuscript of the book. I also owe much to Mr. Alfred Machen, who has shown and explained to me many of the experiments now in progress on the land. The chapters on the General Results from the use of humogen, on the Application of Humogen, and the practical hints in conclusion, are due entirely to him. Miss Mocke-ridge, by her valuable criticism, has saved me from

many errors, and helped me most materially in the general chapter on chemistry.

I have to thank the Editors of several papers for leave to make use of material published, notably the Editors of the *Proceedings of the Royal Society*, and the *Edinburgh Medical Journal*, the *Annals of Botany*, the *Journal of the Royal Society of Arts*, the *Biochemical Journal*, and *Country Life*. The Editor of the *Morning Post* has kindly allowed me to use the papers on the "National Food Supply," contributed by Mr. Charles W. Fielding. I have to thank that gentleman and Dr. N. L. Watson-Wemyss for the ready permission they gave me to make use of their writings. I have consulted several books in the course of my work, particularly *The Geological Survey of Ohio*, by Dr. Alfred Dachnowski; *The Soil*, by Dr. A. D. Hall; *Bacteria in Relation to Country Life*, by Dr. Jacob G. Lipman; and *Soil Conditions and Plant Growth*, by Dr. Edward J. Russell. I have also to thank the Editors of those papers which I have quoted in the text for permission to make use of the extracts that have appeared in their columns.

In typing the manuscript of the book Mrs. Marshall and her staff have very materially assisted me by their promptness and accuracy.

GORDON D. KNOX.

II, GARRICK STREET, W.,

August 9, 1915.

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THE SPIRIT OF THE SOIL

CHAPTER I

THE NITRATE PROBLEM

Geometric progression illustrated by bacterial growth—Geometric character of advancing civilization—Latter-day developments—Present prosperity—Threatened famine in power and nitrates—Science to the rescue—Sources of plant food—Cavendish and Bunsen—Electrically produced nitrates—A nitrate balance-sheet—The outlook—Increased demand—Diminished supply threatened—Bacteria as nitrate builders—Their use in agriculture.

PICTURE an observer suspended above the equator of the earth, unaffected by the swirl due to the earth's turning on her axis, but following closely her movements through space. Assume that at an instant in time he drops a bacterium on the hurrying surface beneath his feet, and that the bacterium, like the seed of the sower that fell on fruitful ground, falls into a medium ideal for its growth and finds nothing to check its power of reproduction. In twenty-four hours, when the same spot of the earth's surface was again beneath his feet, he would find, instead of the single bacterium he had dropped, a bacterial empire one hundred and seventy thousand times as numerous as the present human population

of the world.* If the bacterium were the anthrax bacillus, and the members were well developed, the length of each might be the five-thousandth part of an inch, and, had they developed end to end in a long chain during the short twenty-four hours spent by the earth in turning on her axis, the progeny of the original anthrax bacillus would have engirdled the equator thirty-seven times, welded into a chain close on a million miles in length. The vaunted achievement of Ariel engirdling the earth fades to nothingness beside the astounding energy shown by the bacteria in their passionate longing to perpetuate their kind. The facts of bacterial growth stagger the imagination, but, like most things measurable, they have been brought into some sort of order, and expressed and fixed in rows of figures by the mathematician. Marvellous as is the statement made above, even the enlightened schoolboy of to-day would see little to wonder at in it. Was he not as a child fresh from home tricked into attempting to estimate the value of the nails in a horse's shoe when the first nail was priced at a farthing, the second at a halfpenny, the third at a penny, and so to the last nail, and did he not give up the problem in despair? Since then he has laboured through the mysteries of the geometric progression and realized something of the magic of numbers.

What, however, if it should turn out that in our civilization to-day we have something comparable

* " With division occurring every half-hour, a single individual could become in one day the ancestor of 280,000,000,000,000 bacteria " (Dr. Jacob B. Lipman, *Bacteria in Relation to Country Life*).

with a geometric progression ? There are some who would have us believe that the history of the earth is a succession of cycles, that civilization attains to a certain point, and then, like Sisyphus's stone, falls back to the bottom of the hill, only to be rolled up it again by toilsome effort. With such a conception I have no concern here. Inevitably, recorded history tells us nothing of it. In any case we can know of nothing except a small portion of the hill up which we have been ascending, but the study of that small portion of the hill is amply sufficient to stimulate our imagination, and may be to arouse our alarm.

Quite early in the history of the world we can glimpse at the material origins of civilization. Even to-day there are great areas where the road exists only in the primitive form of the track, where the wheel is unknown; tradition, wrongly perhaps, has brought down to us the tale of when and how the wedge and the screw were first devised as aids to man's enterprise. As we glance back over the pages of history a matter of some three thousand years we seem to see something in it which suggests that the world's progress is a geometric progression, and that we are at a point to-day when each doubling of the terms in the series involves the most formidable consequences. Can we realize that in the thirteenth century lumps of coal were being given to the poor in Scotland as alms, and that as recently as 1735 the coal consumption of England attained only two million tons in the year ? Do we appreciate the fact that it is not until 1925 that we shall celebrate the centenary of the first steam railway, that it

was not until 1878 that the electric dynamo became a practical machine? In ancient Greece the mariner who voyaged as far as the Pillars of Hercules in Spain was a traveller expected to bring back stories of monsters and other wonders, but to-day there is not a portion of the earth's surface which is not more or less exactly mapped.

Despite the poverty of the world, we are for the moment living in a period of abundance, as witness the violence of the attacks made upon Malthus, who wrote at a period when it seemed that man had reached the limits of his food-supplies. Between then and now intensive agriculture has arisen as a new art; the great granaries of the world have been available for all, thanks to the development of the vast transport agencies. The mighty deposits of nitrates in Chili and Peru, Stassfurt, and elsewhere, have been mined to provide the farmer with the necessary fertilizers, and at the moment the supply is ample for the world's needs.

Those who care to look forward to the world's future, however, are uttering, Cassandra-like, doleful prophecies. The inroads made on the great forests of the United States, especially, have been so serious that the world is called upon to face the danger of a timber famine. Commissions have been appointed to estimate how long we may expect the coal reserves which are being worked at a rapidly progressive speed to continue to furnish their abundant energy to the world. It is recognized that the time will come, and is not so very far distant, when Canada, the United States, and the other great wheat-pro-

ducing countries of the world, will be unable to furnish more food than they require for their own consumption. It was Sir William Crookes, now President of the Royal Society, who as President of the British Association first startled the world by warning it of the menace to its food-supply. The increased control gained by man over Nature—a geometrically increased control—has enabled him to draw on the capital stored in the ground to an extent unthought of by his ancestors, and, like the proverbial *nouveau riche*, he has been squandering the treasure to which he has gained access. Appetite has come with eating. The treasures that at first seemed inexhaustible are now harder to win than they were, are now showing signs of becoming exhausted, and Nature is threatening to return our spendthrift cheques to us marked with the red ink comment, "No effects."

Experimental science, when this day arrives, promises to treat us rather as an indulgent guardian than as a hard-hearted money-lender. There is happily in the sun a portion of an estate that we have been able neither to sell nor to mortgage, and when Sir William Crookes startled us into taking stock of our resources, the men of science set to work to see whether it might not be possible to make a better use of our yearly income than under the influence of an apparently unlimited capital we had been doing in the past. Two foodstuffs in bulk are necessary for the life of plants, Carbon and Nitrogen. The first is omnipresent in the air, and under the influence of sunlight the plants from the earliest

times have seized it in the form of Carbon dioxide, and changed it in their leaves to the form in which they could assimilate it. The second, Nitrogen, is also present in the air, but in such a form that no plant is able to assimilate it or to combine it so as to render it available for its use. Sir William Crookes put the problem clearly and succinctly. Either the world in thirty or forty years from the date of his address was doomed to suffer from a wheat famine unexampled in the history of the world, or it was incumbent on the man of science to find a practical means of inducing the inert nitrogen of the air to enter into combination with oxygen, and form the nitrates essential for plant food.

There was one outstanding classical experiment to guide the chemists in their elucidation of the problem. In 1785 Cavendish discovered that when an electric current was passed through air an acid was formed, and seventy-two years later Bunsen established that the acid so formed was Nitric Acid, the Oxygen and Nitrogen of the air having been induced by means of the energy of the electric discharge to enter into combination to form the acid. On this groundwork the chemists set to work, and in a few years' time they had devised a practical method whereby the water-power of the great waterfalls could be used to produce a high-tension electric current. The current was allowed to discharge across a gap, was spread out by means of a powerful magnet into a great disc of blazing, roaring flame, which, on air being forced through it, induced the Nitrogen and Oxygen present to enter into combina-

tion. By this and by other methods the chemists have achieved a partial solution for Sir William Crookes's problem. For they have found a method, dependent on income and not on capital, whereby the nitrates required for agriculture can be produced at a cost that enables them to compete successfully with the nitrates prepared from natural deposits.

The achievement is one of which the chemists may well be proud, but after all it is only a partial solution. We were threatened by Sir William Crookes with a nitrogen famine, but since then men of science have threatened us with an even more serious danger, an energy famine. At present in coal we have an abundant supply of energy available at a low cost, but when this begins to give out the value of water-power must advance by leaps and bounds, and force up with it the cost of the manufactured nitrates to such a point that the farmer will be unable effectively to compete with the other potential users of power.

We are brought back therefore to a reconsideration of the problem, and it may prove of value briefly and roughly to formulate it in tabular form as follows:

<i>Demand for Nitrates.</i>	<i>Sources of Supply.</i>
Agriculture ..	Nitrate deposits (already showing signs of exhaustion).
Explosives ..	Chemical means (in all of these the utilization of power on a large scale is essential).
Various ..	Farmyard manure, sewage, etc. (a decreasing source, which in some cases will not pay the cost of collection). Bacteria (as in those associated with leguminous plants, and as those cultivated by the new system of treating peat). These are only indirectly a source of nitrates, as they form complex nitrogenous food substances rather than actual nitrates.

There seems no reason to believe that there can ever be a lessened demand for nitrates. With the continued increase both of population and of standard of comfort, and with the rapid exhaustion of the virgin soils that were to be met with in the early days of farming in America and Canada, the drain made on the world's stock of nitrates by agriculture must continue to increase; the present war indicates that the demand made by explosives for munitions of war will be more than maintained, while great engineering works will probably absorb more than in the past. Lastly, with the increased activity of the chemical trade it seems inevitable that in this direction, too, a further increase in the production of the world's nitrates will be essential.

From the standpoint of supply the situation at first sight does not seem promising. As Sir William Crookes pointed out, the exhaustion of the natural deposits is already in sight, and there seems no valid reason for believing that new sources of nitrates will be discovered to replace the old. Chemical producers of nitrates will before long find themselves in serious competition with other users of power. With the introduction of the motor car farmyard manure will become less and less available, while at present it has seldom proved practicable to utilize the waste sewage produced in the great towns. As one writer has expressed it, it is no more reasonable to quarrel with the farmer for not utilizing the sewage of the towns than it is to quarrel with the manufacturers for not collecting and burning the vast masses of carbon that are poured out daily from the

FIG. 2

The left of the two lilies shown above was grown in humogen and ordinary soil, while that on the right was grown in a complete food compost. The average number of blooms on the batch (48 size pots) was six as against four, and it should be noted that this is the common effect of humogen treatment on bulbs.

(The Royal Gardens, Kew.)

private chimney-pots of householders in the great cities.

There remains one great source of nitrates and a great army of workers adapted from the beginning of time for the fundamental work of nitrate production, fitted for that work and that work alone, an army of workers that require only the intelligent co-operation of the farmer and the man of science efficiently to perform their duties—the bacteria of the soil. It is the purpose of this book to show how an English man of science working in an English laboratory has set out to solve the problem of facilitating the work of the soil bacteria, how the experiments carried out in laboratory, hothouse and field, all go to prove that the bacteria of the soil intelligently applied cause a growth of crops heavier than that obtained by manures owing to the steady supply of nitrogen that they furnish to the plants, and owing to the potash and phosphate that they render available, and, lastly, how in the course of his researches he has been forced to believe in the existence and potency of certain mysterious accessory food substances produced through the action of the bacteria, which bring about a development of plant life unparalleled by any manure hitherto known, whether natural or artificial.

I have no wish that these statements should be accepted on the *ipse dixit* of the workers themselves, or of those who have conducted field experiments. In the following pages the attempt will be made to describe simply the laboratory results of the last eight years' work at the Botanical Laboratories of

the University of London King's College. At the same time an account will be given of the results obtained in the field. I shall describe, too, what I have seen myself in some stations at which large scale experiments are now in progress, and in conclusion I shall give in their own words the opinion of practical agriculturists on the material used and the results that they have obtained. On these bases, and, if need be, on experiments conducted by himself, each man will decide for himself whether or not the saving of the present situation and the future of agriculture rests with the bacteria of the soil. For my own part I have no uneasiness as to the verdict.

CHAPTER II

ENGLAND'S FOOD-SUPPLY IN PEACE AND WAR

Laissez-aller policy—Two months' famine margin—Wheat-growing in England and abroad—Wheat imports—Decay of wheat-growing in England—Increased acreage yield abroad—Stagnation in stock-raising—Inevitable wheat shortage—Redistribution of crops suggested—Difficulties of the scheme—The competition for nitrates.

BITTER experience gained in the present war is forcing home the lesson that too heavy a price may be paid for the pursuing of an easy-going policy of go-as-you-please. Were the price demanded only that of British treasure, the non-organization of the country would be stupid and suicidal. But the cost of it to-day, as we have had to read the reckoning, is the lives of our fellow-men sacrificed to our past blindness and the unspeakably grave peril, not yet for a certainty surmounted, that Britain may be humbled to the dust through famine.

The voices of those preaching agricultural reform are the voices of men crying in the wilderness, calling attention to a risk as grave as that which Lord Roberts was never tired of voicing; but the country closes its ears to those who tell it of the risk just as they callously ignored the need of anything approaching national service.

It is, however, notorious that Great Britain lives from day to day with a margin of but two months between her and famine. Let the seas be closed only for that period to merchant vessels, or let the nations that send her their corn from the harbours of the Seven Seas be unable to launch their supplies, and the price of wheat will mount by leaps and bounds until the poorer classes of the country will find it impossible to buy a loaf of bread. This is the tragic side of the picture, but on other grounds than those of the immediate national danger the situation calls for reform. It is not the truth that English land is unsuited for wheat-growing, or that the great percentage of the land is inferior to that cultivated in France or Germany. The problem exists in an equally acute form as regards stock-raising, and in that connection is no less urgent in demanding a solution. And from both standpoints the issue is bound up with soil fertility.

Few who are not expert agriculturists can have any conception of the vast discrepancy between the conditions prevailing in England and those obtaining abroad. The situation, however, has been carefully studied and explained by several observers, notably in the early months of this year by Mr. C. W. Fielding in the columns of the *Morning Post*, and it is from his articles based on official figures that the chief conclusions of the present chapter are drawn.

In agricultural produce England buys from abroad the enormous total of £333,000,000 worth of imported soil products, a value £133,000,000 greater than the total manufacturing exports, once deduction

is made of the cost of the raw material imported in connection with their manufacture. The first question naturally arising out of this statement is how far this volume of imports is a necessary condition of England being a manufacturing country, and a provisional answer is given most simply by a comparison between the conditions in the United Kingdom, France and Germany.

	<i>United Kingdom.</i>	<i>Germany.</i>	<i>France.</i>
Total acreage under cultivation	48,000,000	86,000,000	67,000,000
Of which acreage under plough	20,000,000	65,000,000	47,000,000
Of which acreage under grass	28,000,000	21,000,000	20,000,000
Percentage of cultivated surface in grass ..	60 per cent.	60 per cent.	30 per cent.
Acres growing bread grain	1,791,000	20,000,000	19,500,000
Percentage of total cultivated area growing bread grain, about ..	3 per cent.	25 per cent.	30 per cent.
Total quarters bread grain produced ..	7,000,000	73,000,000	47,000,000
Production of bread grain per head of population	90 pounds	485 pounds	500 pounds
Head of cattle	11,000,000	20,000,000	14,000,000
Population	45,000,000	65,000,000	40,000,000
Population engaged in agriculture	1,350,000	10,000,000	8,000,000
Percentage of population engaged in agriculture	3 per cent.	17 per cent.	20 per cent.
Bushels bread grain produced per acre of total arable land ..	3	9	8
Acres grass used per head cattle, about ..	3	1	1½

These statistics are startling to anyone who has the interests of the nation at heart, and the discrepancy between the practice of Great Britain and that of her great Continental neighbours stimulates a further inquiry. There is a grave challenge to British farming in the statement that only 3 per cent. of our cultivated land is employed in growing wheat as opposed to 25 per cent. in Germany and 30 per cent. in France.

The conditions have not always been the same as they are to-day, and the gravity of the problem is emphasized more clearly by a further comparison made with other countries. During the last thirty years in the countries mentioned below the total acreage under cultivation has varied little, but the attention paid to the growing of wheat has enormously increased everywhere except in England, where there has been a large fall in output, as is shown from the following table:

Germany has increased her wheat production	..	25 per cent.	
France	..	7	..
Russia	..	90	..
Hungary	..	25	..
Roumania	..	33	..
Bulgaria	..	22	..
While the output of the United Kingdom has <i>fallen</i>	30	..	

An attractive explanation of the situation would be that the pressure of population in other countries had forced into wheat cultivation land unsuited for it, and that the increased acreage and increased gross yield on the Continent was only obtained by sacrifices of such an order that the farmers of this country did not care to follow suit. An analysis of

the figures, however, shows a further disquieting result. During the period considered the yield of wheat per acre in the United Kingdom has remained absolutely stationary, while in those countries that have increased their acreage under wheat the yield has risen from between 15 to 40 per cent. The following is the detailed comparison:

In Germany the yield has gone up	..	..	40	per cent.
In France	..	..	18	..
In Russia	..	..	20	..
In Hungary	..	..	15	..
In Roumania	..	..	20	..
In Bulgaria	..	..	25	..

Perhaps it may be thought Great Britain makes up for her deficiencies as a wheat-grower by a marked predominance in stock-raising. The facts unfortunately are otherwise, as the figures again show:

In forty years the German stock of			
cattle has increased from	..	..	15,000,000 to 20,000,000
And pigs from	..	..	7,000,000 to 22,000,000
France: Increase of cattle from	..	..	11,000,000 to 14,000,000
Increase of pigs from	..	..	5,000,000 to 7,000,000
Belgium: Increase of cattle from	..	..	1,200,000 to 1,800,000
Increase of pigs from	..	..	600,000 to 1,300,000
Hungary: Increase of cattle from	..	..	5,000,000 to 7,000,000
Increase of pigs from	..	..	4,000,000 to 7,500,000
The United Kingdom has increased cattle only from			10,000,000
to 11,000,000; while the stock of pigs remains practically the			
same—viz., under 4,000,000.			

In normal times the situation is a grave one for the nation, but in view of the European War it offers a menace of exceptional gravity. Let us assume, as we have now perhaps a right to assume, that the allied navies will preserve the freedom of the seas as magnificently inviolate to the end of the war as they have done during the first twelve months of it, and that we

have therefore no reason to fear any artificial stoppage of our overseas supplies. The Navy, despite its success, cannot influence the shortage in corn-stuffs that has been brought about inevitably owing to the war.

As Mr. Fielding points out, it is the richest wheat area of France that has suffered German invasion; East Prussia and Galicia, both of which have suffered invasion, are the most important grain-growing areas in Germany and Austria. Belgium in normal times is a wheat importer, but with her territory violated will have grown less than usual, and will have to make a larger demand than usual on the general supply. Russia, in normal times a large exporter, can now not only have little if any to export, but with the Dardanelles at present closed may be unable to send any supplies to the European market. The shortage of the European harvest is estimated by Mr. Fielding to be very large, and the only source from which an increased supply over the normal can reasonably be expected is from Canada; and the bulk of any Canadian increase of wheat must be at the expense of reduction of other crops in Canada. The situation therefore is that, with the shortage of European output caused by the war, other countries of the world will have to supply enormously increased quantities.

To meet the present deficiency and to make Great Britain self-supporting there is no need to have recourse to such sensational means as the bringing of Scottish deer forests under cultivation. All that would be required would be to reallot the uses to

which the ground under cultivation is put at present, to devote 8,000,000 acres to wheat, 16,000,000 acres to general plough cultivation, and 24,000,000 acres to grass. By these means England would be self-supporting as regards her wheat-supply.

It is not suggested that the situation is an easy one to settle. Many complex interdependent factors enter into it, fiscal, economic, social and practical, and in times of peace a great deal of business and a great deal of thought would be necessary before the problem could be effectively approached. To-day, however, the country is at war, and the food problem is only second in urgency to that of maintaining our armies at the front and of supplying them with munitions. A single condition stands out with unmistakable clearness. The internal wheat-supply of Great Britain must immediately be very considerably increased. Abroad in times of peace our neighbours have solved the problem of feeding their own population by intensive cultivation, but whereas both France and Germany use 105 pounds of artificial fertilizers to the acre, England makes use only of 48 pounds to the acre. The need has now arisen with exceptional urgency to get the utmost food value possible out of the soil—wheat for the direct consumption of man, pasture and other foodstuffs for the purposes of stock. And this exceptional need has arisen at the very moment when the demand on the world's stock of nitrates has attained a maximum hitherto undreamt of. It finds the British soils at a dangerously low ebb in their available supplies both of phosphates and of nitrates, and if

large tracts of our land are to be laid down in wheat, these must be supplied to them at no matter what the cost. To-day the country is called upon to face at once under the exceptional conditions of war the very problem that will have to be faced in years to come as a result of natural developments. The response made by men of science, above all by the bacteriologists, to the note of warning in 1898 by Sir William Crookes suggests that we may be in a position to-day to meet the demand without undue expenditure.

CHAPTER III

BACTERIA AND PROTOZOA

The *annus mirabilis*—Developments of the modern era—The atom—Electricity—Medicine—Greek decadence due to malaria—Extension of human knowledge—Mendel—The new romance—The rôle of the earthworm—Bacterial empires in the soil—Their vicissitudes—Their work—Bacteriology and astronomy—Properties of the bacterium—Advances in pathology—The situation in botany—Broad generalizations—Work and habits of the bacteria—Preparation of farmyard manure—Carbohydrates and proteins—Break-up of carbon compounds—Three groups to deal with proteins—Value of farmyard manure—Denitrifying bacteria and nitrogen fixers—The protozoa.

AN epitaph dating back to the most glorious period in Athenian history has set down in terms of noble simplicity the record of the great Athenians who perished fighting for the country on salients of offence that had been thrown out in all directions into Greece and into all the barbarian hinterland. The world, latinized, has since spoken of the period as the *annus mirabilis*, and the epitaph sums up grandly the stupendous blaze of energy that kindled the intelligence of the world, and still acts to-day as its most potent quickening force. It is open to question, however, whether the Greeks ever realized the astounding phenomenon in which they played their part, just as it is open to question to-day

whether we realize the unparalleled developments of the present era.

Contrast for a moment the position of affairs as it was in 1850 and as it is to-day, looking only along a very narrow front. We had learnt by long and painful experiment that all matter was composed of elements, and Mendeléeff had drawn up his famous table showing that there was some kinship between the atoms. To-day we have made the tiny atom almost visible, been able to watch the spark that its impact makes, traced out its path as it hurls itself through a gas, shattering the molecules that would bar its way, learnt something of the subtler matter of which it is composed. In electricity only the broad foundations of the science had been laid; the telephone was not conceived of even by the dreamer; the telegraph was already doing pioneer service in shortening the world's distances; but no man had conceived of harnessing the ether and forcing it to carry the impulses impressed on it by the electric spark. Medicine was still in an earlier era. Chloroform as an anæsthetic had barely been discovered, and the surgeon, ignorant of the nature of infection, could not dare to take advantage of more than a tithe of what it offered. Then came the work of Pasteur and of Lister, bringing in its train a flood of knowledge that has swept away the dull mass of ignorance, spread since the beginning of time across the path of man's progress. Had the knowledge of to-day been available to the Greeks, there would have been no need for the sudden eclipse of her civilization. It was not her internal dissensions that destroyed

her, but the sudden inroad of malaria that carried off the best of her sons, left the race de-energized, and forced her to hand on the torch of civilization to the victorious Romans.

Just as the genius of Greece quickened into activity the earlier of the arts and sciences, so the genius of modern Europe is to-day extending in all directions the horizons of human knowledge. Are not the biologists following out the great principle glimpsed at by Mendel, analyzing the factors of heredity, and groping after the elucidation of one of the supreme mysteries of the world? Is it not true that the experimental botanist is using a sure method to recombine the qualities of the plants and evolve new species, as a watchmaker might take the parts he needed from a dozen watches and build up a new one to suit his purpose? Have we not found that the earth is something more wonderful than any thought her before? The Greeks looked on the goddess Gæa as the mother of mankind. In their glorious mythology they pictured that men and women had broken into life as the stones cast on to her touched her life-giving soil. Countless legends, expressed in astonishingly beautiful imagery, have told of the sacrament of spring, and the Celt has peopled the soil with gnomes and pixies, friends or enemies to man. Science working with polished microscopes, with bottled reagents, with curiously twisted retorts, and all the paraphernalia of the laboratory, has rent in twain the closely knit and woven veil that barred our access to the mysteries of earth, and as these are revealing themselves to us

the wonder of them far transcends all that the imagination of the poet has conceived. In setting aside the romance of the past the laboratory is guiding us to an astonishingly greater romance of the present. The child's "Let us pretend," a pitiful attempt to furnish the food that its imagination demands, gives place to the cry of "Let us know," and in imaginative splendour the knowledge of to-day presses out beyond all that was previously conceived.

Who in the past could have imagined the mysterious happenings that take place in a small plot of garden soil? It was a revelation to the world when Darwin, lifting a corner of the veil, told of the stupendously great part played by the earthworm that had been "carrying on" unheeded or resented for countless ages of time. But to-day we are beginning to know that the soil which the gardener turns with the spade is the site of countless vast empires of bacteria. They are empires that rise and fall in the short space of weeks, that have great tasks to perform, and devote themselves wholeheartedly to carrying them out, empires liable to countless vicissitudes. Now they are overwhelmed by the vast immigrations that come to them suddenly as gardener or husbandman pours into their borders countless myriads of individuals with each spadeful of his manure. Periods of drought wreak havoc on their colonies, the lives of whole empires being dependent on the chances of the climate. They are preyed on by monstrous protozoa that may exact a greater toll than even they with their astounding

fertility can cope with. Or they may perish through their own activity, their life clogged by the products they have themselves formed. Widely they differ among themselves. Some of them build up, others of them destroy; even in the same species there are vast differences. Like communities of men and like single individuals, there are some that are energetic, others that are lazy, others that are tired; as food fails, or is abundant, they are poorly fed or well nourished. They are healthy or sick. To a bad environment or a good one they respond as readily and as notably as the people in our great cities, and with them, too, their heredity has a dominating influence.

Only within recent years have we realized how intimately our prosperity is dependent on the bacterial population of the soil. Without bacterial activity it would be of no avail to the farmer to dung his crops; it would be useless for him to attempt to enrich his soil by ploughing in green stuff. The plants and trees that have lived and died wresting Carbon from the air would only cumber the land. All vegetation would be choked, and the earth would become a vast wilderness, unbeautiful and silent, save for the winds and seas and other manifestations of lifeless forces.

Though at present we are only groping as pioneer discoverers in a new universe, there are some great features that we are able plainly to recognize, dimly, it may be, as astronomers who map the surface of the moon. As the astronomers can speak with certainty of the mountains of the moon, of the con-

ditions of its atmosphere, of the laws governing its movement through space, so there are many properties of the bacterium on which it is safe to dogmatize. We know that the bacterium is an organism low in the vital scale, consisting of a single cell, the protoplasm or vital unorganized portion of which is surrounded by a cell membrane which may consist of cellulose, but which more often is made up of a horn-like substance. We are on sure ground when we state that it usually reproduces its kind by forming a partition in the middle of its substance and dividing into two. Observation has taught us that the time taken for division is in favourable conditions about half an hour. It is certain that in the vast kingdom of the bacteria there are only a few that are able to give rise to diseases in man and animals. Most of these have certain characteristics that enable them to be certainly identified and incriminated by the bacteriologist. The pathologist has gone farther, and is getting an insight into the means by which the body is able to repel the attacks by which it is constantly threatened. He talks learnedly of opsonins, antibodies, and the like, and his knowledge at any rate is sufficiently precise and accurate to enable him to build up on it a rational system of treatment for the individual struck down by a disease.

While the bacteriologist who has directed his attention to the bacteria connected with the causation of disease stands on a firm foundation of proved and demonstrated fact, and may compare his results with those with which the astronomer deals in

mapping the moon, and in computing her orbit, the position of the bacteriologist who is grappling with botanical and agricultural problems is far less enviable. He must be compared rather with the men who are making a study of Mars. There are certain broad facts of which he can speak with certainty, but as regards others he is beset with controversy, struggling as it were to put a correct interpretation on the vague markings that he speaks of provisionally as the canal system of Mars. There is no dispute now as to the prominent part that bacteria play in relation to soil fertility. It is a commonplace that in an ounce of rich loam soil there may be as many as 150,000,000 bacteria, while in ground polluted with sewage the number may reach the fantastic total of 3,000,000,000. Much, too, of the work that the bacteria accomplish and of their habits is known, proved and accepted. Warmth and a moderate amount of moisture promote their growth; cold and excessive moisture or excessive drought arrest their development. There are some that can thrive in the presence of air, others that can only do their work if air is rigidly excluded. The function of some of them is to break down complex substances to simpler bodies or even to elements; the function of others is to build up substances of high potential energy from inert constituents. Without their activity the world would rapidly arrive at a deadlock. The material of plants and animals that had reached and passed their prime would cumber the ground, and the fabric of their tissues would not, as now, become available as the raw substances

from which other plants and animals can build up their tissues.

Such are some of the broad generalizations that constitute the foundations on which the plant bacteriologist is called upon to build, and already from them he has been able to formulate other narrower generalizations that are of vital importance to the art of agriculture. We shall see more of them in later chapters, **but** it may be helpful at this stage barely to outline the chief points on which, as we know it at present, the question of soil fertility from the bacterial standpoint mainly depends. One may accept it as broadly true that we know the conditions of soil fertility if we are able to trace the processes by which a load of farmyard manure becomes available as plant food.

When the manure is thrown freshly on to the heap it consists essentially of a heterogeneous mass of material, loaded up with bacteria, and containing a great variety of Carbon compounds, with traces of Phosphates, Potash, and so forth. It is with the Carbon compounds that we are concerned. These fall into two great classes—that in which the Carbon is combined with various quantities of Hydrogen and Oxygen, and that in which Nitrogen is also one of the constituents (the proteins). As they are found in fresh manure neither class is available as a plant food. Common farmyard experience tells us that the manure-heap heats and shrinks, and it needs no great effort of imagination to realize that a process is at work comparable with what occurs when a bonfire is being burnt. And this is actually what is

taking place; but whereas in the bonfire a temperature is reached at which the oxygen of the air is able directly to combine with the Carbon compounds and break them down into Carbon dioxide and Water, in the manure-heap a similar but slower and less complete process is occurring. This change is the earliest to be noticed, and though other changes are happening at the same time, they are more logically considered as being later. In the first instance the bacteria—there are varieties that can do the work in the presence of air if the heap is loosely compacted, and varieties that can accomplish it if all air is excluded—break down the complex Carbon compounds, turning them into simpler bodies, and partly into Carbon dioxide that escapes into the air. These nations of bacteria wax and wane, giving place to three separate groups that one after another deal with the nitrogen compounds. The bacteria called upon to deal with these bodies have to be fed with readily assimilable carbon compounds. The first group, some of whose members can work with air and others without, seize on the nitrogen fixed in complex groupings and split off ammonia from the protein (NH_3). Their finished product they hand on to another group. These can only work in the presence of air, and they require lime or some basic material to absorb the acid they produce. Under their influence the ammonia they have had passed to them as the raw material (often in the form of Ammonium Sulphate $[(\text{NH}_4)_2\text{SO}_4]$) is changed into nitrite (NO_2), and this by a third group, also acting in the air, and in the presence of a base becomes

nitrate (NO_3), which will be found in the heap in some such soluble form as Calcium Nitrate [$\text{Ca}(\text{NO}_3)_2$].

Apart from the value of its mechanical structure, and apart from the Phosphates and Potash that it contains, the essential value of farmyard manure to the land is that it possesses sufficient carbon compounds in assimilable form to act as a food-supply for the bacteria, and that it contains a large supply of the nitrogenous food material essential for plant nourishment.

This is not the whole story, however. The bacteria of which I have so far spoken are the fairy godmothers of the romance—the fairy super-godmother has not yet appeared on the stage—but the romance itself would be incomplete if there were no hard-featured, cross-grained witch. Experience has long taught that the loosely piled heap will burn away to waste if it is too loosely stored owing to the excessive amount of oxygen supplied to the first group of bacteria. In agriculture, as in politics, the advice of Talleyrand especially as regards bacteria *surtout pas trop de zèle* is eminently sound, but however carefully he goes to work, the farmer may find that the cross-grained witch has come uninvited to the feast in the shape of a denitrifying bacterium that seizes on the precious nitrates designed as plant food, and wastefully turns them into the nitrogen that is useless for plants, and escapes inert into the open air.

It is the super-godmother, however, that comes to the rescue. A group of bacteria exists; the name of one of the group is *Azotobacter*, and it has the

power of starting with the inert nitrogen of the soil air and of changing it into nitrogenous plant food. The rotted manure gives it the food of which it stands in need, and under favourable conditions it is able to go on steadily adding to the store of nitrogenous food material in the soil.

Such in crudest outline is the function of the soil bacteria and the way in which they lead to an increase in soil fertility. In the chapters immediately following I shall endeavour to describe their work in greater detail, and to show how it is possible for man successfully to co-operate with them. A word, however, in conclusion of this chapter must be written of the protozoa, for though they are not concerned with the general argument of this book, they bear an important relation to the soil bacteria and seriously affect their welfare.

The protozoon is not a bacterium, but a minute animal requiring the magnification of a strong microscope lens to be seen. Small though he is, he is as terrible and monstrous a foe to the bacteria as the vast swamp monsters must have proved to emerging man in the Eocene times. Looked at in water under the microscope he is seen creating in the medium whirlpools against which the hapless bacteria are powerless to contend, and drawing them defenceless into his body. Recent experiments at Rothamsted have shown that these animalculæ in certain conditions may seriously check the bacteria of the soil, and may gravely affect the health of plants, especially in rich, highly-manured soil. Experimentally in horticulture it has proved practicable to get rid of

them by chloroform and other similar means, and it seems as if the burning of cultivated soil by the Indians, a practice dating back to traditional periods of Indian agriculture, may have had as one of its benefits the destruction of the protozoa of the soil.* Fortunately they are less resistant than the bacteria, and when these stringent methods are employed all the protozoa perish, while a considerable number of the bacteria are left, and these, rid of the protozoan enemies, are able to jump into an amazingly rapid development and continue their work of securing a suitable soil environment for the plants. It is, however, only in excessively manured soils that they constitute a serious problem, and this short account given of them may therefore suffice.

* Cf. Virgil, *Georgics* :

“ Often you will find it well to burn
The garnered field and set the flimsy straw
A-cackling in the flames. Whether perchance
The land in this wise finds some unknown force,
Some fat enrichment; or that every fault
Thereby is purified by fire, and all
The useless humours purged; or that the heat
By its own virtue loosens secret pores
And paths unseen whereby the sap may flow
To the young grasses.”

CHAPTER IV

PEAT AND ITS USES

Early investigations of the Royal Society—Continuity of mental processes—Reality of material progress—Diamonds and peat: an analogy—Conditions of peat deposition—Its constitution—Variations in composition—Mineral and organic residues—Peat formation—Peat, lignite, and coal—Extent of peat deposits—Uses of peat—Fuel—Power—Chemical products—Paper—Artificial wood mattresses—Surgical dressings—Litter—Dr. Dachnowski's views—Objections to peat as manure—Experiments with peat-moss litter at Kew Gardens—Deleterious effects—Dr. Voelcker's explanation—Contrast with humogen.

IF those who affect to consider that there has been no advance in the world's knowledge during the last quarter millennium would study the early history of the Royal Society, founded a little more than 250 years ago, they would be amazed chiefly by two points. The first would be the completeness with which the founders and early Fellows of the Society adopted the methods of observation and experiment, reasoning according to completely modern methods of thought, and the second the appalling extent of ignorance that prevailed among those who were the best instructed and most enlightened of their time.

Men steeped in literary lines of thought are frequently pleased to quote with smug expressions of

approval the old French saw, *Plus ça change, plus c'est la même chose*, and affect an almost personal triumph when they are able to show that the passions and mental processes in man to-day are strictly comparable with those prevailing in the earliest historic times. They seem to believe that in emphasizing the fact that the various races of men are fixed types, variable only within the limits of a fixed type, they are confuting the idea of there being any possibility of progress. In doing so they belittle and deny the value of the material advances made, blinding themselves to the real facts of progress.

When one cares to go back to the original records, however, the reality of this material progress is strikingly brought out. In turning over at random notices of the early investigations made by the Fellows of the Royal Society, one comes across such records as the following:

" *March 25, 1661.*—Mr. Boyle was desir'd to bring in the name of the place in Brasil where that wood is that attracts fishes; and also of the fish that turns to the wind when suspended by a thread."

" *May 8.*—Dr. Clarke was intreated to lay before the Society Mr. Pellin's relation of the production of young vipers from the powder of the liver and lungs of vipers."

" *June 5.*—Col. Tuke related the manner of the rain like corn at Norwich, and Mr. Boyle and Mr. Evelyn were intreated to sow some of those rained seeds to try their product."

" *June 26.*—Sir G. Talbot brought in his experiments of sympathetick cures."*

* The following extract from this paper may be of interest:
"An English mariner was wounded at Venice in four severall

" July 10.—The fresh hazell sticks were produced, wherewith the divining experiment was tried and found faulty.

" September 4.—Sir K. Digby brought in a letter from a friend of his in Florence, written in 1656, which treats of a petrified city and inhabitants."*

Instances of this sort could be quoted almost indefinitely to show the extent of the prevailing ignorance of natural phenomena, and a great debt of gratitude is owed to the Royal Society even in those early days for their fearless investigations. A source that they used largely for extending their knowledge was to make inquiries of sea captains and of residents in foreign countries to confirm or refute the astonishing stories that were brought from abroad to this country. Sprat, in his *History of the Royal Society*, prints a long list of the questions addressed by the Society in its early days to Sir Philiberto Vernatti, resident in Batavia, and of his answers. The first of the questions is:

places soe mortally, that the murderer took sanctuary, the wounded bled three days without intermission; fell into frequent convulsions and swounings; the chirurgeons despayring of his recovery, forsook him. His comrade came to me, and desired me to demand justice from the Duke upon the murderer (as supposing him already dead); I sent for his bloud and dress'd it, and bad his comrade haste back and swathe up his wounds with cleane linen. He lay a mile distant from my house, yet before he could gett to him, all his wounds were closed, and he began visibly to be comforted. The second day the mariner came to me, and told me his friend was perfectly well, but his spirits soe exhausted he durst not adventure soe long a walke. The third day the patient came himself to give me thanks, but appeared like a ghost; noe bloud left in his body."

* Weld, *History of the Royal Society*.

“ Q. 1. Whether Diamonds and other Precious Stones grow again after three or four years, in the same places where they have been digged out ?

“ A. Never, or at least as the memory of man can attain to.”

When one turns from the ancient records of the Royal Society to a book published so recently as 1912 on the *Peat Deposits of Ohio*, by Dr. Alfred Dachnowski, it comes as a surprise to read the following remark almost at the opening of his first chapter :

“ Exact and systematic study of peat began in Europe in 1750, when various scientific societies offered prizes for memoirs on the origin, formation, and nature of peat. Then, as to-day, some persons held that peat bogs were useless obstacles to commerce and agriculture; were places of malarious fevers and the causes of spring frosts; *while others advanced the idea that peat, if once dug out, would grow again spontaneously.*”

This quotation is, I think, memorable in showing how greatly the oldest of the sciences, agriculture, in certain of its aspects at any rate, lagged behind at a time when the modern world had begun to show an active, intelligent, scientific curiosity into the causes of all sorts of natural phenomena.

The general conditions under which the deposits of peat were laid down are to-day thoroughly well understood from the general standpoint, though a vast amount of work remains to be done before the various problems connected with peat formation can be regarded as solved. As with most natural substances peat is the name given to a class of

products, and the term no more describes a definite unit compound or mixture than does the term "coal" in the mineral kingdom, or the terms "horse," "dog," "man," or what not in the animal kingdom. As will be seen in the later pages of the book, it would not be possible for the makers of bacterized peat to copy the immortal recipe of Mrs. Beeton, beginning, "Take a hare," and to start off an account of their manufacturing process with the words, "Take a ton of peat." The exact character of any peat that is to be used has carefully to be studied and tested to discover whether or not it will give satisfactory results when converted into humogen.

Generally one may describe peat as disintegrating vegetable matter. It may be coarsely fibrous and matted, and contain plainly recognizable in its substance the roots, rhizomes, and aerial parts of plants. Or it may be highly compact; the fibrous constituents of it may have already decomposed and the great portion of it may consist of disintegrating leaves and woody parts of trees and shrubs. These may be regarded roughly as the limiting substances in one direction, and the other of the various agglomerations that may be described as peat; but both in chemical and mechanical properties there are enormous differences. One has only to consider the conditions in which the peat has been laid down to realize that this is inevitable. Imagine the vastly differing matter that is waterborne by various streams to be deposited in the rankly growing vegetation of the forming peat bog. Bear in mind the dust carried by the air, much of which has inevitably

been trapped on the leaves of the growing plants. Consider the differences in the animal organisms, crustaceæ, and so forth, that have lived and died during the long periods of geological time, and there will be little trouble in recognizing that in mineral content one peat bog will differ widely from another.

This variation in life is a factor that has constantly to be borne in mind when dealing with peat, and the plants of which it is composed. Pond, lake, bog, forest, and swamp, have well-defined differences in the vegetation that grows on them, and the plants growing in each will vary with changing conditions of soil, climate, and general environment. The juicy character of water-plants is perpetuated in the peat they form by a soft structureless material. When sedges and grasses predominate, the peat, as one would expect, tends to be fibrous and of the nature of turf. From trees and shrubs is derived a woody type of peat.

To those not professionally concerned with the problem it is often somewhat of a puzzle to say why in certain cases coal is formed as the result of the decay of vegetable matter, while in other cases peat results. Peat must be regarded as the result of the first of the great changes undergone by organic matter on its way to become coal. What has occurred is that plant débris has accumulated in a relatively permanent body of water or in moist shallow places. Weathering processes set in as soon as the tissues are lifeless, promoted and aided throughout by the action of fungi and bacteria. The products of decay accumulate beneath the surface of the water, and in the

absence of air the bacterial activity is checked, and complete resolution of the plant débris to its simplest constituents is arrested. In the process some of the carbon has disappeared in the form of carbon dioxide or marsh gas, while much has been left behind in the form of humic acid and other relatively complex products, the composition of the mixture depending on the original constituents of the moss, on the bacteria and fungi that have acted on it, and on the atmospheric and other conditions in which they have done their work. The latest materials to be altered are the woody plant tissues, but as the peaty deposit gets covered and subjected to pressure as a result, for instance, of the slow local sinking of the earth's crust, atmospheric air becomes completely excluded, fermentation sets in, the oxygen combined with the tissues tends more and more to disappear, and the moss then goes through the changes, becoming first peat, then, under the influence of time pressure, and further bacterial action, lignite, and, lastly, as the pressure further increases, coal. So much at the present stage for the composition of peat, a subject to which I shall have to return in the chapter on the humus of the soil.

That the problem of the utilization of peat is an important one to the world is shown conspicuously by a glance at the extent of the deposits present in various parts of the world. In Europe there are believed to be 212,700 square miles of bog; in Canada 50,000 square miles; in the United States of America 35,000 square miles; in European and Asiatic Russia 70,000 square miles. Northern Europe alone is esti-

mated to consume annually about 10,000,000 tons of peat, while each year Russia produces 4,000,000 tons, Germany 2,000,000 tons, and Holland and Sweden each 1,000,000 tons.

These may seem brave figures, but despite them peat is a world product little in demand. Many men have tried to utilize it for various purposes. Great works have time and again been set up by the side of peat bogs; there has been abundant activity and enthusiasm, but the wheels of the machinery have slackened more often than not and stopped, and the attempt to utilize peat has in the majority of cases been written down a failure. The fact is the more curious when one knows the many uses to which peat may be put, and, under certain conditions, has been put successfully. As in humogen it is probable that there will be a considerable demand for the raw material, it will perhaps be of interest to consider some of the present uses against which this new use will have to come into competition.

The use of peat as a fuel in the districts from which it is cut goes back to the earliest times. In the minds of English readers it is associated chiefly with Ireland, and the peat fire, like the jaunting-car, is the novelty that impresses itself most obviously on the mind of the tourist as a feature of the typically Irish environment. In Ireland peat really does enter into the life of the people. It has given the peculiar acrid taste of its smoke to the whisky of the country; it is burnt in the tumbledown cottages scattered far away from civilization; and when the tourist wishes to carry away with him a memento of

his visit to Ireland, he usually does so by buying a trinket carved out of the black bog oak that has been lying for centuries preserved from the decaying influences of climate beneath the covering of peat.

While peat is used in this crudely simple way as a fuel in Ireland and elsewhere, there have been many attempts made to employ it on a larger scale. One reads of press peat, pressed peat, condensed peat, machine-formed peat, wet-process peat, briquetted peat, all of which represent the attempts of the inventor to spread the utilization of peat as a fuel over areas remote from the peat bog, but their efforts have met with little success. Peat has a low heating value; special grates are required for its consumption, and the relatively large quantity of ash makes the handling of it a difficult matter. The experiment has even been made of powdering the peat and employing it in special powder burners, and it seems that it is only because of the low price of coal that in this form it has not become really popular. The process of briquetting peat again is one that has given good prospects of success. To prepare the briquette the raw peat is treated and pressed. As a result of the treatment a black heavy compact substance results that is pleasant to handle, and that has a fuel value comparable with that of ordinary bituminous coal. The fact remains, however, that so far the briquettes have not come into public favour. In peat coke one meets with another of the attempts made to establish peat as a common household fuel. On paper the scheme seems promising enough. By-products similar to those obtained

from coal are obtained, and the coke itself forms a satisfactory fuel, which in several ways is superior to charcoal; but the fact has to be faced that the manufactory producing it that seemed the most flourishing has been forced to suspend manufacture because the cost of preparing the coke was too high to make the venture practicable.

Frequently the suggestion has been made that it should be practicable to utilize the peat on the spot as a source of power, and in Germany and Sweden particularly several plants have been equipped for the purpose. Excellent illuminating gas can be obtained by heating the peat in retorts, and the material is also suitable for making water-gas, fuel-gas, and producer gas. There are several plants on the market designed for the manufacture of the gas in one or other of these forms, and the peat bogs in Germany and Sweden have been made use of to a considerable extent in metallurgical operations, in brick and glass making, and in lime burning.

Unquestionably peat as a fuel has a future before it; the trouble at present, however, is that the price of coal is so low that it is difficult for other sources of power to compete against it, a fact that is perhaps most emphatically brought out when one considers that it is found to be less expensive to pump the marsh waters off the land in such places as Norfolk by coal-using steam-engines than it is to utilize windmills for the purpose.

The utilization of peat as a source of chemical products has attracted a considerable amount of attention in recent years. There are processes by

which alcohol can be derived from peat by means of fermentation, and large experimental plants have been equipped and run for the purpose; but here again it has usually been found that the returns do not allow a sufficient profit for the manufacture to be successfully carried on. Both nitrate and ammonium sulphate have been derived from peat, and in the latter case particularly the claims of inventors seem to suggest that the peat might form the basis of a profitable industry. Here, too, however, it is only possible to say that the process is in the experimental stage, and that hitherto it has been of theoretical rather than practical interest.

Paper is another substance that can be derived from certain varieties of peat, but the product is dark in colour, and only suitable for cardboard or coarse brown papers. In this instance, as in so many others, the manufacture has not gone beyond the experimental stage owing to the expense of reducing the peat fibre to a condition suitable for use. The same may be said of the attempts to utilize peat for woven fabrics, and to form out of it a sort of artificial wood.

To many it may come as a surprise to hear that peat possesses absorbent, deodorizing, and anti-septic properties, and in several tentative ways attempts have been made to exploit them. Mattresses made of peat have been constructed for hospital use, and they have the advantage of being light, resilient, soft, inodorous, and very cheap. Further, American surgeons have made use of peat purified and powdered for dressing cuts, burns, and

other wounds, with excellent results. For the same reason, and because of its mechanical texture, it is greatly valued as a packing material.

Lastly, as is well known, peat is in considerable demand for litter. Its value consists chiefly in the facts that it is able to absorb far larger amounts of moisture than any other substance used for bedding, that it is a good deodorizer, and for a considerable period almost entirely prevents the decomposition of nitrogenous and other organic substances. Further, it is springy and durable, and keeps the feet of the animals standing on it in a perfectly healthy condition.

Commenting on the position of peat generally, Dr. Dachnowski writes:

“ Peat can hardly be classed as a satisfactory raw material for making any of the more complicated products under the usual conditions existing in Ohio, where other and established substances are already to be had in any desired quantity and at satisfactory prices. Moreover, these products are obtained from peat only by large investment of capital, and in most cases cannot be manufactured before the plant has passed through a long experimental period, which must be properly provided for by a considerable fund established for the purpose. The simple products, peat litter, mull, mattresses, packing material, and peat fertilizer litter, have a much greater chance of being quickly made profitable, because some of them are already on the market, and present uses for which the peat is especially adapted. Moreover, the processes of preparation are simple, and the cost of equipment for their manufacture with tried machinery is so low that moderate expenditure will fully equip a plant to produce them,

and it is unnecessary to provide for a long experimental development. It is apparent therefore that the more fibrous kinds of peat, when they are found in Ohio, may be put to a number of profitable uses, besides making them into fuel; while the black plastic types, which are of frequent occurrence, have other possibilities, although they are not adapted to the same uses for which the first may be recommended."

Dr. Dachnowski's comments are of considerable interest and importance from my present standpoint. While they show that there are a considerable number of uses to which peat can be put, they indicate clearly that they are not sufficiently important to make any large demand on the world's peat resources, and that the agriculturist who wishes to make use of bacterized peat for the improvement of his land need not fear that it will be necessary for him to compete with other peat users for the raw material.

In discussing the uses of peat I have made no reference to the possibility of its being used for its own sake as a fertilizer for the land. Peat, as such, is useless for the purpose. The nitrogenous and other organic substances in it are almost insoluble, and are not available as plant foods, while the facts that it is acid and antiseptic render its employment raw definitely harmful. As peat-moss manure, however, it has been employed on the land, but it must be used with suitable precautions. In December, 1911, the *Journal of the Board of Agriculture* brought this out very plainly, as the result of an experiment accidentally made at Kew Gardens. Speaking of the litter, the *Journal* states: "It is

neither peat nor moss as these are understood in horticulture, and is entirely unsuited for the growth of plants. It is imported in the form of bales, which are broken up in the stables to be spread as bedding in the stalls. When it becomes saturated with urine and contains a considerable proportion of horse-droppings, it is thrown into a heap to be carted away. Compared with straw-made manure this moss-litter is cheap, but is not looked upon with favour by market gardeners. Its use at Kew has been mainly as a top dressing for lawns and borders, but only after it has been exposed to the air for about six months and turned several times. It has not been used for mixing with the soil, but this spring some of the flower-beds were in error manured with it. Its effect on the health and growth of the plants which were afterwards put into these beds for the summer was markedly deleterious. The plants not only failed to start into growth, but many of them weakened and died, and as this was evidently due to the manure in the soil, in which the plants were set, samples of the soil and manure were submitted to Dr. J. A. Voelcker for analysis and report."

The text of Dr. Voelcker's report appears in the *Journal of the Board of Agriculture*. He points out that nothing in the analysis led him to suspect the presence of disinfectants or deodorizers, nor were there signs of any mineral acid or the like. He notes that market gardeners refuse to use the moss-litter manure until it has been kept for quite two years. He states also: "I have come to the con-

clusion that the ill-effects in the present case are due to the marked acidity of the manure, this acidity being due to organic acids in the soil and not to mineral ones. I find in the soil (in which the manure has been used) iron compounds present in the ferrous—or not fully oxidized—conditions, and it would seem to me likely that these are the result of the liberal use of an organically acid body such as the peat-moss, and that an unhealthy, imperfectly oxidized condition of the soil has been brought about. Very probably, if the manure be kept longer and allowed to rot more thoroughly, it becomes more aerated and oxidized, and then would not show the ill-effects noticed. This, it seems, is the possible explanation of what has occurred in the present case, and it is the explanation at least which would suggest itself to me.”

In a later chapter it will be necessary to consider the composition of peat in some detail, and to show how, in the case of humogen, the process which takes two years to accomplish when the peat is left in a heap is carried out in a few days by suitable bacterial treatment. It may perhaps be as well to insist here that the addition of humogen to the soil is not undertaken so much with the object of enriching the soil with the nitrogenous and other organic compounds contained in the peat, but that it is designed more particularly as a medium to facilitate the growth of the bacteria with which it is inoculated, and to enable them to work vigorously in changing the nitrogen of the air into nitrogenous plant food.

CHAPTER V

FIXATION OF NITROGEN BY LEGUMINOUS PLANTS

Beneficial effect of growing leguminous plants—Liebig and the chemical era—A fundamental error corrected by Lawes and Gilbert—Their experiments on legumes—Pasteur, Schloesing, and Müntz's discovery—Warrington's solution of the nitrogen problem for non-legumes—Hellriegel and Wilfarth's paper—Their experiments on legumes—Behaviour of the plants explained—Importance of bacteria—Ward's inoculation of legumes—Beyerinck's *Bacillus radicola*—Nobbe's culture—Experiments in the United States and in England—Conclusions of the Board of Agriculture—Work at King's College—Field experiments with nitrobacterin—Successes and failures—Unfavourable conditions—Disappointments—Nature of benefit to be expected—The *Bacillus radicola*—Mechanism of symbiosis—Chemistry of the process—Effect of over-rich soils—Balance between plant and bacteria—A trade analogy—Hopefulness of outlook.

FROM the earliest days of agriculture practical men have recognized the fact that the fertility of the soil was increased by the growing in it of leguminous crops. It is only within the memory of living man, however, that it has been possible to state definitely what actually occurs in connection with leguminous plants. A convenient date from which to start tracing out the stages through which the whole problem relating to leguminous plants has been carried is the year 1840. It was then that the

German professor Liebig presented to the British Association the famous report afterwards published as a book on *Chemistry in its Application to Agriculture and Physiology*. By applying the exact methods of chemistry to agriculture Liebig succeeded in establishing that plants derive the Carbon of their tissues from the Carbon Dioxide of the air, and not from the Carbon compounds that may be present in the soil. He did more than this, for he pointed out that "the crops on a field diminish or increase in exact proportion to the diminution or increase of the mineral substances conveyed to it in manure." In one essential point, however, he fell into error. He came to regard the Ammonia of the air as analogous with the Carbon dioxide in the air, and preached the doctrine that the plants were able to derive their nitrogenous food from the atmosphere. In the *Farmer's Magazine*, for instance, he wrote:

"If the soil be suitable, if it contains a sufficient quantity of alkalis, phosphates, and sulphates, nothing will be wanting. The plants will derive their Ammonia from the atmosphere as they do Carbonic Acid."

Liebig's discoveries were of classic importance, partly because of the valuable contribution they made to agricultural knowledge, but still more because of the stimulus they gave to agricultural research along exact lines of experiment. He had not, however, found the whole truth. His patent manure, when tried in the field, was a failure, partly because he presented his mineral foods to the plants in forms unsuitable for their absorption, and partly

because of his mistaken view of the way in which plants obtained their Nitrogen.

Lawes, the pioneer experimenter on agriculture in England, whose work at Rothamsted had been for some years in progress, flatly denied the accuracy of several of Liebig's conclusions, and as a result of further experiments conducted by himself and Gilbert, made several important discoveries in connection with mineral manures. These do not concern us here; what is of importance from our present standpoint is that by 1855 Lawes and Gilbert had established that—

1. The beneficial effect of fallowing lies in the increase brought about in the available nitrogen compounds in the soil.

2. Non - leguminous plants require a supply of some nitrogenous compounds, nitrates and Ammonium salts being about equally good. The amount of Ammonia obtainable from the atmosphere is insufficient for the needs of crops. Leguminous plants behave abnormally.

The experiments had been conducted on the following lines: A long list of plants, leguminous and others, had been grown in surroundings free from Ammonia or any Nitrogen compound. The soil in which they grew had been burnt; the air furnished them was washed and purified, but they were supplied with everything necessary in the form of mineral foods. All but the leguminous plants languished and died. The leguminous plants, however, were found to flourish. They assimilated large quantities of Nitrogen into their tissues, and the soil

in which they were growing was found to become richer and richer in nitrogen compounds.

To the chemist these results were a mystery, and it was not until a fresh method of attack was devised that the truth emerged.

While Liebig, Lawes, Gilbert, and others, were discussing agricultural problems purely from the chemical standpoint, Pasteur had begun to show the paramount importance of bacteria. It was established by him that putrefaction and decomposition were brought about by the action of bacteria, and the successes he had obtained in combating terribly serious plant diseases in France had been so sensational as to attract those interested in agriculture to the importance of bacteria. It seemed possible that bacteria might be closely connected with the changes going on in the soil.

The first of a series of classical experiments was published in 1877. In that year Schloesing and Müntz allowed some sewage water to trickle very slowly through a filter of sand and limestone. During the first twenty days of the experiment the Ammonia in the sewage passed unchanged. Then it was noticed that some of it was changed into nitrate, and after a short time it was found that all the Ammonia which went in at one end of the filter was changed to nitrate, and emerged at the other end of the filter in the form of nitrate. If the phenomenon had been purely a chemical one, there was a mystery as to why the filter should be inactive for the first twenty days; but if it was connected with the growth of living organisms, it was natural that time would have to

elapse to enable them to grow. To test the accuracy of this view Chloroform was passed through the filter. The change of Ammonia to nitrate at once ceased, but on removing the Chloroform and adding a little turbid water extract of dry soil to the filter the action started again. The experiment proved conclusively that bacterial action was responsible for the change.

The publication of this paper furnished Warrington, who was working at Rothamsted on the problem of soil Nitrogen, with the key to the solution. He proved—

1. Nitrification in the soil was stopped both by Chloroform and by Carbon bisulphide.

2. Solutions of Ammonium salts could be nitrified by adding a trace of soil.

3. The change occurred in two stages, two different bacteria being involved in the process, the Ammonia becoming first of all nitrite (NO_2) and then nitrate (NO_3).

So was solved the mystery as to how non-leguminous plants obtained their nitrogenous food. It became generally (if not quite accurately) recognized that in whatever form of manure Nitrogen might be added to the soil, the plants got practically nothing but nitrates as the source of their nitrogenous food.

It was nearly ten years before the problem as affecting leguminous plants was solved. In 1886 the classical paper clearing up the difficulty was published by Hellriegel and Wilfarth. They grew several series of plants in sand, adding the food constituents as they desired, and they found that the

growth of non-leguminous plants was directly proportional to the amount of nitrate that they supplied. In the case of leguminous plants there was no relation between the supply of nitrate and the growth of the plant. If nitrate was not supplied to the leguminous plant after the seedling stages had been passed, the growth of the plant was arrested for a short time, and then it either died or started to grow again and did well. Further, on analyzing the soil, they discovered that whereas, as might have been expected, there was always rather less nitrate in the pots in which non-leguminous plants had been grown than at the start of the experiment, in the case of the pots containing the leguminous plants the soil had been considerably enriched with nitrogen. In three cases, for instance, the gain amounted to 0.910, 1.242, and 0.789 grammes per pot respectively.

Botanists had already noted that leguminous plants were peculiar in the fact that their roots contained swellings or nodules, and without appreciating the bearing of the discovery, had remarked that these swellings or nodules contained bacteria. Hellriegel and Wilfarth, however, found in the experiments they made in growing leguminous plants in sterilized sand that all the plants that lived contained these remarkable swellings on their roots, and they reached at once the right conclusion that leguminous plants had apparently the power of obtaining nitrogenous food material from the air because of the bacteria harboured in their roots.

At last the great puzzle had been solved, and it was found that the difference that seemed to mark

out leguminous plants as distinct from all others was apparent rather than real. The great generalizations, however, emerged:

1. Plants derive their nitrogenous food material from the foods present in the soil, and not from any gases in the air.

2. The nitrogenous plant foods present in the soil are either directly or indirectly* derived almost entirely from the Nitrogen of the soil air, which is combined to form a suitable plant food by the bacteria living in the soil.

This discovery was obviously of fundamental importance. Botanists had hitherto regarded the soil as a complex mixture of chemicals from which the plants derived their food. Now, however, they began to appreciate the fact that the earth's surface was no inert mass of soil, but was the seat of myriads of living organisms necessitating the closest study.

The discovery made by Hellriegel and Wilfarth was rapidly followed up. A year after they had announced the main facts, Marshall Ward, by careful study of the tubercles of leguminous plants, traced the whole process of nodule formation from the infection of the root hairs of the plant by some soil organism up to the formation of the mature nodule, and showed that the tubercles could be produced at will by the inoculation of the roots with soil infusions. In 1888 Beyerinck isolated the organism by growing

* When such a substance as stable manure is added to the land, the nitrogenous bodies which it contains are plant residues, and these have, either directly or indirectly, derived their Nitrogen substance from the Nitrogen combined by bacteria.

FIG. 3

BACILLUS RADICICOLA.—This bacillus is found in the nodules of leguminous plants, only lives in symbiosis, and combines the nitrogen of the soil air to form nitrogenous food material. The beaded rod form, and also the V- and Y-shaped groups, are characteristic.

FIG. 4

AZOTOBACTER CHROOCOCCUM is found in all fertile soils and, living by itself, enriches the soil in nitrogenous food material available for all classes of plants. It is through its activities that soil which is never manured can maintain its fertility. The trees of all virgin forests and most woodlands depend on it exclusively for their nitrogenous food. It is ovoid in form.

it on a pure culture medium, and named it *Bacillus radicicola*.

Two years later, in 1890, Prazmowski succeeded in inoculating the roots of bean plants growing in sterilized soils, and in obtaining luxurious growth by simply watering the plants with a liquid culture of the organism.

It was when this stage had been reached that the direct commercial application of the knowledge newly obtained first fired the imagination as a means of enormously increasing the earth's fertility. The enthusiasm was thoroughly justified, for those familiar with the amazing efficiency of bacterial action, and familiar, too, with the results obtained when the conditions of growth could be satisfactorily controlled, as in the hothouse, were confident that only a little more experience was necessary for similar results to be obtained in the field.

Professor Nobbe of Germany was the first to try and capture the market. His method was to collect the bacteria from various leguminous nodules, plant them in bottles containing nutrient gelatine, and sell them under the trade name of Nitragin. Some of the results Nobbe obtained were satisfactory, but the percentage of failures was so great that the method was to a large extent discredited, just as the imperfections of method employed with Koch's tuberculin in the early stages resulted in the discrediting of a principle thoroughly sound.

Nobbe's work had one good result, however. The successes obtained had been such that in 1901 the United States Department of Agriculture com-

menced "a scientific investigation of the root-nodule organism with a view of making practicable for use in the United States the pure-culture method of inoculation." It was not long before the causes of Nobbe's failures became apparent. The function of the nodule bacteria is to fix free nitrogen from the air. When they were in such an environment as gelatine with combined nitrogen in abundance they became over-fed and lazy, lost their virulence, and no longer had the power to force their way into the roots of leguminous plants and form nodules. The American investigators soon improved on Nobbe's methods. They used a Nitrogen-free medium for cultivating their bacteria, and thus increased the Nitrogen-fixing power of the bacteria. When this stage had been reached the bacteria were dried on cotton-wool and distributed. In the course of the two years, 1903 and 1904, over 12,000 packages were sent out free to farmers in the various districts of the United States, and the report published in January, 1905, showed that 74 per cent. of the trials were successful—that is, gave an increase of crop as a result of inoculation.

These experiments aroused the interest of the Board of Agriculture and Fisheries in this country, and they invited the co-operation of thirteen agricultural colleges and experiment stations to try experiments with the American culture. The *Journal of the Board of Agriculture* for February, 1906, however, issued a most pessimistic report as to the results, stating that "the negative results exceed the positive in number, both in plot experi-

ments and under agricultural conditions." The summing up of the report was as follows:

"As a result of all the reported experiments, it seems evident that the cultures used were not uniform; it is not possible, however, to determine the extent to which the failures are to be attributed to this cause. It seems, however, from the positive results recorded, that not only are these cultures sometimes able to produce nodules on the roots of plants new to a neighbourhood, but that even in cases where the leguminous crop had been grown in the previous year benefit may be derived from inoculation.

"It is quite evident that the subject of plant inoculation in this country has not yet passed the experimental stage, and more work is required before one can feel at all justified in recommending either method for adoption on a field scale; nevertheless, the positive results obtained may lead farmers to hope that in the future benefit may be derived in some instances at least from the treatment of the soil, or the seed before sowing, with inoculating materials preparatory to growing leguminous crops."

It is unfortunate that the Board of Agriculture and Fisheries did not see its way clear to help in carrying out the further work required, for the results, though admittedly unsatisfactory, indicated clearly that a great future lay before the method of soil inoculation. Thus, in Scotland an acre of inoculated beans yielded 3,070 pounds of beans, against 1,800 pounds from an acre non-inoculated, a gain of 70 per cent. In Leicestershire a half-acre plot of treated peas yielded when threshed 108 stones; a half-acre plot untreated only 66 stones. At Woburn

treated *Melilotus* gave 23 per cent. heavier crop than untreated. At Aberdeen, "on a farm where the soil is peaty, and clover had never grown well, the treatment has been remarkably successful, producing a thicker covering of clover and a much stronger growth. The difference has increased between October and the present time in an extraordinary way."

Even before the Board of Agriculture Report had appeared, in the autumn of 1905, American experimenters had discovered a cause of failure. The bacteria when sent out on dried cotton-wool only retained their vitality for a period of from six weeks to a couple of months, a fact that in itself amply explained the negative results obtained in many of the experimental stations in this country. For it was admitted that in several instances the cultures had been kept as much as six or eight months before being applied to the land.

While America was carrying out field experiments on this lavish scale with cultures of the *Bacillus radicicola*, the attempt was being made by Professor Bottomley in the Botanical Laboratories of King's College, London, to clear up several points that were obscure in the life history of the bacteria, and to determine accurately the nature of the chemical changes involved. When the Board of Agriculture discontinued their field experiments he decided to invite the co-operation of farmers, professional growers, and others interested, to test the efficiency of the pure cultures with which he had been working at King's College. To send out the bacteria on

cotton-wool, as had been done in America, would clearly have been to invite failure, and several tests were made to find out the most suitable medium. After many trials it was found that when the bacteria were mixed with earth and the whole was dried, the bacteria lived, and retained their vitality in any case for several months, and in some instances for as much as three years.

During the years 1906 and 1907 more than a thousand packages of the material were distributed throughout the country, and in over 80 per cent. of cases the reports showed that an increase of crop had resulted from its use.

That the results obtained justified the enthusiasm aroused can readily be understood from the nature of the reports received. They are given in Appendix A just as they were originally published seven years ago, but the following short quotations from them are sufficient to prove that the *radicicola* cultures showed promise of revolutionizing the everyday practice both of horticulture and agriculture:

“ The peas were a great success. Inoculation of soil and seed returned a good 30 per cent. more than only seed inoculation, and the seed inoculation showed a good 20 per cent. better crop than the farmyard manured peas. Inoculation in both cases rendered a fortnight earlier marketing possible over the manured.”

“ The inoculated clover was taller by 3 inches than the uninoculated.”

“ The inoculated Broad Beans were up a week and a half before those not treated, and were very much

greener and more weight. Two rows inoculated, 65 yards long, gave $4\frac{1}{4}$ pots. Two rows, not inoculated, 65 yards long, gave 3 pots."

"The inoculated Beans were quite three weeks earlier than the others."

"I put the inoculation liquid on about a quarter of an acre of grass and clover as a top-dressing. In about a week I could see an improvement, and the clover was far higher and thicker than the rest of the field right on until it was cut. There was double the quantity on it, and it was the same with the aftermath; it came up the second time far thicker and stronger than the rest of the field."

"From a quarter of an acre of peas inoculated I picked $33\frac{3}{4}$ pots (42 pounds to the pot), selling them for £7 18s. 9d. From a quarter of an acre not inoculated, but dressed with 1 cwt. superphosphate and $\frac{1}{2}$ cwt. sulphate of potash, I picked only 14 pots, selling them for £2 5s. 6d."

From certain points of view the very success of the results obtained proved unfortunate. Little was known about the bacteria at the time, or of the conditions necessary to their growth. Experience in the form of negative results had yet to show that the bacteria were unable to grow in acid soils, and that in such conditions it was necessary to resort to liming to correct the acidity; that the bacteria would not grow in land already rich in nitrates; that they were sensitive to adverse conditions of weather and climate; that their efficiency would be impaired either when the plant concerned was too weak, in which case the weaker bacteria could force an entrance into the roots, or too strong, when the roots might succeed altogether in resisting bacterial

FIG. 5

The value of the auximones in promoting healthy growth is strikingly illustrated above. Each of the treated plants (*Primula malacoides*) received the water extract of $\frac{1}{150}$ th of an ounce of humogen, but otherwise the treatment was identical. The increase of growth, flowering, and of root development in the treated plant (on the right) is very evident, but typical.

(Dr. Rosenheim, University of London, King's College.)

invasion. These were some of the causes that led to disappointing negative results. There were occasions, too, when failure resulted, because the directions for preparing the bacterial culture on the farm were not accurately followed. Sometimes soils were treated that were deficient in phosphates and potash, and naturally the bacteria were powerless to make up for the absence of these minerals.

For these and similar reasons there were several failures with the cultures. The feeling of disappointment among growers was great, and naturally the men who had gone to all the labour and trouble of inoculating their seed and soil only to find no trace of advantage came dogmatically to the conclusion that nitro-bacterin, as the culture was called, was no good. Such failures were widely advertised, and as some of them occurred at experimental stations, growers were discouraged from making further attempts.

At this stage of the work, however, the successes obtained were for the time being of more importance than the failures, for the successes proved definitely that in England, if the conditions were such as to favour inoculation, the following important benefits resulted:

1. An increased yield of the leguminous crop.
2. The improvement of the land for succeeding crops through the addition of organic nitrogen to the soil.
3. Increase of the nitrogenous content of inoculated crops, carrying with it an increase in feeding value.

4. In many cases hastened maturing of plants, thus allowing the earlier marketing of produce with enhanced value.

The fact that it was possible in certain conditions to obtain such results made it plain that it was worth while to continue working at the problem. As will be seen in later chapters, the further work done has led to results that at the time were unsuspected, and that are far more important than were dreamt of at the time. Before considering them, however, it will be well to conclude this chapter with a short account in view of modern knowledge of the *Bacillus radicum* in its relation to leguminous plants.

The *B. radicum* is a small rod-shaped organism that is found widely distributed in nature. For some reason, as yet unexplained, it is able to attack the roots of the leguminous plants. It forces its way into the delicate root hairs of the growing legumes, and penetrates into the interior of the root branches. When once it has effected an entrance it increases in size and changes its shape, appearing sometimes as irregular rods and at others as V or Y shaped organisms. For its growth it requires food in the form of sugar and mineral salts, and these it takes from the roots of the leguminous plants which it has invaded. There can, as will be seen presently, be little doubt but that the leguminous plant resists the entry of the bacillus. The bacillus, however, forces its way in, demanding, as it were, rights of partnership, and once it has established itself and secured food and shelter, it offers to its host in return Nitrogen that it can take from the air, and give to

FIG. 6

The plant on the left was grown in ordinary potting compost; the plant on the right was grown in a compost containing all the essential plant-foods in addition. The centre plant was grown in humogen, sand, and loam (humogen to soil was 1 : 10). The photograph was taken in the first week in October. The early blooming of the humogen-treated plant is remarkable, and gardeners will recognize how strikingly the difficulty has been overcome of stimulating the growth of the plant and encouraging early blooming.

the plant in a form in which it can absorb it. Present knowledge does not make it possible to state in definite chemical symbols what are the exact Nitrogen compounds formed. What can be seen when the bacteria are cultivated in pure cultures is that a slime forms round the bacteria. The mass of slime and bacteria can be shown to consist of Carbon, Oxygen, Hydrogen, and Nitrogen, and as the only source of the nitrogen is the air, it can be stated definitely that the bacteria have seized the Nitrogen from the air and combined it with Carbon, Oxygen, and Hydrogen. It can also be stated definitely that the nitrogen compounds so formed are such that the plant can absorb them and build them into the nitrogenous bodies or proteins that their tissues require.

In the early stages of the process, as we have seen, it is the bacteria that are the attacking party. The leguminous plant, however, waits and takes its revenge. The V or Y shaped bodies become more numerous, but as the plant grows older many of them are dissolved and absorbed. Some, however, remain behind, and when the plant eventually dies they migrate back into the soil and await their opportunity for invading the roots of the next crop of leguminous plants.

If the ground in which leguminous plants are grown is rich in nitrogen, as, for instance, as a result of liberal treatment with well-rotted stable manure or with nitrates, no nodules are formed on the plant roots. A natural explanation is that the growth of such plants is vigorous, and that their root hairs are strong enough to resist the attacks of

the bacteria. In much the same way it has been found that seeds may be able to resist inoculation—this difficulty in practice can be easily overcome—owing to a protective chemical substance which prevents the bacteria from digesting the cell wall and forcing an entry: a phenomenon roughly analogous with the fact that the cells of the stomach and intestines possess chemical substances that prevent their being attacked by the digestive ferments prepared in the alimentary canal. In such a case inoculation is obviously useless.

From several standpoints a great deal depends on the health and vigour of the root. As we have seen, if the root is very vigorous the bacteria cannot enter it, and in such conditions leguminous crops planted in the soil, instead of enriching it in nitrogenous bodies, would deplete its store of Nitrogen. Suppose, however, that one goes to the other extreme, and that the plants are starved and feeble. In such a case the roots can put up no resistance to the bacteria. These will force an entry, but the roots, instead of giving harbourage only to the most vigorous bacteria, will admit even the weaker strains, such, perhaps, as will be sluggish in forming nitrogen compounds, and in consequence the plants will gain little from their association with the bacteria. It has even been suggested by some bacteriologists that the just balance may be upset and the bacteria become too strong for the plants, and the latter be unable to insist on the former fulfilling their side of the contract and giving up a fair share of the nitrogen compounds that they have prepared. In such a case

the bacteria would be mere parasites, taking the sugars and salts they required from the plants without furnishing a corresponding value in return in the form of nitrogenous foods.

This may seem to some a fanciful pressing of a trade analogy, but it has its foundation in experimental fact, for from time to time it has proved beneficial to give light top-dressings of Nitrate to new fields of alfalfa.* This would increase the vigour and resisting power of the young plants. In this way only vigorous bacteria would be able to force an entry, and the ultimate fixation of nitrogen would be greater. Heavier applications of nitrogen would prove objectionable as the bacteria would be altogether excluded.

Considerations such as these are both interesting and important. They suggest why some of the earlier experiments gave negative results, and hold out the greatest encouragement for the future. Soil inoculation, whether for leguminous plants alone or for all plants, must be practised intelligently. The conditions required for success are becoming every day better known, and the time is not far distant when it will be possible to state the exact degree of benefit that can be looked for with confidence as a result of soil inoculation in any given set of circumstances. Further, it is becoming every day, as a result of the increase of knowledge, more possible so to alter the environment as to increase the circumstances in which the practice of soil inoculation is certain to prove of benefit.

* *Bacteria in Relation to Country Life* (Lipman).

CHAPTER VI

HUMUS

Humus as the home of bacteria—Soil composed of mineral débris and humus—Influence of mineral débris secondary—Bacteria and plants and animals—The sun and food as producers of energy—Humus as a source of energy—Life limited by the food-supply—Mild humus and raw humus—Their properties—Bacteria as chemical agents—Complexity of humus—Four groups of compounds—Only one carbohydrate isolated from humus—Carbohydrates and humic bodies—Effect of boiling carbohydrates with hydrochloric acid—Humic acid formed before humin—Difference between natural and artificial humic acid—The difference reconciled—No real formula for humic acid—Effect of boiling carbohydrates with organic acids—Effect of heating carbohydrates—Nature of humic bodies obtained—Proteins and humic bodies—Nature of changes in formation of peat—Causes of complexity of humic bodies.

EMPHASIS has been laid in the previous chapters on the fact that the attention of all growers, directed until recently on to the chemical and mechanical aspects of the soil, has during the last few years been focussed chiefly on the soil as the seat of changes brought about by the bacteria that inhabit it. In the last chapter, dealing with the fixation of nitrogen from the soil air by leguminous plants, it was necessary to refer briefly to the fixation of nitrogen by bacteria which have no relation with leguminous plants. These will have to be considered at length

in the following chapter, as it is chiefly they and their activities that are the subject of the present volume. Before doing so it is necessary to form a clear idea of the non-living medium in which they live and of its properties.

The soil from the particular standpoint which I am considering may be regarded as a mixture of two constituents—(1) mineral *débris*, and (2) decaying organic matter or humus.

The mineral *débris* in the soil plays no very interesting part in connection with the life of the soil bacteria. It is in most cases only soluble with difficulty, and, with the exception of lime, influences bacterial life rather from a negative standpoint. Thus, a clay soil will retain an excess of moisture and interfere with bacterial growth; a sandy soil, on the other hand, by allowing excessive drainage, will unduly parch the ground, and eventually check bacterial activities. Conditions well known to the practical agriculturist will bring about an acid state of the soil, in which the bacteria will find growth impossible. These and other conditions will be considered in the chapter in which the practical application of the bacterized peat or humogen is discussed, but may be ignored here, as they may fairly be regarded as factors superimposed on normal conditions.

The centre of bacterial activity is the humus or decaying organic matter in the soil. Bacteria differ essentially from plants in that they have no mechanism enabling them to derive their energy from the rays of the sun, but, like animals, must secure it from

the food that they absorb. This central fact is fundamentally important to a proper understanding of the subject. Many perhaps do not realize the magnitude of the work done by the plants in breaking up Carbon dioxide. The chemist in the laboratory can only achieve it by an intense expenditure of energy. Thus it is a common elementary experiment to show that some such energetic substance as Phosphorus must be used to decompose the gas. The Phosphorus is placed in the Carbon dioxide and heated, and in these conditions is able to seize the Oxygen from the Carbon dioxide, and leave the Carbon behind in the form of black particles. Another experiment on which a chemical lecturer will insist is the burning of a wood match. Once the temperature of the match is raised to a sufficiently high point it burns, the Carbon in it uniting with the Oxygen of the air, large quantities of energy appearing during the process as heat and light. It is reasonable and scientifically exact to believe that a corresponding amount of energy would have to be supplied for the converse process to take place—*i.e.*, for the Carbon dioxide of the air to be reconverted into the wood of the match. Yet this is what is being done day by day quietly by the plants, the energy required for the purpose being derived from the rays of the sun and absorbed by means of the green chlorophyll in the leaves.

The animal or the bacterium in taking in food is absorbing materials which are able to give him the vast quantities of energy he requires for his life. From the point of view of energy there is no funda-

mental difference between the process occurring when a wood match is burnt and that occurring when a horse eats a meal of hay or corn. The only differences are that in the case of the match the energy is delivered rapidly and in the form of light and heat, while in the case of the horse it is delivered slowly and is utilized for warmth, for locomotion, for performing complex chemical reactions, and so forth. In both cases the underlying principle obtains that Carbon on being oxidized or degraded to form Carbon dioxide yields energy.

Looked on in a somewhat similar way the decaying organic matter in the soil, or humus, may fairly be considered as a unit substance, and the soil containing it regarded as a storehouse of energy. From time immemorial gardeners and farmers have recognized its value. Under the dominating influence of chemical ideals they ignored more or less completely the energy factor, and regarded the manuring of the crop as an act undertaken with a view of supplying to the plant the chemical constituents of which it stood in need. In so doing, of course, they tacitly accepted the value of manure, both mineral and other, as a source of energy—for what else is food in its varied forms?—but they focussed their attention on constituents necessary for plant life, and only emphasized energy considerations so far as the direct utilization of the sun's rays by the leaves of the plant were concerned.

With the growing recognition of the importance of bacteria, there has been in recent years a marked increase in the attention paid to the nature and

constitution of humus, and it may perhaps be most convenient to consider it first rather from the biological and physical standpoints, and then from the point of view of its chemical constitution and relationships.

The commonplace of natural history that the growth of living beings is chiefly conditioned by the extent and character of the food-supply is abundantly borne out in the case of soil bacteria. Apart from the organisms connected with the fixation of Nitrogen in leguminous plants, which are only partially dependent on decaying organic matter for their food-supply, the growth, development, and activity of the soil bacteria depend on the abundance and character of the humus in the soil. It is this that provides them with the energy they require in the form of food, which improves the moisture and temperature conditions of the medium in which they live, tending to keep the latter more or less stable, and preventing violent changes in temperature that would prove injurious to their growth. It is only for very broad generalizations such as these that one can regard humus as a simple substance of uniform composition.

Biologically it falls into two grand classes—the mild humus or mull met with in arable soils and woodland, and the raw humus found in heaths, meadows, and swamps.

Mild humus is either neutral or alkaline in reaction, and is formed in conditions that allow the free entry of air, and facilitate the development of the so-called aerobic bacteria—that is, of the bacteria that are able to develop in the presence of oxygen. Raw

humus, on the other hand, is acid in reaction. The conditions under which it has been formed have largely checked the growth of bacteria, and result in putrefaction rather than in decay. Whereas in the former the organic material liberates Carbon dioxide in quantity—is decomposed in fact by slow combustion—the latter, acted on in the absence of air, takes the Oxygen it needs for the oxidation of its Carbon from the organic substance itself, and eliminates also from the mass such gases as marsh gas (CH_4). It is for this reason that the end-products in the two cases are different. In mild humus organic bodies are formed from which the Nitrogen-fixing bacteria can derive their energy and food, and on which, too, the plants can feed directly. In raw humus the end-products are a mixture of compounds known as Humic acid, or Humin, that prevent the growth of bacteria, that are in fact anti-septic, and that do not furnish the plants with food material in a form in which they can assimilate it. Peat, in fact, is raw humus. It not only fails to undergo decomposition while remaining in the swamp, but when put on the land in its raw state it undergoes decomposition very slowly, and definitely retards the growth of crops. It is only necessary to contrast peat with the humus that can be seen as a rich, dark liquid oozing out of a manure-heap to realize the difference between the humus rich in the substances required for plant food, and that in which available food substances are wanting.

In stating that great progress may be looked for

in agriculture as a result of emphasizing the importance of bacteria instead of restricting the outlook to the chemical composition of the soil, it has to be realized that from one very important point of view agriculture must always be regarded as a purely chemical process. It will always be possible to express what happens when a crop has grown from seed to mature plant, by an analysis of the completed plant on the one hand and an estimate of substances taken from the air and the soil on the other. So long as the botanist or agriculturist bears in mind that, in so doing he has not expressed the full process it is as desirable to-day as ever it was that all information possible should be derived from the chemical conditions underlying growth. While it is correct to state that one of the most important properties of the humus is its power of enabling the bacteria to develop in the soil, it is also well to bear in mind that the value of the bacteria so growing in the soil lies in the products of their activities, which are essential for satisfactory plant growth.

Humus, when one starts to consider it from the chemical standpoint, is a highly complex mixture of various compounds, which it has hitherto proved impossible for the chemist either to separate or satisfactorily to analyze. For very many years it has formed the subject of keen interest and discussion. Naturally enough, perhaps, in early days it was regarded as being of very simple composition. De Saussure, for instance, in 1804 described it as a "brown combustible powder soluble in Alkalies and

Ammonia compounds." Mulder was one of the first in 1849 to attempt really to describe it chemically. He explained that it consisted of seven organic compounds closely related to each other—namely, Crenic acid, Apocrenic acid, Geic acid, Humic acid, Humin, Ulmic acid, and Ulmin. Modern workers would recognize the problem as being one of far greater complexity, but fortunately the early stages of any investigation into it are easily carried out and understood. Few terms have to be used, and to them it is possible to give a well-defined meaning.

Humus, according to the modern views held as to its structure,* can be divided somewhat artificially, perhaps, into four chief groups of substance—Crenic acid, soluble Humic acid, insoluble Humic acid, and Humin. If a sample of humus is taken and extracted with alkali, a portion of it, known as *Humin*, is insoluble. On treating the soluble alkaline liquid with acid a precipitate is formed, but *Crenic acid* derived from the humus remains in the liquid. If the precipitate is boiled with alcohol, a portion of it is soluble, *soluble Humic acid*, and a portion insoluble, *insoluble Humic acid*. To some extent these bodies are not present in the original humus, but they represent groups of bodies that are present, and as the classification is very valuable if one wishes to get as clear an understanding as possible

* The latter portion of this chapter is based on the paper by Professor Bottomley in the *Biochemical Journal*, June, 1915, "The Formation of Humic Bodies from Organic Substances." Those wishing for fuller details should consult the original paper.

of the nature of humus, it may be well to set the position out diagrammatically:

From the Crenic acid group and from the soluble Humic acid group—it cannot be too often insisted that we are dealing with groups of substances and not with pure bodies—as many as twenty distinct compounds have been isolated, while so far the constituents of the two other groups (insoluble) have defied chemical analysis. About the compounds so isolated the curious fact has been recognized that only one of them is a carbohydrate. A carbohydrate is a compound that consists of a certain amount of Carbon combined with Hydrogen and Oxygen in such a proportion as would result in the formation of water. It can be expressed generally in the formula, $C_mH_{2n}O_n$, where m and n are any whole numbers. In view of the fact that a very large percentage of plant substance consists of carbohydrates, it is curious that they should not be represented largely in the decomposition products of organic material.

In the course of the researches on Nitrogen-fixing bacteria at the Botanical Laboratory in the University of London, King's College, it became desirable to try and determine what relation existed between carbohydrates and the unknown Humic

acid and Humin groups. Exact definitions became necessary at the outset of the research, and the groups were therefore defined as follows. The term Humic acid was given to substances thrown down as brown colloid precipitates by mineral acids from the water or alkaline extracts of humus, and the term Humin to substances insoluble in water and alkalies, but rendered soluble by fusing with caustic soda or potash, from the solution of which Humic acid can again be precipitated.

Three different kinds of sugars were taken as convenient carbohydrates, Lævulose, Sucrose, and Dextrose, and boiled under a reflux condenser with a 3 per cent. solution of Hydrochloric acid for varying periods of time. A series of colour changes take place, and the colourless solutions turn successively yellow, red, and brown, and then begin to precipitate. It was obvious at once that there were conspicuous differences with the different carbohydrates, Lævulose and Sucrose changing rapidly, but Dextrose going very much more slowly. This is well shown by the following table:*

				<i>Yellow.</i>	<i>Red.</i>	<i>Brown.</i>
Lævulose	..	..	..	1 minute	5 minutes	8 minutes
Sucrose	..	..	..	2 minutes	8 "	12 "
Dextrose	..	..	..	11 "	60 "	90 "

* A simple experiment illustrating this can be done by pouring concentrated sulphuric acid on to a thick syrup of cane-sugar. By this violent method these changes can be more or less well observed, but once the reaction starts, it is completed almost immediately.

In each case the precipitate first formed from the brown liquid was found to be Humic acid, and it was not unless the reaction was continued that Humin made its appearance. The experiment seemed to suggest that Humic acid might be an intermediate product between Carbohydrate and Humin. On testing the hypothesis it was found that on boiling the Humic acid from Lævulose with a 7·5 per cent. solution of Hydrochloric acid for four hours, 98 per cent. of it became Humin, while on treating Humic acid derived from peat in the same way 3·5 per cent. of it became Humin.

The result, while confirming the possibility of Humic acid being a transition stage between Carbohydrate and Humin, was a curious one, and suggested a reason for the great variations between the analytical results obtained by different chemists with peat. Further, while the Humic acid from the sugars and that from peat were almost identical in appearance, solubility and behaviour to alkalis, they showed striking differences in composition. Neglecting decimals, the analyses of the two acids gave—*

	<i>Carbon.</i>	<i>Hydrogen.</i>	<i>Oxygen.</i>
Humic Acid from sugar ..	65 per cent.	5 per cent.	30 per cent.
Humic Acid from peat ..	54 "	5 "	38 "

The authors responsible for the analysis given in this table concluded that there must be structural

* Robertson, Irvine, and Dobson.

differences between the material and the artificial Humic acids. Recent work, however, done by Baumann in 1909 had shown that freshly precipitated natural Humic acid possessed colloidal* properties, and especially the power of forming adsorption compounds. Now these compounds can be removed without much difficulty, and it seemed possible that the differences observed between natural and artificial Humic acids might be due to impurities which had been adsorbed by the Humic acid in the peat, and which were not present in the artificially produced acid because it had had no opportunity of ever becoming contaminated. It will be remembered that it was the discrepancy noted between the weight of the Nitrogen in the air and the Nitrogen prepared by chemical methods which led Sir William Ramsay to undertake the brilliant series of researches resulting eventually in the discovery of the rare gases of the atmosphere. It will be seen later that the study of the difference between natural and artificial humic acids has led to conclusions of far greater importance than had been suspected.

Elaborate means were taken to purify the naturally produced Humic acid. Some finely divided peat was powdered and treated with 4 per cent. Hydrochloric acid until all soluble salts had been extracted, and then treated with 5 per cent. Ammonia. The filtered Ammonia solution was acidified

* A colloid is a substance possessing a very large molecule, and, unlike most inorganic chemical compounds, is unable to pass through an animal membrane. By adsorption is meant the power possessed by colloids of holding other substances not in actual combination with them, but in a very close association.

with strong Hydrochloric acid, and a flocculent brown precipitate obtained. This was filtered off, redissolved in ammonia, reprecipitated, and washed. The Humic acid so obtained was divided into two portions. The first was dried in a steam oven at 100° C., while the second was purified by boiling for an hour under a reflux condenser with absolute alcohol. These two portions were analyzed, and the following figures were obtained:

	<i>Carbon.</i>	<i>Hydrogen.</i>	<i>Oxygen.</i>
Natural Humic Acid ..	48.64	4.55	46.81
Natural Humic Acid, after extraction with alcohol..	60.37	5.39	34.24

It will be noticed that after purification with alcohol the natural Humic acid was closely comparable with that obtained from Dextrose, as can be seen from the table:

	<i>Carbon.</i>	<i>Hydrogen.</i>	<i>Oxygen.</i>
Artificial Humic Acid ..	60.74	5.13	34.13
Natural Humic Acid (purified)	60.37	5.39	34.24

This does not mean that a real formula can be written for Humic acid, for it is well known that the Carbon content of Humic acid does vary with the substances from which it has been prepared, but it emphasizes that a very close similarity exists between

the Humic acid obtained from peat and one of the Humic acids artificially prepared.

Now in the ordinary decomposition of cellulose it cannot be expected that Hydrochloric acid would be present, but as a result of decomposition a large number of organic acids would naturally be formed, and tests carried out with Lactic, Acetic, Propionic, Butyric, Citric, Tartaric, and Oxalic acids on Sucrose, Dextrose, and Lævulose, all showed that the sugars or carbohydrates went through the same colour changes as had been observed with Hydrochloric acid, and gave rise both to Humic acid and Humin. In other words, it was demonstrated that it was reasonable to suppose that the natural process by which Humic acid and the Humin were formed in peat from carbohydrates had been successfully imitated in the laboratory.

While this work was in progress some interesting results were obtained merely by the heating of sugar, which are perhaps worth noting here, because they may help to give a clear idea as to the nature of Humic acid and Humin. It has long been known that Sucrose fuses at a temperature of 160° C., and is converted into a mixture of Dextrose and Lævulose. If the temperature is raised to 190° C. it yields a substance similar to the caramel of commerce, Caramelan, and at higher temperatures it blackens, becoming carbonized. When Sucrose was heated to 220° C. four distinct groups of substances were formed.

(1) Water-soluble caramelan; (2) a water soluble substance precipitated as fine particles by Hydro-

chloric acid; (3) an alkali-soluble substance giving the typical flocculent precipitate of Humic acid when treated with Hydrochloric acid; and (4) a black residue insoluble in water and alkalies, and giving the typical Humin reactions. Curious differences were found to occur when Dextrose and Lævulose were similarly treated, but these are points of detail that hardly concern us here. The points to which I would call attention are—(1) that the heat-formed Humic acids differ from the acid-formed Humic acids, in that on being dried in a water-bath at 100° C. they are no longer soluble in dilute alkali solution, but are only rendered soluble on fusion with caustic potash or soda; (2) that by heating or by treating with acid the change to Humin is via Humic acid; and (3) that in both cases the general effect of the treatment is, as in Nature, to take the elements of water out of the molecule of carbohydrate.

Plant tissues consist chiefly of carbohydrates and proteins. The latter are of varied composition, but consist of Carbon, Hydrogen, Oxygen, and Nitrogen in combination, and the Hydrogen and Oxygen may or may not be in the proportions necessary to form water. Similar tests to those made on sugar have been carried out with the proteins, and it has been found that Humic bodies are produced only in so far as the proteins contain carbohydrate. For instance, while a gramme of Mucin, which contains carbohydrate, on boiling for eight hours with a 7·5 per cent. solution of Hydrochloric acid, yielded 0·028 gramme of Humic acid, no Humic acid was

formed either with Tyrosine or Asparagine which contain no carbohydrates.

It is to some extent on the basis of the above experiments that Professor Bottomley has established his method for introducing bacteria into the soil. In his paper in the *Biochemical Journal* he drew the following conclusions, which in view of their important bearing on the subject of this book I am quoting textually:

“The general result of the investigation so far,” he writes, “has been to indicate that carbohydrates generally and certain sugars in particular pass through a regular series of changes when submitted to the reactions described. It was also found that air-dried *sphagnum* moss is readily acted on by acids, with the formation of a brown, peat-like mass from which Humic acid can be extracted.

“One hundred grammes of air-dried *sphagnum* moss, when boiled for twenty-four hours with 5 per cent. solutions of Hydrochloric, Oxalic, and Lactic acids respectively, yielded the following results:

				<i>Humic Acid.</i>
Hydrochloric Acid	..	..	..	11.7 grammes.
Oxalic Acid	..	..	..	2.3 ”
Lactic Acid	..	..	..	1.8 ”

“The humic substances comprising the Humic acid and Humin groups probably pass through a series of changes characterized by a progressive increase of their Carbon content. In ordinary cultivated soils these changes cannot be traced, owing to the constant addition of fresh organic matter and cultural operations, but in peat beds,

where the deposits remain undisturbed for many years, the stages are indicated by the increasing Carbon content of the Humus from varying depths. This was shown by Detmer (1871), who gives the following figures:

	<i>Carbon.</i>	<i>Hydrogen.</i>	<i>Oxygen.</i>
Light brown peat, surface..	52.14	7.03	40.19
Brown peat, 1 foot.. ..	57.75	5.43	36.02
Dark peat, 7 feet	62.02	5.21	30.67
Black peat, 14 feet.. ..	64.07	5.01	26.87

“ Thus, in peat bogs the carbohydrates of decaying organic matter may possibly pass through changes very similar to those observed when sugar is heated to a high temperature—Sugar, Caramelan, Humic acid, Humin, and finally Carbonization (peat coal). The fact established by van Bemmelen (1900) that Humic acid is a colloid body, which has the property of uniting with certain radicles, explains the various empirical formulæ ascribed to Humic acid, and the complex nature of Humus in general. But underlying this complexity there is the possibility of finding in the series of sugar changes described above two fairly definite groups of substances, which serve as a basis for Humus formation, the Humic group gradually merging into the Humin group.”

CHAPTER VII

BACTERIZED PEAT: ITS PREPARATION AND GENERAL PROPERTIES

Need for a mixed culture—Why peat was used as a medium—Other possible media—Decomposition of peat by aerobic bacteria—Superiority of artificial over natural methods—Effects of decomposition—A simple experiment—Treated peat contains fifty times as much plant food as stable manure—Peat the ideal medium—The aerobic bacteria—Sterilizing the peat—*Bacillus radicolica*, *Clostridium pasteurianum*, and *Azotobacter*—Conditions of growth—Symbiotic relationships—Inoculating the peat—Why the soil should benefit—Effect of nitrogen fixation—Influence on phosphates and potash—Accessory food bodies—Claims advanced on behalf of humogen.

A CONCLUSION of supreme importance was reached as a result of the experiments made in the Botanical Laboratories of King's College on *Bacillus radicolica*, the micro-organism responsible for the fixation of nitrogen in connection with leguminous plants. The discovery had been made that the bacillus, when mixed with soil and dried, was able to retain its vitality unimpaired certainly for a considerable number of months, and in favourable conditions for at least as long as three years. Unquestionably soil, for the introduction of the bacillus, was a medium vastly superior to the cotton used in America. In a previous chapter I have attempted

to show why it was that in several instances the culture gave negative results when applied to the land. The difficulties met with were not insuperable, but as the experiments continued it became evident that however successful a leguminous culture might prove, it could never yield more than a fraction of the results that might fairly be expected if bacterial inoculation were practised from a broader outlook. It was realized that *Bacillus radicola* was only one of several organisms connected with the work of changing into nitrogenous plant food the nitrogen present in the air circulating from the atmosphere to the soil, and that the full benefit of soil inoculation could only be obtained by supplying to the soil a mixed culture which would contain the various groups of bacteria acting in different ways for the common end of supplying nitrogenous food in soluble form—that is, in a form in which it can be utilized by plants.

Chance to some extent decided the selection of peat as a medium for the purpose. As a matter of fact, however, there was not a large option. Some substance was required that had or could be made to yield a high percentage of soluble humus, for it was known that it was on this that the bacteria had to rely for their food. Farmyard manure was a possible medium. The supply of it, however, was diminishing; it was, and must always remain, unpleasant to handle, and it was objectionable because of the host of mixed organisms it was bound to contain. Leaf mould was objectionable on most of the same grounds, and had the further disadvantage

of being very bulky to handle if it was purchased raw, and of being very costly and difficult to obtain in bulk if it was to be delivered already rotted. In peat there was a substance rich in humus-forming material, available in indefinitely large quantities, cheap, pleasant to handle, highly concentrated as a result of natural processes continued over immense periods of time, varying in composition over a wide range, and for practical purposes sterile.

In its raw state peat contains practically no soluble humus. The nature of its deposition has been such that free access of air has been prevented, and its Carbon compounds (the carbohydrate, protein, etc.) have only slowly and partially decomposed. Instead of the neutral or alkaline humus required as food both by plants and bacteria, acids have been formed, and the peat is unable to support the life either of ordinary plants or of nitrogen-fixing organisms. If the peat, however, is left exposed for a considerable period, such as two years, for instance, the long-delayed change that occurs in the case of vegetable matter to which there is free access of air readily takes place. Carbon dioxide and Ammonia are formed freely as a result of the action of aerobic bacteria, and the peat slowly loses its acid character. Soluble humus accumulates to a considerable extent in the form of Ammonium humate, and the peat which was valueless as a plant food now contains available nitrogen compounds. As with most other natural changes, so with this, it is possible in the laboratory, as in the factory, greatly to accelerate it. Despite the ill-informed attitude

usually adopted, a laboratory-performed change is frequently more effective for a given purpose than one carried out under natural conditions. In the present case, for instance, if the peat were simply thrown upon sandy soil, enormous quantities of it would be lost. Much of the valuable soluble humus would be leached out by rain, and pass deep into the sand, or be wasted so far as the farmer is concerned by being carried off in the drains. In the laboratory and factory, however, it is a simple matter to control the air-supply and the temperature so as to give the aerobic bacteria the conditions under which they can work best. Only the inevitable amount of Carbon dioxide is given off and wasted. The process throughout the mass is homogeneous, and the reaction carried to the exact conclusion desired.

In such conditions the results obtained are amazing. In this connection there can be no question as to the result, for it can be tested as often as the observer cares with the greatest ease in any laboratory, no elaborate appliances or delay being involved. All that is required is half a dozen test-tubes, a couple of filters, and a little Hydrochloric acid, some well-rotted stable manure, and samples of treated and untreated peat. The value of the rotted stable manure lies in its soluble content, and the amount of it is easily gauged approximately by the eye and accurately by the balance. Supposing that equal weights of rotted stable manure, raw peat, and treated peat are taken, well steeped with equal volumes of water and filtered, the liquid from the untreated peat is found to be almost colourless,

that from the stable manure is a lightish brown, while that from the treated peat is so concentrated that it has the appearance of being black. In other words, the water extract of untreated peat contains only traces of soluble humus, that from stable manure—one of the best, if not the best, ordinary source of humus—contains relatively little, while that obtained from treated peat is extremely rich in the substance. Supposing now that these three tubes are left standing for purposes of comparison and the experiment is repeated, we have, by continuing it a stage farther, a very simple means of getting a more precise measure of the difference between our three samples. By adding Hydrochloric acid to the filtered liquids the soluble humus, chiefly Ammonium humate, makes its appearance in insoluble form as a brown flocculent precipitate of Humic acid. When Hydrochloric acid is added to the water extract of the untreated peat scarcely any precipitate appears. When it is added to the water extract of the manure a precipitate forms that may settle down to occupy $\frac{1}{4}$ or $\frac{1}{2}$ inch of the test-tubes, but when the acid is added to the water extract of the treated peat a closely compacted precipitate results that may be as much as 6 or 8 inches in depth. To get an exact measure of the food values of the three substances it is only necessary to filter off these precipitates, to dry and weigh them. Experiment has shown that the untreated peat gives almost zero as its value, the manure a unit weight and the treated peat as much as fifty or eighty-times that obtained from the manure. The following are the

actual figures of one of a score of experiments that have been done somewhat on these lines, only on a more elaborate scale. It shows the enormous preponderance of treated peat in available nitrogenous plant food.

	<i>Soluble Humate.</i>	<i>Soluble Nitrogen.</i>	<i>Total Nitrogen.</i>
Raw peat	0.028	0.214	1.267
Bacterized peat	15.194	2.694	4.310
Garden soil	0.012	0.026	0.427
Fresh stable manure ..	0.433	0.291	2.533
Well-rotted stable manure	1.460	0.439	2.848
One-year-old peat-moss litter manure ..	1.050	0.826	2.587

If the object of the experiments undertaken at the Botanical Laboratories of King's College had been merely to find some new source of manure to replace the supplies of stable manure, which both market gardeners and agriculturists know are year by year steadily shrinking, the successful conversion of insoluble peat into a material rich in soluble plant food comparable in value, but far less bulky than that obtained in stable manure, would have been a notable achievement. It is true that there would have been nothing startling in the idea that it was possible by means of the decomposition bacteria to speed up the natural process which was known to occur slowly in peat, and thus secure a valuable fertilizer for the land. It is true also that the chemist has been perfectly well aware that the same

change can be effected even more quickly than with bacteria by treating the raw peat with alkalies, but so far it had not occurred to anyone that peat could be valuable as a manure, except when it had been well rotted by natural means. Farmers and horticulturists would have probably long rested content with buying the peat used in stables as bedding, and storing it up to rot into good condition, though, as has been done in practice, they could have hastened the process by mixing it with lime.

The aim of those working at the problem, however, was not to discover a fertilizer, but to find a medium in which the bacteria connected with the fixation of nitrogen could be cultivated and put on the land. In the peat treated with aerobic bacteria they found such a medium, which was far superior to anything they had hoped for. When once the peat has been treated with these bacteria, from between 20 to 25 per cent. of it is available as soluble plant food. To effect the change all that is necessary is then to keep the peat moistened at a temperature of 26° C. (79° F.) for about a week. Steam can then be forced through the mass for as long as is desirable to insure that all organisms, bacterial or other, have been destroyed, and the result is a sterile medium, neutral or slightly alkaline, and suitable for the cultivation either of plants or of bacteria.

Once a suitable medium had been found for the growth of Nitrogen-fixing organisms, the question to be settled was what bacteria could best be utilized for the purpose in view. As has been seen in earlier chapters, if the best obtainable results were to be

gained, it was necessary to include two groups—the *Bacillus radicicola* group, which acts only in association with leguminous plants, and the other group or groups that were able to fix Nitrogen while they remained free-living in the soil. As regards the *radicicola* group enough has already been said, except for the statement that in the specially treated peat the bacillus found a material better suited for its needs than the old form of culture. There was no longer any need for the farmer to dissolve up the materials supplied him, and grow the organisms for himself in home-made apparatus with temperature and other conditions quite unsatisfactory for the process. He had only to spread the material on the land or to mix it with his seed, or if he desired it in liquid form he could extract the peat easily with water, and use the resulting liquid to water the roots of his crop.

Of the other organisms connected with Nitrogen-fixation it is necessary now to write in rather greater detail. Experiment has shown that just as land on which leguminous crops are grown becomes richer in Nitrogen, so, too, there may be an increase of the Nitrogen content of the soil in cases where the ground has been left bare of vegetation. In such circumstances the increase will be comparatively slow, but at Rothamsted it has been observed to increase in a year by as much as 25 pounds an acre. There are two groups of bacteria by the aid of which the Nitrogen circulating in the soil air can be changed into forms of nitrogenous plant food. The first is anaerobic, working only in the absence of Oxygen;

and the second aerobic, working in the presence of Oxygen. The former of these bacterial groups was first described by Winogradsky in 1893, and was named by him *Clostridium pasteurianum*. It is a small rod-shaped organism, and can readily be grown in solutions containing the requisite organic food, such as sugar and mineral salts. But nitrogenous material must not be present. In such circumstances, if Oxygen is absent, it develops rapidly. It can even grow in the presence of Oxygen, provided other bacteria are mixed with it to take up the Oxygen from the culture. After growing for a few days there is no difficulty in showing that the bacteria have added appreciable quantities of combined Nitrogen to the medium in which they have been developing.

Several bacterial groups that are capable of fixing Nitrogen in the presence of Oxygen have been isolated. In 1901 Beyerinck described two species, *Azotobacter chroococcum* and *Azotobacter agilis*. Three additional species have since been described by Dr. Lipman of the New Jersey Agricultural Experiment Station. For the development of these bacteria a good supply of air is essential, a fact that goes a long way towards explaining why it is desirable for the ground round the roots of plants to be kept well aerated. *A. chroococcum*, the type with which we are most concerned, is an egg-shaped organism with a marked tendency to form agglomerations. It requires for its development far less food material than is needed by *Clostridium*, and flourishes best in soil where lime is abundant. When cultivated by

itself a slime forms round it, the nitrogen compounds either composing the whole of the slime or constituting a large portion of it. It appears to be able not merely to fix atmospheric Nitrogen, but also to transform nitrogenous bodies present in the soil that are unsuitable for plant food into available nitrogenous foodstuffs. Curiously enough, like *radicicola*, *Azotobacter* very readily enters into some sort of symbiotic relationships. Thus it is frequently found living in association with green algæ. The association of certain other bacteria in some way as yet not understood appears to increase its power for fixing nitrogen. Thus, while *Azotobacter vinelandii* is able to fix more nitrogen than *Azotobacter beyerinckii*, the output of the latter can equal that of the former if a certain other small bacterium is present. Commenting on this remarkable fact, Dr. Lipman writes: "In what manner the *Azotobacter* are favoured by the accompanying organisms is not known. It is likely, however, that the latter use up much of the Nitrogen fixed by the *Azotobacter*, and that these are therefore compelled to increase their activities."

The importance of the fact in relation to bacterized peat would seem to be considerable. When *Azotobacter chroococcum* is grown together with *Bacillus radicicola*, Nitrogen fixation proceeds more satisfactorily and in greater amount than if the two organisms are grown separately. The characteristic slime seen round *Azotobacter* is no longer apparent, but long-continued experiment leaves no doubt but that there is something in the nature of

FIG. 7

Hyacinths respond readily to humogen treatment. All the bulbs were grown in ordinary potting compost, but those on the right also received humogen. There was marked improvement in the roots and foliage, and in the colour, scent, and size of the flower.

(Grown by Messrs. Barr and Sons, Covent Garden.)

sympiosis between the two organisms, and that the work of both is facilitated by the co-operation.

We are in a position now to appreciate the second and concluding stage in the production of bacterized peat. The treated sterilized peat, rich in organic material that the bacteria are able to utilize, receives a mixed culture of *Bacillus radicolica* and *Azotobacter chroococcum*. The bacteria, being at a temperature best suited to their growth and with an abundant supply of the food material that they require, multiply rapidly and permeate the mass of the peat. When the whole peat mass is saturated, the action is stopped by drying the peat, and the material is ready to be applied to the seed or to the soil.

From what we have already seen, there are three ways in which the soil might be expected to derive benefit from the application of the peat. In the first instance, the richness of the peat in soluble humus should increase the richness of the soil from the point of view of the food elements it contains. Secondly, if leguminous plants are present, they should derive special benefit from the fact that the ground is being inoculated with the bacteria necessary for the infection of their roots and the resulting fixation of Nitrogen. Lastly, whatever the plants grown, the soil should become enriched in nitrogenous foodstuffs available for the plants, because the bacteria necessary for taking Nitrogen from the air in the soil and for transforming it into nitrogenous food material have been added to the soil and supplied with the exact foods which they require for healthy growth. So much for what was

expected. In a later chapter dealing with the results obtained from the use of the peat I shall have to come back to the subject, but in the meantime I will quote from an article contributed by Professor Bottomley to the *Illustrated London News* a short paragraph describing the influence of the treated peat on the soil as observed in one of many laboratory experiments:

“ When ordinary soil,” he wrote, “ is mixed with this inoculated peat there is a marked increase in the Nitrogen content of the soil if the temperature be suitable for the growth of the bacteria. A mixture of 9 ounces of soil from Rothamsted and 1 ounce of inoculated peat, incubated at 26° C. (79° F.) for twenty-eight days, gave an increase of 54 milligrammes of Nitrogen per 100 grammes of soil—a gain equivalent to a dressing of 28 cwt. of nitrate of soda per acre, if the increase had been proportional throughout an acre of soil 3 inches deep.”

In the last chapter, it will be remembered, some emphasis was laid on the peculiar colloidal properties of Humic acid, and of its power to adsorb materials from the surrounding medium. In the course of experiments with the peat the apparent paradox has been noticed that the peat enriches the soil in the phosphates available for plant food to a far greater extent than can be explained by the amount of available phosphate in its substance. That it can increase the amount of phosphate actually present is obviously impossible, but that the treated peat itself contains available phosphate and available potash seems clearly settled by such experimental evidence as that plants have been grown and

have flourished in sterilized moss that has had no other treatment than watering with the water extract of treated peat. It would seem possible that these substances are brought into solution, it may be as the result of the action of the Carbon dioxide liberated during the breaking down of the peat, and that they are held or adsorbed by the humate molecules in such a form as to be readily utilizable when they are required by the plant. This result was, of course, quite unexpected, and is a side issue to the main object of the research; but the value of peat is obviously greatly increased if a result of its action is to render available to the plants grown in soil so treated two substances that are only second in importance to nitrogenous food material, phosphate and potash, which were previously present in unavailable form. While the exact mechanism of the change remains uncertain, the fact is that during the process of decomposition the organic matter of the soil combines with such bases as Potassium and Calcium to form humates. In the words of Mr. Alfred Machen: "The practical importance of this change lies in the fact that by adding animal or vegetable matter to the soil we not only improve the mechanical texture, but by providing the necessary bacterial food and stimulus we unlock and make available the insoluble potash and phosphates of the soil, and give them to the plants in the form required—viz., potassic humate and phospho-humates. The fact that (1) plants feed on humate compounds, and (2) that organic matter broken down by bacterial activity in the soil

produces humate from the insoluble potash and phosphate are very important, for they point out a way of cheaply converting the inert plant foods of the soil into more active and available forms. Consideration of these facts makes it understandable why the application of organic manures has such good effects."

In the course of experiments made with bacterized peat on the growth of plants some very remarkable effects were noted. The plants which were treated with the material exhibited a characteristically marked root development, they frequently, almost normally, matured at an earlier stage, and they were generally more robust than those which had not received the bacterized peat. When it is remembered that these plants were being grown against others which were receiving what the growers regarded after long experience as the fertilizers best suited to their requirements, it is clear that the increased vigour of the plant could not be due to the organic material known to be in the peat, nor to the phosphates and potash that had become available, nor even to the lavish supply of nitrogenous foods derived from the air. The hypothesis was formed that the treated peat might perhaps be rich in accessory food bodies similar to the vitamins that in recent years have been found to be essential to animal growth. Experiments have now been in progress on this subject for over two years, and the accuracy of the hypothesis either in its present form, or in some closely similar form, may be regarded as established. As the subject is so novel, so striking, and of such fundamental importance, certainly in

connection with the nutrition of plants, and perhaps also so far as the treated peat is concerned in connection with the nutrition of animals, I am reserving it for a special chapter.

To conclude the present chapter it may perhaps be convenient to the reader if I append a summarized statement by Mr. Alfred Machen, who has been closely associated with Professor Bottomley in the later stages of the research, as to the claims that can be made on behalf of bacterized peat or humogen. It appears in the course of an article contributed to the *Fruit, Flower, and Vegetable Trades Journal* for June of this year, and is as follows:

“ Manure has been discovered which possesses the following remarkable properties:

“ 1. Humogen is an entirely organic material (humus), a large proportion of which is soluble ammonium humate.

“ 2. It directly introduces into the soil the Nitrogen-fixing organisms, and provides the food necessary for their rapid multiplication.

“ 3. During the bacterial decomposition of the peat comparatively large quantities of ‘ accessory food bodies ’ are liberated. These bodies enable the plant to utilize the food in the soil by stimulating the natural growth activities.

“ 4. It is free from smell, dust, weed seeds, disease spores, and insect pests, and is clean and pleasant to handle.

“ 5. An ideal and complete liquid manure is made by steeping in water. So efficient is this liquid that plants will actually grow in it.

“ 6. The soil is made more fertile without subsequent dressing, owing to the continual bacterial action.”

CHAPTER VIII

VITAMINES, ACCESSORY FOOD BODIES AND AUXIMONES

Importance of accessory food bodies—The perfect physiological diet—Beriberi and milled rice—Vordermann's contention and deficiency diseases—Experimental beriberi in fowls—Funk's vitamins—Their origin—Beriberi vitamins and scurvy vitamins—Moore's experiments on growth—Accessory food bodies and bacterized peat—Rosenheim's experiments on the primula—Extraction of accessory food bodies from peat—First experiments on wheat seedlings—Effects of Silver nitrate and Phosphotungstic acid fractions on wheat—Water culture experiments—The same with elimination of seeds—Funk's vitamins compared with Hopkins's accessory food bodies—Auximones—Tests with *Azotobacter*—A soil experiment showing Nitrogen fixation—Bacteria as a test for auximones—The scum-forming organisms—Sensitiveness of the test—Analogy with Hopkins's accessory food bodies—Auximones in rotted manure—Leguminous plants as sources of auximones—Nature of scum-forming organisms—The "food of the gods"—An experiment with chicks and a provisional deduction—The "standard bread" agitation.

THE discovery of accessory food bodies has been without question one of the most remarkable advances of modern Biology. It is rather the fashion nowadays to talk of recent discoveries having hurried to the scrap-heap the work of earlier generations. When the isolation of radium aston-

ished the chemists and physicists, there really were people in plenty who believed that all the patient endeavours of 150 years had gone by the board. In the same way in medicine, while we say with justice that the knowledge gained of bacteria has revolutionized the science and art of medicine, many of us are inclined to forget that the solid foundations on which the art rested in the fifties still remain established, even though the successful nature of modern achievement has to some extent hidden them from view.

For many long years it was an established principle among animal physiologists that the perfect physiological diet consisted of so many grammes of carbohydrate, so many grammes of fat, and so many grammes of protein, with a few necessary salts in addition. It was believed that by increased perfection in the art of measurement the whole of an animal's activities could be expressed in the form of an energy equation, reduced for purposes of convenience to terms of heat. On the one side were placed the heat units or calories contained in the food; the other side of the equation showed how this energy had been spent, and consisted of such items as the residual energy value of the waste products of the body, the heat dissipated to the air through the lungs and skin, the heat absorbed to turn liquids into gases, the energy spent in work and locomotion, and so forth. The work so done was, and remains, valuable, but all the time physiologists had a feeling that everything could not be explained by a consideration of energy factors.

Some men, as they do still, took refuge in conceptions of vitalism, shelving in fact the problem as insoluble; others are pressing on in search of fresh material evidence to illuminate what remains obscure. It may well be that the problem of the living organism will never be solved by the physiologist, for as the research proceeds fresh factors are continually bringing themselves into evidence, and with the increase of knowledge it becomes more and more possible to form some appreciation of the extent of the unknown.

It was through researches undertaken on disease that the physiologist was brought to recognize the existence and importance of accessory food substances. Both experiment and observation had long ago accustomed him to the idea that minute quantities of substance might have astonishingly important results on the welfare of the body. Cretinism, with all the disarrangement of growth and function associated with it, had been proved to be conditioned by the absence of the excretions of the thyroid gland. Starling and others had been pressing their researches to elucidate the elaborate chemical mechanism by which the conduct of the body tissues is regulated, and the blood had come to be regarded no longer as a simple liquid in which red and white blood corpuscles floated about their business, but as an intensely complex aggregate of chemical substances, some of which were necessary for the hourly needs of the body, while others were present there on the bare chance of the emergency arising that they were designed to meet.

Since the year 1896, when Vordermann put forward the theory that beriberi occurred after the long-continued use of milled rice—that is, of rice from which the outer layers of the grain had been artificially removed—a whole group of diseases has come to be recognized under the common class name of “deficiency diseases.” They comprise beriberi, scurvy, and its congeners, pellagra, and possibly rickets, tetany, osteomalacia, and sprue. Vordermann’s view was not long in receiving confirmation, and the further fact was soon noted that persons whose diet consisted of unmilled rice—that is, of rice which retained its outer layers—were exempt from the disease. The more exact method of experiment was at once introduced to supplement observation. Eykman, attempting to produce the disease in fowls, fed some birds purely on polished rice. They rapidly lost weight and developed neuritis (polyneuritis gallinarum). Birds fed on whole grain rice developed no such disease. The outbreak of the disease was prevented by adding the rice-polishings (the pericarp of the grain) to the diet, and even when the disease was established it could be cured by administering a water extract of the rice-polishings. It had in fact been shown experimentally how the disease could be brought on in fowls, and also how it could be cured.

Casimir Funk then attacked the problem chemically, and after a series of investigations he succeeded in isolating a substance from the alcoholic extract of rice-polishings, which appeared as colourless, needle-shaped crystals, and was markedly valuable for

curing experimental beriberi. Its formula is not definitely known, but it is a nitrogenous substance, appears to be a pyrimidine base, and probably exists in food as a constituent of nucleic acid. Of this substance Dr. Watson-Wemyss, in an article on "A Summary of Recent Work on Vitamines," published in the *Edinburgh Medical Journal* for last March, writes:

"As a result of this valuable work, the prevention and cure of beriberi came to rest for the first time on a scientific basis. Funk's vitamine has been proved to be the most powerful and rapid remedy we possess in beriberi. It is present in food in such minute quantities that simple dietetic treatment of the disease brings about recovery very slowly, and the difficulty of obtaining isolated vitamine, together with its expense, make its general use at present impossible. It is hoped that it may prove possible to produce Funk's vitamine synthetically."

Once this new line of research was suggested to workers, it was soon found that vitamins were widely distributed both in the animal and vegetable kingdom. Yeast, milk, yolk of eggs, meat, wheat, oats, and barley, have all been shown to contain them. They are not identical in character. While, for instance, dried corn only contains beriberi vitamine, scurvy vitamine also appears as soon as the corn begins to germinate. Fresh-growing plants, potatoes, juicy fruits, and vegetables, are rich in scurvy vitamins, but they disappear on drying or on heating to 100° C. Beriberi vitamine resists drying, and is also more resistant to heat. A point requiring emphasis at this stage is the minute

quantity of vitamine that is present. In rice, for instance, only the ten-thousandth part of the rice consists of vitamine, a fact that suggests that the action of vitamins is in some way comparable with that of hormones and the secretions of the ductless glands.

It has long been recognized that scurvy is a disease conditioned by the absence of fresh food, and that if fresh food is obtainable the disease yields rapidly to treatment. Sea experience of long standing has proved the efficiency of lime-juice in its treatment, and Funk has shown both that lime-juice is rich in scurvy vitamine, and that the acidity in its composition helps to increase its stability. While scurvy and beriberi are similar, there seems to be no doubt that they are different diseases, caused by the absence of different vitamins from the diet, for whereas scurvy vitamine by itself can prevent both beriberi and scurvy, beriberi vitamine will prevent only beriberi, and will not affect scurvy.

For those interested in the subject of vitamins there is already a long literature available, and no useful purpose would be served here by further considering the relation between vitamins and other diseases. Reference, however, must be made to the experiments conducted by Benjamin Moore and others, on the relations between vitamins and healthy growth. On feeding young rats with a diet of white bread growth was very soon arrested, whereas they flourished on a diet of wholemeal bread. The experiment had many interesting features. It showed, for instance, how the vitamine-starved

animals recovered when their diet of white bread was replaced by wholemeal bread. To describe it in detail would take up too much space, and to do so is the less necessary because it formed the basis of the campaign instituted a few years ago in favour of "standard bread." The fact that I wish to emphasize is that vitamins are as essential to growth as they are to health; in fact they are more so, as in diet where they are abundant the normal rate of growth is stimulated. So much is this the case that it has even been suggested that they may be responsible for tumour growth, and that the formation of tumours might be checked by the elimination from the diet of the substances exciting growth.

In the course of the experiments made with bacterized peat or humogen some very surprising results were obtained. In the first instance, in a whole series of experiments conducted at Kew Gardens and at the Chelsea Physic Garden during the summer of 1913, on various pot plants—wheat, barley, oats, maize, salvia, fuchsia, carnation, primula, etc.—it became evident that the bacterized peat possessed a certain growth-stimulating property that could not be accounted for by any known manurial constituents present. Further experiments showed that the stimulating substance was soluble in water and effective in very minute quantities. Dr. Rosenheim of King's College, in an experiment with seedlings of *Primula malacoides*, potted up in loam, leaf mould, and sand, found that plants watered twice with the water extract of only

0·18 gramme of bacterized peat were after six weeks' growth double the size of similar untreated plants, and it was noted that flower production and root development were promoted equally with increase of foliage. In view of what was then known as to the effect of vitamines on the growth of animals and on their health, it was decided as a preliminary experiment to follow the method adopted by Cooper and Funk for the isolation of beriberi vitamine. A considerable quantity of bacterized peat was extracted with absolute alcohol in a shaking machine for three hours, and the extract was filtered off and evaporated to dryness *in vacuo*. The residue was taken up in distilled water, filtered, and to the filtrate Sulphuric acid was added until the concentration of the latter reached 5 per cent. A slight precipitate of Humic acid was filtered off, and to the filtrate an excess of a 30 per cent. solution of Phosphotungstic acid was added. The whole was then left to stand overnight, when the liquid was decanted off through a filter, the precipitate repeatedly washed with a 5 per cent. solution of Sulphuric acid, and finally decomposed with an excess of Baryta. The liquid was filtered off from the precipitate of Barium phosphotungstate, and the filtrate, freed from the last traces of Baryta by means of a very dilute solution of Sulphuric acid, was evaporated to dryness *in vacuo*. From 7 kilogrammes of bacterized peat the amount of dry substance thus obtained amounted to 12·0096 grammes. For purposes of testing, this dried residue was dissolved in such a way that the amount extracted from 10 grammes of the original

peat should be contained in a litre of water. In other words, the proportion of the dry Phosphotungstic acid fraction in the final solution employed consisted of 17 parts per 1,000,000.

Wheat seedlings were the first plants selected for trial. Nine pots were taken, filled with sand, and divided into groups of three. Ten wheat seeds were planted in each pot. Three separate solutions were made up. Each of these contained Nitrogen, Phosphate, and Potash in the ratio of 400, 200, and 1,200 parts per 1,000,000 respectively. The first solution was then left as such; to the second was added the alcoholic extract from 10 grammes of peat per litre of solution, while the third received instead (in addition, of course, to the Ammonia, Phosphate, and Potash) 17 parts per 1,000,000 of the dry substance obtained from the Phosphotungstic fraction. Each week after sowing each pot received 100 c.c. of solution. At the end of the period the plants were uprooted, washed, dried, and weighed. The results were as follow:

<i>Series.</i>	<i>Weight of Thirty Plants.</i>	<i>Increase over Series 1.</i>
	Grammes.	Per Cent.
1. Complete food solution	11.94	—
2. Complete food solution <i>plus</i> alcoholic solution of peat	14.46	21.1
3. Complete food solution <i>plus</i> Phosphotungstic fraction	15.45	29.4

This experiment indicated clearly that the substance in bacterized peat, which had proved its

efficiency in stimulating plant growth, was also precipitated by Phosphotungstic acid, and that the Phosphotungstic acid fraction was quite as effective as the original alcoholic extract of the peat. Further, some confirmation was given to the hypothesis that the peat contained bodies similar in action to vitamins.

Funk found that on treating his Phosphotungstic acid fraction with Silver nitrate he had been able to obtain his vitamins in crystalline form. To determine, therefore, how far the growth stimulant in bacterized peat resembled the vitamins, the Phosphotungstic acid fraction of the peat was treated similarly. It was decomposed as described above with Baryta, and to the filtrate from the Barium salt Silver nitrate was added until no further precipitate was produced. The brownish precipitate was filtered off, well washed, suspended in dilute Sulphuric acid, and decomposed with Sulphuretted hydrogen. The filtrate from the Silver sulphide was then exactly neutralized with Baryta, the clear liquid filtered off from the precipitate of Barium sulphate, and evaporated to dryness *in vacuo*. The weight of dry substance obtained from the Silver fraction from 7 kilogrammes of bacterized peat amounted to 0.2452 gramme, and as this also was made up into a solution so that a litre of it should contain the silver fraction from 10 grammes of peat, the solution contained the Silver fraction to the amount of 0.35 part per 1,000,000—*i.e.*, approximately 1 part per 3,000,000.

To test the efficiency of this Silver extract three

series of trials were made. Nine pots in all were taken, and 15 grains of wheat were planted in each in sand. All nine pots received Ammonia, Phosphate, and Potash, as in the previous experiment. The first series had this alone, the second series also received some 17 per 1,000,000 solution of the Phosphotungstic acid extract, while the third was given some of the 0.35 per 1,000,000 solution of the Silver nitrate extract. As before, the plants were first treated a week after planting, and then each pot received 100 c.c. of its food solution once a week. At the end of the seventh week the results after drying were as follow:

<i>Series.</i>	<i>Gross Weight of Forty-Five Plants.</i>	<i>Increase over Series 1.</i>	<i>Dry Weight.</i>	<i>Increase over Series 1.</i>
	Grammes.	Per Cent.	Grammes.	Per Cent.
1. Complete food	64.5	—	13.3480	—
2. Complete food plus Phosphotungstic fraction	96.8	50	16.3818	22.7
3. Complete food plus Silver nitrate fraction	96.5	49.6	15.7148	17.7

As this experiment showed that the silver nitrate extract gave results comparable with those obtained with the Phosphotungstic acid precipitate, it was decided further to try the experiment of growing wheat seedlings in water culture. Two sets of eighteen similar seedlings were selected, each set being originally of equal weight—4.73 grammes.

The first set were distributed among three bottles, each having a capacity of 200 c.c. The bottles were filled with physiologically pure water, to which the pure salts necessary for Detmer's nutrient solution—Ammonia 400, Phosphate 200, and Potash 1,220, parts per 1,000,000—were added. The second set were grown in a solution precisely similar, except that 0.35 parts per 1,000,000 of the Silver nitrate fraction of treated peat extract had been added. The bottles were aerated daily, and the solutions changed twice a week. Every sixteen or seventeen days the plants were removed, dried, and weighed. The results obtained were as follow:

<i>Series.*</i>	<i>Weight of Sets of Eighteen Plants.</i>		<i>Gain or Loss on Original Weight.</i>
		Grammes.	Per Cent.
1. Pure food solution	Original weight ..	4.73	—
	After sixteen days	5.42	+ 14.7
	After further seven- teen days	5.29	+ 11.8
	Ditto	4.33	- 8.4
2. Pure food solution <i>plus</i> Silver nitrate fraction	Original weight ..	4.73	—
	After sixteen days	5.57	+ 17.7
	After further seven- teen days	6.65	+ 40.6
	Ditto	7.33	+ 54.9

The distinction between these two experiments is brought out strikingly in the following diagram, where the weights of the two series of plants are

* The poor growth of the seedlings in this series is explained by the fact that the experiment was made early in the year, when the plants obtained very little sunshine.

plotted against time, the dotted line showing the plants that had no Silver extract, and the unbroken line those which received the extract:

This experiment, particularly when taken in conjunction with the previous ones and others, proves conclusively that bacterized peat contains a substance or substances which stimulate the growth of the plant and enable it to utilize the normal food constituents supplied to it. In nature the need is doubtless supplied by the decaying organic matter in the soil.

As has been pointed out above, anti-scorbutic vitamine is not present, so far as can be ascertained, in dry seeds, but it makes its appearance two or three days after the young roots have begun to show, and extracts from them have proved as effective as

extracts of green vegetables in the treatment of scurvy. The hypothesis was suggested that special growth substances were formed during germination, which enabled the young embryo to utilize the food material present in the seed. To test this it was decided to remove the source of these growth substances by cutting off the seed as soon as possible after germination, as in that case the addition of food substances would have a much more marked effect. For the experiment two series of wheat seedlings were taken at a rather earlier age than in the previous experiment. Before removal of the seeds both sets weighed 3.97 grammes, and after removal of the seeds 3.2 and 3.17 grammes respectively. Both were fed on Detmer's solution, but the second set also received Silver nitrate fraction exactly as before. The results, which in this case were even more striking, were as follow:

<i>Series.</i>	<i>Weight of Sets of Eighteen Plants.</i>	<i>Gain or Loss in Weight.</i>
	Grammes.	Per Cent.
1. Complete food solution	Original weight .. 3.20	—
	Weight after sixteen days 3.37	+ 5.3
	After further seven-teen days 3.20	0.0
	After further seven-teen days 2.85	- 10.9
2. Complete food solution <i>plus</i> Silver nitrate fraction	Original weight .. 3.17	—
	After sixteen days.. 3.63	+ 14.5
	After further seven-teen days 4.29	+ 35.3
	After further seven-teen days 5.05	+ 59.3

When the variation in weight is plotted as before against time in days, the effect of the Silver nitrate extract which, it will be remembered, was added to the extent of only about 1 part in 3,000,000, is most remarkably emphasized. As before, the dotted line represents the growth of the plants fed on pure culture, the unbroken line that of the plants supplied with Silver nitrate extract of treated peat.

In view of the very slight increase of growth made by the untreated plants, the assumption seems justified that during germination certain substances are developed which enable the embryo to utilize the food material present in the seed, and that these substances can be replaced in whole or in part by the Silver fraction from an extract of bacterized peat.

As we shall see in a later chapter, these experiments do not stand alone. They are confirmed not only by other experiments definitely undertaken to test the effect of the Phosphotungstic and Silver nitrate fractions, but the whole series of the experiments made with the treated peat becomes intelligible when considered in relation to the accessory food bodies.

In describing the results obtained it has seemed simpler so far to draw only a slight distinction between the vitamins, as described by Funk, and the accessory food substances, as described by Hopkins. There is a close similarity between the two classes of bodies, in that both are prepared by means of Phosphotungstic acid and Silver nitrate from such substances as the husk of grain, yeast, egg-yolk, milk, and so forth. There are, however, certain differences. Thus, for instance, whereas the vitamins of Funk appear to be in the nature of a pyrimidine base, in the experiments made by Hopkins it was insisted that the bodies used were free from amino-acids, purine and pyrimidine bases. It should be noted also that, like Hopkins's bodies, the plant accessory substances are resistant to heat. This is shown by the fact that after the Phosphotungstic extract from bacterized peat had been treated in an autoclave at 134°C . for half an hour, it still gave the characteristic scum reaction (*vide* later this chapter). At present analytical difficulties make it unwise to dogmatize on this point. What has to be emphasized is that the treated peat contains substances which are able to promote growth

on lines similar to those promoted both by the vitamins of Funk and the accessory food bodies of Hopkins. And it should also be stated that, in the opinion of Professor Bottomley and his co-workers, the substances with which he is dealing are more closely related to the accessory food bodies of Hopkins than to the vitamins of Funk.

When Professor Bottomley first called attention to the existence of these substances in peat, he stated that further work was being undertaken with a view of clearing up the nature of the substances involved, and of defining their properties. While the present volume was in course of preparation a further paper was published in the *Proceedings of the Royal Society*, and in it he describes the bodies under the new term of auximones (from *αὐξίμος*, promoting growth).

While the experiments described above were very necessary to establish conviction, they had the great drawback that long periods were required for carrying them out. The delay involved in order to test whether or not a given solution contained auximones was considerable, five or seven weeks being required to enable the plants tested to grow sufficiently to put the matter beyond dispute. It is clear that there would be an immense saving of time if the same result could be obtained by treating rapidly growing bacteria with the substance, and further it was obviously of great importance from the standpoint of the main research to know what influence, if any, the auximones had on the growth of the nitrogen-fixing organisms. *Azotobacter chroococcum*

was used for the experiment. Nine flasks were taken and divided into sets of three. The same culture solutions were placed in all three flasks—1 gramme of Mannite, 0.2 gramme of Di-potassium phosphate (K_2HPO_4), 0.02 gramme Magnesium sulphate ($MgSO_4$), and 0.2 gramme Calcium carbonate ($CaCO_3$). The first three flasks had nothing in addition, the second three received 0.00017 gramme of the Phosphotungstic acid fraction—that is, the amount obtained from 1 gramme of treated peat—and the third set received a corresponding fraction of the Silver nitrate fraction, the amount being 0.000035 gramme. Two flasks were sterilized to act as a control. At the end of ten days no nitrogen had been fixed in the sterilized flasks, 3.9 milligrammes had been fixed by the first series, 9.7 milligrammes by the second, and 10.4 milligrammes by the third.

In view of the encouraging results obtained in these experiments it was decided to ascertain more definitely how far liquid cultures of nitrifying organisms* could be used as a test for the auximones. A culture was originally obtained by incubating garden soil in Winogradsky's medium. Two sub-cultures were taken from this initial culture, and eighteen flasks were filled with pure uninoculated culture solution (Winogradsky's). These were all inoculated with material from the second sub-culture. The first series received nothing in addition, each flask of the second series received

* These are organisms which have the property of converting Ammonium salts into nitrates.

the Phosphotungstic acid fraction derived from 1 gramme of the treated peat, while each flask of the third received the Silver nitrate fraction from 1 gramme of the treated peat. Incubation was carried on at 26° C., and at the end of forty-eight hours no scum had formed on the flasks which had received no auximone, but nitrification had proceeded at a normal rate. Both sets of flasks that had received auximones showed scum, but no nitrification. Only two interpretations of these results were possible: either the subculture furnished a satisfactory test for auximones, or scum-forming organisms had been introduced with the auximones. To test this possibility a flask containing a subculture was incubated at 26° C. for four days with no result. One half of this culture was sterilized by heating in an autoclave for half an hour at 160° C. To this and to the unsterilized half the Phosphotungstic acid fraction derived from 1 gramme of peat was added, and the two flasks were incubated for three days at 26° C. The unsterilized flask contained a thick layer of scum, while the sterilized flask had none. The explanation was that the scum-forming organism is present in soil cultures, but that the formation of the scum in this medium is due to the presence of the auximone.

This experiment was several times repeated, and the scum organism was found in each of several soils tested. Under the microscope it proved to consist of a mixture of beaded rod forms and spindle-shaped forms

Further experiments emphasized the amazing sensitiveness of this bacterial test to the Silver

extract. To quote one of the experiments: Six flasks, A to F, were taken and filled with 100 c.c. of normal culture solution. To the first nothing was added, but to the others decreasing amounts of Silver nitrate extract. The quantities used and the results obtained on incubation are shown in the following table:

	<i>Parts per Million of Silver Nitrate Ex- tract added.</i>	<i>Result.</i>
A. 100 c.c. culture solution ..	0	None
B. Ditto	4.0000	Extremely thick scum
C. Ditto	2.1000	Thick scum
D. Ditto	0.3500	Moderate scum
E. Ditto	0.0070	Fair scum
F. Ditto	0.0007	No appreciable re- sult

In other words, when the Silver nitrate extract was added to the amazingly small extent of 1 part in 15,000,000 an appreciable result was obtained.

Tests were made with a large number of other organic substances to see whether the scum would be formed in their presence. The result in every case was negative until 100 parts per 1,000,000 were added. Even then the characteristic scum was not obtained, as the whole liquid was found to turn cloudy.

Further comparative tests were made with the accessory food bodies that had been found to give results on animals. When they were derived from germinated wheat, dry wheat, peas, or yeast, the

scum organisms made their appearance. They did not appear when the accessory food bodies were derived from dry maize or dry peas. It seems evident that these scum-forming organisms are able to serve as a satisfactory test both for auximones and for the accessory food bodies of Hopkins.

Tests were also undertaken with fresh and rotted manures. The result with these was that it was found that the quantity of auximones present increased with the progressive decomposition of the organic matter of manure. The amount of it was relatively small. In two-year-old rotted manure, compared as against bacterized peat, a better scum was obtained with the fraction from $\frac{1}{5}$ gramme of peat than with 10 grammes of the manure.

A source from which the auximones can readily be derived is the leguminous plant. Thus the Phosphotungstic acid fraction derived from $\frac{1}{10}$ gramme of bean nodules gave a very thin film of scum. The fraction from $\frac{1}{25}$ gramme of bean root gave a fair growth, while with $\frac{1}{10}$ gramme a good growth was obtained. When, however, beans were grown in sterilized sand without the formation of nodules no scum at all appeared, even though the extract of $\frac{1}{10}$ gramme of root was used.

As regards the scum-forming organisms used for the test, it may be noted that they require no organic Carbon, but, like the nitrifying organisms and the sulphur and iron bacteria, they are able to assimilate Carbon dioxide by chemo-synthesis. They are unable to live on nitrates, but must derive their Nitrogen from an Ammonium salt.

I have dealt in this chapter with the auximones at greater length and in fuller detail than some readers may think that the subject warrants.

I make no excuse for so doing, as there is a possibility that in the auximones derived from bacterized peat we may have a substance of enormous value. Wells, in his book of brilliant imagination, *The Food of the Gods*, galvanized the public into an appreciation of the meaning of vitamins. In treating the subject he took the full licence of the novelist, and he would doubtless be the last to suggest that by vitamins or any other product it would be possible to upset the unknown factors that determine the limits of the growth of various species. Auximones will never threaten the world with the menace that he so graphically painted, but it is a fact that they do aid plants to attain their fullest normal growth, and it may prove to be a fact that they will prove valuable in diseases of malnutrition. A preliminary experiment, to which too much importance must not be attached, has already been carried out at King's College. Some chicks were taken straight from the egg. One batch of them were fed on a physiologically complete diet, and all naturally developed *polyneuritis gallinarum* and died. The other batch in addition to this diet also received Phosphotungstic acid extract. They died also, but later, and of ordinary chicken diseases. The details of the experiment have not been published, and I am mentioning it here rather in the hope of attracting physiologists to undertake a research that seems as if it might yield valuable results than as stating a

conclusion. If further experiments were to prove that either auximones themselves, or auximones subjected to some further treatment, were able to act similarly to Hopkins's accessory food bodies, or to Funk's vitamines, it would no longer be necessary to say as I did, quoting Dr. Watson-Wemyss at the outset of the chapter: "The difficulty of obtaining isolated vitamines, together with its expense, make its general use at present impossible."

The subject is one of proved general interest, as was shown by the public notice that was taken of the recent agitation on the subject of standard bread. As in most public agitations, there were occasions when the truth was lost sight of, when a proved fact was applied more widely than was scientifically justified, but the fact stood behind the exaggerations that at times threatened to conceal it, and has become part of the stock of common knowledge. Such harm as resulted was trivial, and only good can come of the general recognition of the fact that without vitamines and without accessory food bodies it is impossible for either plant or animal to be satisfactorily nourished.

CHAPTER IX

ELEMENTARY CONCEPTIONS OF CHEMISTRY IN RELATION TO THE SOIL

Difficulties of chemistry—The elements and their symbols—Atoms—Mixtures and compounds—Molecules—The formula and the equation—Affinities—Grouping in the molecule—The structural formula—Acids, neutrals, and bases—The COOH group—Series of acids—Seventeen possible acids with one formula—Neutralization of acids—Oxidation—Reduction—Hydration—Dehydration—Ammonia—Carbohydrates, proteins, fats, and amides.

Few subjects present such impenetrable difficulties to those who have not made some sort of a set study of it as Chemistry. Range through the Arts and Sciences as you will, and the subject-matter of them obtrudes itself on your everyday life. Zoology seems simple and intelligible to those who have not studied it, because such people think of it in terms of the animals with which they are familiar. Our everyday knowledge of plants makes all of us somewhat of amateur botanists. The man who can recognize the Great Bear and a half-dozen of the constellations feels confident that if he set his mind to it he could become an astronomer. The bicyclist imagines himself to be, and to some extent is, an engineer. Experience of roads and soils makes most men in a way geologists. Electric light and motor-

ing have taught men something of electricity. When the untaught man, however, finds himself confronted with chemistry, he is apt to feel himself in a strange world with no means of determining his bearings. He has seldom been brought face to face with the elements of which chemistry deals. The air he breathes is not only a mixture of Oxygen, Nitrogen, water vapour, and Carbon dioxide, but he finds that it is a storehouse of half a dozen of the so-called rare gases. Iron, the metal he is perhaps most familiar with, he learns, has Carbon in combination with it, and by the addition of traces of other elements may change its properties and develop astounding degrees of hardness. The gold, silver, and copper coins that he has been wont to regard as pure are each and all of them alloys. Nor is this all. The first book that he opens on the subject bristles with an apparently infinite number of mysterious symbols. Figures are scattered about among them, some on the line and some beneath it, and if he chances to light on the simplest calculation he sees it at once stretching to four places of decimals.

For these reasons I am including in this volume a short chapter on the chemistry of the soil so far as we are concerned with it in connection with Nitrogen fixation, in the hope that it may help those who have no knowledge of the subject to get a clearer appreciation of the problems involved.

Despite the complexity of nature as we see it around us, the world contains only a few elementary substances, known as elements. They are some

eighty in number, and only a few of them are widely distributed. About a score of them are concerned with the life of man and animals. These substances, however, are found combined in all sorts of different ways, and to study them intelligently it is necessary to know exactly how they are built up. Take, for instance, such a substance as starch. A single grain or molecule of starch may be considered without serious error from our standpoint as containing 6 unit grains or atoms of Carbon, 10 unit grains or atoms of Hydrogen, and 5 unit grains or atoms of Oxygen. If 2 unit grains or atoms of Hydrogen, and 1 unit grain or atom of Oxygen are added to it, the starch becomes sugar. All this clumsy statement is stated in the language of the chemist in the simple equation:

The mysterious symbols of chemistry are in most cases the first letter or the first two letters of the name of the element. Thus, Carbon is written C, and Calcium, to differentiate from it, Ca. In some instances the symbols are derived from the Latin names. Thus, Iron (Ferrum), Fe, etc. The elements with which we are concerned in agriculture (with their symbols) are the following:

Carbon C	Sulphur S
Hydrogen H	Calcium Ca
Oxygen O	Magnesium.. .. Mg
Nitrogen N	Iron.. .. Fe
Phosphorus P	Potassium K
Sodium Na	Copper Cu
Chlorine Cl	Aluminium.. .. Al
Silicon Si	Manganese Mn
Lithium Li	Zinc.. .. Zn

Experiment has proved that any given weight of an elementary substance consists of a certain number of ultimate particles or atoms of substance. One may conceive, for instance, of a speck of Carbon enormously magnified. In such a case one could—to assist the imagination—regard it as consisting of myriads and myriads of round black grains, each of them the exact replica of the others. Each of these grains would be an atom of Carbon. For the purposes of general chemistry one may say that these atoms are indivisible.

The enormous majority of substances, all, in fact, except the elements themselves, are either mixtures or compounds. In a mixture the atoms would lie more or less any way like a series of differently coloured marbles jumbled together in a bag. In a compound there would be no single atoms at all, but groups of atoms, two, three, four, or even hundreds and thousands firmly held together, each group being the exact counterpart of each other group. In most instances, too, the atoms of an element by itself form little groupings or *molecules*. Thus, the gas Oxygen does not exist in the air as single, but as twin atoms. As will be seen, the chemist, therefore, writes it as O_2 , and not O_1 .

In connection with chemical work figures are used in two ways. Take such a substance as Sulphuric Acid. This might be written $H_2S_1O_4$ (it is written H_2SO_4), and means that the unit or molecule of Sulphuric Acid has, combined together, 2 units or atoms of Hydrogen, 1 unit or atom of Sulphur, and 4 units or atoms of Oxygen. In other words, the

little figures placed below and immediately after the chemical symbol state the number of atoms contained in the molecule. Where no figure is given it is understood that only a single atom is present. When an expression has a figure on the line before it, such as $2\text{H}_2\text{SO}_4$, or $3\text{H}_2\text{SO}_4$, it means that two or three molecules of Sulphuric acid are concerned. It is also possible to bracket subgroups in a compound, and place a small figure below the line following the bracket. In such a case there is that number of the group in the compound. Thus, when the chemist writes—

he means, if six molecules of Sodium Cyanide (composed each of one atom of Sodium, one of Carbon, and one of Nitrogen) are mixed with one molecule of Ferrous Hydroxide (composed of one atom of Iron combined with two groups, each consisting of one atom of Oxygen and one atom of Hydrogen, reaction occurs, and we get [that is the chemical meaning of the symbol =] one molecule of Sodium Ferrocyanide (consisting of four atoms of Sodium combined with one atom of Iron, and six groups, consisting each of an atom of Carbon and an atom of Nitrogen), and two molecules of Caustic Soda (consisting of one atom of Sodium combined with one atom of Oxygen and one atom of Hydrogen).

The question naturally suggests itself how these various compounds are held together. Various workers have suggested explanations of the problem, but we are concerned here with what happens rather

than with why it happens. Experiment has shown that the different atoms have varying affinities. We may regard these affinities as hooks sticking out from the smooth surface of the atom, one hook corresponding to one affinity. Of the commoner elements in agricultural chemistry, we can state that carbon

has four affinities $\left[\begin{array}{c} | \\ -\text{C}- \\ | \end{array} \right]$ usually written more simply

$\begin{array}{c} | \\ -\text{C}- \\ | \end{array}$; Hydrogen one, H—; Oxygen two, —O—;

Nitrogen sometimes three and sometimes five, —N—

or $\begin{array}{c} | \\ -\text{N}- \\ | \end{array}$; Phosphorus five, $\begin{array}{c} | \\ -\text{P}- \\ | \end{array}$; Sulphur six,

or two, $\begin{array}{c} || \\ -\text{S}- \\ | \end{array}$ or —S—; Sodium one, Na—; and

Potassium one, K—.

The statement can be made generally that there cannot exist any compound in which any hooks are left free, or, in chemical terms, all affinities must be satisfied. Thus, while the substance water exists, $\text{H}-\text{O}-\text{H}$, usually written $\begin{array}{c} \text{H} \\ \text{H} \end{array} \text{O}$, the substance OH cannot exist because it would leave an affinity unsatisfied, thus:

In organic chemistry especially it is of vital importance to know how the atoms are arranged in the molecule, because the different groups give very different results, and two substances may contain exactly the same atoms with the same number of

each, but the resulting properties be quite different. Thus, Methyl Cyanide—

is a colourless liquid, possessing a strong but not disagreeable smell, and is readily soluble in water. Methyl Isocyanide, however—

is also a colourless liquid, possessing, as Perkin and Kipping state without exaggeration, an almost unbearable odour and poisonous properties.

It is extremely important, and also rather difficult, to get a clear appreciation of what is meant by the terms acid, neutral, and base, but a rough definition is easy enough. An acid is a substance that reddens blue litmus-paper and that has a sour taste, a neutral substance has no effect on litmus-paper, a basic substance turns red litmus-paper blue, and the more common bases, such as Caustic Potash, Caustic Soda, etc., have an astringent caustic taste. It is generally true that an acid body has a Hydrogen that can easily be replaced by a metal. Thus—

It is also generally true that bases are formed by metals combined with the group OH—*e.g.*, NaOH, etc.—and that acids are formed when non-metals are combined with the group OH—*e.g.*, H₂SO₄ (Sulphuric Acid).

But there are many exceptions, some more apparent than real, such as HCl (Hydrochloric Acid) and all the organic acids, such as CH₃COOH (Acetic Acid), where the CH₃ group may be regarded as acting as if it were a non-metal element.

There are not many groups that we have to consider for the present purpose of this book. The group of chief importance is the COOH group. This is the standard grouping that gives acid properties to organic bodies, and that can be neutralized when the hydrogen in it is replaced by such a substance as the Calcium of Lime. The atoms are combined as follows: $-\text{C} \begin{array}{c} \diagup \text{O} \\ \diagdown \text{OH} \end{array}$, and it will be noticed that the Carbon has one affinity unsatisfied. If a Methyl group (CH₃) is linked on to this we have Acetic Acid, one of the simplest of all organic bodies:

From this a whole series of organic acids can be formed by the simple system of inserting any desired number of the group CH₂.

Thus—

Propionic Acid.

Butyric Acid.

and so forth.

This does not end the degree of complexity of the formation of organic compounds. The formula for Butyric Acid, for instance, adding up the Carbons, Hydrogens, and Oxygens, is $\text{C}_4\text{H}_8\text{O}_2$, but the formula can also be written—

in which case you get a substance with different properties, known as Isobutyric acid. When three more CH_2 groups are added, you get a body called Heptylic Acid.

It is possible to write no fewer than seventeen different structural formulæ for Heptylic Acids satisfying the necessary conditions, though the formula is a simple one ($\text{C}_7\text{H}_{14}\text{O}_2$), and of these seventeen hypothetically possible bodies nine are actually known. The number of hypothetically possible acids from stearic acid, which is far from being the most complex of the series known ($\text{C}_{18}\text{H}_{36}\text{O}_2$), can be imagined.

The complexities of these substances do not concern us. What has clearly to be borne in mind as regards them is the simple means by which their acid properties can be neutralized. This can be done readily by means of Lime [$\text{Ca}(\text{OH})_2$] or Ammonia (NH_4OH , or NH_3). Thus—

or—

Four fundamental processes occur in the soil in connection with the decomposition of organic matter. Oxygen is added to or taken from the molecule, and the elements of water are added to or taken from the molecule. If some indication can be given to the reader as to how these processes can occur, the general scheme of soil chemistry will easily be grasped.

In the changes that carbohydrates undergo in becoming peat the most striking feature is the way in which the molecule is continually increasing the

percentage of Carbon that they contain. One way in which this is effected is by the loss of water. The exact changes which occur are not known, but the following formulæ show how such a change might be effected. The first formula shows how two molecules of Glucose, $2\text{C}_6\text{H}_{12}\text{O}_6$, might be concentrated by loss of water, and form a molecule richer in Carbon, $\text{C}_{12}\text{H}_{14}\text{O}_7$; the second how this, with one other molecule of Glucose, could change to the third, showing a still greater amount of Carbon. Thus—

A reaction very commonly met with is the change of substances through the addition of the elements of water. This is often effected by boiling the substance with dilute acid. Thus, the sugar Lactose, if boiled with dilute Hydrochloric acid, yields the sugars Glucose and Galactose, a molecule of water being added in the process according to the formula:

At first sight it seems curious that the effect of boiling with such a substance as a dilute acid should be to add the elements of water. It has to be remembered that when such a body as Hydrochloric Acid is in solution it splits up. The molecules of the acid no longer move in the liquid as the unit HCl, but in a peculiarly active form as H— and Cl—, con-

* These two substances, though they have the same composition, and in a sense the same structural formulæ, have their atoms differently arranged, so that one would be the looking-glass picture of the other.

tinually combining and breaking apart. The water also will be going about in the form of H— and —OH. Then in the solution we may get some such combination as—

These might recombine on the lines—

The elements of water may split away through the formation of Hydrochloric acid, as shown by the dotted ring, and it is a commonly known chemical fact that compounds in the act of formation or decomposition will have more active chemical properties than when they are in a stable state. It is perhaps for some such reason as this that a common means for adding the elements of water to a compound is to boil with dilute acids.

The addition of Oxygen to an organic compound may readily result in an acid being formed. Thus, if

groups in the structural formula given above, an atom of Oxygen would pass in between the Carbon and the Hydrogen to form the typically acid group

Oxygen may destroy the acid properties by eliminat-

ing the Carbon altogether from the molecule, the group splitting, leaving the —O—H to link on to another carbon, and forming $\text{O} \parallel \text{C}$ (CO_2). Thus Formic acid and Oxygen will yield CO_2 and water :

By adding Hydrogen to an organic compound its constitution may be profoundly modified. Thus, the

influence of nascent Hydrogen, be changed into an alcohol, thus:

or, to give an actual equation:

Another reaction of considerable importance in connection with organic decomposition is concerned with Ammonia. The Nitrogen contained in protein molecules is frequently given off during decomposition in the form of Ammonia, and acids present in

the soil are in this way neutralized. Thus one would get the equation:

In conclusion, a few definitions may prove useful:

A CARBOHYDRATE is a compound of Carbon, Hydrogen, and Oxygen, the two latter elements being present in the same proportions as they are present in water. To this class belong the various celluloses, starches, and sugars.

PROTEINS.—These all contain Carbon, Hydrogen, Oxygen, and Nitrogen. Phosphorus, Sulphur, and a few other elements are also often present. It is a characteristic of the class that the molecule is large, and contains a number of complex groupings.

FATS.—These are neutral bodies consisting of a combination of Glycerine and the so-called Fatty Acids—*i.e.*, acids of the Formic and Acetic Acid group, which has $\text{C}_n\text{H}_{2n}\text{O}_2$ as the common formula of the group, n being any whole number.

AMIDES.—These enter largely into decomposition and other changes. They may be regarded as derivatives of Ammonia (NH_3). They are written $-\text{N} \begin{array}{l} \nearrow \text{H} \\ \searrow \text{H} \end{array}$ and the NH_2 group is able to take the place of simply attached Hydrogen in organic compounds. Their importance in Nature may be

appreciated by the statements that the formula for Urea is—

and that the amide is an important constituent of the various alkaloids.

In reading this chapter the caution must be made against too literal an interpretation of many of the above statements. No one, for instance, imagines that an atom is a rounded body with a number of hooks on it. Recent research, in fact, would suggest rather that it would be found to be comparable with a firmament. To derive any value from these more modern conceptions, however, a chemical training is necessary, and I have thought it better to describe the cruder views that very largely obtained in the recent past, as they are rigidly true in so far as they gave and still give a true expression to the majority of the facts with which the working chemist is called upon to deal.

CHAPTER X

THE TESTING OF HUMOGEN

Difficulties in sciences dealing with living organisms—Complexity of biological problems—Masking of cause and effect—Nitrobacterine—Adoption of the method by America—Essential to supply bacteria with food—Nature's methods with the embryo—Comparison with bacterized peat—Richness of the peat in humus—Response of the laboratory plants—Experiments at Kew—General results of three years' work—Plant fertilizers used—Details of improvement noted—Experiments at Tuckswood Farm: Tomatoes. Beans. Potatoes—A curious failure—Need for early use of humogen—Mr. Weathers's experiments: Marguerites. Pyrethrums. Forget-me-nots. Rhubarb. Cabbages—Digging in of humogen.

THERE is one inherent difficulty attaching inevitably to all sciences that have to deal with living organisms—the looseness of the causal relations. Hence many of the volumes on philosophy. Hence the fierceness of the fighting between those who insisted on the doctrine of predestination and those who championed the doctrine of free will. Hence, too, the keen controversy that is waged even to-day on such matters as vitalism in physiology; or, to go from large issues to small, the campaign of the anti-vivisectionists. Perhaps the latter question illustrates the argument best. Many people who know that the injection of morphia into a cat violently

excites it, whereas the injection of it into a man and into most other animals serves to soothe the nerves and induce sleep, will have it that the experimental physiologist is following a will-o'-the-wisp when he attempts to draw general conclusions from the experiments he performs on the lower animals. I have frequently been told that experiments conducted on the dog, such as problems of digestion, are valueless because the dog will swallow and digest bones, whereas the normal man who ate his meals on similar lines would suffer terribly from indigestion. The main underlying fallacy vitiating the anti-vivisection campaign—when the opposition is not due merely to sentimentalism—is the common belief that in cases where living tissue is concerned the relation between cause and effect is less rigid than it is in the case of lifeless matter. Scientific biology is frankly based on the principle that causal relations do obtain rigidly so far as the material side of life is concerned, and many biologists—returning to the problem of predestination and free will—would hold something closely akin to the doctrine of predestination, and contend that every act is the inevitable result of an intensely complex set of causes.

In tracing out causal relations in biology the worker is confronted with formidable difficulties. While the physicist or chemist is usually able to simplify his problem by eliminating all confusing issues, the biologist has present, as the basis of nearly all his work, the intensely complex animal or vegetable cell, or the even more complex living

organism. No one cell is exactly the same as any other cell, but the cell of any given tissue possesses certain properties varying within limits round a common mean. Some chemists believe that a similar doctrine holds about the elements—for instance, that one atom of Nitrogen is not the same as another atom of Nitrogen, but that the atoms themselves have certain limits within which they, too, are able to vary.

The complexity of the living cell, and the consequence of this complexity—that cause and effect are frequently masked—has created considerable difficulties in the researches connected with bacterized peat. The problem of Nitrogen fixation by means of bacteria in the case of leguminous plants had been satisfactorily worked out in the laboratory some years ago, and in his nitrobacterine Professor Bottomley had obtained a form of culture which gave satisfactory results. Tested a little prematurely, perhaps, under glass and field conditions, the nitrobacterine gave several failures because various factors that were eliminated successfully in the laboratory upset the necessary conditions when the bacteria were set to work on the land. Scientifically, nitrobacterine was a success. As has been stated previously, the American Board of Agriculture during the last few years has studied these field difficulties, and is now using a preparation similar to the nitrobacterine that in this country was too hastily condemned by many who failed to get results.

One of the essential difficulties in connection with the old material was to insure that the bacteria,

when placed in the ground, should have a suitable medium in which to work. The principle is one universally recognized in Nature. The young embryo in the seed is sent out by the parent plant with a stock of food material that makes it independent for several days of the soil on which it falls. In the egg the embryo starts its life with a store of material ready for its needs several thousand times greater than itself. In the mammal the young embryo develops firmly fixed to its parent, and even after birth, by the strength of the maternal instinct, Nature insures that it shall have for months to come an abundant supply of the food that it requires.

Nitrobacterine was a compromise between the earlier system of the Germans and Americans and that used with bacterized peat. In the cotton-wool preparations the bacteria were sent out with no food-supply to nourish them, and many of them died before ever they reached the land they were intended to fertilize. Nitrobacterine (earth impregnated with bacteria) through the humus it contained, insured that the bacteria should have some food to support their life during the period of waiting; but the system of utilizing them carried with it the objection that on being applied to the soil they had at once to secure their food from the ground in which they found themselves. The failures with the preparation showed that an important factor had been neglected, and, unconsciously to some extent, the laboratory workers were thrown back to imitate the system followed by Nature in the egg and seed. Peat was a substance rich in the raw material of

humus. It was known that in time, under the influence of bacteria, the peat changed, forming soluble humus, and experiments were made to see whether the process could not be hastened by artificial means so that the bacteria might be distributed in the soil with an abundant supply of food to enable them to start their growth.

The success of treating the peat with bacteria was startling in the unexpectedness of its results. On testing peat that had been exposed to bacterial action it was found to be amazingly rich in soluble humus, to yield, in fact, fifty to eighty times as much as could be obtained from a corresponding weight of the best rotted stable manure. Laboratory experiments followed. As was to be expected, the Nitrogen-fixing bacteria, *Bacillus radicola* and *Azotobacter chroococcum* flourished and multiplied when placed in such a medium. Plants, too, responded readily to the peat. When grown in sterilized sand watered with the peat extract they grew luxuriantly, developing healthy roots, giving luxuriant foliage, and coming more rapidly to maturity, thus proving that Humogen contained everything necessary for plant growth.

The exact position of the work at this stage was defined by Professor Bottomley in a paper he read before the British Association at Dundee in 1912. His official summary of the paper giving the essential facts was as follows:

“ Peat-moss litter is said to be ‘ entirely unsuited for the growth of plants.’ It is acid in reaction, and contains no soluble humates.

“ It has been found, however, that when peat is treated with certain micro-organisms a large quantity of soluble humate is obtained, and the peat is rendered alkaline. An aqueous extract of this treated peat (1 part peat to 200 parts water) will supply all the plant-food necessary for successful water-culture experiments. As no trace of nitrate was found in the culture solutions during the whole course of the experiments, it is evident that the nitrogen need of the plants was supplied by some form of organic nitrogen present in the solution.

“ Water-cultures with tomato seedlings, germinated in sterilized sand, showed that the plants failed to grow in raw peat extract, but in treated peat extract the plants grew well, flowered, and produced fruit. Experiments with buckwheat, radish, and barley gave similar results.”

In view of the disappointment with nitrobacterine it seemed unwise to attempt to generalize from the laboratory results, and three years ago the authorities at Kew Gardens were asked if they would be willing to conduct experiments with the new material.

The authorities at Kew consented. It is unnecessary to state that Kew Gardens are ideal for such a purpose, having the facilities necessary for conducting large scale experiments, and the personnel competent to experiment on rigidly scientific lines. There was an additional advantage, however, about Kew. Experiments had already been tried there with nitrobacterine, and had given negative results. Naturally, therefore, the authorities were inclined to be sceptical, and the stringency of the tests to be made was insured.

In the first year the effect of using the peat in various quantities on plants grown in ordinary soil was tested, and plants were grown in ordinary soil and other media as a control. Commenting early in 1914 on the results obtained, Mr. J. Coutts, of Kew Gardens, said (*Journal of the Royal Society of Arts*, March 15, 1914) that "the plants, beyond ordinary details, had no special attention during growth other than that devoted to starting them; after a fortnight or so they were left to themselves. The results in some cases were extraordinary, and not comparable with those obtained from ordinary nitrogenous manure. Experiments had been made to determine whether peat afforded plants a greater power of resisting the eel-worm, and in this connection the carnations showed the most striking results. In the case of the peat-treated plants there was little trace of eel-worm after two months' growth, whereas the nitrated plants were badly affected within a fortnight. Another experiment was made with chrysanthemum plants in the open, planted at the same time and under the same conditions. One section of this planting was treated with 2 ounces of peat to the square yard, a second with 4 ounces, while a third section was treated with dried sewage sludge, and a fourth with nitrates. The differences in results were marked. The section treated with the smaller quantity of peat seemed as good as that which had received a larger allowance. Again the sludge section was considerably superior to that which was nitrated, although much inferior to the peat-treated sections, the action being slower. It

was evident that there was something in the nature of manurial effects in the peat, the root development of the plants being very marked."

The experiments conducted during the first year at Kew—other experiments, as is shown in Appendix B, were in progress elsewhere—were very striking, and when in the second year they were considerably extended, the beneficial results obtained from the bacterized peat were fully confirmed. During the present year I visited the gardens to see the progress of the experiments now in progress. The final results of this year's work have, of course, not yet been obtained, but the influence of the peat on the plants at present growing there is extremely striking. For the various classes of work there nine different soil mixtures have been used for comparative purposes. They are as follows:

					Per Cent.
1.	Soil	..	..	..	66
	Leaf mould	..	..	..	22
	Sand	..	..	..	12
2.	As No. 1, but sterilized soil.				
3.	Sterilized soil	..	..	..	54.6
	Leaf mould	..	..	..	18.6
	Sand	..	..	..	8 to 9
	Lime rubble	..	..	..	8 to 9
	Sewage sludge	..	..	..	8 to 9
	Basic slag	..	..	..	0.5
	Bone meal	..	..	..	0.5
	Soot	..	..	..	0.5
	Sulphate of potash	..	..	..	0.3
4.	Sterilized soil	..	..	..	80
	Humogen	..	..	..	10
	Sand	..	..	..	10
5.	As No. 2, but newly sterilized soil.				
6.	No. 2, <i>plus</i> 0.04 per cent. Gafsa Phosphate.				
7.	No. 6, <i>plus</i> 12.5 per cent. Humogen.				
8.	No. 2, <i>plus</i> 0.43 per cent. Gafsa Phosphate.				
9.	No. 8, <i>plus</i> 12.5 per cent. Humogen.

FIG. 8

One of the chief surprises in connection with the use of humogen is the fact that it intensifies variegation in the foliage of a plant. The above specimens of coleus—the right plant received humogen while the left had the usual potting compost—were two typical specimens of plants grown at the Royal Gardens, Kew, and exemplify this. The symmetrical development of humogen-treated plants is also noticeable.

A great variety of plants have been used for experiments, Cotton, Tobacco, and Fuchsia being among the numbers. In most instances the plants grown in mixture No. 4 are so markedly superior to those for which any other mixtures have been used that the difference is apparent to the casual glance in the increased size and improved healthiness of the treated plants. Occasionally the complete fertilizer mixture, a mixture containing every possible form of food that a plant can require, has given as good results, but this is exceptional. What is especially noticeable at Kew Gardens is the increased root development of the plants treated with the peat. On taking the plants from the pots an abundance of root is characteristic, there being a striking differentiation in this respect between the plants grown with peat and those grown with other soil mixtures. Another feature, commonly noticed with variegated plants, is the intensification of the variegation which is comparable with that noticed in the colours of the flowers. This has proved one of the unexpected results of treatment with peat. Both foliage and blooms are often richer in tone, the improvement in foliage emphasizing and reinforcing that obtained on the blooms. An increased sturdiness of the stems may be regarded as being naturally connected with the general symmetrical growth of the treated plants, but in several instances it is strikingly marked, notably at Kew in the case of the cotton and tobacco plants. Generally, also, the plants are larger and tend to mature earlier.

While writing the present volume I took advantage

of an invitation from Mr. Robert Holmes, of Tuckswood Farm, Norwich, to visit some experiments he has been conducting with the bacterized peat. His gardens cover a large area of ground, and are devoted chiefly to the growing of sweet peas and tomatoes, but this year, particularly as a consequence of the war, potatoes have also been grown on a considerable scale, and a fair number of small parcels of ground have been laid down for the experimental raising of beet, mangel-wurzels, sugar-beet, etc.

Unfortunately, a single factor, the persistent dry weather of the spring, has so far made several of the results obtained of little value, as will be realized when it is stated generally that in several of the fields it was not possible to detect the slightest difference between crops that had been grown in ordinary soil and those grown beside them, which had received extra treatment with farmyard manure.

In the glass houses devoted to tomato-growing, where the plants have been treated under the best known conditions, the effect of humogen has been so striking that even the amateur can tell at a glance which of the pots have received dosage with humogen and which have been grown under strictly comparable conditions, except for the non-addition of the humogen. Four groups of experiments in all were tried. Five pots received ordinary soil alone, five received soil and manure, five received soil and humogen, and five soil, manure, and humogen. In all cases the plants were strong and healthy, and had fruited well, but those treated with humogen were taller plants than the others; their leaves, which

FIG. 9

The tomato plant above is representative of a group grown from the seedling stage with the aid of humogen. The darker fruits at the base of the plant had ripened at a time when only one or two fruits on the untreated were beginning to redden. The treated plants averaged about sixteen pounds of fruit per plant, that ripened from three weeks to a month earlier. (Note yard measure.)

(Grown by Mr. Holmes, Tuckswood Farm, Norwich.)

were rather smaller, showed the peculiar rich bluish-green tint that is associated with vigorous growth, and in the case of the humogen-treated plants there were clusters of red fruits, while on the others the fruits were only beginning to change from green to red. The tomatoes on the humogen-treated plants were indeed over-ripe, as they had been left on the plants so that full opportunity might be given for a comparison between the humogen-treated plants and the others. Also, as the accompanying illustration demonstrates, the humogen-treated plants showed a greater quantity of fruit than the plants not treated.

In one of the houses near to the tomato houses a somewhat similar experiment had been conducted with the Guernsey Runner Bean. In this case humogen-treated beans have made striking progress both in growth and in quantity of fruit. They stood several inches higher, and had large, well-formed leaves, showing a deeper green than that on the plants near by. From both groups of plants pods had been pulled, and neither group had as yet finished fruiting.* Already there had been a marked increase in yield; the humogen-treated plants showed

* While this book was going through the press a report was received from Mr. Holmes giving the weights of beans pulled from two typical plants. They are—

			Plant grown with Humogen.		Plant grown without Humogen.	
			Lbs.	Ozs.	Lbs.	Ozs.
June 30	..	..	..	0 13½	0	15½
July 11	..	..	..	0 12½	0	7½
July 23	..	..	..	1 13½	0	1½
August 4	..	..	..	1 4	1	0
Total			..	4 11½	2	8½
					10	

signs of improving their present lead; already 2 ounces more of pods had been pulled from the treated than from the untreated plants, and their increased vigour was manifest.

A chance experiment conducted casually outside one of the houses gave an astonishing result. Mr. Holmes told me that he remembered reading some years ago of some French experiments in which ordinary moss had been used as a medium for growing plants, while the plant food had been supplied in the form of liquid manure. It had occurred to him that it would be interesting to try the effect of growing potatoes in moss, moistened from time to time with the water extract of humogen. He planted four potatoes in sterilized moss in a shallow box, $15\frac{1}{2}$ inches long, 6 inches wide, and 4 inches deep. No special care was given to the potatoes. As a start the moss was soaked in humogen extract; they were watered from time to time, and occasionally were sprinkled with the water extract of humogen. The box, as we saw it, showed a luxuriant growth of leaves standing about a foot from the level of the box, but when the plants were pulled the roots were found to be crowded with tubers, several being of considerable size, and the majority being still immature. Their total weight was 2 pounds $10\frac{1}{2}$ ounces, all contained in an area of a fifth of a cubic foot.

Most of the field experiments here this year at the time of writing are inconclusive, for the crops have not yet been dug up. In several instances, however, it was possible to appreciate at a glance that the potatoes, sugar-beet, etc., which had been

FIG. O

These potatoes were grown in sterilized moss soaked with humogen extract, in a shallow box containing one-fifth of a cubic foot. Four potatoes were planted, and in less than eight weeks nearly three pounds of tubers were obtained, while the plants had not nearly finished their growth.

(Grown by Mr. Holmes, Tuckswold Farm, Norwich.)

treated with the peat, were markedly superior to those which had not received treatment.

Mr. Holmes's experiments were interesting for another reason. There was a single field of potatoes—the whole was a markedly poor crop—one large corner of which had been treated with humogen, but had otherwise received exactly the same manure as the rest of the field, and to the eye the crop on this area was markedly inferior to that on the rest of the field. It is the first instance that I have met with personally in which apparently the treatment with humogen has retarded growth. The soil is now being analyzed and the other conditions studied to find out why this unusual result should have been obtained.* That the treated peat of itself can do harm is impossible, as plants have been planted in pure humogen and done well. It is possible that the plot may improve before the potatoes are dug up, but the fact remains and has to be faced that there is a *prima facie* case here that there may be certain rare soil conditions other than mere acidity which will need correction before humogen can be successfully applied. It has to be remembered that the present season has been abnormal, and that the lesson it teaches is that it is advisable to dig the humogen into the soil early in the year at a time when the chance of drought has not to be feared.

As will be seen from Appendix B, there are many other places where experiments have been made with

* While the book was going through the press I heard from Mr. Holmes that with the advent of an ample rainfall the plot improved, and now (September 3) at least equals any other portion.

the treated peat. There is only one other garden, however, that I have been able to find time to visit while writing this book, a market garden kept by the well-known horticultural writer, Mr. John Weathers, at Isleworth. The conditions under which he has had to conduct his experiments have not been very favourable to the peat, as in most cases it could not be delivered to him until the plants were already in the ground. In such circumstances, combined with the drought, he obtained only negative results by top-dressing in the case of bulbous plants. With Marguerite daisies, however, a striking and valuable result was obtained. His crop generally was top-dressed with the peat, but there was one portion of ground in which he was able to dig in the humogen in the quantity of $2\frac{1}{2}$ ounces to the square yard. Marguerites were planted in this, and though they were planted later than the others, they flowered a week earlier.

With Pyrethrum the peat gave excellent results. By May 25 the treated plants were being cut, while by June 4 cutting had not commenced on the plants which had not been treated. Lily of the Valley responded well to treatment, while Forget-me-nots bloomed in greater abundance when treated with the peat and compared with untreated beds. On Rhubarb the rows receiving humogen were considerably in advance of a row that was left untreated. Apart from the experiments on wheat, described in the chapter on General Results, the most striking of Mr. Weathers's results were those he obtained with some cabbages. The peat was applied, 1 ounce to the square yard, to a plot of

ground in which the throw-outs from another bed were planted. At the start the cabbages were miserably weakly plants. Under humogen treatment, however, they picked up well, and though they matured rather later, there was in the end nothing to choose between the originally weakly plants after the treatment with humogen, and those cultivated along ordinary lines.

In discussing the results generally Mr. Weathers emphasized to me the importance of digging in the humogen instead of merely using it as a top-dressing, but there was no doubt left in his mind as to the marked improvement to be obtained through a use of the peat, both in the increase of the crop and in the early maturing of it.

In the short space available in this chapter I have tried to indicate the basis on which the case for humogen stands. Both from the laboratory standpoint and from the standpoint of the grower under glass the value of humogen as a routine method of treatment seems to me definitely established. The experiments made to extend the use of humogen to field-work on a large scale are extremely encouraging, and at present there seems no reason to doubt that, when suitably applied, results comparable with those got in the laboratory and greenhouse will be obtained in the field. If this result, however, is to be obtained rapidly, the co-operation of the farmers and the farming stations throughout the country is essential, as it is only by extensive experiments carefully carried out that the conditions necessary for the best results will be satisfactorily determined.

CHAPTER XI

THE PREPARATION OF HUMOGEN

importance of cost and availability of humogen—The works at Greenford Green—Railway facilities—The raw material—Incubating with humating organisms—Sterilizing the peat—Inoculation with Nitrogen-fixing organisms—New system of sterilization—Project for rapid drying—Possibilities of extension—Price as compared with manure.

IN the course of the discussion on a paper read by Professor Bottomley before the Royal Society of Arts on "The Bacterial Treatment of Peat," Dr. J. A. Voelcker said that from a practical point of view the cost of the material was paramount, and he asked the question whether there was any likelihood of the material being put on the market in an accessible form. In the eighteen months which have elapsed since the date of the reading of that paper, the situation as regards the bacterized peat has changed very materially. Two seasons of experiments have confirmed the results that were then announced, and the peat is already being manufactured on an experimental scale. While the whole story of soil inoculation and of the auximones is keenly interesting for its own sake, in so far as it throws fresh light on the nature and mechanism of plant growth, from the national standpoint at any rate, and from that of the practical grower, the

essential considerations are, firstly, whether the use of humogen will increase the yield of the crop to the extent that is believed will be the case by those responsible for its production, and, secondly, how far the grower can rely on getting the peat in the quantity he requires at a reasonable cost. The preceding chapters in this book constitute the answer to the first of these questions, and it is for those who are not satisfied with the evidence brought forward to conduct further experiments for themselves on their own land.

To furnish an answer to the second question, I have visited the factory at Greenford Green, near Harrow, partly to see how the process of preparing the peat is conducted in bulk and partly to determine how far it would be possible to increase the output to meet a large demand. The factory where the raw peat is changed into humogen is situated on six acres of ground, and occupies the old buildings used by Sir William Perkins for his dye-works. So far only a fraction of the ground is employed, and the old chimney-stacks are still standing as a relic of the great industry which, partly as a result of the attitude of the Government towards science, and partly owing to the national apathy, has been developed into a world-wide industry by Germany. Both for rail and water transport the factory is admirably situated. It is well served by the Grand Junction Canal and both the Great Central and the Great Western Railways.

The peat is brought to the works in the large bales most familiar to the general public as the way in

which the peat is distributed to stables as peat-moss litter, and on arrival is broken up and stored at one end of a large shed. Water-heated pipes pass through half a dozen bays, and into these the peat is thrown when it has been moistened and thoroughly well impregnated with the aerobic bacteria which change the insoluble Humic acid of the peat into the soluble humates required, both as a bacterial and as a plant food. The peat lies in these bays for about ten days, remaining all the time at the temperature which is best suited for the development of the bacteria. During the process it tends to settle down. It darkens in colour, but otherwise there is to the unaided senses no sign of any change taking place. Notably the whole process occurs without the development of any smell. Close to the bays the large boiler is situated. It is designed to carry an 80-pound pressure of steam. The steam from it passes through pipes, and ends in two large water-jacket cauldrons of the type used in melting tallow. It is set free in these cauldrons through holes pierced in the pipes to insure that the steam shall thoroughly saturate the peat. Once this has been fed into the cauldrons steam is applied to them for a period of about an hour, a period that has proved sufficient to insure the death of all the humating organisms.

From the cauldrons the peat, now sterile and rich in plant foods, is removed to another shed, where it is impregnated with Nitrogen-fixing organisms, *Bacillus radicicola* and *Azotobacter chroococcum*. These require only a short time to develop in the fertile sterilized peat, and this is then spread on the

floor in heaps and air-dried. As soon as it is dried it is packed in bags and is ready for use.

Such is the process as it has been worked for some time now at Greenford Green. The description, however, only gives a slight idea of what has been done. While I was at the works, an experiment, suggested by Mr. Holmes of Tuckswood Farm, Norwich, as a result of the work he has done in sterilizing soil, was in progress. It appears to be practicable to avoid the use of the cauldrons for sterilizing the peat and to substitute for them a rough frame which lies on the ground, and carries his patent "norvic" cover. Steam on being applied to this light frame, so far as the experiments have gone, is able effectively to sterilize the peat, and if the process on further experiment proves satisfactory, there will be a considerable saving of labour and space, and an increase of convenience in the handling of the peat.

Already in view of the increased demand a machine is in course of installation which at first sight resembles a tubular boiler. There are steam compartments at either end, and a large number of pipes running between them. The proposal is to mount this apparatus and to keep it revolving while the prepared and inoculated peat is being automatically shovelled against the warm pipes, a method that would greatly shorten the time necessary for the whole operation, and facilitate the very difficult process of drying.

I have been at pains to describe the system employed to prepare the peat at some length, as it is clear from the description that the present rate of manufacture could be very greatly extended. For

the time being only a portion of one of the sheds is being used, but there would be no difficulty in meeting an increased demand at once by duplicating or triplicating the present plant. Hitherto it has not seemed desirable to manufacture on a large scale, as the work at the factory has as yet been only experimental. Various samples of peat are continually being tested, as experience shows that different samples of peat show large differences in the quantity of soluble humus that they yield, and it has been thought better to carry through the necessary preliminary work on a small scale before fitting up a plant which might prove better or worse suited to the particular quality of peat ultimately adopted as the standard.

As regards cost it is difficult to state anything definitely. While the process was in the experimental stage the price of the peat was provisionally fixed at 15s. for 3 bushels. This price was fixed arbitrarily to meet the convenience of those who wished to conduct experiments, but there is reason to believe that when the substance is dealt with commercially a price will be practicable at considerably less than £10 per ton. For purposes of comparison with ordinary fertilizers it may be assumed, for the moment therefore, that the cost of it is about £10 per ton. In view of the fact that the available plant food in peat, as compared with that in rotted stable manure, is as between fifty and eighty to one, the superiority of the peat from the standpoint of its food value alone, when considered in relation to its cost, is strikingly apparent.

CHAPTER XII

PRESS AND OTHER CRITICISM

Early hostile criticism—Lines of attack—Sound basis of criticism—Need for experiment—Growth of opinion in favour of inoculation—Support from the Board of Agriculture—Royal Society of Arts meeting—Two opinions of experts—Press criticisms.

THERE has been no lack of criticism of the work done by Professor Bottomley on Nitrogen-fixing organisms. Of this it is possible for me to speak personally with some authority, as it has been my business as a journalist ever since the earliest publications were made on the subject, not only to keep in touch with the various stages of the work in King's College Laboratory, but to make inquiries of agricultural experts and others as to their opinion of the work. I have also from time to time attended not only popular meetings where the method has been explained, but also scientific meetings where the views put forward have been discussed by critical audiences.

In the earlier years I heard a great deal of hostile criticism; it was criticism of the sort that is invaluable to the journalist, given to him in confidence for the guidance of his paper. I was advised repeatedly to be very cautious in what I wrote; I was

warned of the extreme difficulty of field experiments. It was pointed out to me that, even when every care was taken to give the whole of a field identical treatment, such a field, if divided into plots, would yield returns from certain plots that would vary by as much as 50 or 100 per cent. from the mean, and that long-continued experiment, therefore, was necessary before the results claimed for soil inoculation could be accepted. Professor Bottomley, I was told very truly, was an enthusiast with more laboratory than field experience, and might have been misled by results apparently due to the bacteria, but due in reality to other causes of which he had no knowledge. Facts and figures were quoted to me showing how frequently in the past generalizations have been made by men of science in connection with agriculture on insufficient experiments, and that the result has been disappointment and the discrediting of science among practical farmers.

Experience has shown that there was real wisdom underlying these criticisms. From the standpoint of the practical man nitrobacterine was a failure, because it was not realized that certain conditions were essential for its successful application. Scientifically, however, it was a success, as is proved by the fact that after seven years of experiment the American Board of Agriculture is distributing a similar preparation to farmers and recommending its use.

As against the criticisms I heard, there were the results that were obtained. The laboratory experiments proved conclusively that under controlled conditions nitrobacterine gave results of an order

that could be obtained by no other means. The reports received from growers showed that there were instances, too many to be accounted for by chance, in which results of the same order as those gained in the laboratory were obtained, but under glass and in the field. I considered then, as I consider still, that it was desirable in the interests of agriculture that extensive field experiments should have been carried out by farmers, as the evidence indicated that in nitrobacterine there was a new means available for increasing the returns that could be won from the soil, and that it was only by experiments conducted on a large scale that it would be possible to determine the best conditions for its use.

Seven years have gone by since nitrobacterine was tested on at all a considerable scale, and during that period there has been a marked change in scientific opinion. There is still scepticism in many quarters, but whereas in the early days Professor Bottomley stood almost alone in this country in advocating the practical use of inoculation, he has to-day a considerable body of expert opinion that is with him. Experience with nitrobacterine has resulted in what might have been expected. Certain of the conditions necessary for successful inoculation are now understood. In humogen a means of introducing the bacteria has been discovered, which very materially reduces the risk of negative results. The Board of Agriculture and Fisheries has recognized the value of the work by making a grant in aid of the researches, and the time is ripe to-day for the conducting of experiments on a large scale. To

show that this is a general opinion I have thought it desirable to quote here a couple of the views to which experts have given expression during the last two years, and also to quote the views of several leading newspapers.

At a large meeting held early in 1914 at the Royal Society of Arts, Professor Keeble, F.R.S., who was in the chair, opened the discussion, and said "he could put it that Professor Bottomley was able to take material of small commercial value, used mainly for the making of fuel and oil, and extract from it not only the humates in a form in which they could be used for plants, but also to use these humates as a seed bed in which the *Azotobacter*, a Nitrogen-fixing organism, could thrive. If more extended trials than those so far undertaken could establish that Professor Bottomley could do these two things, he would have earned the encomium of Swift for those who made two blades of grass grow where one grew before."

Dr. O. Rosenheim said "he believed that bacterized peat was a substance having remarkable properties as a stimulant to growth. He had himself carried out a few experiments for the purpose of investigating the minimum quantity of the peat which would produce the results which Professor Bottomley had shown; the quantity proved to be very small indeed. He had found that a solution prepared from the peat, containing only about 30 milligrammes of solid substances, produced striking results on plant growth. His results showed that the effect of peat was out of all proportion to what

FIG. II

The above illustration of crotons demonstrates the extraordinary effect on the root development of treated plants. The top growth was in proportion, and the colour of the foliage was strikingly emphasized.

(Grown by Mr. Baldwin, Greenford, Harrow.)

would be expected from an equal weight of a mere manurial substance. The amount of Nitrogen in it could not supply the needs of the plant, and that remark was equally applicable to the amount of phosphates, etc., present. There appeared to be some fundamentally new substance at work, a substance which was at the bottom of plant growth. It had struck him that the active principle in prepared peat had some analogy to a newly discovered factor of animal nutrition, which was still in its infancy. He believed that, directly or indirectly, the plant obtained what it required from the humus, and that in the peat as prepared by Professor Bottomley the essential substance for growth was present. Of course it was advisable to be very cautious in bringing forward such a view, but the experiments so far carried out seemed to support it, and he believed that Professor Bottomley's bacterized peat contained in relatively large quantities a substance of fundamental importance."

Country Life, October 25, 1913.

"Professor Bottomley's results, both in the field and the laboratory, have been extremely good. His prepared peat contains over fifty times as much available plant food as farmyard manure. . . . There is no doubt that the prepared peat is of great value as a manure; but whether its fertilizing action is due to the presence of Nitrogen-fixing bacteria, or merely to the larger quantity of soluble humates produced during the preparation of the medium, cannot yet be said to have been definitely proved, while the peat has also a beneficial mechanical action on the soil. If only the product can be

manufactured at a reasonable cost, its value will be immense to those who go in for intensive cultivation, to market gardeners, to horticulturists, to farmers, and for use on golf greens."

Eastern Daily Press, May 8, 1915 (Mr. F. I. Cooke).

"In the course of our Bournemouth experiments it was clear to me, a fairly old campaigner in manurial experiments, scientifically conducted, that there must be some other key to our remarkable results, and to the far more extensive ones at Kew Gardens. All who are scientifically acquainted with the subject, and have studied it in practice, know very well that amongst the foods of plants the only one hitherto shown to be an excessive stimulant is Nitrogen, in one or other of the forms in which it is usually applied. The various manures of mineral origin, such as phosphates, potash, etc., are all mild in their action, tending to sound and steady growth to well-ripened seed, or fruit or wood, whilst too much Nitrogen upsets the balance, and merely tends to sappy growth and more abundant foliage than can be properly matured. But the striking feature of our experiments with the peat was that the entire development of some of the plants, both above and below ground, was almost doubled in the short period of six weeks, and yet was perfectly sound and well balanced. I felt sure, therefore, that some factor previously unknown, other than the excess of Nitrogen, provided by the peat, was thus indicated. I do not mean that it had not been at work before, but that its identity as a separate nutrient had not been recognized or even suspected before. Later developments of the peat investigations have apparently shown this conclusion to have been fairly well justified. The Professor was perhaps building better than he knew, and was on the track of an accessory

plant food new to science, and one which in addition to its extraordinary scientific interest, may prove of very great practical importance."

The Field, May 21, 1914.

"There is good reason to think that Professor Bottomley has solved the problem of enhancing the fertility of the soil by the application of bacterial cultures. As has already been explained in the garden department of the *Field*, peat has been utilized as the medium for impregnating the land with the cultivated bacteria, and the results at Kew, the Chelsea Physic Garden, and other centres, exceed even the expectations of the inventor. The farmer is not entirely dependent upon the experiments with garden plants for his appreciation of the discovery. The bacterized peat, as the preparation has been aptly termed, has been used for potatoes, turnips, beet, onions, and carrots, and the effect in all cases has been pronounced, the treated peat easily surpassing farmyard manure and a mixture of artificials in influencing production. The average increase in potatoes over artificials was 75 per cent., and over dung 41 per cent.; turnips, 47 per cent. and 26 per cent.; beet, 54 per cent. and 53 per cent.; onions, 110 per cent. and 46 per cent.; and carrots, 20 per cent. and 28 per cent. Most of these crops are of chief interest to the market gardener, but it may be assumed that the material will be similarly effective upon field crops. The discovery promises to be of the greatest importance to intensive cultivators, whose prosperity has been menaced by the reduction in the supplies of town manure. Mineral and chemical fertilizers are valuable substitutes, but a vegetable preparation such as treated peat would be attended with less risk of ultimate injury to the land. The preparation will not be put upon the

market until its qualities have been thoroughly tested, and, of course, until an estimate of its cost is available it will be impossible to appraise its value as an agricultural accessory. The prospect at present, however, is exceedingly bright, and farmers will do well to watch its progress and developments during the coming season."

The Field, August 7, 1915.

"Humogen is the name given to what has hitherto been known as bacterized peat, a preparation which Professor Bottomley has made famous by proving that it stimulates plant growth, not only with respect to fatness of leaves and shoots, but also with respect to the free development of flowers, fruit, and roots. Exactly what it is that causes ordinary farm and garden soil to become so exceedingly fertile when humogen has been added to it may be known to Professor Bottomley, but it is not clear to the practical cultivator, who understands well enough the action of fertilizing manures, natural and artificial, but is puzzled by the stimulating influence of ordinary peat moss to which nitrogen-fixing bacteria have been added. This peat before treatment is of very little value to the cultivator. It may contain plant food as well as the humic acid, the presence of which is said to render the food unavailable; but assuming that the whole of this food is freed by the treatment to which it is subjected by Professor Bottomley, that alone would not account for the growth made by the plants fed with it.

"It appears likely that we are on the track of important revelations respecting plant food, for we are assured by men like Dr. Russell that the text-books are quite wrong on the subject. What cultivated plants really require, and the easiest and best way to supply it, are questions of great import-

ance, the answers to which, according to the most recent investigations, have hitherto been misleading. Meanwhile we have Professor Bottomley's highly interesting experiments with bacteria and peat or peat-moss, showing that even soils which are considered to be worthless for agriculture or horticulture contain a rich supply of plant food which only requires to be released by a process of inoculation to produce abundantly. Evidence of this is gradually accumulating as the result of experiments with farm and garden crops by trustworthy persons. One of these is Mr. R. Holmes, Tuckswood Farm, Norwich, to whom we are indebted for the two photographs here reproduced, showing the influence of humogen on the potato and the tomato.

"The tomato plant is a sample of a number that were grown in ordinary garden soil, to which humogen had been added in the proportion of one in eight. As can be seen in the photograph (p. 146), the plant grew vigorously, but did not develop large leaves, as tomatoes grown with ordinary stimulating foods generally do. On the other hand, it bore an exceptionally good crop of well-formed fruit, which ripened perfectly, and when gathered weighed 16 pounds.

"The potato plants were grown in a wood box, 21 inches by 6 inches by 4 inches, which was filled with ordinary wood-moss that had been steamed to sterilize it, and then saturated with a solution of humogen. Four potato sets were planted in this on May 18, and the box was placed on a border in the open, where it was watered weekly with the same solution. On July 22—that is, two months after planting—the contents of the box were exposed and photographed. The new potatoes were clean and well formed, and they weighed 3 pounds. No doubt the moss contained a certain quantity of plant food, and the sterilizing would improve it, but no experienced cultivator would expect to get a

good crop of potatoes from it, and we must therefore conclude that the humogen was both food and stimulant.

"These results are similar to those obtained previously with a large number of different kinds of plants grown in pots, for which humogen was used. So far as we understand this peat preparation, nothing is added that would be called a manure, either chemical or organic, and the question we would like to ask Professor Bottomley is, would any kind of soil other than peat or peat-moss be similarly affected by his treatment? If by adding certain bodies to peat he can change its plant food properties so enormously, would it be possible to add these bodies direct to, say, a ten-acre field or a fruit orchard, applying it as guano, for example, is applied? Or is the peat an essential part of the fertilizer?"

Gardeners' Chronicle, October 25, 1913.

"It will be patent to everyone that if it should prove possible to make peat plant food cheaply, and if further trials confirm the results of those which have been made at Kew and elsewhere, Professor Bottomley's discovery will be of great service to horticulture and agriculture."

Gardeners' Chronicle, March 21, 1914.

"Briefly these new facts are that extremely small quantities of a watery extract of bacterized peat are potent stimulators of plant growth. For example, it is stated, on the authority of Dr. Rosenheim, who carried out the experiments, that plants treated twice with the water extract of 0.18 gramme ($= \frac{1}{156}$ ounce) respond very readily to the treatment, and grow away from untreated 'control' plants.

FIG. 12

The above photograph shows the difference between two sets of barley grown in ordinary soil with and without humogen. The humogen-treated plants (on the left) showed greatly improved growth, richer foliage, and a markedly improved tillering.

(Grown by Messrs. Carter, Raynes Park.)

“ If the result of other more extended and similar experiments is to confirm the correctness of this observation, we shall be face to face with a discovery of prime importance, for it is wellnigh certain that this growth-accelerating effect of the extract cannot be brought about by the nitrogenous or other ordinary substances contained in that extract. The actual amounts of nitrogen—and of phosphorus—contained in $\frac{1}{150}$ ounce of the bacterized peat must be extremely small—far too small, as it would seem, to produce a marked increase in the rate of growth of plants potted in ordinary garden soil.”

Gardeners' Magazine, October 3, 1914.

“ Professor Bottomley, of King's College, London, has found that when peat has been subjected to the action of bacteria it becomes transformed, and acts as a manure of considerable value.”

Pall Mall Gazette, June 6, 1914.

“ The whole conception of the growth of plants may have to be altered as the result of some important experiments that have been made at King's College, London, and since submitted to successful tests at Kew and Chelsea. Just as modern research has discovered that growing animals cannot get the full value out of pure food, and will not continue to grow unless there is some trace of what is termed “ accessory food body ” used with it, so it is thought there is in bacterized peat a substance similar to the accessory food bodies necessary for growing animals. And the theory is that plants, just like animals, must have some of this substance, otherwise they will not be able to utilize the food material in the soil. . . . Some very striking results have been obtained with barley. Seven is usually

the maximum number of shoots from barley plants manured in the ordinary way. With bacterized peat, however, as many as eighteen have been obtained. This means that instead of seven ears there would be eighteen to every seed originally planted."

The Times, October 7, 1913, and May 21, 1914.

"Agriculture's debt to science is already large, but 'bacterized peat'—a new stimulant of plant life produced at King's College, London, by Professor W. B. Bottomley—promises to make the debt incalculably larger.

"Tomatoes of quite a respectable size have been grown from seeds set in pure sand, and watered with an extract of this product. An eggcupful sprinkled on the surface of the soil doubled the size of arum lilies; carnations inoculated with eel-worm shook off the pest with the aid of the 'peat,' and plants of every kind grew more strongly, flowered more profusely and with intensified colours, and quickly became pot-bound through root-development. Equally striking results have been obtained with barley, wheat, and oats.

"The evidence already obtained in regard to the efficacy of this new manure is reassuring. It has been subjected to severe tests in the open fields as well as in the laboratory, and in every instance its effect has been pronounced. Professor Bottomley's estimate of its value is more than confirmed by those who have co-operated with him in practical experiments under different sets of conditions and with different crops. Chemical analyses of the prepared peat show that it contains over fifty times as much available food material as farmyard manure—that is to say, 1 ton of the prepared peat is superior to 50 tons of farmyard manure. This is a bold

FIG. 13

Eel-worm is a serious disease in many plants, but carnations are especially liable to it. Both the carnations shown above (typical specimens of a group experiment) were potted in soil known to be infected, with the object of testing whether humogen gave resistant powers to the plant. The humogen-treated carnation, although infested in the early stages, gradually grew away from the pest and developed into a perfect plant. The untreated, although receiving various stimulating plant-foods, reached the stage shown and then collapsed.

(The Royal Gardens, Kew.)

claim to make, but it is based upon practical demonstration, and has not merely a laboratory justification.

“ While the discovery is of more immediate importance to horticulturists and market gardeners, it is also of great interest to farmers. Should present expectations be fulfilled, it would prove of great service to those engaged in any form of intensive culture. The primary need of the intensive cultivation is an organic manure. The market is fairly well supplied with salts or minerals, natural or by-products, but it has been found that, although these materials are useful, they cannot take the place of a good organic fertilizer. The need of a new vegetable manure is emphasized by the great reduction in the quantity of town manure available, owing to the substitution of motor power for horses in street traffic. The market gardening industry at a critical time in its development has suffered a severe loss by the reduction in the supply of town manure. Horticulture in its diversified forms, from the smallest suburban plot to the Royal Botanic Gardens at Kew, has shared in the resulting disabilities; and although recourse has been had to artificial materials, the chief effect has been to demonstrate the serious disadvantage at which intensive culture is placed without an adequate supply of organic manure. The keen interest shown in Professor Bottomley's treated peat reflects the measure of the need of something to supplement the diminishing quantities procurable from London and other towns.

“ As every farm is a producer of organic manure in greater or less quantity, the need is not so pressing in agriculture as in horticulture. It would be a great gain for the former, however, if the supply of home-made dung could be added to in so simple a form as that prepared by Professor Bottomley.

There are few who have as much as they could use to advantage, with the result that they have either to apply it sparingly or rely entirely on artificials for a portion of the green crop and grass areas. Its action being quicker than that of dung, it might be thought that its stimulating energy was largely expended in the first year. Recent tests made in the laboratory, however, show that the treated Kew soil after a season's growth still contains a large amount of available food material, and that the nitrogen-fixing bacteria are still active and capable of producing further nitrogenous plant food. Experience alone can decide this and other important points, but in the meantime it is satisfactory to have evidence that an important addition is likely to be made to our resources. It is interesting to know that there is virtually no limit to the production of the material. If there is any limitation it is in the quantity of the moss available, since the bacterial cultures are capable of indefinite multiplication."

CHAPTER XIII

HOW HUMOGEN IS APPLIED

How humogen is applied—Humogen suitable for all soils and all crops—Analogy with air, carbon dioxide, and water—Importance of aeration of soil and of presence of lime—Evils of acidity—Test for presence of lime—Humogen in field work. With herbaceous flower borders. With pot plants. With grass—Liquid extract of humogen—Humogen used with other fertilizers—Humogen and monocotyledons—Humogen in agriculture—Its mixture with farmyard manure—Results to be expected.

IN the course of previous chapters it has been an easy matter to demonstrate the reasonableness of the view that humogen is a substance suitable for all plants and for all soils. Hitherto I have not insisted on the point, as by stating the facts connected with humogen, and explaining the mechanism of its working, I have been confident that the conclusion would inevitably suggest itself to the minds of all readers. At first sight the statement is apt to be startling, and it is always so inevitably when made to those who have not a clear idea as to the nature of humogen. It becomes more intelligible when one remembers that in adding humogen to the soil one is doing nothing more than assisting Nature. Humus of a better or worse quality is universally present in all cultivated soils; the bacteria which

effect the Nitrogen reactions are to be found either themselves or replaced by similar ones in all soils in which vegetation is growing, and, as in the peat, so in untreated soil, they are to be found fixing Nitrogen and giving rise to the necessary auximones. All that the humogen does in essence is to furnish the healthiest possible strain of Nitrogen-fixing organisms, to provide the bacteria with improved conditions which favour their rapid growth and development, to supply both them and the plants with an ideal organic food that they can readily absorb, directly or indirectly, to furnish an increased supply of auximones, and in a very marked extent to improve the texture of the soil. When, therefore, the statement is made that humogen is a substance suitable for all plants and for all soils, it is a statement comparable with such a one as that Carbon dioxide and air and water are necessary for all plants and for all soils.

In this respect a comparison with water may make the matter somewhat clearer. While water is essential for all plant growth, its addition to a water-logged soil would only be productive of harm, a condition of affairs closely analogous with what occurs when an excess of artificial or natural manure is added to a soil that is already rich in the material supplied. The analogy, so far as the peat is concerned, is in no way comparable, for if humogen is added to a soil already rich in foods the bacteria grow luxuriantly, they increase in numbers, and enable the plant to use to advantage the foods already present.

In order to obtain the best results from the use of

humogen two facts have to be borne in mind. The soil must, as in cultivation generally, be open to the air, and its neutral or alkaline condition must be insured by the presence of a sufficiency of lime. As regards the soil texture it is unnecessary to write here, because every farmer and every gardener is fully aware of the importance of having an adequate air-supply for the roots of plants, and recognise why the ordinary methods of good cultivation have to be employed. Experience in the past with nitrobac-terine and with other fertilizers, however, has shown that the necessity of the ground being adequately limed has often not been sufficiently recognized.

No soil, it has been proved abundantly, can be fertile unless it is free from acidity. In many instances the neutral or alkaline condition of the soil is obtained by general good cultivation and adequate aeration of the soil (see Chapter IX., on the chemistry of the soil). If the land after this treatment remains acid, acidity can be removed by dressing with quicklime to the extent of about $\frac{1}{2}$ ton to the acre, or by dressing with air-slacked lime to the extent of about a ton to the acre. The general practice should be to apply the lime in the late winter, or, with heavy clay soils, in the late autumn or early winter. Lime is an essential soil constituent, because it is a plant food, because it renders the potash and phosphates in the soil available to the plants, because it insures the alkaline conditions necessary for bacterial activity, and because of the mechanical effect it produces on soils generally and especially on clays.

Fortunately it is a simple matter for the farmer, even if he is no chemist, to determine for himself by a simple test whether or not the land is sufficiently limed. To find out whether there is a sufficiency of lime or not in a field, handfuls of soil should be taken haphazard from all parts of the field. These should be well mixed together, and a wineglassful of the mixture should be poured into a tumbler, and the tumbler three parts filled with water. A teaspoonful of spirits of salts (Hydrochloric acid) should be poured into the water, and if a sufficiency of lime is present bubbles will be liberated in the same sort of way that occurs when soda-water is poured out from a soda-water syphon. If the water does not bubble freely, there is a deficiency of lime in the soil, and this must be made good before either humogen can be usefully applied, or the land yield a satisfactory crop. In some soils not greatly deficient in lime basic slag may be used as a substitute.

When humogen is required for field work on the principles of intensive culture that obtain in market gardens as contrasted with farm work, it should be used in the proportion of 10 cwt. to the acre. It should be spread over the ground, and then ploughed or dug in so as to be well mixed with the soil, and to lie some 3 to 6 inches below the level of the ground. So far as possible it should be applied a fortnight or three weeks before using the ground. That single application should be all the treatment required in the course of the year. In the event of it not being possible to put on the humogen at the

time of digging, the same quantity may be top-dressed and harrowed in at a later date when the plants are in the soil. In that case the results would be less certain for many reasons, an important one being that the comparative dryness of the soil may interfere with the proper growth of the bacteria. In any case it should be borne in mind that it is essential that the humogen should be got well into the ground. Another practical point of great importance is that the humogen and the lime must not be applied together. After lime has been applied, at least six weeks must elapse before the application of the humogen, and the longer the intervening period the better. Failing that, the soluble humates in the humogen may be changed into insoluble Calcium humate, which is not immediately available as a plant or bacterial food, and there is a considerable waste of nitrogenous food liberated in the form of Ammonia.

The method of application described above is that recommended generally for kitchen gardens, market gardens, and orchards.

When it is desired to apply humogen to herbaceous flower borders, to roses or sweet peas, the humogen should be worked into the soil as described above either in February or March. Eight or twelve ounces should be applied to the square yard, because such gross feeders will repay for the extra manuring and throw a constant succession of blooms. Fruit borders, with espaliers, cordons, vines, peaches, nectarines, strawberries, etc., require the same treatment as the above; but if the plants are being

grown under glass, the ground should be watered well after application.

In the case of pot plants generally, including cucumbers, melons, and marrows, the compost suitable for the requirements of the plants should be used, omitting leaf mould. The best results so far have been obtained by using 1 part of humogen to 9 parts of compost.

For grass, lawns, golf-greens, and tennis-courts, humogen should be applied in February as a top-dressing, at the rate of 4 ounces to the square yard, or approximately 10 cwt. to the acre.

A valuable liquid stimulant can be obtained by soaking a pint of humogen in 2 gallons of warm water, allowing it to stand overnight, and using the liquid undiluted when watering. Such a liquid has all the advantages of a Nitrogen stimulant without the drawbacks. In applying the liquid extract of humogen the grower is enriching the soil with bacteria, which will continue yielding available Nitrogen and auximones. By this means the plant is developed completely, and there is not simply a stimulation of leaf development as occurs with nitrate stimulants. There is very seldom any danger of the plant being injured by even extreme strength of the liquid. It can be given as dark coloured as black coffee, and in that concentration it is most effective if a powerful stimulant is required. As is the case when the humogen is applied in other forms, free and perfectly balanced growth is promoted.

Good results can be obtained by using humogen with other fertilizers, particularly if they are not acid in character, as is the case with many artificial manures and fresh dung. Old rotted stable manure, when mixed with a twentieth part of its bulk of humogen, is a valuable fertilizer, easily applied, and combines the good qualities of both dung and humogen. There is no reason, however, why humogen should not be used alone without any other fertilizer, and so far experiments have demonstrated that alone it will do all that dung and artificial manure, either separately or together, are able to effect. A basis of dung or other bulky organic manure has distinctly beneficial effects on the mechanical texture of the soil apart from any manurial value that it may have. Its presence is definitely advantageous in extreme soils—that is, heavy clays or light sands—and well worth consideration.

It should be noted carefully that when humogen is applied to bulbs and corms only 1 part of humogen to 20 parts of soil should be used. In all experiments carried out with monocotyledons it has been found that one-half of the dressing required for ordinary plants is sufficient.

In considering the application of humogen to agricultural conditions it is not possible to speak as yet with the same degree of certainty as it is in horticultural and glass work. The present year, for instance, with its seven weeks of continuous drought, has resulted in many field experiments giving, so far as can be seen at present, nega-

tive results. It had been hoped that the information gained this year would have made it possible to lay down definite rules as to quantities advisable in varying conditions, and so forth. At present, unfortunately, one has still to be guided by the experience gained in the market gardens. A difficulty, however, that will occur to every practical farmer can at once be stated and met. Inevitably a large quantity of farmyard manure will be produced year by year under present farming conditions, and the supply will perhaps reach the half of all the manure required on the farm. The question naturally arises as to what is to be done with this manure if humogen is used. Probably the best solution would be to spread this over the whole farm, and to supplement it with humogen. In this way the level of the fertility of the soil would be raised to a higher standard than has obtained in the past. Five hundredweights of humogen to the acre applied in the spring, top-dressed and harrowed in, should greatly increase the yield of the farms if the results obtained in small plot experiments hold good when the treatment is transferred to the farm. Up to the present the results are indefinite, and do not bear tabulation. The results given in the appendices, with rare exceptions, are of a market garden or greenhouse order, but it is hoped in later editions of this book that it will be possible to give definite statements as to the amounts of material used and so forth. Generally one may advise the application of from 5 to 10 cwt. to the acre for roots generally, potatoes especially responding well to the larger amount.

Experiments now in progress seem to justify the anticipation that the crops will be greatly increased. It is perhaps worth noting again here that under experimental conditions wheat and other cereals have responded well to humogen treatment, showing improved tillering, larger ears, and increased growth of the straw.

CHAPTER XIV

GENERAL RESULTS

Experimental character of horticulture and agriculture—
Benefits from inoculation—Selection of results—Difficulties
of exact measurements—Need for farm experiments—
Three arguments justifying them—Experiments on apples.
Asparagus. Asters. Auricula. Balsam. Barley. Beans.
Beetroot. Begonia. Broccoli. Brussel sprouts. Cabbages.
Calla. Carnations. Carrots. Cauliflowers. Celery. Chrys-
anthemums. Clover. Coleus. Cordyline. Cotton. Crassula.
Cress. Crocuses. Crotons. Cucumbers. Cyperus.
Daffodil. Dahlias. Daisies. Ferns. Fuchsia. Geranium.
Gloxinia. Grass. Grevillea. Hippeastrum. Hyacinths.
Iresine. Iris. Isoloma. Jacobinia. Lantana. Leonitis.
Lettuces. Lilium. Maize. Marrows. Mustard. Nas-
turtium. Nerium. Nicotiana. Onions. Orchids. Parsnips.
Peas. Potatoes. Primula. Pyrethrum. Radishes. Rhu-
barb. Roses. Schizanthus. Scutellaria. Streptocarpus.
Sweet peas. Tomatoes. Turnips. Wallflowers. Wheat.

THE contention of the present volume is that soil inoculation scientifically carried out will greatly increase the yield of the land that is already under cultivation, that it will bring into cultivation large tracts of land that it has hitherto not paid to cultivate, and that by the stimulation of plants it will be possible to bring fruit and flowers to maturity earlier than can be done by other means. In the present chapter I propose briefly to indicate the results that experience has shown can be achieved by the grower.

I am not pretending that such results will always follow on the application of bacterized peat. However careful the directions given, it is inevitable that from time to time mistakes will be made in the methods used for employing the peat, and the complexity of Nature is such that special conditions will inevitably arise where results will fall short of anticipation. The practical grower and the amateur gardener hardly need to be told that both horticulture and agriculture are still, despite centuries of accumulated experience, to a large extent in the experimental stage, and it would be unreasonable to expect that after ten years of experimental work, much of it perforce done in the laboratory and the hothouse, there can be the same degree of certainty which may fairly be expected from methods which have stood the test of centuries.

It has not been an easy matter to select typical results from the evidence available. Experiments have been tried with success on many species other than those of which mention is made, but I have attempted to select those species which are more commonly under cultivation. At the outset I would state frankly that the presentation of the results is faulty. Scientific methods would require the statement of exact comparative weights and measurements with standardized tests of colour, and so forth. The conditions under which such work can be done, however, cannot readily be complied with. The horticulturist and the farmer who in the past years have been willing to give a trial to bacterized peat are inevitably men who have other business to

attend to beside that of undertaking the extremely difficult work of accurate measurement. To have carried such work out on a satisfactory scale from the standpoint of exact science would have required a large number of highly trained workers, and even had that policy been pursued there would have been people to raise the objection that the results were results obtained by the laboratory man, and not by the practical worker. Several cases where exact measurements have been taken will be found recorded in Appendix B, and as regards the results which follow here the statement may be made that authority can be given for each generalization made. In some cases the deductions are based on a single experiment, but in most instances the claims put forward can be endorsed by evidence obtained from several growers.

A characteristic of supreme importance from the material standpoint will be noted. The majority of the results refer to experiments carried out by horticulturists rather than farmers. So far bacterized peat has been tested chiefly by the horticulturist, the man who stands midway between the experimental botanist and the farmer. The value of soil inoculation effected by means of bacterized peat has been proved conclusively in the laboratory. The experiments conducted at Kew Gardens and those carried out by horticulturists and market gardeners, both under glass and in the open, have endorsed the laboratory experience. Such experiments as have been made under farming conditions indicate that there is every reason to believe that

the results obtained in the laboratory and the field are also available to the farmer, and the main object of the present book will have been attained if it induces those who alone are in a position to carry out these experiments on a grand scale to extend the scope of our present experience. Three arguments should serve to convince them: The first, that the experiments have proved successful both in the laboratory and market garden; the second, that the American Board of Agriculture are encouraging the farmers in America to make use of inoculation even on lines only slightly modified from those which a few years ago were partially successful in this country; and the third, that the use of the bacterized peat, even if it were not to benefit the crop, is incapable of doing it harm.

For purposes of convenience I have thought it simplest to describe the experiments in alphabetical order, and to save space I have compressed the results into the smallest possible compass. It should be borne in mind that the nature of the treated peat is such as to make it valuable in the case of all plants.

Except where otherwise stated, control plants have received the manure or fertilizers commonly accepted as suitable for them, while often the best known treatment has been given.

APPLES.—Increased vigour of growth followed treatment. The wood was stronger and riper. The foliage was a rich dark green. There was an average gain of $1\frac{1}{2}$ ounces on each fruit, and the fruit ripened about a fortnight earlier than on untreated trees. In the second year there was no further application

of the treated peat, but the trees showed a robust health, and were more heavily laden than usual with fruit. The experiments were tried with the Blenheim Orange and Cox's Orange Pippin.

ASPARAGUS.—The tests were made with asparagus seedlings. At the end of the season the growth was such that the plants were a year nearer bearing than those which had not been treated, to judge by the increased size of the roots. The foliage of the treated plants was of better colour and substance.

ASTERS.—The seeds sown in the soil treated with bacterized peat gained from the seed-leaf stage until the time of flowering, when the plants were more than double the size of those which had not been dressed with the peat. They formed bouquets of flowers averaging 5 inches across (Comet Aster), as against 4 inches in plants not treated. The foliage and the stems were both stronger and larger.

AURICULA.—Increase in growth followed treatment, and the plants treated were quite free from woolly aphid, while those which had not been treated, though in the same house, were attacked.

BALSAM IMPATIENS.—The results obtained with Balsam were very striking. One object of the experiment was to determine how far the plant, notoriously liable to eel-worm, would be rendered immune. Experience showed that there were no signs of eel-worm among the treated plants, whereas those not treated succumbed to the disease.

BARLEY.—Laboratory experiments conducted with barley were very promising. There was a deep

FIG. 14

French runner beans as grown in Guernsey. The plant on the right was treated with humogen and yielded more beans than the plant on the left. The total increase of the two such treated plants over the two such untreated plants was 86.5 per cent.

(Grown by Mr. Holmes, Tuckswood Farm, Norwich.)

green colouring to the leaves, and the culms were much stronger. The tillering was better.

BEANS, RUNNER.—The treated plants were earlier above ground than those not treated. Their growth was more rapid, and they attained a greater height and developed enormous healthy green leaves, in some cases as large as dinner-plates. In some instances the pods were as much as 15 inches long, while they averaged about 12 inches. They retained their vigour when the untreated plants yellowed off, and the yield was increased by 20 per cent. or more.

BEETROOT.—This root responds quite exceptionally well to humogen treatment. A gain of 50 per cent. over other fertilizers has been the rule rather than the exception, this gain being maintained with turnip and long beet, and also with the sugar beet. The quality of the beet has been found to be greatly improved. The roots, although very much larger, were excellent in colour and flavour, woolliness being conspicuous by its absence.

BEGONIA.—The peat-treated plants were more robust and heavier flowered than those receiving soot or guano.

BROCCOLI.—The main difference between the broccoli and the cauliflower is the superior power of resistance of the former vegetable to cold. Both respond admirably to treatment with peat (see under Cauliflower), and the results obtained with broccoli were closely comparable with those got on cauliflower. The fact is especially interesting as showing that the effect of the treatment is to stimulate the

plant into active growth without producing a soft, sappy plant that would succumb to frost. The effect was to make the plants resistant, sturdy, and vigorous.

BRUSSEL SPROUTS.—In this instance the effect of testing peat against both artificial manures and dung was to give an increased yield of better quality. The buttons were hard, firm, and closely set, giving a much greater average yield per plant. The plants themselves grew taller, and the flavour was distinctly improved.

CABBAGES.—Growth was earlier and sturdier. The plants showed a rich bluey green, denoting perfect health. The hearts were larger, harder, and crisper than in untreated plants. They were ready for market earlier.

CALLA.—In calla the effect was very noticeable. There was great profusion of bloom, and the root action was excellent. The foliage was a rich deep green, and the blooms were splendid. A top-dressing of 1 ounce of humogen on a 10-inch pot full of food more than doubled the growth in a month.

CARNATIONS.—One carnation specialist has had plants 13½ inches high in thumbs. They were then still growing, and were the equal of plants which had been grown in 3-inch pots, but without the peat. Tested against various carnation specialities, the peat-treated plants gave much more satisfactory growth. They broke freely and flowered abundantly. The plants grown in the humogen resisted eel-worm, while those without it succumbed. One of the principal prizes at Chelsea and Holland House

this year (1915) was awarded to carnations grown with humogen.

CARROTS.—The yield from ground treated with peat, as compared with dung, showed an increase of 28 per cent., and of 20 per cent. as compared with artificial manures. The roots were clean, straight, and of good colour. The tops were not so big as might have been expected, considering the size of the roots, a point that should be borne in mind by users of treated peat who wish to estimate the progress of plants under treatment from week to week. The remark applies generally to all root crops, including potatoes.

CAULIFLOWERS.—There was a 10 per cent. improvement shown by plants treated over plants not treated. The heads formed earlier, were closer, and generally more satisfactory.

CELERY.—The sticks of treated celery were 20 per cent. larger than those untreated, and were hard and nutty. They were pulled three weeks earlier, and the crop was altogether much heavier. The colour of the plants was a rich, dark, glaucous green, and the stems were free from frothiness. Owing to the increased vigour and hardier nature of the plants, they were much less affected than the untreated plants by early frosts.

CHRYSANTHEMUMS.—The leaves of the treated plants were large, well formed, thick, and of a dark green colour, while the foliage was retained from the base upwards throughout the season. Growth was free, abundant, and sturdy, and there was a maximum number of side-breaks. In the blooms a

striking feature was the improved colour and substance of the petals, while the flowers of treated plants retained their freshness and beauty a fortnight longer.

CLOVER.—Clover is stimulated in a very marked manner, the plant spreading and increasing in size rapidly. It very soon acquires sufficient strength to displace its neighbours.

COLEUS in variety. A striking feature apart from the increased growth was the extraordinary intensity of the colours in the foliage. It has always been held generally that while an abundance of stimulating food produces growth, it sacrifices variegation and colour. With bacterized peat both increase in size, and very vivid colouring were obtained. Similar results were obtained with abutylon. (Photo, p. 143.)

CORDYLINE DRACENA.—The effect of humogen on small plants of this species was to produce a plant fit for the market in two months, whereas under ordinary treatment six months would be the usual time necessary. In the experiments made the root action was particularly vigorous.

COTTON.—The plants grew taller, and they were very markedly thicker and stronger stemmed. The leaves were larger, and the plants generally had every appearance of being stronger and healthier. The root formation in the pots was very noticeable.

CRASSULA COCCINEA.—As with other potted plants, the points particularly noticeable were the perfectly balanced growth, the profusion of bloom, and the increased root action. Foliage responded

well to the treatment, and the colour of the blooms was intensified.

CRESS.—The effect of the treated peat on cress is excellent, and this plant is admirably adapted for showing the effect of peat experimentally on a small scale. In the opinion of one grower the improvement in size, flavour, and substance was such as to justify 100 per cent. increase in the price charged. To repeat the experiment it is only necessary to sow cress seeds in a shallow box containing ordinary garden soil, and to compare this with a box under similar conditions with treated peat added in the proportion of 1 : 12. Germination may be slightly delayed, but the ultimate effect is assured. The second cutting of the treated cress has in many cases been heavier than the first cutting of the untreated cress.

CROCUSES.—Foliage and flowers were greatly improved. The resulting corms were bigger and heavier, giving promise of better results in the following year.

CROTONS.—The plants were much finer, and the colour in the foliage was greatly intensified. Root action was very strong. (Photo, p. 159.)

CUCUMBERS.—Twenty days after planting the cucumbers which had been peat-treated, cutting commenced, 72 cucumbers, weighing 73 pounds, being cut from 18 plants before the untreated plants yielded a fruit (June 7). A fortnight later 119 cucumbers, weighing 119 pounds, had been cut from the treated, as against 58 cucumbers, weighing 51 pounds, from an equal number of untreated

plants. The fruits were heavier; the foliage was slightly smaller, but of a much deeper green. The root action was very vigorous, top-dressings being required much more often than for the untreated plants.

CYPERUS VEGETUS.—There was three times as much growth and bloom. The treated plants were still in full vigour when the control plants, in a complete soil mixture, were showing signs of starvation.

DAFFODIL.—Stronger growth was observed, and there were 45 per cent. more blooms from the same number of bulbs. The flowers stood well above the foliage.

DAHLIAS.—The effect on the growth of dahlias was very striking. Although growth was so strong the flowers were thrown well away from the foliage. The colours of the blooms had a glowing richness, and in their number and quality fully corresponded with the growth.

DAISIES (*Chrysanthemum Max*).—The flowers were larger, earlier, and better, and cutting commenced a fortnight earlier.

FERNS (*Adiantum*, *Pteris*, *Asparagus Plumosa* and *Sprengeri*).—Ferns respond very quickly to treatment, and produce good saleable plants in a third of the time usually taken. Experiments confirming this result—as in many of the other cases here quoted—have been in progress for three years.

FUCHSIA.—The usual characteristics of the effect of humogen on pot plants have been well marked in the case of the fuchsia—the well-balanced symmetrical growth, profusion of bloom, energetic root action, rich foliage, and intensification of the colour

of the bloom. The pyramidal formation of the plants has been very noticeable. In one typical series of experiments the plants bloomed six weeks after potting at the end of May, and continued in flower until October.

GERANIUM.—Several tests have been made with geraniums, and it has repeatedly been found that the treated plants continued growing and blooming when plants without the peat were starved. One grower has reported that he has by means of the peat been able to obtain geraniums by May or June, selling them at 4s. a dozen, whereas under former conditions he used to obtain only 2s. 6d. a dozen.

GLOXINIA.—These made excellent glossy foliage, and flowered profusely. The plants generally were better and bigger in every way.

GRASS.—In connection with golf-greens, cricket-pitches, and lawns, humogen has been tried against a mixture of malt culms, soot, and ammonium sulphate, and in every way the peat has proved superior. The grass becomes a beautiful dark green, the clover in it is thickened, and a much better bottom is developed. A well-known golf professional has described how a week after the application of the peat the portions of greens treated could easily be distinguished from a long distance off.

GREVILLEA ROBUSTA.—After treatment the plants grew so rapidly that they became too big for the greenhouse. A notable feature was the way in which the plant branched, breaks occurring at axils, and resulting in a dense mass of foliage. (Photo, Frontispiece.)

HIPPEASTRUM.—Seedlings by the end of the season had made bulbs two and a half times as heavy as in the case of untreated plants. They were therefore so much the nearer by that extent to the flowering stage.

HYACINTHS.—Increase in the root action was well marked. The foliage was rich in colour. The flower spikes were heavier, and both colour and scent were strongly intensified. The bulbs were heavier. (Photo, p. 91.)

IRESENE LINDENI.—The purplish red attained in the foliage was very striking. The growth obtained was less remarkable, but the colouring was far more intense, deeper, and richer.

IRIS HISPANICA.—Growth was more vigorous; the flowers were bigger, and matured a week earlier.

ISOLOMA.—Fine healthy plants were obtained far larger than in the case of non-treated plants. Those receiving humogen showed greatly increased root action, much improved foliage, intensification of flower coloration, and a notable symmetrical development.

JACOBINIA.—Results were obtained similar to those in the case of isoloma, but owing to the intensification of colouring the blue flowers made a striking picture against the dark green foliage.

LANTANA SABRIFOLIA.—The rapidity of growth obtained without spoiling balance was very marked. The plants were more than double the size of those not treated.

LEONITIS LEONURUS.—Symmetry, strongly promoted root action, intensification of colour of foliage

FIG. 15

The maize plant was one of the earliest on which auximones were tested. All the plants shown above were grown in sterilized sand (washed silver sand). The plant on the right received nothing but distilled water. The middle one received a complete chemical diet (Detmer's). The one on the left received Detmer's +0.35 part per million of the Silver fraction derived from the Phosphotungstic precipitates obtained from bacterized peat. The photograph had to be taken at an early stage, as the plant grown with distilled water was beginning to die.

(Botanical Laboratories, University of London, King's College.)

and flower, and perfectly balanced growth, with increase in size, were well marked in the treated plants.

LETTUCES.—A series of experiments carried out in a dry spring showed a superiority of the peat over dung of 123 per cent., and of the peat over artificial manure of 176 per cent. The plants were markedly good-looking, and hearted well.

LILIUM HARRISII.—In addition to showing the characteristics usually following the use of peat with pot plants there was an average increase of 8 inches in height, though the pots were smaller than those ordinarily used. The number of blooms per plant was usually six or seven.

MAIZE.—Remarkable results were obtained with experiments conducted in sand culture with maize to test the effect of auximones. The weights of the dried plants under different treatment were as follows:

	Grammes.
Sterilized sand and distilled water ..	66
Sterilized sand and Detmer's solution ..	215
Sterilized sand, Detmer's solution, and phosphotungstic fraction from humogen (17 parts in 1,000,000)	255
Sterilized sand, Detmer's solution, and Silver nitrate fraction from bacterized peat (0.35 part in 1,000,000)	325

MARROWS (*Bush*).—When marrows were treated with artificial manures the average weight of the fruits obtained per plant was 16 pounds 5 ounces. When treated with peat the fruits weighed 37 pounds 11 ounces. The plants fruited a week earlier, and continued bearing after the others.

MUSTARD.—Peat treatment gave an increased yield of 174 per cent. The leaves were darker all

the time the plants were growing and had thicker stems, the effect being most marked when the crop was ready to cut.

NASTURTIUM.—When peat was used in *small* quantities the plants improved in every respect, but when a full dressing of peat was used the plants became too vigorous, developing a huge foliage that concealed the flowers.

NERIUM OLEANDER.—In addition to increased root and foliage development, and a marked increase in the size of the plants, the flowers themselves were larger and more numerous, and showed a striking increase in colour.

NICOTIANA (*Tobacco Plant*).—The plants were stouter stemmed, broader leaved, and taller.

ONIONS.—In one experiment treatment with the peat was followed by an increase of 41 per cent. In another experiment, when no manure was used as a control, the treated plants showed an increase of 110 per cent., and where dung was used as a control, of 46 per cent. The plants grown in soil mixed with humogen, as compared with those that had received dung, had much smaller tops, the necks were thinner, and the bulbs harder and bigger, and they proved better keepers.

ORCHIDS (*Veitchii Calanthe*).—The plants produced spikes earlier and heavier than those which had not received peat.

PARSNIPS.—Three drills were dressed with humogen this year (1915), and grown against eight drills undressed. Those treated with humogen are much more forward and growing more evenly.

PEAS.—In one of many experiments there was a 31 per cent. gain in weight of the pods pulled for eating. The plants were taller, and the pods were both larger and more numerous. In another experiment on peas grown for seed three rows untreated gave 18 pounds of dry seed, while three treated rows gave 28 pounds of seed, an increase in weight of 55 per cent., representing to the grower a money gain of 18s. 3d.

POTATOES.—Compared with no manure, artificial manures and dung, peat has given an increase in potatoes over no manure of 123 per cent., over artificial manures of 75 per cent., and over dung of 41 per cent. These results were obtained in a light sandy loam in 1913, the land not having been previously cultivated for nine years. In 1914 the same ground treated with humogen gave an increase of 59.5 per cent. over land not manured. A part of each of the plots manured in 1913 was left unmanured in 1914. The land which had received artificial manures showed an increase of 27 per cent. over the unmanured land, the peat-treated land showed an increase of 83.3 per cent., while the land that had received dung showed an increase of 37.7 per cent. The treated peat appeared to leave the land as fertile the second year as in the season of application.

PRIMULA (*Malacoides*, *Kewensis*, *Obconica*, etc.).—All varieties of primula tested responded equally well, the plants in each case showing 100 per cent. superiority. The flowers were more prolific, and individually larger and better coloured.

PYRETHRUM.—Cutting was ten days earlier. Stems were markedly longer, and the characteristic feathery foliage better developed.

RADISHES.—A striking result has been obtained with radishes grown in soil as against the same soil and humogen. Two rows were grown against each other. The weight of the best twelve plants in the humogen row was $6\frac{3}{4}$ ounces; of the second best dozen $5\frac{1}{2}$ ounces. Only a dozen weighable radishes were obtained from the untreated row, and they weighed only $3\frac{3}{4}$ ounces. (Photo, p. 194.)

RHUBARB.—Early this year (1915) a very small dressing of peat was given to a portion of a plot of growing rhubarb. By June 5 the treated portion was very much better than the untreated. It was ready for pulling earlier, and growth continued longer, stalks being pulled from it after growth had ceased in the other part of the plot.

ROSES.—Excellent results have been obtained with roses. The plants increased in vigour, and the healthiness of the foliage and the colour of the blooms were intensified. So well marked is the latter quality that two beds of Dean Hole, one of which was treated and the other untreated with the peat, appeared as if stocked with two distinct varieties of roses. The grower has secured five first prizes in open competition this year. In one case the better colour was the deciding factor between first and second prizes.

The intensification of the colour is especially marked in the case of Maréchal Niel. In the hands of at least one well-known market grower humogen

FIG. 16

The radishes on the left were treated with humogen and soil, those on the right being grown in soil alone. The best dozen of the humogen-treated plants weighed $6\frac{1}{4}$ ounces as against $3\frac{3}{4}$ ounces from the untreated. The second best dozen of treated plants weighed $5\frac{1}{2}$ ounces, while in the other case the second dozen plants were not weighable.

(Mr. Holmes, Tuckswood Farm, Norwich.)

and soil is giving considerably better results than his own soil mixture.

SCHIZANTHUS.—The plants proved finer and heavier flowered, and the individual flowers were larger than the controls.

SCUTELLARIA COSTARICANA.—The plants were grown with humogen and soil as against a complete manure. There was differential improvement in the case of the humogen-treated plants in root development, nature of foliage, symmetry, and size. The increased sturdiness of growth was notable, while the flowers were distinctly heavier and earlier.

STREPTOCARPUS.—Excellent growth was made with glossy foliage and abundance of flower.

SWEET PEAS.—The effect of humogen on sweet peas is marked. There is increase in growth, height, and length of flower-stems, and intensification in the colour and veining of the bloom. The foliage is healthier looking and deeper in tint. The Bide Challenge Cup was won this year (1915) by an amateur at the National Sweet Pea Society Show by blooms from plants grown with the aid of humogen. The second prize was also won by a grower who had used humogen. The same grower (who got first prize) has won at different shows this year five first prizes and one second prize, in every case with humogen-treated plants. In two gardens where humogen was used streak was absent, though untreated plants collapsed from the disease.

TOMATOES.—Stimulation of growth is very marked with tomatoes. Rapid growth takes place, but plants remain short-jointed and small foliated,

setting and fruiting heavily. According to reports received treated crops have frequently given double the yield of untreated. Several growers state that ripening is advanced by from three to four weeks. (Photo, p. 145.)

TURNIPS.—Several experiments have been made with turnips. In one of these, in poor soil, peat increased the yield by 100 per cent. over no treatment, by 47 per cent. over artificial manures, and 26 per cent. over dung. In another experiment humogen increased the yield by 121 per cent. over no manure, while farmyard manure gave an increase of 67 per cent. over none, and artificial manures gave an increase of 52 per cent. over none.

WALLFLOWERS.—Fine bushy plants resulted from treatment. Masses of fibrous roots were formed which transplanted well, yielding plants that were perfect mounds of bloom.

WHEAT.—Wheat treated on an experimental scale in a market garden with humogen, and compared with the untreated garden soil, was taller, stronger, and greener than the non-treated wheat. It was well in spike on June 15, and the tillering was better, averaging twenty-three ears as compared with fifteen. The humogen was applied on the scale of 5 cwt. to the acre, and used as a top-dressing. The culms were very much heavier, and the untreated plants were in comparison very yellow, dwarfer, weaker, and more backward in bloom. The plants showed a gain of a foot in height, and the ears were $1\frac{1}{2}$ inches longer and fuller. Unfortunately both treated and untreated plants were beaten down during one of the heavy storms, and the experiment could not be concluded.

CHAPTER XV

HINTS AND EXPERIMENTS

IN this chapter I have collected together the points that must be borne in mind by those who wish to test humogen experimentally, expressing them in the briefest possible form. I have suggested a few model experiments as a guide, but naturally the most interesting results will be obtained by those who design and carry out experiments for themselves. In conducting experiments every fact observed should be carefully noted down at the time, and the progress of experiments should be recorded by photographs at frequent intervals. All dates, especially such as that of the first appearance of the shoot above the soil, of the first bloom and of the first matured fruit should be noted. Invariably there should be control experiments—that is, experiments in which plants have been treated without any other difference except for the omission of humogen. Valuable results can also be obtained by testing humogen against other manures.

MISTAKES TO BE AVOIDED.

Don't expect humogen to do all the work of the gardener. The better the cultivation, the better the results.

Don't attempt to grow plants out of their season in the open.

Don't attempt to grow plants in sour soil. Lime must be given in this case to render the soil neutral or slightly alkaline.

Don't give too much water. Pot plants do not require watering until the pots ring when struck.

Don't judge the water condition of the soil by the surface.

Don't overcrowd the plants, but leave room for root growth.

Don't use humogen in greater concentration than 1 part in 10, or you will waste the material.

Don't be disappointed if a slight retardation is evident at first when using sterilized soil.

Don't leave bags of humogen where they can get wet. An ordinary dry garden shed is a suitable place.

Don't be afraid that the humogen can injure plant growth.

Don't be afraid of the bacteria in humogen. They are perfectly harmless.

Don't attempt to grow plants in rooms with coal fires or gas.

POINTS TO BE REMEMBERED.

One part of humogen to ten of soil gives the best results, with the exception of bulbs (monocotyledons), when 1 in 20 should be used.

Mix up your compost in accordance with the requirements of the varying species, using humogen instead of leaf mould and dung.

When growing plants in moss and humogen extract sterilize the moss.

When possible mix humogen with the soil.

Treat the plants with humogen from the seed-leaf stage.

When using moss, water once a week with a coffee-coloured extract of humogen. Use plain water at other times.

When using as a top-dressing incorporate the humogen as deeply as possible in the soil.

When preparing the ground lightly dig in the humogen some few days before sowing.

Apply humogen to the land early, so as to give the bacteria time to multiply in the soil while it is moist.

On poor ground use at least 10 cwt. per acre.

For kitchen garden crops it pays to use liberally. Eight to ten pounds per rod should suffice. Roses and flower borders the same.

If you wish to co-operate in advancing soil bacteriology keep accurate accounts of all you do, and especially measure the humogen employed and the resulting produce. The model experiments are a guide how to keep results.

Remember if you don't get results to write direct to Mr. Alfred Machen, 48, Frances Road, Windsor, giving full details of what you have done. Either failure is due to avoidable error, or your experience will help to advance knowledge.

MODEL EXPERIMENT I.

Radishes.

The French breakfast radish is a convenient plant for a preliminary experiment. Use two small boxes about 3 inches deep. Fill one with your garden soil or loam obtainable from a seedsman. To the other box add humogen, using one-ninth of the bulk of the soil (conveniently measured by a teacup). Mix the humogen and soil well. Plant the same number of seeds in each box about $1\frac{1}{2}$ inches apart and about $\frac{1}{2}$ inch deep. Water thoroughly, interchanging the position of the boxes weekly, so as to insure similar treatment. A window-ledge or a site in the open garden is suitable, but in the former case care must be taken with the watering, as in such conditions the soil dries rapidly. The best plan is to plunge the box up to the edge in the soil, when watering will be reduced to a minimum.

The radishes should be pulled when ready for eating from both boxes at once, and the following points noted:

1. Number of plants in each box.
2. Weight of complete plants in each box.
3. Weight of edible portion in each box.
4. Divide weights in each box by number of plants in each box to get a comparison of the average weight of the roots.
5. Notice the quality as well as the quantity.
6. Determine percentage increase by multiplying the weight in the box treated with humogen by 100.

Divide this by the weight of the untreated plants, and subtract 100 from the answer.

Thus, to work out the percentage increase in the humogen-treated beans obtained by Mr. Holmes, and described in the chapter on "The Testing of Humogen," one would calculate as follows:

$$\frac{4 \cdot 11\frac{1}{2} \times 100}{2 \cdot 8\frac{1}{2}} = \frac{151 \text{ (half ounces)} \times 100}{81 \text{ (half ounces)}}$$

$$= \frac{15,100}{81} = 186 \cdot 5.$$

$\therefore$ Percentage increase = $186 \cdot 5 - 100 = 86 \cdot 5$ per cent.

NOTE that experiments with radishes can be conducted in the open at any time between the middle of March and the first week in September. The plants *can* be grown in a greenhouse or in a light and airy room at any time of the year.

MODEL EXPERIMENT II.

Primula (any Variety).

Primula plants ready for their final potting are easily obtained in the early autumn. The new pots should be filled (1) with good potting soil, as recommended by nurserymen from whom it may be obtained; (2) with some rich mixture such as that described in the chapter on "The Testing of Humogen," as used at Kew, or according to what the experimenter regards as the best possible obtainable; (3) the good potting mixture used for (1), with one-ninth of humogen well mixed. From this time ordinary cultivation is all that is necessary.

NOTE.—(1) The comparative growth of the plants at various stages.

- (2) The development of the root.
- (3) The colour and thickness of foliage.
- (4) The date at which blooms first appear.
- (5) The date at which the plants stop blooming.
- (6) The number of blooms obtained from each plant throughout the season.
- (7) The size and colour of individual blooms.

MODEL EXPERIMENT III.

Moss Culture.

Sterilize any variety of moss by heating it in steam. The moss should not be boiled in water. The best rough way of sterilizing the moss is to cover the bottom of a large saucepan with $\frac{1}{2}$ inch of water. Then cover the bottom of the saucepan 2 inches deep with well-broken clean road-metal, or some similar substance to prevent the water from reaching the moss. Fill the rest of the saucepan with the moss, and boil well for a quarter of an hour. Avoid heating to dryness, and if necessary add water. The saucepan should be covered. Better still an ordinary kitchen steamer should be used. Nearly any plant can be used for moss culture, but the following are recommended: Potatoes, bulbs of all sorts, ferns.

All that is necessary is to water the plant once a week with humogen extract. Use the proportion of 1 pint of humogen to 2 gallons of water. To prepare the liquid mix the humogen in a jug with water not warmer than can easily be drunk. Stand over

night, and decant the liquid in the morning. Water the moss once a week with humogen extract, and in between times with ordinary tap-water.

NOTE.—(1) The weight of the bulb when planted and its weight at the end of the season.

(2) The same points as in the primula and radish experiments.

(3) The weight of the crop when tubers are grown.

MODEL EXPERIMENT IV.

“Top-Dressing.”

The effect of humogen may be tried on any plants or grass growing in the garden at any time from March to September. Use 4 to 6 ounces to the square yard, and work well into the soil. On grass spread the humogen over the surface. For this experiment humogen should be applied only in plots. Thus, half a bed should be treated and the other half not treated, so that improvements resulting may be noted. Apparently inconsistent results must be expected in this experiment, as humogen will not usually force a plant into fresh growth if the normal resting stage has been reached for the season.

NOTE all such points as described in the primula and radish experiments, and especially compare the condition of the treated and the untreated plants.

NOTE TO FARMERS AND GARDENERS.

As a measure of prudence it would be wise for farmers and gardeners wishing to experiment with humogen on a large scale to write direct to Mr. Alfred

APPENDIX A

NITROBACTERINE AND LEGUMINOUS PLANTS

IN connection with the use of nitrobacterine, in over 80 per cent. of the reports made to Professor Bottomley there was evidence that the use of the material had shown a distinct advantage gained by the crops through inoculation. As a method similar to Professor Bottomley's is still being employed in America, the original American method having been abandoned, the following reports, which were published by *Country Life* in a pamphlet, *Seed and Soil Inoculation for Leguminous Crops*, in 1908, may be of interest. It has been found since that many of the failures were due to preventable causes. The successes obtained, however, remain of considerable historic and practical interest. As in the original pamphlet, the reports are grouped by counties.

CORNWALL.

MARAZION—*Peas*.—The peas were a great success. Inoculation of soil *and* seed returned a good 30 per cent. more than only seed inoculation, and the seed inoculation showed a good 20 per cent. better crop than the farmyard manured peas. Inoculation in both cases rendered a *fortnight earlier marketing* possible over the manured.

CHESHIRE.

CHESTER—*Peas*.—Taking a piece of poor ground in an old garden we planted one portion with inoculated seed, and in another portion inoculated the soil. Against this and adjoining we sowed the same kind of peas untreated, half upon ground treated with ordinary farmyard manure, the other half with a little bone manure in addition. As regards the result it was easily discernible which peas had been treated, the foliage being stronger, and the pods larger and more freely produced than those grown on the manured ground.

CHILDER THORNTON—*Clover*.—They have just begun cutting the oats, and are very pleased with the inoculated clover; it is almost too good, very strong plants.

HALE—*Sweet Peas*.—The inoculation of my sweet peas has been an immense success. Unfortunately the unfavourable weather this summer prevented me showing in London on July 16, but with blooms $2\frac{1}{4}$ inches across, and stems 18 inches long, in addition to numerous four blooms per stem (very few less than three), I can say with confidence that there were none better. Whilst in this district and Manchester they have been generally remarked upon. From the very commencement of operations the inoculated seeds showed more vigour than the others.

DORSET.

WEYMOUTH—*Peas*.—For experiment with peas I sowed one-third without and two-thirds with culture treatment to seeds previous to planting. Results as follows:

1. Stages of early growth little difference.
2. As soon as flower blooms appeared the haulms of "culture" gained considerably in strength, height, and show of blossom.

3. Pods of " culture " fairly 20 per cent. better—both in size and quantity.

4. Flavour decidedly superior to " non "-treated.

5. A few haulms of " culture " bore pods of far larger size than the type.

DEVON.

TAVISTOCK—*Clover*.—The inoculated clover was taller by 3 inches than the uninoculated.

DENBIGHSHIRE.

WREXHAM—*Sweet Peas*.—Inoculation has been quite a success. The flowers are greater in number by at least 20 per cent. than those not treated, and the size of the flowers is much larger.

ESSEX.

EPPING—*Peas*.—First sown peas, inoculated, a fine crop with haulms of great thickness, and fruit large and juicy. Second sowing, uninoculated, results very poor, haulm thin and weakly, crop almost useless. The ground on which first crop was sown had had no peas on it for several years, whereas the ground on which second crop was sown had had peas grown on it in the previous year.

CHAPPEL—*Sweet Peas*.—The inoculating material you sent me was a distinct success. The sweet peas started to blossom earlier than the non-inoculated, and grew 2 feet higher. I gained three prizes with them in open classes at local shows. My soil is very light and shallow, and was never cultivated until two years ago, and numbers of people have been surprised at my display of sweet peas on such poor ground.

WOODFORD — *Peas*. — Seeds treated; plants also watered with solution at later period of growth. The

treated peas show a very much more vigorous growth, and much better yield of fruit.

HORNCHURCH—*Peas*.—The row which I treated with your preparation seems generally stronger and certainly earlier than the others. As regards earliness, the row treated, although planted out a fortnight later, began to flower before those not treated.

GLOUCESTERSHIRE.

STAUNTON—*Vetches*.—The inoculated were greener and thicker than those not treated.

Broad Beans.—The inoculated were up a week and a half before those not treated, and were very much greener and more weight.

2 rows *inoculated*, 65 yards long, gave $4\frac{1}{4}$ pots.

2 „ *not inoculated* „ „ „ 3 „

a gain nearly half as much again, $1\frac{1}{4}$ pots, or 52 pounds, a pot being 42 pounds.

Peas.—The inoculated peas were a great success. They were from the beginning very much greener than those not dressed, and the pods were $\frac{1}{2}$ to 1 inch longer, and much larger peas. I had the best crop of peas round here for 2 or 3 miles, and was the first to sell to the greengrocers in Gloucester in quantities. From a quarter of an acre planted with 1 bushel *inoculated* seed I picked $33\frac{3}{4}$ pots (42 pounds to the pot), selling them for £7 18s. 9d. From a quarter of an acre planted with 1 bushel *non-inoculated* seed, but dressed with 1 cwt. superphosphate and $\frac{1}{2}$ cwt. sulphate of potash, I picked only 14 pots, selling them for £2 5s. 6d. I also planted a quarter of an acre with 1 bushel inoculated seed, and manured with $\frac{1}{2}$ cwt. superphosphate and $\frac{1}{2}$ cwt. sulphate, and picked $54\frac{1}{4}$ pots.

This village is composed of about 80 small holdings from 2 to 4 acres, and most of the people grow market garden stuff. They were surprised at me being able to pick so much off the small amount of ground. I shall be pleased to obtain more inoculation material next year, when I want to try it on some heavy clay land which is very poor, and has been laid down two years.

GUERNSEY.

RAMEE—*Runner Beans*.—The beans were grown with the material you were kind enough to send us, and we may say that we have never had a better and earlier crop. The seeds came up very strong, and the leaves had a nice dark colour. We picked the first beans *six weeks after sowing*.

A more detailed report states: On October 5, 1906, we planted the house with beans, which did not crop very well. The house is 200 feet long and 30 feet wide. This crop was finished on February 21, 1907. We then cleansed the house, burned some sulphur, washed the glass, and trenched the ground about 18 inches deep, and worked in 2 cwt. pulverized chalk, and 1½ cwt. Cross's organic manure. We replanted the house with *inoculated* seed on February 22, and our first beans were sent to market on April 8. We can assure you beans have never before done so well in our ground.

HANTS.

WINCHESTER—*Peas*.—The inoculated peas are growing and bearing well, especially as none of them were manured. My opinion is that inoculation is a great help on such poor soils as mine.

JERSEY.

ST. OVEN'S—*Lucerne*.—The inoculated seed came up better than the untreated, and the crop is now a lot thicker and of more even growth.

Peas.—I found the culture increased the pea crop a great deal, and they were at least a week earlier than the non-inoculated. The land is very poor gravelly soil.

KENT.

FAVERSHAM—*Clover*.—Culture applied by being mixed with earth, then spread and harrowed. Treated half acre yielded $2\frac{1}{2}$ waggon loads of clover fodder; untreated, 2 loads. The clover on the treated part was stouter and larger than on untreated. Soil rather thin near the chalk.

BECKENHAM—*Sweet Peas*.—I have not grown sweet peas before this year, and therefore cannot compare with any previous results. I may say, however, that my plants have excited the admiration of my friends. I treated the seeds with your culture, and some of the plants have run up to 8 feet in height. The flower-stalks have been in some cases 16 inches long, and while threes have been general, there have been several fours, the blooms being of fine size.

LYMINGE—*Peas*.—The peas greatly benefited by your inoculating process. I had as many as 13 peas in a pod, and the general run of the pods contained 8 or 9.

CANTERBURY—*Beans*.—Strip 20 furrows wide through centre of field sown with seed not dressed yielded 11 bushels 5 gallons; strip 20 furrows wide (above) sown with *inoculated* seed yielded 14 bushels 1 gallon; similar strip (below) yielded 14 bushels 7 gallons. The whole of the field where seed was treated gave a yield of 6 quarters 2 bushels, which was very good indeed for such

poor land, and speaks very well indeed for the farms you so kindly set to work on our account. Now that this has been such a success, may I hope you will kindly furnish me with some more bacteria for the coming year, or tell me how I can obtain it.

LANCASHIRE.

GRAPPENHALL—*Beans*.—I had a bed inoculated and one without. In early stages those inoculated seemed the stronger plants, but at maturity there did not seem much difference; but I shelled them myself, and consider those inoculated yielded fully 30 per cent. more than those non-inoculated. I planted them in ground that had no manure for two years, and I consider the results very satisfactory.

WHALLEY RANGE—*Peas*.—The plot treated with culture was approximately a fortnight in advance of a similar plot planted with untreated seed. The plants are exceptionally good.

Sweet Peas.—Seeds which were treated did exceptionally well, growing plants a third higher than similar seeds untreated. Also on the plants which have been treated with culture I notice an unusually large proportion of flowers, with fours and occasionally fives on one stem.

LEICESTERSHIRE.

DESFORD—*Peas*.—The crop is 20 per cent. better on the untreated peas. The haulm is much more robust and healthier in appearance also, and flowers are still being produced, while the non-inoculated plot is over.

LINCOLNSHIRE.

WOODHALL SPA—*Green Peas and Sweet Peas*.—Inoculated were most successful; uninoculated but a poor crop.

Scarlet Runners promise a full crop, though growing in very poor sandy soil—in fact, little more than sand. They are certainly as prosperous, if not more so, than the non-inoculated plants in manured soil.

MIDDLESEX.

WHITTON—*Peas*.—The results of treating the peas with bacteria have been eminently satisfactory. My experience was as follows:

“*Gradus*,” *without inoculation*, a fair crop, but they were soon over.

“*Sutton’s A1*,” *inoculated*, heavy crop, with abundance of well-filled pods.

“*Veitch Perfection*,” *inoculated*, a very heavy haulm packed with pods, so much so that the weight of the crop broke the haulm down, though they were “re-sticked.”

“*Exhibition*,” *inoculated*, showed a wonderful crop; these were so prolific that the haulms broke down under their weight of produce, growing 6 to 7 feet high, with pods 6 and 7 inches long.

All the above were sown in new ground, having never grown anything before except grass. I estimate the produce from inoculation was from 30 to 40 per cent. more than from the untreated seed. I was told that my peas were the finest in the district.

HARROW—*Runner Beans*.—I tried your system of inoculation upon some runner beans during the past season, and was surprised at the results. The inoculated beans yielded 45 to 50 per cent. more in weight than those grown under ordinary conditions.

NORFOLK.

NORWICH—*Peas*.—The inoculated peas were three weeks earlier for market, and decidedly 50 per cent. more prolific than the non-inoculated.

FIG. 17

The number of blooms thrown and the size and colour of the individual blooms are the main results obtained by the application of humogen to the primula. The above photograph shows two specimens of *Primula Kewensis*. Both were planted in ordinary potting compost, but the one on the right was watered continually with humogen extract, while the one on the left was watered with guano extract.

(Grown at the Royal Gardens, Kew.)

MARSHAM—*Peas*.—We made our experiments with the greatest care, inoculating six rows of peas, planting different sorts. In every case the yield from the inoculated rows (we planted fifteen rows in all) is *three times* as good as from the uninoculated, the pods hung in clusters, and the yield was excellent, and earlier than we have ever had before.

SWAFFHAM — *Peas*. — Result excellent. An exceedingly heavy crop. Beyond this, the most noticeable features about the different varieties are that the inoculated have continued bearing *much longer* than usual, and the almost complete freedom from maggots in the pods, and from any appearance of mildew on the foliage.

NOTTS.

SOUTHWELL—*Clover*.—The clover seed was sown on land which before had failed to produce a crop. The treated seed has come up very thick, much better than the untreated, and there is a fine crop.

SHROPSHIRE.

OSWESTRY—*Vetches*.—Where the vetches were dressed, your dressing seems to have acted wonderfully, and a fine crop has resulted.

Peas.—Our inoculation experiment has turned out a complete success. We have had a splendid crop. The inoculated crop overtook another crop, not inoculated, by four weeks.

BRIDGNORTH—*Peas*.—The bacteria culture was very successful. The seed peas were treated strictly according to instructions, and I had a check lot of untreated peas sown parallel (and 4 feet away) to the treated peas. The haulm of the treated peas grew very large, and the foliage was fine, and remained clean and healthy. The

plants blossomed very freely, and very many pods were produced. In the case of the untreated peas the pods were few, and did not fill well, and the peas produced were not as sweet as those on the treated peas. I gave some of the culture to a friend, who was sceptical and gave a grudging consent to its use. He has never before been able to grow a good crop of peas in his garden. This year he says: "The only things to do any good are the peas," so you may rely on it that the culture has done a lot of good.

STAFFORDSHIRE.

TAMWORTH AGRICULTURAL COLLEGE.—*Clover* sown with rye-grass inoculation gave an increase of about 15 per cent. *Tares* inoculated showed an increase of about 10 per cent.

SOMERSET.

BATH—*Sweet Peas*.—The inoculation with sweet peas was quite successful, the inoculated seed producing the best flowers that I have ever had, and much stronger than the seed which was not inoculated. Inoculation was by watering the planted seeds. My soil is loam, and always kept well manured.

SURREY.

HINDHEAD—*Sweet Peas*.—The inoculation experiment has been very satisfactory. We planted the inoculated sweet peas in poor sandy soil which had not previously borne flowers—dug-up bracken and heath land. The flowers have been beautiful and plentiful, and at this date, when the non-inoculated peas are over, the inoculated are still plentiful and seem to have an unusually sweet odour.

SUTTON—*Sweet Peas*.—Some freshly dug meadow-land was sown; one half the seeds were treated with the solu-

tion and the young plants watered as advised, the other half untreated. The treated seeds produced the finest show of flowers we have ever raised, but the young plants from the undressed seeds were unfortunately so badly attacked by slugs and snails as to make comparison useless. Some of the solution was given to a gardener at Carshalton. He divided his seed into two lots—treated and untreated. His soil was a light loam on chalk. The untreated seeds produced a good show of flowers, but the treated seeds did far better. He estimates that the yield of flowers was increased by about a third.

WOKING—*Peas*.—The “pea culture” is a great success. Those peas watered with the solution have yielded in an astonishing manner—the yield has been more than double.

Peas.—I planted the inoculated peas on land that has not been manured for many years, and had a crop of peas quite equal to those grown by a friend on manured soil.

Broad Beans.—I had similar results with broad beans, which produced a later growth almost equal to the first.

REDHILL—*Peas*.—From 1 pint of peas inoculated the yield was at the very least 35 to 40 per cent. more than from the pint not treated. We are still gathering from the inoculated peas, and several pods when opened show 8 and 9 peas in each.

Scarlet Runners.—The inoculated scarlet runners are quite a sight, reaching the tops of the 8 and 9 feet sticks, and I have had to run strings (like they do hops) to help the runners. The blossoms are a wonderful sight, and the lower ones are showing runners of 8 to 10 on one stem.

KNAPP HILL—*Beans*.—I am pleased to say that inoculation has been a splendid success. I treated half of

each row of broad beans with the solution direct to the roots. The photos I send you show the comparative sizes of the bean pods at the time I commenced to pick them. The inoculated ones were $7\frac{1}{4}$ to 8 inches long; the non-inoculated only $4\frac{1}{2}$ inches long. I left four of the best plants in both inoculated and non-inoculated plots to grow to maturity. The average length of the pods from the inoculated plants was 11 inches, averaging 8 beans to the pod; the non-inoculated $8\frac{1}{2}$ inches long, with 6 beans. The inoculated beans were quite *three weeks earlier* than the others.

Peas.—The peas were treated in the same way, and inoculation was equally successful. The inoculated were ready quite *two weeks* before the others. My garden is old orchard land, and the ground received no manure other than that from the grass which was trenched in about June, 1906.

SUSSEX.

BATTLE—*Clover.*—I sprayed part of a field of grass, cut over each year then pastured, with the culture solution. Now the sprayed part shows a great deal more white clover than the rest of the field. On a piece of very poor land of 7-year-old pasture I sowed inoculated white clover seed. The result has been a great improvement in the clover compared with other portion of the field, which had formerly the best clover.

BRIGHTON—*Peas.*—We planted the inoculated peas in the poorest ground we possess, and they have done exceedingly well.

Sweet Peas.—We also sowed some inoculated sweet peas on a cinder path at the top of a low wall, and they have grown and blossomed very freely, and looked very

nice hanging over and covering the wall. Our friends have been quite astonished to see them growing in cinders.

WILTSHIRE.

CHIPPENHAM—*Peas*.—The experiments have much exceeded my expectations. I applied the culture at three different periods—at planting seed, and twice during growth, on a piece of remarkably poor land. They grew half as high again as usual, strong haulm, of lovely deep green, and simply smothered with blossom; peas large and well-filled pods—double the usual crop.

Sweet Peas, treated in same manner as peas, have been the admiration and envy of my neighbours, growing from 8 to 9 feet high, and literally a feast of blossom, with stems 12 inches and more in length; in bloom early in June, and are still (August 26) making a brave show. It is truly a wonderful discovery this microbe, and bids fair to revolutionize ideas of gardening.

WORCESTERSHIRE.

EVESHAM—*Peas*.—I am sorry I am unable to give you accurate comparative results on inoculated and uninoculated plots owing to reasons given below, but in comparison with my neighbours I cropped, through your assistance, the best return on my peas in the immediate neighbourhood, and they were picked quite *ten days* earlier than others who planted on the same day. Though the land where they were grown is extremely good "black soil," for some reason it will not grow peas, and this is, I believe, the first time anyone has matured a crop on it.

Lucerne.—I have grown, with the help of your bacteria, a lucerne crop far above the average.

YORKSHIRE.

BRADFORD—*Sweet Peas*.—The sweet pea rows which I inoculated twice with your bacteria have been an eye-opener to all the other sweet pea growers in this district. The ground has had no manure for 3 years, but had a good top-dressing of lime 2 years ago. The foliage, bloom, and height of the plants are far superior to others grown in same district which have been fed with artificials and farmyard manure.

Peas.—On culinary peas the result has been marvellous. The haulm was very large and thick, and the pods very large and of a lovely dark green colour.

SHEFFIELD—*Runner Beans*.—Inoculated and non-inoculated rows were grown in soil which had had no manure for 10 years. The produce from both lots was carefully weighed, and showed an increase of inoculated over non-inoculated of 43 per cent. Better beans were not to be found in the neighbourhood.

Peas.—The peas were grown on clay soil. Equal quantities of inoculated and non-inoculated peas were sown, and yielded: Inoculated, 631 pods; non-inoculated, 433 pods—a gain of 45·7 per cent. The inoculated pods were longer and fuller, and a *fortnight earlier*.

Sweet Peas.—The inoculated sweet peas bloomed remarkably well, and were the best in the neighbourhood. Nurserymen and market gardeners came from miles round to see them. They carried off Firsts wherever they were shown, and the proceeds from the sale of flowers were abnormal.

SCOTLAND.

KELSO—*Peas*.—Three-quarters of a pound of inoculated pea seed yielded more than 1½ pounds uninoculated;

the inoculated peas had larger pods, were better filled, of finer flavour, and more uniform in shape than the uninoculated. The inoculated peas gained the second prize at the District Show.

MELSETTER—*Clover*.—I put the inoculation liquid on about a quarter of an acre of grass and clover as a top-dressing. In about a week I could see an improvement, and it (the clover) was far higher and thicker than the rest of the field right on until it was cut. There was double the quantity on it, and it was the same with the aftermath; it came up the second time far thicker and stronger than the rest of the field.

WORMIT (FIFE)—*Peas*.—Of those that have already come to maturity, I find that the pods from the inoculated seed are more numerous and much better filled than the pods from seed not treated, the ratio of produce being about 2 to 1.

Beans.—Of the beans I cannot yet speak with certainty, as the crop is so late this year, but the pods of the treated portion appear to be filling up much better than the rest.

ELGIN—*Clover*.—The inoculation experiment has been a great success. I sowed the clover with oats. The part I left untreated has been a failure, where treated there is a good crop. I thought when I sowed it it would have no effect on the corn crop, but only on the grass next year, but I am glad to say that on the top of the field which is inoculated, where the land is very poor and no depth of soil, there is a good crop of oats where it was never anything before. The neighbouring farmers are wondering what I have done to it. On the part of the field I left uninoculated the oats are not nearly so high or so thick as where it is inoculated.

FORRES—*Clover*.—I am glad to say that the crop of

inoculated clover is the best we have ever had, quite *double, if not more*, than usual, and it has grown where in one part clover never would grow before. I must congratulate you on your success, and trust I may be allowed to have some more inoculating material next year.

RUTHERGLEN—*Beans*.—On April 17, 1907, I took 1 pound 10 ounces of Bunyards' Exhibition Long Pod Beans, of which I planted 1 pound 6 ounces after inoculating as directed, the other 4 ounces were planted uninoculated at the same time. The former, when from 3 to 4 inches above ground, were again inoculated with the dilute solution, the latter were not. The garden slopes to the north pretty steeply, and the soil is heavy clay, which a month before planting had dug into it farmyard manure in about the proportion of 14 cart-loads per acre. Yesterday (October 9) I took 20 stalks as they came from an inoculated and a non-inoculated row, and found the weight of *all* the pods of each were $7\frac{1}{2}$ pounds and 1 pound 9 ounces respectively, and of the beans alone $2\frac{3}{4}$ pounds and $\frac{1}{2}$ pound. The stalks from inoculated seed are quite remarkable for their vigorous growth both in weight and length, and if attention had been given to pruning of side-shoots the harvest of pods would in the end, I feel quite sure, have been appreciably heavier, although even as it is it is quite remarkable. The stalks are still green with a considerable show of blossom, although at this late season they must soon shrivel and die down.

IRELAND.

THURLES—*Clover*.—The inoculation experiment is a great success. All the clover is growing wonderfully thick through the barley, though it is said locally that clover will not grow in this townland.

KING'S COUNTY.—*Peas*.—Inoculated rows have borne most excellent crops, much better than in former years.

Beans.—A very marked difference was shown in growth of the broad beans—those which I had not inoculated being much smaller and fewer.

During the year reports have come to hand of various experiments in different parts of the country, with inoculating material obtained from abroad. In many cases excellent results have been obtained, as indicated by the three following reports:

ENGLAND.

ROTHAMSTED—*Clover*.—Land which was known to have carried no leguminous crop for the last 50 years was planted with red clover seed, and yielded as follows:

Plot A. Inoculated with Hiltner's preparation from	Cwts.
Germany	76.4
Plot B. Inoculated with Moore's preparation from	
America	72.9
Plot C. Uninoculated	61.9

SCOTLAND.

WEST OF SCOTLAND AGRICULTURAL COLLEGE—*Beans*.—Professor Wright reports: "On all the farms (five) on which the inoculation proved beneficial the increase of crop obtained was enough to give a very satisfactory return for the labour and cost. An average increase of 304 pounds grain per acre, as compared with $3\frac{1}{2}$ cwts. of straw, shows clearly that the inoculation, while it gave a larger crop of straw, increased the yield of beans in a much greater degree, and hence the effect of this additional treatment has been to enhance still further the

grain-producing character of the bean crop. The average return, amounting to about $4\frac{1}{2}$ bushels beans and $3\frac{1}{2}$ cwts. bean straw per acre, would have formed a sufficient return for a much higher expenditure.

“But, apart from one failure, and making due allowance for the discrepancies inseparable from field experiments, the results on the whole tend to show that, under suitable conditions and on ordinary bean soils, the practice of inoculation appears likely to be beneficial and profitable.”

Lucerne.—At the College Experiment Station, Kilmarnock, experiments on the inoculation of a growing crop of lucerne have been in progress during the past three years. A growing crop of lucerne was subdivided into three plots. All received equal dressings of superphosphate and potash; but as regards nitrogen, A had no nitrogenous manure, B was dressed with nitrate of soda at the rate of 2 cwts. per acre, C was inoculated with culture material from Germany. Last year the green produce from each plot was carefully weighed, and gave—

			Tons.	Cwts.	Qrs.	
A. No Nitrogen	..	..	7	0	3	per acre.
B. Two cwt. Nitrate Soda ..	..	..	9	8	2	„
C. Inoculated	..	..	12	5	0	„

IRELAND.

Vetches.—The inoculated seed produced 23 tons of vetches (cut green) per acre, while the uninoculated produced only 11 tons 7 cwts.; showing an increase of 11 tons 13 cwts., or more than double, in favour of inoculation.

APPENDIX B

EFFECTS OF TREATING PLANTS WITH HUMOGEN

THE following are among the reports that have been received from growers as to the effect of using bacterized peat. The first groups of results are those obtained by Mr. Machen (who is now assisting Professor Bottomley) from experimental plots at Eton Experimental Gardens in 1913 and 1914. In some instances it has been possible to tabulate the results. As further reports are received from growers they will be added to this appendix in subsequent editions.

ETON EXPERIMENTAL GARDENS (1913-1914).

(Report by Mr. Machen. The first report was quoted by Professor Bottomley in the lecture he delivered before the Royal Society of Arts in 1914.)

The whole plot was 51 feet long by 36 feet wide. The plot was divided across its breadth into three equal portions of 15 feet each, and a smaller portion of 6 feet. This gave three plots of 60 square yards each, and a small plot of 24 square yards. These plots were treated as follows: Plot 1, complete artificial manure (top-dressing), 4 ounces per square yard; Plot 2 (small plot), no manure; Plot 3, bacterized peat (top-dressing), 9 ounces per square yard; Plot 4, one ton farmyard manure (half dug in subsoil and half in top spit).

The rows of plants ran across each of these four plots. As each crop matured careful weights were taken, and are shown in the table on p. 225.

The percentage increase of the produce from the peat-treated plots over those with no manure, artificials, and farm dung is as follows:

	<i>No Manure.</i>	<i>Artificials.</i>	<i>Farm Dung.</i>
	Per Cent.	Per Cent.	Per Cent.
Potatoes ..	123	75	41
Turnips ..	100	47	25
Beet.. ..	281	54	43
Onions ..	110	110	46
Carrots ..	260	20	28

It will be noticed that in all cases the yields are small. This is accounted for by Mr. Machen in the following notes:

1. Sandy soil over gravel. No manure for nine years, and had been continuously cropped with potatoes, followed by brassica.

2. The previous season (1912) crops were a complete failure. Land as nearly exhausted as possible.

3. The mixture of artificials used usually gives better results than dung, but owing to the exceptionally dry spring of 1913 the wet farmyard manure had an advantage.

4. All the crops were much below the normal owing to—(a) starved land; (b) exceptionally dry season on a hot, dry soil. Potatoes were all first earlies.

5. The land was specially selected for testing food values on an exhausted soil.

In 1914 experiments were carried out on similar lines, giving the results tabulated on p. 227. A striking feature

<i>Crop.</i>	<i>Artificial.</i>	<i>No Manure.</i>	<i>Peat.</i>	<i>Dung.</i>
Potatoes ..	Roots, 42: Weight, 26 lbs. 7 ozs. Average, 9·7 ozs.	Roots, 18: Weight, 8 lbs. 9 ozs. Average, 7·6 ozs.	Roots, 40: Weight, 42 lbs. 10 ozs. Average, 1 lb. 1 oz.	Roots, 48: Weight, 32 lbs. 4 ozs. Average, 12 ozs.
Turnips ..	Roots, 14: Weight, 7 lbs. 9 ozs. Average, 8·6 ozs.	Roots, 6: Weight, 22 lbs. 6 ozs. Average, 6·3 ozs.	Roots, 14: Weight, 11 lbs. 12 ozs. Average, 14·5 ozs.	Roots, 13: Weight, 8 lbs. 3 ozs. Average, 10·1 ozs.
Beet ..	Roots, 20: Weight, 16 lbs. 4 ozs. Average, 13 ozs.	Roots, 10: Weight, 3 lbs. 4·5 ozs. Average, 5·25 ozs.	Roots, 20: Weight, 25 lbs. Average, 1 lb. 4 ozs.	Roots, 20: Weight, 17 lbs. 8 ozs. Average, 14 ozs.
Onions ..	Roots, 61: Weight, 6 lbs. 2 ozs. Average, 1·6 ozs.	Roots, 37: Weight, 3 lbs. 10 ozs. Average, 1·6 ozs.	Roots, 60: Weight, 12 lbs. 10 ozs. Average, 3·4 ozs.	Roots, 58: Weight, 8 lbs. 8 ozs. Average, 2·3 ozs.
Carrots ..	Roots, 28: Weight, 7 lbs. 8 ozs. Average, 4·3 ozs.	Roots, 14: Weight, 1 lb. 4 ozs. Average, 1·4 ozs.	Roots, 28: Weight, 9 lbs. Average, 5·1 ozs.	Roots, 28: Weight, 7 lbs. 1 oz. Average, 4 ozs.

of them was the residual effect of peat on the plots that had been treated in the previous year. As regards these plots, the last in the table, no fresh humogen, artificials or manure were applied.

MID-SURREY GOLF COURSE.

The remarkable results obtained on the Mid-Surrey Golf Course are described as follows by the Editor of the *Garden*, writing in *Country Life* on November 1, after inspecting the greens in the company of Mr. Lees, the groundsman at Mid-Surrey: "The first to be dressed was a practice green, which, owing to the very hard wear to which it is subjected, and the fact that it is on sand, always gives a great deal of trouble, particularly in the autumn. This green was treated on August 28, and at that time was in a very worn condition. Now (November 1) it is as perfect as a green could be, the turf being very close and hard, and of a particularly healthy colour. Near to this practice green, and also on sand, is an undulating green that Lees assured me has always been a worry to him at this season. This, when dressed with the prepared peat a little more than a fortnight ago, was very brown in places, but now the brown patches have almost disappeared, and the turf is very healthy, and of excellent substance. A third green, also of an undulating character, was treated on Tuesday of last week, and three days later was showing signs of improvement. After experimenting with different quantities to ascertain the proper amount to use—2, 4, 6, 10, and 12 ounces per square yard respectively—Lees has come to the conclusion that 3 ounces per square yard produces the most satisfactory results. This is applied in a pulverized state as a top-dressing, and for the first few days

<i>Crop.</i>	<i>Artificial, 4 Ozs. per Square Yard.</i>	<i>Peat, 4 Ozs. per Square Yard.</i>	<i>Artificial + Peat, per Square Yard.</i>	<i>Farmyard Manure, 30 Tons per Acre.</i>
Potatoes: Royalty and British Queen	Plants, 29: Weight, 38 lbs. 1 oz. Average, 1 lb. 5 ozs.	Plants, 30: Weight, 38 lbs. 6 ozs. Average, 1 lb. 4½ ozs.	Artificial, 2 ozs.; peat, 3 ozs. Plants, 16: Weight, 27 lbs. 7 ozs. Average, 1 lb. 1¼ ozs.	Plants, 30: Weight, 38 lbs. 12 ozs. Average, 1 lb. 4¾ ozs.
Peas: Marvel	4 ozs. pods: Weight, 8 lbs. 1 oz.	—	Artificial, 4 ozs.; top-dressed peat, 2 ozs. Pods' weight, 10 lbs. Gain, 31 per cent.	—
Radish: French breakfast	Roots, 95: Weight, 30 ozs. Average, 0 31 ozs.	—	Roots, 82: Weight, 39 ozs. Average, 0 47 oz.; gain, 51 per cent.	—
Vegetable marrow: Carters' Bush	Weight cut per plant, 16 lbs. 6 ozs.	—	Weight cut per plant, 37 lbs. 11 ozs.; gain, 131 per cent. Cut one week earlier.	—
<i>Crop.</i>	<i>Artificial Manure.</i>	<i>No Manure.</i>	<i>Humogen.</i>	<i>Farmyard Manure.</i>
Potatoes	Plants, 44: Weight, 47½ lbs. 5 ozs. Average, 1 lb. 1½ ozs. Gain 50 per cent.	Plants, 23: Weight, 16 lbs. 11 ozs. Average, 11 6 ozs.	Plants, 48: Weight, 55 lbs. 7 ozs. Average, 1 lb. 2½ ozs.; gain, 59½ per cent.	Plants, 49: Weight, 48 lbs. 10 ozs. Average, 15 8 ozs.; gain, 36½ per cent.
Lettuce	Average, 8½ ozs.; gain, 190 per cent.	Average, 3 ozs.	Average, 14 ozs.; gain, 366 per cent.	Average, 10½ ozs.; gain, 243 per cent.
Turnips	Plants, 13: Weight, 5 lbs. 11 ozs. Average, 7 ozs.; gain, 52½ per cent.	Plants, 5: Weight, 1 lb. 7 ozs. Average, 4 6 ozs.	Plants, 13: Weight, 8 lbs. 2 ozs. Average, 10 ozs.; gain, 121 8 per cent.	Plants, 14: Weight, 6 lbs. 12 ozs. Average, 7 7 ozs.; gain, 67 per cent.
RESIDUES FROM 1913.				
Potatoes	Plants, 15: Weight, 16 lbs. 12 ozs. Average, 11½ ozs.; gain, 27½ per cent.	Plants, 6: Weight, 3 lbs. 6 ozs. Average, 9 ozs.	Plants, 15: Weight, 15 lbs. 8 ozs. Average, 1 lb. 0½ oz.; gain, 83¾ per cent.	Plants, 17: Weight, 13 lbs. 2 ozs. Average, 12¼ ozs.; gain, 37¾ per cent.

seems to open up the soil and to let the grass through, after which this slight sponginess disappears. Not only have these dressings had a most remarkable effect on the blades of the grasses, but root growth has also been increased to a very considerable extent."

TABULATED RESULTS.

ADDLESTONE.

DATE, JUNE 27, 1915.

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
Tomatoes	1-10	Mixed in soil	Tomatoes treated when put into 48 pots took the lead of the others. Very pronounced within a week, and still retain their extra vigour, etc.

THOMAS STEVENSON, Woburn Place Gardens, Addlestone.

BIRMINGHAM.

DATE, JULY 17, 1915.

Auricula	?	Mixed in soil	I find that auriculas potted with humogen are quite free from woolly aphis, and those not so potted are still showing same. A friend I gave some to finds the growth better, and confirms what I say with regard to aphis.
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T. E. ASTON, 25, Grosvenor Road, Handsworth, Birmingham.

ILFORD.

DATE, OCTOBER 17, 1914.

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
Flowers in hanging-basket	—	Periodical top-dressing	I had a hanging-basket containing geraniums and asparagus ferns, to which I have applied periodically a dressing, with most remarkable results. Under ordinary circumstances I should have been obliged to replenish the basket with later flowering plants at least once, but under humogen we have had a successive crop of new spikes and buds, with the result that the plants, which were put in last May, are still flowering, October 17, 1914.

J. B. P. HARRISON, Ilford.

KEW.

DATE, 1913.

Pot plants, in variety	1-9	Mixed in soil	The plants, beyond ordinary details, had no special attention during growth other than that devoted to starting them; after a fortnight or so they were left to themselves. The results in some cases were extraordinary, and not comparable with those obtained from ordinary nitrogenous manures, the root development being very marked.
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MR. COUTTS, the Royal Gardens, Kew: *Journal of Royal Society of Arts*, March 13, 1914.

THE SPIRIT OF THE SOIL

SLOUGH.

DATE, JULY, 1913.

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
Tomato	A. Watered with bacteria once	—	A. Equal to D.
	B. Rough humogen placed on crocks	—	B. 25 per cent. superior to A and D.
	C. 1-10	Mixed with soil	C. Equal to B.
	D. Control	1-4 old rotted dung. Fed with Chelsea Horticultural Fertilizer every three days	D. Equal to A, inferior to B and C.

General Remarks.—Tomato plants in pots gave better results with far less trouble than any other known method of feeding, at a minimum of expense.—J. ALLGROVE, Langley, Slough.

SLOUGH—Continued.

DATE, JULY, 1914.

Garden peas	Water extract	4 gallons to 60 yards	The plants responded to its application quickly, the growth was much stronger, and continued after untreated plants were quite yellow. The pods were much finer and more abundant.
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General Remarks.—Three rows, each 20 yards, untreated; weight of dry seed, 18 lbs. Three rows each 20 yards, treated; weight of dry seed, 28 lbs. Percentage increase, 55.5 per cent. Increased value, 18s. 3d.—JOHN ALLGROVE, Langley, Slough.

WINDSOR.

DATE, JUNE, 1915.

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
1. Pteris Major	1-10	Mixed in soil	<p>I repotted a few Pteris Major on August 20 in humogen mixture. I think the growth is wonderful. They are already (October 27) much finer plants than I usually get in six months.</p> <p>From the small amount I had I think the result is wonderful. During my thirty years' experience I have never come across anything to show such quick results. <i>Twenty-six</i> days after potting, maiden-hair have made nice plants, while those without are just making a start.</p> <p>The growths of asparagus are much stronger and a much better colour.</p>
2. Maiden-hair	1-10	Mixed in soil	
3. Asparagus			
a. Sprengeri	1-10	Mixed in soil	
b. Plumosa	1-10	Mixed in soil	

F. DAVIS, Nurseryman, St. Leonard's Road, Windsor.

WINDSOR—Continued.

DATE, AUGUST 4, 1915.

Begonia	1-10	Mixed in soil	Extraordinary profusion of bloom. Over 100 blooms on a semi-double variety, quite twice the amount of growth and bloom over untreated. Very free and vigorous, with healthy green leaves.
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WINDSOR—*Continued.*

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
Celery	—	—	Never had such splendid plants, now averaging 30 inches high, deep rich green foliage, and perfectly free from fly. (Aug., 1915.)
Kale	4 ozs. per sq. yd.	Mixed in soil	Grown in ash-heap, soil more than half ashes and broken pots. "Growing wonderfully strong."
Onions	6 ozs. per sq. yd.	Mixed in soil	Crop promises to be half as heavy again as untreated.
Carnation	1-10	Mixed in soil	Growth was both vigorous and free, without being soft. The quantity of growth and flower was remarkable.
Carnation eel-worm	—	—	Plant in border collapsed through eel-worm. The soil where plant was growing received 3 ozs. of humogen stirred in, and new plant from pot, planted in early May. Now (August 4) the plant is perfectly healthy, and without a trace of eel-worm.
Runner Beans	4 ozs. per yd. run	Mixed in soil	More vigorous growth, thicker stems, and heavier crop. Better quality produce; full of vitality, deeper green foliage, and much larger leaves. Beans earlier 1 week. Average length, 12 in. Untreated, 9 in. 40 plants averaged $\frac{1}{4}$ bushel, gathered $1\frac{1}{4}$ bushels per week. Every bloom set, resulting in large clusters.

WINDSOR—*Continued.*

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
Asters	1-20 ?	Mixed in soil	When pricked out into boxes, plants grew at tremendous rate and produced very much stronger plants. The blooms were ready thirteen days earlier on stems averaging 15 in. as against 10 in. on untreated. The colour of the foliage was a rich blue green, and plants were very stiff and sturdy.
Stocks	1-20 ?	—	As asters. Fourteen days earlier, heavier flowers, and very fine plants.
Roses	4 ozs. per plant	Lightly forked in	Growth both stronger and freer, the breaks being very numerous. The colour of both foliage and blooms greatly intensified, particularly with Dean Hole and Lyons. Treated and untreated, growing side by side, almost appeared distinct varieties. Won 3 firsts, 1 third, 1 cup—5 entries.

G. W. BISHOP AND SONS, *Windsor.*

Tomatoes	1-20	Mixed in soil	Plants grew away quickly, making small dark green foliage, and setting fruit freely. Treated plants are better 25 per cent., both in quantity and quality of fruit. Fruits were ripe at least three weeks earlier than untreated.
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WINDSOR—*Continued.*

<i>Crop.</i>	<i>Quantity.</i>	<i>How applied.</i>	<i>Result : Weights when possible.</i>
Garden peas	3 ozs. per yd. run	Top-dressed, hoed in	Treated rows much stronger in haulm, a better colour, and with a heavier crop of well-filled pods.
Sweet peas	3 ozs. per yd. run	Lightly dug in	Taller, stronger, and greener; flower-stems averaged 3 in. longer than untreated. Colour of flower intensified. Continued growing longer.
	Coffee - coloured liquid	Watered in	When growth for season had apparently finished and plants were yellow, a watering of strong liquid produced new growth, which a fortnight later gave good blooms for sale.

F. DAVIS, *Nurseryman, Windsor.*

Sweet peas	A small quantity sprinkled amongst plants and hoed in		There was a distinct gain in height; vigour of stem and foliage very marked, and colour and veining in flowers distinctly improved. Won Bide Cup and silver-gilt medal at National Sweet Pea Show, 1915, besides securing 5 firsts, 2 seconds, 1 fifth, N.S.P.S.—8 entries, 8 prizes.
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G. W. BISHOP AND SONS, Windsor.

OTHER RESULTS OF WHICH LESS EXACT DETAILS ARE AVAILABLE.

BUCKS.

WINDSOR.—The *Potatoes* treated with the bacterial culture gave an increase of 35 per cent. over the untreated; and the *Lettuce* were practically 100 per cent. better.

ESSEX.

RAYLEIGH—*Onions*.—Inoculated, 8 pounds 3 ounces; uninoculated, 5 pounds, 14 ounces. Increase, 39 per cent.

GUERNSEY.

Tomatoes.—Inoculated 144 plants, gave yield of 8.06 pounds per plot; uninoculated 1,340 plants, gave yield of 7.02 pounds per plot. Increase, 14.8 per cent.

KENT.

CATFORD.—The *Rose-trees* watered with the bacterial culture yielded quite twice as many blooms as the untreated trees.

W. RAMSGATE.—*Tomatoes*—where treated the foliage was a darker green, and produced an enormous crop, double that of the plants not treated.

MIDDLESEX.

GREENFORD GREEN (AUGUST, 1915)—*Tomatoes*.—Two shallow boxes were taken. To one 56 pounds of dung were added, to the other 2 pounds of humogen. Three plants were grown in the first and four in the second. Both sets of plants are far superior to others

grown in the same house without fertilizers. There is not much to choose between the humogen-treated and the dung-treated plants in size, but those treated with humogen are yielding ripe tomatoes, while those treated with dung are only beginning to ripen. The fruits on the humogen-treated plants are generally in a more advanced stage.

“ Having had such extraordinary results during the past season by the use of humogen, I thought perhaps the following particulars might be of interest to you:

“ *Sweet Peas*.—I purchased the seeds from reliable seedsmen, potted them last October, and planted the seedlings out the second week in April as follows: On the more favourably situated side of the garden I planted eight seedlings to form clumps of 2 feet diameter. I treated the ground in January with a well-known sweet pea manure, and when the plants began to show bud I watered them with liquid manure made from half cupful of sweet pea manure and $1\frac{1}{2}$ gallons of water. On the other side of the garden I planted eight seedlings as before, but treated the ground this time with humogen, something like 1 in 10. When these plants began to show bud I watered them with liquid manure made from one cupful of humogen to $1\frac{1}{2}$ gallons of water. This I gave in each case once a week. Both clumps are still in flower, and approximate heights are: Sweet pea manure, 8 feet 6 inches; humogen plants, 10 feet. I have had considerably more blooms, larger size, and longer and stronger stems on the ones treated with humogen than those treated with sweet pea manure. The neighbours around are astonished at them, and no wonder. I have never had such plants before.

“ *Dahlias*.—These were treated with humogen, with

the result that I have magnificent blooms as regards quantity, size, and shape.

"*Roses*.—These along with dahlias have been special favourites of mine for some years past. For the last three years I have had some good blooms, but nothing like I have had this year. The only way I can account for it is the use of humogen. To sum up, I have been a keen amateur gardener for many years, and have tried many fertilizers, but up to the present I have struck nothing like humogen.

"T. ATKINSON.

"CARNWATH,
"CHATSWORTH AVENUE,
"WEMBLEY HILL,
"August 4, 1915."

HARROW—*Onions*.—Treated rows, 41 pounds; untreated rows, 29 pounds. Increase, 41 per cent.

RUTLAND.

OAKHAM—*Mangolds*.—Two rows, 9 yards long. Treated, 7 stones 10 pounds; untreated, 5 stones 2 pounds. Increase, 50 per cent.

Strawberries in pots and out of doors both showed an improvement.

Sweet Peas more still.

Peas and Beans.—These showed a more vigorous growth.

Early Potatoes gave a heavier crop and much brighter sample than those treated with manure only.

Celery were more free from fly, and had a better growth.

SURREY.

"In a plot of ground used as a vegetable garden I had obtained, up to this year, very poor results. This year I determined to use humogen; the results have been quite remarkable. The largest of last year's turnips only reached the size of a fairly large strawberry; this year I have had turnips the size of one's fist, and the smallest are larger than the largest of last year's crops. I am having very much better results with tomatoes, beans, and lettuce, and I can without hesitation state that it can only be due to the feeding properties of humogen.

"GEORGE F. WEST.

"4, HILBURY ROAD,

"BALHAM,

"August 4, 1915."

LIST OF PAPERS

BY PROFESSOR WILLIAM BEECROFT BOTTOMLEY,
M.A.

DEALING WITH BACTERIAL FIXATION OF NITROGEN AND THE
EFFECT OF SOLUBLE HUMATES IN THE SOIL.

- "The Assimilation of Nitrogen by Certain Nitrogen-Fixing Bacteria in the Soil." (Proc. Roy. Soc. B., vol. lxxxii., 1910.)
- "Some Effects of Bacteriotoxins on the Germination and Growth of Plants." (Report Brit. Association, 1911.)
- "The Fixation of Nitrogen by Free-living Soil Bacteria." (Report Brit. Association, 1911.)
- "Some Conditions influencing Nitrogen Fixation by Aerobic Organisms." (Proc. Roy. Soc. B., vol. lxxxvi., 1912.)
- "Some Effects of Humates on Plant Growth." (Report Brit. Association, 1912.)
- "Ammonium Humate as a Source of Nitrogen for Plants." (Report Brit. Association, 1913.)
- "The Effect of Soluble Humates on Nitrogen Fixation and Plant Growth." (Report Brit. Association, 1913.)
- "The Bacterial Treatment of Peat." (*Jour. Roy. Soc. Arts*, vol. lxii., 1914.)
- "Some Accessory Factors in Plant Growth and Nutrition." (Proc. Roy. Soc. B., vol. lxxxviii., 1914.)
- "The Significance of Certain Food Substances for Plant Growth." (*Annals of Botany*, vol. xxviii., 1914.)
- "The Formation of Humic Bodies from Organic Substances." (*Biochem. Jour.*, vol. ix., 1915.)
- "A Bacterial Test for Plant-Food Accessories (Auximones)." (Proc. Roy. Soc. B., vol. lxxxix., 1915.)

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