DISEASES OF GLASSHOUSE PLANTS

" Stripe " disease of the tomato. [*Frontispiece*

DISEASES OF GLASSHOUSE PLANTS

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WITH A FOREWORD BY

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PREFACE

The main object of this book is to bring before growers of glasshouse plants the fundamental principles of disease control, in the hope that it may be of some assistance to them in the course of their business. Its preparation was stimulated by a desire to supply more detailed information in reply to many inquiries than can be set forth in routine correspondence.

An attempt has been made to describe the chief diseases of glasshouse plants in this country. Structural details of the causal organisms have been purposely omitted as these do not concern the practical man, but special attention is paid to methods of control.

I have to acknowledge my indebtedness to Sir John Russell, D.Sc., F.R.S., and Dr. W. B. Brierley for the kindly assistance they have so freely given during the preparation of this work.

I am indebted to Mr. E. R. Speyer for the photographs on pages 42, 69, 88, 114 and 161, and to Mr. O. Owen for kindly reading the manuscript.

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Finally, I have to record my gratitude to Miss Helen Marchant, who kindly undertook the preparation of the manuscript.

W. F. B.

Cheshunt, *September*, 1923.

FOREWORD

Since Dr. Bewley left the Rothamsted Experimental Station to proceed to the daughter station at Cheshunt he has had unrivalled facilities for studying the diseases of the plants grown under glass in that area. Few people realize the highly specialized nature of the market garden glasshouse industry in the Lea Valley, or the extraordinary skill of the more successful of the growers engaged therein. The traveller to Cambridge on the London and North Eastern Railway line sees a multitude of glasshouses between Enfield and St. Margaret's, but probably does not know that here are grown the bulk of the English tomatoes and cucumbers which find their way to the London markets and the industrial regions of the North, and that here too the growth of plants is carried out to so high a level of efficiency that growers have actually sold palm-trees to Africa and peaches to New York.

Naturally, enterprises of this sort are possible only to those with keen powers of observation and a sound instinct for the growth of plants. Among these men there is a great body of empirical knowledge which Dr. Bewley has been able to explore. Further, he has been able, at the Experiment Station at Cheshunt, to test thoroughly whatever seemed worth following up, and from his own investigations he has succeeded in elucidating much that was shrouded in mystery.

The book thus combines the best empirical knowledge of the grower with the results obtained by the scientific observer; the facts have been carefully sorted, the deductions thoroughly examined, and, in consequence, Dr. Bewley has been able to present to the growers sound information which cannot fail to help in the management of their nurseries, while his record of observations will prove of great assistance to plant pathologists.

E. J. RUSSELL.

September, 1923.

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CHAPTER I

HYGIENIC CONDITIONS OF GLASSHOUSES IN RELATION TO HEALTH AND DISEASE IN PLANTS

One of the most important things that every grower of plants has to learn is the intimate relationship which exists between the health of a plant and the many factors which make up its environment. A discussion of plants and their diseases with growers of wide knowledge and experience invariably culminates in a general agreement that the ravages of many plant diseases may be restricted, if not entirely prevented, by providing suitable conditions of growth. In the case of outside crops the cultivator is largely in the hands of the weather, but with those grown under glass the conditions should be thoroughly well under control. Great advances have been made in this direction since the building of the first commercial glasshouses, but those who have opportunity to study the existing appliances and methods realize only too well that there is yet much to learn, and that a great deal of very careful investigation will be needed before we may be reasonably satisfied with our methods.

Situation

It has long been recognized that the position of a nursery is an important factor in relation to the health of the plants to be grown, and careful attention to this point when choosing a site will save the grower much worry and perhaps serious loss in ensuing years.

(*a*) *Slope.*—An important point is the slope of the land. Wherever possible a slope with a southern aspect should be chosen; but the degree of slope is also important, for it has a considerable bearing upon two factors of the plant's environment: (1) the temperature of the air within the glasshouses, and (2) the efficiency of the drainage. In houses built in the block formation without dividing partitions there is a tendency for the heated air to accumulate at the highest part of the block. This uneven distribution of temperature has a detrimental effect upon the total yield per acre and increases susceptibility to diseases. Several instances have been observed in big blocks of tomato houses built on severe slopes, where "mildew" (*Cladosporium fulvum*) has completely destroyed the plants at the highest parts of the block. This is because the rapid spread and vigour of attack is intensified by reason of the accumulation of moist hot air at these parts. Reducing the number of houses in a block by building dividing partitions at every seventh or tenth house has invariably resulted in preventing a recurrence of severe attacks of "mildew." To maintain an even temperature, therefore, the slope must be gentle. The presence of depressions in the surface of the ground should be avoided by careful levelling, as at these places the atmosphere tends to stagnate. By taking careful records it has been demonstrated that the percentage humidity of the air over a depression is appreciably higher than that above the general level of the ground, and observations have shown that certain diseases generally begin at these places.

(*b*) *Drainage.*—Upon the nature of the soil and the slope of the land depends the all-important factor of drainage, and consequently the former must be taken into account when the drainage of any particular site about to be chosen is considered.

The tomato, one of the most important crops under glass, is especially sensitive to the drainage factor, and serves as an example of the way in which plants react to the water conditions existing round or near the roots. Generally speaking, tomato plants thrive best in a well-drained alluvial soil, such as is found in many parts of the Lea Valley. It is well known that the tomato produces its highest yields in soils where it may be given abundant water which readily drains away through the subsoil, and some of the best crops have been produced in the neighbourhood of sandpits, where the water may be seen literally pouring away. On the other hand, the application of too much water on lands where the drainage is poor will give rise to a poor, unhealthy crop.

While the best results are obtained with abundant water accompanied by efficient drainage, it is of paramount importance that where these conditions do exist the water supply must be sufficient to keep the soil uniformly moist and yet allow for loss by drainage. Should a deficiency occur even for a day in the water supply of a tomato nursery the effect on the plants will be evident at a later date. Where insufficient water is provided over a number of days "blossom end rot" of the tomato fruits is almost sure to appear a few weeks later. When the result is as marked as this, however, the bad effect of insufficient watering is obvious; but in many cases the outward signs are not so evident and are to be looked for in a reduced yield and vitality. Lands, however, in which the drainage is too rapid are in the minority, and by far the greater amount of trouble arises from insufficient drainage. The existence of insufficient drainage in the subsoil is not always apparent, but careful observation on the grower's part will generally reveal it. This is the case when on apparently ideal soils, with a suitable inclination, there exists a hard pan or impervious stratum of soil at some distance below the surface. The existence of such may be a limiting factor in the health of the crop, for if the pan is saucershaped the water will lie in the depression and harmful effects invariably follow. Cases similar to this have been investigated, and all remedial measures were of no avail until the pan was broken up mechanically.

(*c*) *Relation to Neighbouring High Land.*—In choosing the site for a future nursery it is important to consider the relation of the particular area to the height of the surrounding land, for upon this depends two other important factors: (1) the height of the water table in the soil, and (2) the extent of drainage water passing through the site.

Upon the level of the water table depends the nearness of stagnant water to the plant roots. Should the water table be high the plants become " chlorotic " or yellowish in appearance as soon as the roots reach the waterlogged soil. The " tops " become weak and sickly, and the vitality of the plants is much reduced, with the consequence that they become an early prey to parasitic fungi or bacteria.

Such conditions have been found to exist at the base of hills which border low-lying plains near to rivers, and sites in such regions should be avoided wherever possible.

Upon the surface drainage water depends to an important extent the question of contamination with fungus and bacterial diseases introduced by such drainage water from the neighbouring high lands.

Two cases, personally investigated by the writer, in which epidemics originated in this manner will serve to emphasize the importance of this factor.

In the first, the tomato nursery in question was situated in a natural depression at the base of a wide ridge, and running close to the block of houses was a natural watercourse draining the high land. A heap of soil, part of which had been used each spring during the previous six years for raising seedlings and young plants, lay at the side of the watercourse. In 1919 tomato seedlings raised in nurseries on the top of the ridge had suffered badly from "damping off" caused by a fungus, *Phytophthora cryptogea.* During the winter 1919–20 a heavy rain caused the drainage water from the high land to flood the depression below. The heap of soil by the watercourse was half submerged for about eight days, and remained in a sodden condition during the rest of the winter. The nursery in the depression had previously been free from "damping off," but in 1920 an epidemic broke out which caused the death of thousands of young plants and threatened to prevent the cultivation of tomatoes for that season at least. Careful tests showed that the heap of propagating soil was badly infected, and indicated that infection had been introduced in the drainage brought down during the winter flood.

In the second case, a tomato nursery lost 70,000 plants from the same disease, and the infection was traced to the surface drainage water brought from another nursery, where tomatoes, asters, and wallflowers were badly attacked. It is thus evident that disease organisms in contaminated drainage are of immense importance, especially in areas where nurseries are congested together, and if a site is chosen in which there is danger from this source, the nursery should be protected by laying drains round it, so as to divert the natural drainage.

Glasshouse Construction

By reason of the marked improvements which have resulted from the evolution of modern glasshouses from the older types, and the consequent alteration in glasshouse management, the grower is now in a better position to control the environment of his crops and to eliminate many troubles which formerly were of common occurrence.

Of all the many factors which are intimately connected with the construction and management of glasshouses there is probably none which has not a direct bearing upon crop production and the ability of the plant to resist disease. Not only are the physical, chemical, and biological factors of the soil of great importance, but a whole series of others which are related to the supply of heat and light are equally important. Among these may be cited the aspect of the house, angle of the roof, size and quality of the glass, size, position, and number of purlins, posts, bars, etc., amount of air space, and system of ventilation.

(*a*) *Light in Relation to Plant Growth.*—The importance of the light factor will be immediately realized when one considers that practically 95 per cent of the plant substance is produced from the carbon dioxide of the air by the chemical activity of light, working in conjunction with the chlorophyll, or green colouring matter, of the leaves. All parts of the spectrum rays do not have the same effect upon plant development, for the orange and red rays are especially concerned with the assimilatory processes, while the blue, indigo, and violet rays stimulate growth.

Contrary to the general idea, plants grow most at night and least in the day; but during the day they manufacture their food from the air under the influence of light. Investigations in the past have indicated that light has a markedly inhibiting effect upon plant growth, but, on the other hand, that it assists the development of the supporting tissues. When grown in darkness plants become yellowish white in colour owing to reduced chlorophyll production. They become etiolated and develop long, weak leaves and shoots. It is thus obvious that the light intensity and the nature of the light rays which penetrate the glass have an important bearing upon success in glasshouse culture. This being so, it is important to consider the many factors in glasshouse construction which influence the quality and quantity of light available to the plants the houses may contain.

(*b*) *Glasshouse Construction in Relation to the Light Factor.*—When compared with the modern types, the earliest glasshouses appear as dimly lighted structures. In their construction a large amount of timber was used, and the glass, of inferior quality, was cut into small panes, in the fitting together of which big overlaps were allowed. Gradually, as the importance of good lighting was better realized, there commenced an evolution in methods of building which to-day finds expression in our much-improved structures, and which must still continue if the best results are to be obtained. In the process of development less heavy and clumsy superstructures and larger glass of superior light-transmitting qualities were employed, with a consequent improvement in the health of the crops. While improvements in house construction have continued to make steady progress, it is unfortunate that so little attention has been given in the past by scientific investigators to glasshouse construction in relation to light intensity. Important contributions, however, have been made recently by Stone (48), whose work clearly shows the immense importance of further study along these lines.

His investigations were concerned with a study of light intensities in glasshouses of different construction and under different conditions, and while important results were obtained, the ultimate proof of the superiority of any given type of house will depend upon direct evidence obtained from a study of crops grown in such houses. Unfortunately these investigations cost money, which, in these days of strict economy, is difficult to obtain; but the ultimate end of such investigations must lead to information of great economic importance, far outweighing in money value the comparatively small sum required to gain it.

Stone showed that morning light is more intense than afternoon light, his experiments giving a difference of intensity varying from 10 per cent to 30 per cent, in accordance with the time of the year. These results indicate that the orientation of glasshouses in relation to a north and south aspect has an important effect upon the yield and health of the crop, and suggests that houses built so that the crop receives the maximum morning light will give the best results. Another point of importance, in view of the uniform construction of glasshouses in this country, is the effects produced by roofs of different angles. Past work has shown that the more nearly the roof is placed at right angles to the sun's rays the more light is transmitted. Records made by Stone in February showed that a house with a roof angle of 46° gave 18 per cent more light than one with a 32° roof angle.

Considerable differences exist in the light-transmitting properties of various types of glass, as was evident to purchasers of this material shortly after the war years; and it is common knowledge that irregular surfaces, flaws, bubbles, etc., in the glass are detrimental. Experienced growers are extremely careful in selecting glass for their houses, and panes with flaws are invariably rejected. Bubbles and irregularities act as lenses and may cause "scorching" in leaves near to the glass, and the former frequently are painted over by growers of such delicate plants as lilies. Stone has shown that the amount of light excluded by different samples of glass may vary from 13 per cent to 36 per cent of the total light.

Researches of some interest to practical glasshouse growers were performed by Flammarion (21), who compared the light and heat values of white glass with those of red, green, and blue glass. He showed that the temperature within the house varied with the colour of the glass. Blue, in virtue of its great absorbing power, gave the lowest temperature, while green, red, and white gave increasingly higher temperatures. The height of sensitive plants grown in a red house was fifteen times as great as that in a blue house. Plants in a red house came into bloom first, and their foliage was lighter in colour than those grown in a white house, while the foliage under blue glass was still darker in colour. After three months Flammarion found that the height in the red house was 0·5 metres, in the white house 0·38 metres, in the green house 0·1 metres, and in the blue house 0·035 metres.

While plants in the red house were the highest they were not the heaviest, for the weight of stem and leaves in the white house was 8·4 gms., in the red house 4·6 gms., in the green house 0·3 gms., and in the blue house 0·15 gms. Lettuce plants grown under white glass developed large, thick leaves with good heads; under red glass the leaves were drawn, long, and drooping; under green glass they made a slight growth; while under blue glass practically no growth occurred. Experiments with peas, beans, and coleus plants yielded similar results.

Further experiments were concerned with root development under different glasses, and indicated that the root systems were greater under white glass than under red glass, while poor root action was exhibited under green and blue glass. Similarly, the mechanical tissues showed better development in plants under white glass than those under red, green, or blue.

Flammarion showed that the colour of many flowers can be changed by growing them under different coloured glass. Thus certain blue flowers become pink in a white glasshouse and white under red, green, and blue glass. Also, if pale blue lilac flowers are placed under a dark bell jar they become a clear red-violet. He also showed that the normal amount of red pigment in coleus leaves is reduced under red glass, and practically disappears under green and blue glass.

These experiments of Flammarion are of practical interest to growers of plants under glass as pointing to the importance of using glass of consistent purity, because the preponderance of any group of light rays has an important bearing upon the plant cultivated under their influence.

(c) *Glasshouse Construction in Relation to Air Capacity and the Ventilation Factor.*—Just as the light conditions of the modern glasshouse are an immense improvement upon those of the earliest houses, so advancement has been made in air capacity and ventilation.

There is still, however, much to be done in the latter respect, for the ventilation of modern glasshouses is far from satisfactory from a plant disease standpoint. It is true the air capacity has been greatly increased by the building of higher and larger houses, but the methods of circulating the air need much improvement. It is a well-known fact that the incidence of many diseases is so intimately connected with stagnant air rich in water vapour that they may be greatly reduced, and in many cases entirely checked, by increasing the amount of ventilation.

Necessary investigations should be concerned with a study of the number, size, and position of ventilators in houses of different shapes and sizes which are required to produce the correct number of complete changes of air in any given time. There is evidence to show that the mere movement of air in a house, apart from introducing fresh air and expelling the old air, has a beneficial effect upon the plant, and adequate experiments should be arranged. The importance of the relation between the cubical contents of a house and the area covered is apparent from several standpoints. High houses, exemplified by the "aeroplane" type of tomato house (14 or 15 feet wide, 7 feet to the gutter, and 11 feet to the ridge), allow unrestricted development of the plant, the tops of which in low houses become congested towards the end of the season. Another effect of abundant head space is improved ventilation and circulation of the air.

On the other hand, the larger volume of air in houses of the high type requires more heat to raise it to a given temperature and maintain it at this than does the smaller volume of a low house. The evolution of the larger, better lighted glasshouses has produced a marked change in methods of crop management, with the result that modern crops are better grown and less susceptible to disease than were those in the earliest glasshouses.

The Heating of Glasshouses

While it is common knowledge in a general way that different crops require different temperatures to enable them to resist disease and produce their maximum yield there is yet but scanty information as to the exact limits of temperature required by each crop. It is, however, obviously of great importance that this information should be obtained as soon as possible. Not only do different crops require different temperatures, but each requires a different temperature at particular stages of growth. A plant's activity reaches its maximum at the optimum temperature, other conditions being suitable. Below the optimum temperature growth is retarded and vitality reduced; while above this temperature the plant also suffers, for the rapid growth, unaccompanied by proper maturing of the tissues, not infrequently leads to death through disease.

Recent investigations have shown that the temperature of the soil is equally as important as that of the air, and if the two temperatures are very different the plant suffers accordingly. For instance, cucumber plants grown in cold, damp beds in a warm house frequently wilt badly, and will die if the soil conditions are not improved quickly. This is caused by the inability of the cold roots to supply the leaves with sufficient water to compensate for the loss of water by transpiration. The soil and air temperatures have an important bearing upon disease. If they are too low or too high the resistance of the plant is appreciably lowered and it becomes an easy prey to disease. On the other hand, the optimum temperature for the plant may coincide with that of a fungal root or stem parasite which is attacking it, and it may be beneficial to lower or raise the temperature slightly to make the conditions less favourable for the disease.

Investigations upon temperature requirements are thus of great importance, both from the point of view of the grower and the pathologist, but unfortunately they are expensive to carry out, for specially controlled chambers are necessary.

The present methods of heating glasshouses by means of pipes in which either steam or hot water circulates are undoubtedly expensive, as is indicated by the fuel bill each season, and to those who have studied the question it is obvious that many improvements could be made. It is a little surprising, perhaps, that the various associations of glasshouse growers have not enlisted the services of a skilled engineer to study the heating question, for this would certainly lead to a considerable saving in the cost of heating.

The Humidity of Glasshouse Atmospheres

The importance of this factor deserves to be appreciated to a much greater extent by glasshouse growers than it is at present, for upon it depends such important matters as the condition of foliage and flowers, the setting of fruit, and the incidence of leaf, stem, flower, and fruit diseases.

As with temperature, so the optimum conditions of humidity vary with the kind of plant grown. Ferns and plants of similar habitat thrive in an atmosphere of high humidity which would result in disease in plants like the tomato and vine. If the atmosphere is too dry the leaves, flowers, and fruits of most plants are undersized and hard, but if too moist there is a tendency towards a soft, sappy growth possessing a low disease resistance. The humidity of the atmosphere is a limiting factor in many fungous and bacterial diseases of the aerial parts of plants.

In general, a large proportion of moisture in the air is favourable to abundant spore production, while a dry atmosphere with suitable air currents is favourable to the efficient dispersal of the spores. The presence of a film of moisture on the surface of the plant enables the spores to germinate and enter the tissues. Consequently high humidity should be avoided when plants are exposed to infection.

An intimate relationship exists between the humidity and the temperature, for an increase in the latter produces a proportional decrease in the former. The humidity in glasshouses of the taller types is generally less than that in low houses, for the larger volume of air in the former requires more water to raise it to a given degree of humidity than the smaller volume in the latter. Consequently leaf diseases are the more easily controlled in houses with high gutters and ridges.

Watering

The process of watering plants is probably one of the most important of all horticultural practices. Many experienced growers have reduced it to a fine art, but their methods are largely intuitive and difficult to explain. Insufficient watering prevents the plant from reaching its maximum development and produces physiological disorders, but error on this side is preferable to watering in excess. Excessive watering leads to waterlogged soil conditions, except on extreme sandy soils. An excess of water in the soil produces a deficiency of air about the plant roots, and serious complications result. Such conditions produce a reduction in yield and resistance to disease, and in extreme cases death by suffocation. The careless splashing of water about the base of plants causes harm in many ways. It may chill the plants and so reduce their vitality ; it changes the physical nature of the soil, which puddles and dries hard at the surface ; and it leaves the lower foliage hanging in water, providing ideal conditions for infection by certain organisms. It increases the rate of spread of such diseases as "buck-eye rot" of the bottom trusses, "foot rot" and "damping off" of tomatoes, and also "canker" of the cucumber and melon. Surface watering by means of hoses is almost universally adopted by the practical man, and ingenious methods have been devised to regulate the rate of distribution.

In this country overhead watering is still in its infancy, but it possesses the advantage of uniform distribution. A dry atmosphere can be moistened quickly, which is an advantage during hot summer days, but a disadvantage in dull weather, as the excessive moisture on the leaves encourages disease. Also, because it is purely mechanical, it does not cater for the special needs of individual plants.

The use of perforated hoses, laid on the ground in such a manner that the issuing jets make impact with the soil midway between the plants, has lately been adopted and has proved an efficient and labour-saving device. Sub-irrigation has not so far found favour with the practical man, but experimentally it has proved extremely successful. The absence of surface moisture prevents the rapid spread of fungus parasites, and consequently diseases such as "damping off" and "foot rot" are avoided.

Mulching

The process of mulching, so familiar to nurserymen, fulfils the dual purpose of conserving the soil moisture and providing a top-dressing of plant foods. While it is recognized that on some lands mulching is a necessary adjunct to the growing of profitable crops, the view is gaining favour that on other lands the cost of this practice is out of all proportion to the effect produced.

During the years of war stable manure was difficult to obtain, and where procurable was obtained at a high cost. In the tomato industry, where mulch is applied at the rate of 20 to 25 tons per acre, these conditions induced some nurserymen to refrain from mulching their crops. As a result it was found that on moderately heavy soils the unmulched tomato plants did not produce a lower yield than those mulched with stable manure, and preliminary experiments at Cheshunt Experimental Station have confirmed this. It is apparent that the need for mulching varies with different nurseries, and nurserymen will be wise to carry out experiments on their own soil.

While mulching on some lands may not appreciably affect the yield per acre, it does bear an important relation to plant disease. Mulching with contaminated stable manure may introduce serious diseases into previously healthy houses, but the use of such materials as spent hops, peat, or straw has a beneficial effect, by preventing splashing of soil on to the lower parts of the plant, and helps to keep the houses clean. "Buckeye rot" of the bottom trusses of tomatoes may be controlled by mulching sufficiently early to prevent the disease organisms from being splashed on to the trusses from the soil; but while early mulching will result in healthy bottom fruit, it must not be applied too early. Experiments have been performed whereby a mulch of straw was laid on the ground prior to planting, the straw having to be moved aside to allow the plants to be placed in position. It was found that such plants grew very slowly compared with those planted in the usual way. Temperature records showed that the soil covered with straw was many degrees colder than that uncovered, and accounted for the slow growth of plants in the former. On removing the straw mulch for ten days the soil became warm and the plants grew rapidly. It is necessary, therefore, to allow the soil to become thoroughly warmed before applying the mulch. The kind of mulch, its condition, and rate of application have an important bearing upon plant diseases, for, apart from the introduction of disease organisms, such factors influence the plant's susceptibility to disease.

To obtain the best results mulching should be regulated by the individual crop requirement and cannot be performed by mere rule-of-thumb methods.

Pruning and Training

These processes are necessary for the production of clean, good quality fruit, for, as a general rule, plants which are pruned produce fewer flowers and fruits, but these are of a better quality than plants which are not pruned. Methods of pruning and training are of considerable importance in disease control. Not only does skilful pruning determine flower and fruit production, but by opening up the foliage it allows free circulation of air and prevents stagnation, which is so favourable to disease. At the same time the resulting wounds are important. All cutting should be done with a sharp knife, and the wound must be quite clean. Where leaves and laterals are removed, they must be cut off close to the point of origin. Stumps must not be left to dry up and decay, for these provide suitable entrances for fungi of all kinds. Even those fungi which normally do not attack the living plant may do so after growth on these half-dead tissues. It is especially important to realize this in tomato cultivation, where careless pruning and defoliation, which leaves jagged wounds, is the primary cause of stem rot by *Botrytis sp.*

Disposal of Dead and Diseased Tissue

The problem of destroying the remains of healthy and diseased plants is one which every grower has to face, and the degree of freedom from disease exhibited by his crops depends very considerably upon the thoroughness of this process. In many places the dead plants are allowed to lie for many months in large heaps close to the houses. The plants decay and become centres of infection from which disease is spread broadcast. There is only one satisfactory way of disposing of such remains, which is to burn them immediately they are removed from the houses. Every nursery should possess an incinerator for this purpose, and the beneficial results of its use will far more than compensate for the initial cost.

Sources of Infection of Plant Diseases

(*a*) *The Water Supply.*—The possibility that contaminated water supplies are a frequent source of infection to glasshouse crops was indicated in 1919, when there were attacks of "damping off" of tomato seedlings, caused by *Phytophthora cryptogea*, and "buck-eye rot" of tomato fruits, caused by *Phytophthora parasitica.*

By spraying healthy seedlings and bunches of fruit, under properly controlled conditions, with samples of the suspected waters it was possible to reproduce the diseases in question, and it thus became evident that a centre of infection existed in certain nursery waters. A suitable method of examining water supplies was devised by filtering large volumes through special wire and cotton wool filters, and a systematic examination of the waters used in nurseries in the Lea Valley district was made.

Important results (8), were obtained, for it was demonstrated that while water from some sources was free from contamination, that from others contained many fungal and bacterial parasites of glasshouse crops. Water from the Water Company (Metropolitan Water Board) and deep artesian wells was generally free from contamination. Samples from wells receiving surface drainage contained large numbers of plant pathogens, deep wells of this kind being only slightly less contaminated than shallow wells; but shallow wells placed some distance away from the glasshouses were generally purer than those surrounded by houses. Wells whose waters contained a large amount of decaying organic matter were richer in fungi than those whose waters were clearer. Water from brooks and ponds was also highly contaminated, but a slight reduction in the number of fungus species results from thoroughly clearing away the vegetation on the banks. Water which had passed through an uncovered tank was more highly contaminated than that from a covered tank. The importance of a pure water supply is obvious, and every nursery should possess a deep artesian well, suitably protected from contamination by surface drainage.

(*b*) *Straw Manure.*—Straw manure has frequently been regarded with suspicion as a possible source of infection with plant diseases, and investigations at Cheshunt Experimental Station have indicated that such may be the case (7). Some disease-causing fungi thrive on this material and readily permeate large masses when they gain access to them. Our investigations were concerned primarily with the introduction of cucumber anthracnose caused by *Colletotrichum oligochætum*, but they also showed that other plant parasites may be introduced in this manner. Straw manure from different sources was examined, and while many were found to be free from plant pests others were badly contaminated. Manure from country farms was mostly free from disease, but that obtained from town stables was frequently contaminated. Heaps of straw manure lying adjacent to those of decaying plant debris on commercial nurseries were found to be contaminated.

Growers should exercise particular care in the choice of their straw manure, and that which is obviously contaminated with half-rotten potatoes and roots should be avoided.

(*c*) *Imported Plants.*—Growers whose land is free from disease should be warned against importing plants from other nurseries, but where this is unavoidable the imported plants should be isolated until it is certain they are free from disease. *It must be clearly understood that it is easier to keep disease away from a nursery than to* *eradicate it once it has gained entrance.* Our experience in the Lea Valley has shown quite clearly the danger of growing plants other than those raised from seed on the nursery, and many serious diseases have been introduced in this manner.

(*d*) *Baskets, Sacking, etc.*—Another source of infection which becomes more and more evident is the contamination carried in " strikes " or baskets, and a considerable number of cases have been noted where infection with various diseases came from these articles. Such baskets may be so mixed at the market that when they are returned those from one nursery are sent to another, and so disease is spread. Baskets should not be taken near to the growing plants for fear of introducing some new trouble, and during the winter months all baskets should be sterilized in readiness for the coming season.

(*e*) *Nursery Workers.*—Diseases of all kinds are readily spread by the workers in the houses. Infection may be carried on the hands, clothes, and boots, as well as on pruning knives, and therefore assistants working in diseased houses should not enter houses where healthy plants are growing unless their hands have been washed and their clothes either stoved or exposed to direct sunlight. The careless visiting of nurseries by workers from other places should be prevented, for cases are known in which disease was spread in this manner.

Much of the existing knowledge of crop management has arisen from skilled growers as the result of long experience, and as most of it is intuitive it is difficult to explain to others. Many a grower has learned how to produce good, healthy crops on his own sample of land and under conditions operative on his own nursery, but can give no definite reason for many of his practices. It is thus evident that the fundamentals concerned in crop management should be exactly determined by careful investigation, so that definite reasons for each operation may be available, and the grower may be in a position to apply the correct methods of treatment for the existing conditions or for new conditions. Such investigations are in progress at the Experimental and Research Station situated at Cheshunt, in the centre of the glasshouse industry in the Lea Valley, and their aim is to supply a rational basis for existing practice and to improve this practice.

CHAPTER II

DISEASED CONDITION OF PLANTS DUE TO ENVIRONMENTAL FACTORS—LIGHT, HEAT, HUMIDITY, SOIL, ETC.

THE various factors which comprise a plant's environment have an important bearing upon its health; and while certain conditions have a detrimental effect upon its power of resistance to disease, others actually induce a diseased condition.

Light

It is common knowledge that plants grown in darkness become elongated, slender, whitish in colour, and immediately wilt when exposed to the heat and light of an ordinary glasshouse.

Similar effects are produced in a lesser degree when glasshouse plants are exposed to long periods of dull, cloudy weather.

For instance, plants grown during November and December possess imperfectly coloured weak leaves, with slender petioles and badly developed stems. The weak light is insufficient to mature the mechanical and resistant tissues, and consequently such plants wilt in the bright sun of early spring. This physiological wilting is well known to growers of early cucumbers, and indeed may appear later in the year if after long periods of dull weather the plants are exposed to high temperatures and bright light. Such plants recover during the night, but wilt again during the day. The trouble becomes accentuated in weak plants grown in houses which are badly ventilated and too hot. It is thus apparent that the physiological condition of a plant may be adversely affected by light conditions.

As a general rule, insufficient light produces immature tissues, which are more susceptible to disease than those developed under well lighted conditions. Thus the mildews of the grape, cucumber, and strawberry develop most rapidly in shaded positions or in dull weather, and may entirely disappear when exposed to strong sunlight. "Damping off" of seedlings also has been found to increase most rapidly in the shade. De Bary was able to induce susceptibility to attack by *Botrytis* in petunias by placing them in the dark for some days, and it is a matter of common observation that those parts of the tomato which are shaded are the most easily attacked by this fungus.

On the other hand, numerous observations have been made which indicate that half shade has a beneficial effect upon certain plant diseases. Thus, shaded celery plants are generally free from early blight caused by *Cercospora apii*, and asparagus rust caused by *Puccinia asparagi* is reported to react in a similar fashion. Again, observations at Cheshunt Experimental Station have shown that shade has a beneficial effect upon tomato plants attacked by *Verticillium albo-atrum*.

Sunlight which is too intense may have an effect upon plants by burning them. Thus "tip burn" of lettuce and tomato occurs under glass when brilliant sunshine follows periods of dull weather. In lettuce plants the outer leaves wither at the tips and the affected areas curl backwards and turn brown. "Tip burn" of the tomato consists of a withering, curling, and browning of the tender tissues at the growing point. During the dull days which precede the burning the plants have been transpiring very little because of the high percentage of humidity in the glasshouse atmosphere, and the tissues become gorged with water. The sudden appearance of brilliant sunshine produces a rise in temperature and a decrease in the humidity. Consequently the plants transpire more freely and the roots may be unable to replace the water lost by the leaves. If this continues for any length of time the more tender parts collapse, and finally turn brown and wither. The practical remedy is to damp the soil surface on bright days following dull weather, and by thus keeping the air moist prevent any sudden increase in the rate of transpiration of the leaves.

Tomato fruits suffer from sunburn during prolonged periods of intense sunshine. The tissues round the stalk end of the fruit become dry, brown, and hard. Small cracks appear, giving the surface a rough powdery appearance. In most commercial nurseries sunburn of the tomato fruit is comparatively rare, and the little that does appear may be disregarded, but where it is prevalent the houses should be shaded with limewash and varieties with dense foliage should be grown.

Heat

The relation between temperature and disease must be considered with regard to its effect upon the plant complex and the pathogen complex, both singly and combined.

The Plant Alone.—The heat requirements of glasshouse plants vary considerably, for not only do different crops require different temperatures for their maximum development, but different temperatures are required at different stages of growth. The minimum growth temperature is just sufficient to prevent the cessation of plant processes, which are speeded up as the temperature rises, and attain perfection at the optimum temperature. A further increase in temperature upsets the balance of the processes and produces abnormal plants. Maximum development, flower and fruit production, and resistance to disease occur at optimum temperatures, which do not necessarily coincide; but any deviation from the particular optimum produces an adverse effect proportional to the extent of deviation.

The temperature of the soil is just as important as that of the atmosphere, and both must be taken into account when considering temperature effects. Harmful effects are produced in the plant when these two temperatures do not approximate to one another, as instanced by the wilting of cucumbers planted in cold beds in a warm house. The chilled roots are unable to absorb water from the soil with sufficient rapidity to replace that evaporated from the leaves. Similar adverse effects upon the physiological processes, while not so obvious as this, are produced whenever an appreciable difference occurs between the two temperatures, the effects being proportional to the difference between them. In consequence the plant's vitality is impaired and its power to resist disease is reduced. Generally speaking, temperatures between the optimum and maximum tend to the development of soft, sappy growth and an increased susceptibility to disease, while those below the optimum encourage slow, hard growth accompanied by an increased resistance to disease. Exceptions, however, are found in respect of certain vascular diseases, to which hard, slow growing plants with thin stems are more susceptible than soft, rapidly growing plants with thicker stems.

The Pathogen Alone.—The fungus or bacterial parasite reacts to temperature in much the same way as the plant, and possesses minimum, optimum, and maximum temperatures for growth. As a general rule fungi can survive very low temperatures. Most fungi are uninjured by exposure to a temperature of 0° C. and can be frozen solid without undue harmful results. Fungus spores are not destroyed to any useful extent by the normal winter conditions which prevail in this country.

Similarly, many fungi and bacteria are able to survive exposure to high temperatures. The thermal death point of some fungi has been found to be as high as 75° C., but usually few will grow at temperatures above 40° C. The spores of certain bacteria are highly resistant to high temperatures, and in some cases have not been killed by boiling for two or three hours.

Comparatively little information is available concerning the resistance of fungus spores to high temperatures, but it would appear that some resting spores and sclerotial bodies are capable of withstanding high temperatures.

The optimum temperature for growth of many fungi does not coincide with that for spore production, and it is important that this should be taken into account when studying plant diseases. Thus, at a certain temperature the fungus will progress most rapidly through the plant tissues, and at another temperature most readily produce spores and increase the rate of spread from plant to plant.

Plant and Pathogen Combined.—While the temperature relation of many fungi in pure culture has been studied, it is only within the last decade or so that any research has been carried out on the relation of temperature to the process of infection. This is largely the result of investigations by the United States Department of Agriculture and by Professor L. R. Jones and his colleagues at the University of Wisconsin.

The temperature of the soil has been shown to be a limiting factor in certain diseases, among which may be mentioned the *Fusarium* wilt of tomatoes. Edgerton (20) has shown that infection takes place and the disease develops most rapidly if the soil temperature is maintained around 29° C. Very little infection occurs if the temperature is much below this for any length of time. Investigations upon the *Verticillium* wilt of tomatoes carried out at Cheshunt Experimental Station illustrate the importance of air and soil temperatures in conditioning the progress of disease (10). It was shown that temperatures between 16° C. and 24° C., with an optimum of 21°–22° C. are favourable to the rapid spread of the

Verticillium wilt, which below 16° C. and above 24° C. is exceedingly slow. Plants badly wilted at a temperature of 20° C. recovered when transferred to a temperature of 25° C., and cultural methods based on these facts were devised for controlling the disease. Recently Johnson (26) has demonstrated that Mosaic disease of the tobacco is most virulent between 28°–30° C., and that above 36°–37° C. mosaic plants send out new leaves showing no symptoms of the disease, and the chlorotic leaves may recover their normal colour.

The value of such work will be appreciated by all growers of glasshouse plants, who are more favourably situated for controlling the temperature to which their crops are exposed than those who cultivate outside crops.

Water

(*a*) *Humidity of the Atmosphere.*—In a similar manner the presence of moisture in the air is related to the incidence of disease by reason of its effect upon the plant and the pathogen, both separately and combined.

As is well known, different plants do not require the same amount of atmospheric moisture for their maximum development. Thus the atmosphere of a cucumber house must contain a higher percentage of humidity than that of a tomato house, otherwise the plants will suffer. When plants are exposed to an atmospheric humidity lower than that normally required they remain under-developed and produce small, thin leaves, but are generally more resistant to disease. With humidities above the normal the rate of transpiration of water from the leaves becomes reduced. In consequence, the plants become gorged with water, the tissues become tender, and sappy growths are produced, which are very susceptible to disease. Abundant moisture has an important effect upon the fungus parasites, for it increases spore production and is essential to spore germination, which is the first step towards infection of the host.

Much general observation and experiment has demonstrated the association of fungus and bacterial diseases with a moist atmosphere, and many epidemics have been intimately connected with abundant rainfall and consequent high humidity. In the glasshouse industry it is common experience that leaf diseases originate during periods of dull, humid weather, when the atmosphere of the houses remains constantly moist. The humidity of glasshouse atmospheres is thus important as influencing both plant growth and resistance to disease.

(*b*) *Soil Moisture.*—Water is essential to life, and glasshouse soils, being untouched by the natural rainfall, must be artificially watered.

The most successful growers are those who have the good fortune to possess the faculty of knowing when to water and how much to apply at any given time. Unfortunately, much of the process is performed without an adequate knowledge of cause and effect, and much experimental work is necessary to set the practice of watering upon a sound scientific basis, for improper methods are a fruitful source of harm to glasshouse crops.

An excess of water in the soil fills up all the spaces, and there is less room for air in the soil; consequently soils saturated with water contain practically no air and the plant roots are suffocated. Under such conditions the roots cease to function and the plant wilts. Examples of this may be found in almost every nursery, where plants growing in the sodden patches near to a standpipe may be seen in a wilted condition. On digging up these plants the roots will frequently be found to be brown and decaying. Such dying roots provide a ready means of entrance to soil fungi. Should the waterlogged conditions persist for any length of time the plant will die; but if the soil is allowed to dry out and become aerated new roots will form and the plant recovers. The dead roots still remain as places of entry for soil fungi, and it will thus be apparent that waterlogged conditions, although they may persist only for a short time, have a deleterious effect upon plants and reduce their resistance to disease.

The appearance of plants grown under waterlogged soil conditions is admirably illustrated by an experiment conducted with tomatoes. A metal trough ten feet long, two feet wide, and two feet deep was placed on the ground and one end tilted up to rest on a support a foot high, as in Fig. 1. A perforated wooden board was

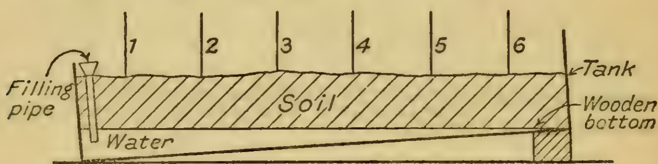

FIG. 1. Diagram illustrating an experiment on the relation of waterlogged soil conditions to chlorosis of the tomato.

placed in the trough, resting on the bottom of the tilted end, laid parallel to the ground, and supported on bricks at the other end. The space between the board and the trough bottom was filled with water and a siphon with tap was fitted at the deeper end. Nine inches of compost was placed on top of the board, and six tomato plants (Kondine Red) were planted at equal distances. The soil was well watered, and after a time the level of the water was adjusted to the level of the board by means of the siphon, and was kept at this level throughout the experiment. The plants were numbered for purposes of description, No. 1 being at the low end of the trough and No. 6 at the tilted end. Within five days plant No. 1 began to show signs of ill health. The lower leaves turned yellow and withered and the plant showed no new growth. The yellowing and the withering of the leaves continued up the stem until in 17 days the plant was dead. Plant No. 2 developed similar symptoms in 14 days and was dead in 43 days. In 31 days No. 3 began to show signs of yellowing and lost the five bottom leaves. The top of the plant became a light green colour and yellow blotches appeared on the leaves. This gradually became worse, the yellow blotches dried up, and the plant developed the typical symptoms of "chlorosis." After 60 days the new growth was weak and yellow and the flowers dropped without setting. In 37 days plant No. 4 developed symptoms of chlorosis, which are so familiar on some nurseries, but they were not so serious as in plant No. 3. The leaves became a light green colour mottled with yellow and the tops were decidedly weak. Plants Nos. 5 and 6 developed in the normal way and produced healthy leaves and large trusses of fruit.

Stagnant water is a common cause of chlorosis of tomatoes, and may be found on all lands where the water table is near to the soil surface. Experiments conducted on such lands have demonstrated the importance of efficient drainage, which has produced satisfactory results when all other efforts of soil amelioration have failed. "Yellows" of many plants have been shown to be directly connected with waterlogged soil conditions. Thus ferns lose their green colour and turn white, the leaves drop off, and all growth ceases. When such plants are re-potted into fresh soil they quickly outgrow their diseased condition. Cucumbers grown in beds placed on excessively damp borders become chlorotic when their roots reach the base. If the beds and borders become waterlogged the plant wilts, and will die if the water is not quickly drained away.

On the other hand, a deficiency of water in the soil has a harmful effect upon plant growth. Every plant requires water to enable it to reach its maximum state of development, and if the soil moisture is not sufficient the growth is less than normal. Not only is the rate of growth affected, but the leaves are small and flower and fruit production limited. "Blossom-end rot" or "point rot" of the tomato, which is found wherever tomatoes are grown, serves to illustrate the intimate relation between plant disorders and an insufficiency of soil water. The first sign of the disease is the appearance of a small, bruised, water-soaked spot near the blossom end of the fruit. The spot rapidly increases in size, turns a brownish-black colour, and becomes hard and leathery. The discoloured area extends deep into the fruit, the affected tissue shrinks, and the fruit flattens. Occasionally saprophytic organisms enter the affected region and complicate matters by inducing a soft rot. Careful investigations have shown that soil moisture conditions affect the development of this disease.

Many cases of this disease have come within the author's experience, and drought has been an important factor in each of them. Perhaps the most striking is that of a nursery situated at the top of a hill where the only water obtainable was pumped by means of a gas engine. Three times within one year the engine broke down and no water was available for a week. The plants wilted badly during the day, but recovered at night, and from 25 to 30 days after each breakdown "blossom-end rot" appeared on the plants on trusses at the same level. Five tons of diseased tomatoes were gathered from 34,000 plants during the three outbreaks, but during the rest of the season, when water was given at the rate of 35,000 gallons per acre per week, no disease appeared. Plants growing rapidly and producing soft, sappy shoots are most susceptible to a check caused by drought, and are therefore more susceptible to the disease. Heavy dressings of stable manure and ammonium compounds favour the progress of the disease, while nitrate of soda and lime appear to check it.

A disease of glasshouse plants which is the result of a number of different factors is that termed "Dropsy" or "Œdema." In this country it occurs mainly on the tomato and geranium, and in the case of the former is distinguished by a whitening or yellowing of the leaf

FIGS. 2 and 2*a*. Œdema of the geranium, showing swellings on the leaves and stem.

[*Facing page 42*

veins and adjacent tissues. This is easily noticeable from the upper surface of the leaf, but an examination of the lower surface reveals a peculiar powdery appearance on the veins. These are seen to be much swollen, and in places the swollen tissues have become ruptured. Similar pimples appear on the lamina above small veins. The lesions are seen to best advantage on the older leaves, and show as translucent areas when held up to the light. In bad cases the spots dry up and tiny holes are produced in the leaves. The lesions on the geranium become corky, and in bad cases the leaves and petioles are covered with corky spots and ridges. Microscopic examination shows that the cells have become much swollen and distorted, and the chloroplasts are few in number—the excessive enlargement of cells causing the tissues literally to burst. The disease is favoured by poor light, a high soil temperature, and over-watering. Frequently the plant recovers when removed out of doors, and control may be effected by lowering the soil temperature, reducing the water supply, and providing abundant light and ventilation.

The Soil

The intimate relationship between soil conditions and the growth and health of plants has been apparent to growers from the earliest times, and successful cultivation largely depends upon a knowledge of the effect of the many factors which influence the conditions operative about the plant roots. Many excellent treatises have been written about the soil, and as these are available to every one there is no need to discuss the problem in any but the briefest way.

The physical conditions, chemical conditions, and vast population of microscopic animals and plants in the soil influence its fertility and freedom from disease, and therefore are important factors in crop production and health.

THE PHYSICAL CONDITION OF THE SOIL

The nature, size, and manner of arrangement of the particles of the soil very largely determine its texture, which is so intimately related to plant growth and resistance to disease. Upon the texture of the soil depends its water-holding capacity, food-holding capacity, degree of aeration, suitability as an anchorage ground for plant roots, and degree of compactness.

(*a*) *Water-holding Capacity.*—The soil particles vary in size from the very finest silt to coarse sand and stones. The smaller the particles of soil the smaller the spaces between them, and therefore the more retentive is the soil of moisture. Thus soils containing a large percentage of sand are more porous than those with a large proportion of clay or silt. The addition of straw manure to a soil, and the consequent increase in humus, increases its water-holding capacity.

The quantity of water, the length of time it remains, and the ease with which it leaves the soil are important factors in glasshouse cultivation, with its specialized water requirements. Different crops have different requirements, but generally speaking the best soils possess efficient drainage and are neither too wet nor too dry. Perhaps the most important condition is that of constancy of water content. Soils which are alternately very wet and very dry produce unhealthy plants, which are more susceptible to disease than those in uniformly moist soils. Waterlogged soil conditions also induce an increased susceptibility to disease.

(*b*) *Food-holding Capacity.*—Porous soils are generally deficient in plant foods. They allow the rapid drainage of water through them, and soluble foods are washed away very quickly. Bacterial, fungal, and algal growth is at a low ebb, and consequently the rate at which these organisms manufacture plant foods is greatly reduced. Fertilizers, therefore, should be given in an organic form, for these are not easily washed out of the soil and yield only small quantities of available plant foods at a time as the result of bacterial and fungal action.

(c) *Aeration.*—Plant roots require air for their successful development. Artificial aeration experiments conducted with tomatoes at Cheshunt, in which warmed moist air was blown through a system of underground pipes, indicated that increased aeration produces beneficial results as regards crop yield and resistance to disease. In India, Howard has also shown that artificial aeration induces an increased resistance to disease.

(d) *Anchorage.*—This factor is important in certain tender crops where in loose soil there is danger of rubbing at the stem base, with the consequent bruising and wounding of the tissues and the possible entrance of disease organisms.

(e) *Degree of Compactness.*—This is important as influencing root development and the diffusion of fertilizers and sterilizing agents. Preliminary experiments upon the effect of ramming the soil have indicated that root development is improved by moderate ramming. In loose soil and in very tight soil the roots are less abundant than in moderately tight soil. It was found that soft, sappy plants could be made to produce a harder and more resistant type of growth by ramming the soil round the roots. Also in soils containing large lumps it is difficult to ensure a thorough dispersion of fertilizers or sterilizing agents.

THE CHEMICAL CONDITION OF THE SOIL

Upon the chemical condition of a soil depends its acidity, neutrality, alkalinity, and the balance of plant foods, all of which may be limiting factors in plant growth.

(a) *Soil Reaction.*—Soils which deviate to an appreciable extent from the neutral point are generally unsuitable for the cultivation of crops, and many methods have been devised for their amelioration. Fortunately, in this country most soils are neutral or approximately so; strongly acid soils are occasionally found, while alkaline soils are comparatively rare. Acid soils result from the decomposition of large masses of luxuriant vegetation in the presence of water, and are found chiefly in low marsh lands and on some upland moors. In such soils most crops never reach their maximum development, but are stunted in growth, turning yellow and chlorotic, and their roots are slowly destroyed. In alkaline soils the effect is much the same. Such abnormal conditions assist the incidence of disease by reducing the vitality of the plant, by producing suitable places of entrance for fungal or bacterial parasites through injured roots, or by providing increasingly favourable conditions for fungal or bacterial growth.

On the other hand, some diseases, such as potato "scab," may be prevented by making the soil slightly acid.

(*b*) *Balance of Plant Foods.*—The amount and balance of the three most important plant foods—nitrogen, phosphates, and potash—bears an intimate relation to crop production and disease resistance. An excess of nitrogen induces a rapidly growing, soft, and sappy plant, highly susceptible to disease, which condition may be counteracted by suitable additions of phosphates and potash. Potash is especially valuable by reason of its hardening effect, which produces an increased resistance to disease. This may be illustrated by results obtained at Cheshunt in connexion with "Stripe" disease of the tomato, caused by *Bacillus lathyri* (36). The number of striped tomato plants were counted on each of the plots in the experimental houses. These plots were laid down in 1915 and have received the same treatment each year since that time.

Table 9, page 130, indicates that manurial treatment has an important effect upon the disease, for plots receiving no added potash yielded the greatest number of striped plants, while on those receiving no added nitrogen the number of striped plants was considerably less. Further experiments were arranged in which inoculated tomato plants were given increasing amounts of potash and nitrogen. The progress of the disease was estimated by measuring the distance up the stem from the point of inoculation that the "stripe" lesions had travelled in a given time. The results showed that the lesions had travelled furthest where the largest amounts of nitrogen were given, and as the nitrogen was gradually reduced the height of the lesions became consistently shorter. As the amount of potash was increased the progress of the disease was reduced. Later experiments on commercial nurseries confirmed these results, and it is now common practice to induce tomato plants to grow away from "stripe" by suitable additions of potash.

An excess of nitrogen in the soil has long been known to increase susceptibility to some diseases, and in this respect the most easily assimilated forms, such as nitrates, have the most marked effects. On the celebrated Broadbalk wheat plots at Rothamsted, those receiving an excess of nitrogen show a high susceptibility to rusts and *Epichlœ typhina*, while the plots receiving the normal balanced fertilizer mixture are free from these diseases, although equally exposed to infection. Similar results were observed in respect of mangold leaf spot caused by *Phoma betæ*.

The manurial trials with wheat and barley at Woburn also indicated that the high nitrogen plots, especially those receiving sodium nitrate, are more susceptible to mildews than the normal plots. At Cheshunt the tomato experiments have long indicated similar results with regard to the incidence of some diseases. Thus the plots receiving heavy dressings of straw manure have consistently shown a greater number of casualties from root diseases than the other plots. Observations in the tomato and cucumber industry in the Lea Valley have provided abundant proof that methods of cultivation favouring heavy feeding with nitrogenous manure produce a soft, sappy type of plant predisposed to disease.

On the other hand, all diseases are not affected in this way, as instanced by the *Verticillium* wilt of the tomato, which is more destructive to hard, underfed plants than to the softer rapid growing types produced by abundant nitrogen.

Phosphates have the effect of inducing the production of abundant fibrous roots, and are generally regarded as causing an increased resistance to disease, but in this respect they are not nearly so effective as potash.

Many cases might be quoted in which potash-starved plants have shown a strong susceptibility to disease, which has been readily corrected by suitable dressings of potash salts. At Rothamsted the potash-starved plots of wheat and mangels show a marked susceptibility to rusts and other diseases, while in the glasshouse tomato industry it has been found that potash manuring is necessary to keep many fungus and bacterial diseases in hand. As previously shown, tomato plants attacked by "Stripe" disease can be made to grow away clean by feeding them with sulphate of potash.

Lime is used in cultivation to "sweeten" the soil and is generally considered to be beneficial. It is especially useful on acid soils and those rich in humus, where its addition serves to neutralize the acidity. It is a common belief that the addition of lime to a soil assists in controlling disease organisms; and while this is usually true, it should be borne in mind that some diseases are increased by liming. Thus, before applying this treatment for the purpose of disease control it is necessary to know its effect upon the disease in question. Soft rot of the calla lily caused by *Bacillus carotovorus* is increased by treatment with lime or lime water, as is "damping-off" of tomato seedlings due to *Phytophthora cryptogea* or *Ph. parasitica*. On the other hand, both the *Fusarium* and *Verticillium* wilts of the tomato are reduced by treatment with caustic lime in the winter.

An excess of lime in the soil has also been shown to induce chlorosis of many plants.

(*c*) *Soil Population.*—The micro-organisms that inhabit the soil bear an important relation to its fertility. By feeding upon the organic matter and chemical salts they produce important changes in the soil. These may be classified into two groups: (1) Down grade and (2) up grade.

Down Grade Changes.—These are concerned with the decomposition of complex compounds and the production from them of simple compounds, such as carbon dioxide and ammonia. Among the different kinds of organisms which are instrumental in these changes the bacteria, fungi, protozoa, and algæ are important.

Up Grade Changes.—These are concerned with the building up or synthesis of valuable plant foods from the simple compounds liberated by the down grade processes. The bacteria are mainly responsible for these changes, but in the light of recent knowledge it is probable that the algæ also are concerned. In fertile soils the down grade and up grade changes are in equilibrium, but this is easily disturbed by a change in soil conditions, as these affect the growth and behaviour of soil micro-organisms much in the same way as they do those of plants.

While much information has been obtained regarding the behaviour of micro-organisms present in agricultural lands, but little is known about the population of the soil under the abnormal conditions prevalent under glass. Investigations of these problems are very desirable and should elucidate many obscure problems connected with the infertility of glasshouse soils.

Beside these organisms which assist in the maintenance of soil fertility there are to be found in the soil organisms which are distinctly harmful, namely, those which cause plant diseases. While most soils are comparatively free from these organisms, many become contaminated and the infection spreads so rapidly that susceptible plants cannot be grown. The disease-causing organisms live upon the decaying organic matter of the soil and attack the young plants at the most suitable opportunity.

It is thus apparent that the soil cannot be regarded as consisting of dead particles of rock, but rather as teeming with life, having a determining effect upon soil fertility and freedom from disease. Science has shown that fertility remains so long as the beneficial organisms are not swamped by those which are harmful. In the latter case, especially if parasitic organisms are abundant, the soil is said to be "sick" and many attempts have been made to devise methods for bringing the soil back to a healthy condition.

Malnutrition

Plants suffering from malnutrition have a stunted appearance and a light yellowish-green foliage, which is especially noticeable between the veins, which are yellowish or brown in colour. The flowers and fruits are small and misshapen; the roots are ill developed and the secondary ones die prematurely. Investigation has shown that the disease is not attributable to parasitic organisms, but is the result of unsuitable soil conditions, generally set up by incorrect manuring.

Fresh cow or pig manure has been shown to cause malnutrition of the tomato, and excess of acid fertilizers has a similar effect. An excess of readily available nitrogen in cucumber beds produces an incurling of the leaves, the margins of which turn brown and wither. On the other hand, cucumbers grown in frames and supplied with an insufficiency of available nitrogen become light in colour. Such fruits turn darker when the plants are given a soluble nitrogenous fertilizer.

Growers of roses are familiar with the bronzing of the leaves of certain varieties. This begins as a bronze mottled patch, and the entire leaf may become bronze in colour or may develop bronze spots surrounded by a yellow zone. The affected leaves soon drop and spoil the appearance and health of the plant. Generally the disease appears on new branches below the place where the blooms have been removed. It is most prevalent on young plants, and especially those which have been forced too rapidly. Over-feeding appears to be an important factor in connexion with the disease.

The dropping of flower buds is an important malady closely related to malnutrition. The flower bud appears in due course, turns yellow, and drops off the peduncle or stalk. In some cases the cause may be of fungoid origin, but generally it is due to an unbalanced food supply. Thus the tomato and sweet-pea both drop their flowers when there is an excess of available nitrogen in the soil, which causes them to grow too rapidly. The sweet-pea also drops its bloom in starved soil, and hot, dry weather may cause tomato flowers to drop.

An excess of nitrogen and potash has a distinctly harmful effect upon carnations, as is well known to growers of this plant. The former produces weak flowers liable to scorch and attack by *Botrytis*. Such blossoms are malformed and frequently do not open. An excess of potash salts produces a hardening and wrinkling of the petals, and at times the margins turn brown and wither. The buds do not open properly and are distorted. The plants become stunted and the leaf tips turn yellow and die. Occasionally carnation flowers split prior to opening; and while the cause is yet obscure, there are indications that unsuitable manuring is an important factor.

If the tomato is overfed in the early stages of its growth and starved at a later period it develops a hollow stem, and becomes physiologically weak and liable to disease. Similar symptoms develop in the tops of tomato plants which have borne an exceptionally heavy crop on the bottom trusses; such plants are physiologically weak and highly susceptible to disease. It is of the greatest importance in the prevention and control of plant diseases that the physiological strength be maintained. In order to resist disease it is necessary to pay careful attention to all environmental conditions and feeding, for every check to which plants are submitted reduces their physiological strength.

Chlorosis

An excess of lime in the soil has been shown to produce a chlorosis of many plants, and as these are more susceptible to disease than normal plants this soil factor is one to be avoided. Lack of iron in the soil is said to be productive of chlorosis, which in this case may be remedied by the application of small quantities of iron sulphate.

Stigmonose

Aphides and other sucking insects puncture the tender tissues of young leaves and produce minute lesions which have frequently been attributed to bacterial causes. Such spotting is called stigmonose. A suitable example is furnished by the carnation. The spots are at first pale yellow in colour and later turn a reddish-purple. The surface tissue dries, the spots enlarge and become sunken, the leaves turn yellow and wither, and the whole plant may be stunted. The changes have been traced to the injection of an irritant by the insect into the plant cells and their consequent reaction. Tomato fruits are attacked in a similar fashion, but the spots are circular and resemble small white blisters with minute dark purple centres. As the fruit colours, the spots become indistinct and are practically unnoticeable.

Gas Injury

The presence of poisonous gases in glasshouses produces marked effects upon the plants. Thus fumigation with nicotine and hydrocyanic acid gas under unsuitable conditions causes discoloration and scorch of certain flowers and plants. The presence of such vapours as paraffin and petrol produces similar injurious effects.

Diseases of Unknown Origin

Several diseases of glasshouse plants exist which cannot be attributed to definite causes. Among these may be mentioned tulip blindness, or the failure of apparently normal bulbs to produce flowers. Tulip bulbs which have bloomed well one year may be blind the next and bloom again the year after. The hyacinth and other bulbous plants frequently develop a disease called " gummosis," in which a white gum is produced by the sub-epidermal tissues. The gum-bearing cells swell, and finally the epidermis ruptures and the gum exudes. The " yellow stripe " disease of the daffodil is another of the same category. In an advanced stage the leaves develop parallel yellow bands coinciding with the veins, and in bad cases the leaves wither and the blossoms die prematurely. Another such disease is the failure of rosebuds to open. The buds develop normally, when suddenly the outer petals turn yellow and cease to grow. Such buds may open partially but never reach normal development, and are distorted.

CHAPTER III

DISEASES DUE TO FUNGI

THE fungi comprise a big group of plants which do not possess the green colouring matter common to flowering plants generally. They are thus unable to manufacture the carbohydrate part of the food from the atmosphere, and are dependent upon organic material for their food. Some of them live upon dead vegetable matter and are called *saprophytes*, but most of the plant disease organisms are *parasites* and obtain their food from the living plant. The most successful plant parasites, however, are able to exist upon dead vegetable matter when no living tissues are available. They thus live upon decaying plant remains during the winter, but retain their ability to attack and destroy the living plant when such is available.

Instead of developing stem, leaves, and roots in the way the higher plants do, the fungi produce tiny thread-like structures called hyphæ. The hyphæ intertwine and spread in all directions, and by continued growth produce a weft or mat-like mass called the mycelium. The hyphæ penetrate the plant tissues, through which they ramify and produce the spots, cankers, or other lesions typical of the particular disease. Certain threads of the mycelium grow up clear of the substratum and cut off small bodies called spores. These have thin walls, and being very light are suitable for quick distribution and immediate infection of neighbouring plants. They are unable to withstand abnormal conditions, and are often called "summer" spores. Frequently other spores with thick, dark walls are produced, called chlamydospores, which are highly resistant to external conditions and carry over the disease from one season to another. Sometimes the spores are enclosed in tiny flask-like structures buried more or less deeply in the leaf, stem, or fruit tissues, and being thus protected are able to

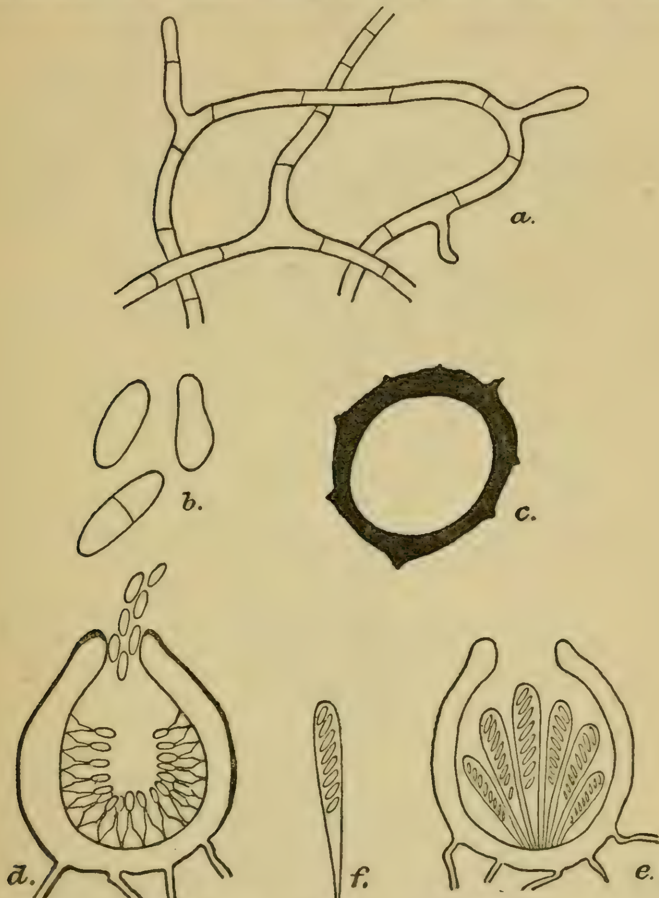

FIG. 3. (*a*) Hyphæ, (*b*) thin-walled "summer" spores, (*c*) thick-walled resting spore, (*d*) a pycnidium, (*e*) a perithecium, (*f*) ascus containing eight ascospores.

resist abnormal conditions. These bodies are of two kinds—the pycnidia and perithecia. In the former the spores are produced on small stalks which line the inside of the vessel; in the latter case a number of small sacs are produced within the vessel, each of which contains eight tiny special spores or ascospores. The pycnidia and perithecia do not open except when conditions are favourable, and then there are often special devices for ejecting the spores from the inside (Fig. 3).

I. Root Diseases

"DAMPING OFF" OF TOMATO SEEDLINGS

Symptoms.—Typically the plants are attacked at the soil level (Fig. 4), where the tissues are browned, become

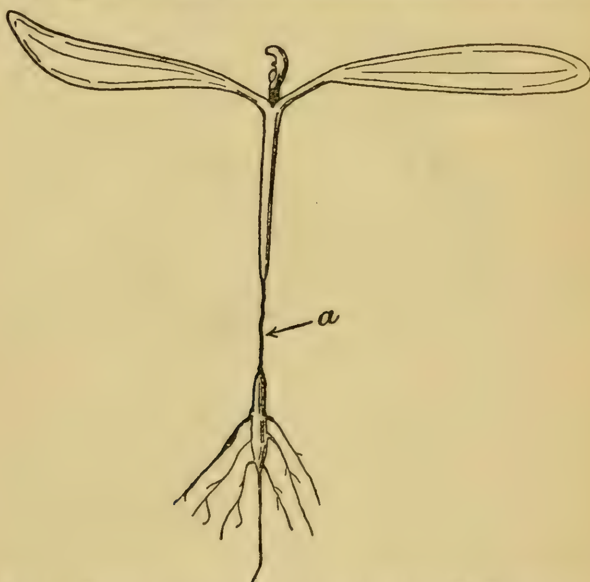

FIG. 4. Tomato seedling attacked by "damping off" disease at *a*.

softened, and collapse, causing the plant to fall over. The disease spreads rapidly from seedling to seedling in the film of water covering the soil surface. Thick sowing is to be deprecated, for this assists the spread of the disease, as shown by the following experiment. Seeds were sown in infected soil in thicknesses varying from 600 to 25 seeds per box, in sets of four boxes at each degree of thickness. In half the boxes the seedlings were removed as they became infected to eliminate the factor of spread. The remainder were untouched and indicated the rate of superficial spread of the fungus (5).

TABLE 1.

No. of Seeds per Box.	Average per cent Diseased Seedlings Removed when Attacked.	Average per cent Diseased Seedlings not Removed.
600	51	100
300	45	100
200	49	100
100	42	78
50	37	46
25	35	41

The second column, Table 1, shows the uniform results obtained when the seedlings were removed as they were attacked, and indicate that the number of seedlings primarily attacked depends upon the number of disease centres in the soil and not upon the closeness of sowing when the factor of superficial spread of the organism is eliminated. In the third column, where the fungi were allowed to remain, the spread of the organism is more rapid where the seeds are sown closely than where they are sown thinly. In the closer sowings the density of the plants increases the film of water adhering to the seedlings and offers a ready means of spreading the disease through the box. Sowing above fifty to the box should be avoided, for this materially assists the disease. A film of water over the surface of the soil is necessary for the rapid spread of the disease, and water-logged conditions are also in its favour. Moistening the soil through capillary attraction by standing the boxes in shallow trays of water is less favourable to the disease than watering from the top. Temperature is important, and relatively low temperatures—about 10° C.—are less favourable to the disease than high temperatures of 23° C.–27° C. Thus summer sowings of tomato seeds are more liable to " damp off " than early spring sowings—

a fact that is well known to nurserymen. The disease thrives upon rich composts, and such are therefore more favourable for it than loam alone.

Causal Organisms.—Considerable experience of this disease has shown that it is caused mainly by three fungi —*Rhizoctonia solani* Kuhn, *Phytophthora cryptogea* Pethybridge and Lafferty, and *Phytophthora parasitica* Dastur. The first is less common than the latter two fungi, which are consequently the most important cause of the disease. *Rhizoctonia solani* is the sterile stage of a spore-bearing fungus, *Corticium vagum* B. & C., var. *Solani* Burt. The young hyphæ produce branches which generally leave the mother filament at an acute angle and subsequently turn and lie parallel to it. The branch is constricted near the point of origin and a cross wall is formed a little beyond the constriction (Fig. 5). In age, the angle of branching becomes more nearly a right angle, and the hyphæ turn first yellow and then a deep brown colour. Resting bodies or sclerotia, capable of resisting abnormal conditions, are produced, being at first small, soft white masses, but later they increase in size and turn dark and hard. The *Corticium* stage, which forms later, shows as an ashy-grey tufted layer at the base of the stem, from which innumerable small spores are produced. These are easily carried by the wind, and so disseminate the disease. This stage is not always produced, and indeed requires special cool, moist conditions for development. *Rhizoctonia solani* is commonly found in rich soils, where it constitutes an important disease of many plants. *Phytophthora parasitica* Dastur (16) was first described by

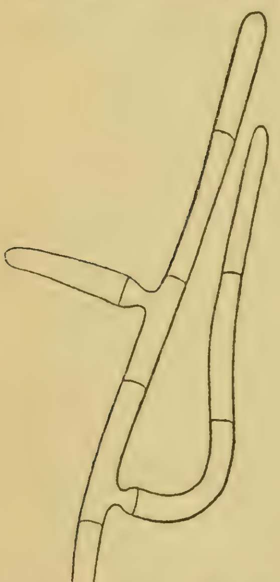

FIG. 5. Hyphæ of *Rhizoctonia solani.*

Dastur in India, during 1913, as causing a disease of the castor bean. In 1917 Sherbakoff (43) described "buckeye" rot of tomato fruits as caused by a new species of Phytophthora—*Ph. terrestria*—which he also found attacking citrus trees and lupins. In pure culture tests it appears that *Ph. terrestria* is the same as *Ph. parasitica*, the latter name having priority. It is highly probable that *Ph. parasitica* is a universal organism considerably more important than is at present imagined. *Phytophthora cryptogea* was first described by Pethybridge and Lafferty (37) in 1919 as the cause of tomato foot rot. From inoculation experiments they concluded that it produced the same kind of disease in the potato, *Gilia tricolor*, and elm seedlings. It was also found attacking the petunia, cineraria, aster, and wallflower. The genus *Phytophthora* develops non-septate thin-walled hyphæ of a relatively large diameter and characteristic appearance. It produces egg-shaped conidia or sporangia, from the inside of which are liberated a number of active zoospores, each of which is supplied with two lash-like processes or cilia, enabling it to swim away in a film of moisture. Thick-walled vegetative cells, or chlamydospores, are also produced as well as thick-walled oospores, the product of sexual fusion. It is by means of the zoospores that the disease is able to spread rapidly. The zoospores settle down against the outside of the plant and produce germ tubes which enter the tissues. The thick-walled chlamydospores and oospores are able to resist abnormal conditions and so tide over the barren season or other adverse conditions. *Ph. cryptogea* and *Ph. parasitica* are closely allied species, differing only in minor details. Perhaps the best way of distinguishing between them is provided by the different way in which the two species produce sporangia. In *Ph. cryptogea* the stalk or sporangiophore grows up through the old sporangium after the zoospores have been liberated, and produces a second sporangia beyond the old one, and this process may be repeated several times (Fig. 6). In *Ph. parasitica* the sporangiophore does not do this, but the new sporangium is produced on a side branch of the old sporangiophore some distance below the old sporangium.

Sources of Infection.—The main sources of infection are the soil and water supply, but experiment has shown that the disease organisms are also carried over from one season to the next by seed-boxes and pots. Cracked pots are especially dangerous, and the discoloration and destruction of plant roots have frequently been traced to some crack or crevice which has harboured the resting spores of the fungus. These organisms, like many others, spend part of their existence in the living plant and the rest in hibernation over the winter in the decomposing soil humus. Composts rich in humus, such as old mushroom beds, are relatively more suited to permeation by infection than poor soils. The water supply and drainage has proved to be a potent source of infection, and preliminary experiments upon this disease led to the examination of many nursery water supplies and the consequent proof of their powers of infection. Surface drainage is also dangerous, and has been shown in many cases to be the indirect cause of many epidemics of this disease.

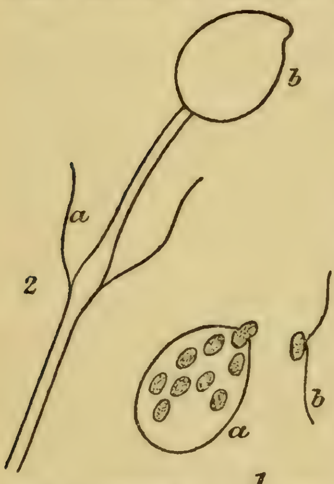

FIG. 6. *Phytophthora cryptogea*: (1) Reproductive bodies—(*a*) conidium, (*b*) zoospores. (2) Typical arrangement of conidia, showing how one conidium after another is produced on the main axis—(*a*) empty conidium, (*b*) young conidium.

Control.—Sterilization of infected soil by steaming, baking, or with a 2 per cent solution of formaldehyde (1 gallon of commercial 40 per cent pure formaldehyde in 49 gallons of water) will completely rid it of the disease organisms. Pots may be sterilized by boiling in water or by treatment with formaldehyde, while boxes are best sterilized with formaldehyde, as steam and hot water soon destroy the wood. A contaminated source of water is more difficult to purify, but the general method will be treated in a later chapter. Frequently the propagating soil becomes contaminated by a chance infection, which is not realized until the disease reaches the epidemic stage. Such cases have emphasized the necessity of devising methods of checking the disease when it appears, and as the result of investigations (6) at the Cheshunt Experimental Station it was found that a solution of a mixture of copper sulphate and ammonium carbonate will do this. The mixture, which for convenience has been named "Cheshunt Compound," consists of two parts by weight of copper sulphate and eleven parts ammonium carbonate. The ammonium carbonate, *which must be fresh*, is reduced to a fine powder by crushing out the lumps. It is then thoroughly mixed with powdered copper sulphate in the correct proportions, and stored for twenty-four hours in a tightly corked glass or stone jar before using. The solution is prepared by dissolving one ounce of the dry mixture in a little hot water and adding to two gallons of water. It should not be put into vessels of iron, tin, or zinc, as it corrodes them and loses its strength, and just as much as is required for immediate use should be prepared. Plants may be watered with this solution without injury, while the "damping off" organisms in the soil are destroyed, but infected plants receive no benefit from the solution, for the fungus is already inside the tissues where the liquid cannot reach it, and such plants eventually die. The seed-boxes should be thoroughly watered with the solution after sowing and covering the the seeds. When potting up, the seedlings should be watered first with the solution while still in the boxes, to ensure that the roots are thoroughly wetted, and after transplanting into the pots the solution should again be applied. To enable sufficient solution to be given to each plant the level of the soil should be one inch below the level of the pot. The solution may be used in the houses by adding a pint to each of the holes prepared for the plants. In replacing diseased individuals the method should be to remove the dead plant, water the hole with a pint of solution, replant with a healthy individual, and again water with the solution. The compound has been successfully employed on commercial nurseries, and has a beneficial effect apart from killing the disease organisms, for the nitrogen it contains imparts a greater vigour to the plants.

During an epidemic at one nursery the grower replanted two houses four times, and each time lost practically the whole of his plants. When replanting for the fifth time the soil was treated with "Cheshunt Compound," with the result that only four plants were lost out of two thousand.

The disease may be aggravated by certain cultural conditions of moisture and temperature. Thus a relatively high percentage of moisture in the soil and the air is favourable to the disease organisms, and careful regulation of the watering, so as to keep the seed-boxes uniformly moist, combined with efficient ventilation of the propagating houses to dry out the surface soil, will help to keep the disease under control. The optimum temperature for growth of *Ph. parasitica* is about 30° C. (86° F.), and that of *Ph. cryptogea* and *Rhizoctonia solani* about 25° C. (77° F.). Below 12° C. (54° F.) the growth of all three species is very slow. When the disease has started among the plants the grower should endeavour to keep the temperature as low as possible without impairing the health of his crop.

Diseased plants may be saved only by cutting away the lower diseased portion and treating the healthy tops as cuttings.

"DAMPING OFF" OF CUCUMBER SEEDLINGS

Two fungi mainly concerned with "damping off" of cucumber seedlings are *Pythium de Baryanum* Hesse and *Colletotrichum oligochætum* Cav.

FIG. 7. *Phytophthora* foot rot of the tomato. [*Facing page 62*

The former has been reported as a common cause of "damping off" in many plants, and probably has been confused many times with various species of *Phytophthora*, from which genus it differs but slightly. Ward reported it as being very prevalent in the garden soils of Europe. *Colletotrichum oligochætum* is fully described under "Anthracnose of the Cucumber," and is a common cause of "damping off" of cucumbers in this country.

The methods of control recommended for "damping off" of tomato seedlings apply equally well to that of cucumber seedlings.

FOOT ROT AND COLLAR ROT OF THE TOMATO

These terms have been applied to diseases due to a number of different fungi, and in order to avoid confusion the name of the fungus concerned is here placed before the general term. The most important of these diseases are *Phytophthora* foot rot, *Botrytis* foot rot, *Macrosporium* foot rot, and *Verticillium* collar rot. Typically these diseases appear about the soil level, and while the disease symptoms may vary the final result is the death of the plant.

Phytophthora Foot Rot.—Two species of *Phytophthora* produce foot rot of the tomato, the most common being that described by Pethybridge and Lafferty (37) as *Phytophthora cryptogea*, which, as already stated, causes "damping off" of tomato seedlings. The symptoms of foot rot are identical with those of "damping off," except that older plants are concerned (Fig. 7), and there is a gradual transition from "damping off" to "foot rot" in accordance with the age of the plant at the time the disease appears. In some cases plants eighteen inches high have been known to be attacked. The disease is characterized by a dark brown or black discoloration of the outside tissues of the stem. At such parts the stem tissues shrink and collapse, causing the top of the plant to fall over. The disease organisms enter the plant via the roots or a leaf touching the soil. In the former case the fungus passes rapidly up the stem, and ultimately causes the collapse of the tissues at some definite part. This collapse usually occurs at or near to the soil level, but many cases have been examined where the constriction appeared at a height of twelve to sixteen inches above ground, whereas in other cases the root is destroyed and separated from the upper portion of the plant. Generally speaking, this fungus rapidly kills the plant, and the losses caused are considerable, not infrequently 50,000 to 90,000 plants being destroyed in two or three weeks on a single nursery.

Another species, *Phytophthora parasitica*, described previously as a cause of "damping off" of seedlings, also produces foot rot. In this case the plant is attacked in much the same way as by *Ph. cryptogea*, but death is slower. Tomatoes planted out on March 1st may be destroyed by *Ph. cryptogea* up to the end of April, while it is not uncommon to find *Ph. parasitica* as the cause of death in June and July.

The methods of controlling this disease are the same as recommended for "damping off" due to these two species of *Phytophthora*.

Botrytis Foot Rot.—Symptoms.—The first sign of this disease is the appearance of smooth, slightly sunken grey patches on the stem just about the soil level. These lesions enlarge, become dry and brown until finally they encircle the stem, when the top of the plant wilts and may fall over. Under moist conditions a grey fungal growth of *Botrytis* appears over the diseased area (Figs. 8 and 9). On cutting open the stem it can be seen that the fungus has penetrated the cortex, vascular system, and pith, and is travelling up the stem in the wood. The diseased tissues are dark reddish-brown in colour.

Causal Organism.—The cause of the disease is a species of *Botrytis*, which is one of the most common

FIG. 8. *Botrytis* foot rot of the tomato.

FIG. 9. *Botrytis* sp. growing on tomato stem.

[Facing page 64

fungi found on vegetation. The fertile hyphæ stand up in dense grey, velvety tufts and masses, producing oval conidia or spores on branched heads. These conidia are extremely light, and, being carried long distances in strong air currents, provide a most efficient method of spreading the disease. Numerous hard, black sclerotia are produced on the plant, and being highly resistant to abnormal conditions enable the fungus to hibernate from one season to the next.

Sources of Infection.—The infection is present at the surface of the soil, and may have been introduced by air currents, or with water supply, or manure.

Control.—Warm, moist conditions at the base of the plant favour this disease and therefore should be avoided. Once a plant is attacked nothing can save it, but the fungal infection present at the soil surface and plant base may be destroyed by spraying with a 2 per cent solution of calcium bisulphite, which is specific for *Botrytis*.

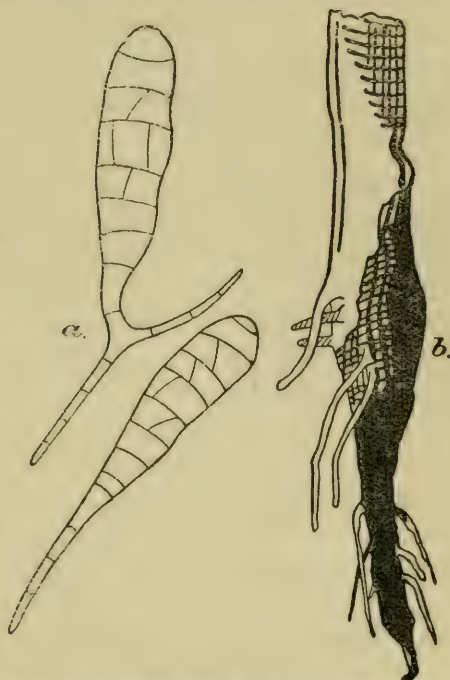

FIG. 10. *Macrosporium* foot rot of the tomato: (*a*) spores, (*b*) diseased stem.

Macrosporium Foot Rot.—Quite recently Rosenbaum (42) has described a foot rot of the tomato due to *Macrosporium solani* E and M.

Symptoms.—The symptoms are described as resembling those of black-leg of potato stems. The stems turn dark brown at the ground line, and the tissues shrivel up and may break, causing the plant to fall over. At times the lesions appear higher upon the stem, and the entire shoot and blossoms may be affected. The brown rot spreads deep into the tissues, both above and below ground (Fig. 10). Rosenbaum states that in one case 40 per cent of the plants on a nursery were affected, which indicates that the disease may at times be a serious one.

The Causal Organism.—*Macrosporium solani* was first described in 1882 as causing an early blight of potatoes, and since then has been recorded on many plants. The fungal hyphæ vary from light brown to an olive colour, and produce characteristic brown septate spores.

The disease has not yet been reported in England.

Verticillium Collar Rot.—Pritchard and Porte (38) have described a collar rot of tomato seedlings caused by a new species of *Verticillium* to which they have applied the name *V. lycopersici*. Dark brown lesions, similar to those produced by *Macrosporium solani*, appear girdling the stem, mainly at the soil level. These enlarge and the tissues become weak and brittle ; but, unlike the *Macrosporium* disease, there is very little infection of the roots. The authors found that diseased plants were readily snapped off by the wind, and while some recovered by forming a callus over the wound, these individuals were seldom as productive as healthy plants. The disease is chiefly one of the seed-bed, where the tender nature of the plants renders them highly susceptible.

The fungus produces a similar disease of the potato and horse nettle—*Solanum carolinense* L. As the disease is typically one of the seed-box, sterilizing the propagating soil is recommended as a means of control. Susceptible hosts should not be allowed to grow in infected areas, as these assist in the spread of the disease.

CROWN CANKER OF THE ROSE

This disease is commonly found under glass, and while the percentage of plants actually killed is small, there is no doubt that the loss of vigour caused by this fungus is the cause of considerable financial loss. Infection takes place at the crown or collar of the plant, frequently at the graft. The disease appears as a slight discoloration of the bark, which later becomes water-soaked and black. Gradually the lesions girdle the stem and cracks appear in the sunken infected area. The disease spreads down into the roots and the diseased tissue becomes brown and powdery. Such developments have a detrimental effect upon the health of the plant, which becomes weak and spindly and produces small, valueless flowers.

The disease is caused by *Cylindrocladium scoparium* Morgan (34), which produces cylindrical, one-septate spores in characteristic heads. Over-watering is highly favourable to the disease, and alternating periods of drought and excessive dampness should be avoided. The disease organisms live in the soil and may be destroyed by steam sterilization. To some extent it may be controlled by planting grafted individuals, so that the union of scion and stock is above the soil.

ROOT ROTS

The roots of most plants are susceptible to disease when the soil conditions are wrong. The extent of root rot may be slight and produce results equivalent to those produced by root pruning. On the other hand, should the rot get the upper hand, death of the plant is the ultimate result. Numerous root-rotting fungi have been recorded, and the list is by no means complete. An excess of soil water, and consequently lack of aeration, is a potent factor in inducing root rot, and beds rich in organic matter, especially of a nitrogenous nature, favour the disease. Generally speaking, root rots due to fungi may be divided into two main classes—those caused by wound parasites and those caused by fungi capable of attacking healthy roots in the absence of wounds. Thus soil insects, by opening up wounds in the roots and stem base are the indirect cause of many root diseases. The soil temperature is also important, and fungi which at one temperature do little damage may rapidly destroy the whole root system at a suitable temperature.

Tomato Root Rots.—*Phytophthora cryptogea*, *Phytophthora parasitica*, and *Rhizoctonia solani*, as already described, may produce a rapid root rot of the tomato. Other root rots are due to various species of *Fusarium* and *Sclerotium.*

Fusarium Root Rot of the Tomato.—Various species of *Fusarium* have been isolated from tomato roots in England, and have been found invariably to follow wounding by woodlice or wireworm. The fungus causes a reddish-brown discoloration of the roots, which spreads rapidly during the summer months when the soil temperature is high. The affected plant becomes stunted in growth, the leaves turn yellow and wither, and finally death ensues. When the plant is dead the fungus grows out over the surface of the tissues and, unless the dead plant is removed in time, produces an abundance of spores, which rapidly spread the disease.

Sclerotium Root Rot of the Tomato.—In America *Sclerotium rolfsii* Sacc. has been described as producing a root rot of the tomato (23), but this disease is as yet unknown in England. Infection takes place at the base of the plant in about the top inch of soil, and becomes evident as dark brown lesions, at which stage the plant wilts slightly. Later the lesions become covered with a mat of white radiating hyphæ, which surrounds the base of the plant. The fungus works into the stem tissues and the plant wilts and dies. The fungus does not pass up the stem to any height, but works down into the roots, especially those near the surface. On pulling up a dead plant the roots are seen to be covered

FIG. 11. *Colletotrichum tabificum* on tomato roots, showing typical minute black sclerotia.

FIG. 12. *Sclerotium* disease of the tulip. [*Facing page 68*

with a white fungal growth. If a diseased plant in the soil is kept under moist conditions the fungus grows out from the stem and spreads over the soil surface in radiating fans. The disease is carried from season to season by sclerotia as small as the smallest mustard seed. At first they are milk white in colour, but on maturing they turn a dark mahogany-red or black colour. Sclerotia are not produced on the plant until the final stages of the disease, and on dead plants may usually be found in abundance. Rolfs, who first discovered the disease, reports that it also attacks potatoes, cabbages, beets, and melons, as well as *Hydrangeas* and *Daphnes*.

Control.—The disease grows rapidly in compost heaps, and indeed in any soil rich in decaying vegetable matter. Clean methods of culture and the omission of stable manure from the soil will prevent the disease, while efficient ventilation at the base of the plant and deep cultivation are also beneficial. Spraying the soil surface and base of the stem with a solution of "Cheshunt Compound" is recommended as a preventative.

Colletotrichum Root Disease.—This disease has recently been identified in England. The symptoms of the disease are similar to those generally present when tomato roots are slowly destroyed by a parasitic organism. Such plants cease to develop normally, the lower leaves turn yellow and wither prematurely, and the new growth is thin and pale in colour. In many cases the stem becomes hollow and the plant dies prematurely, being relatively stunted in growth.

On pulling up a plant the roots offer no resistance, for they are dry and shrivelled, and the decayed base readily leaves the soil. The cortical tissues of the roots readily come away from the centre core of wood, and the distinctive feature of the disease is the presence of innumerable minute sclerotia the size of begonia seeds (Fig. 11). These are produced inside the woody tissues as well as external to them. The affected wood is only brown in colour, and somewhat darker than when infected by *Verticillium* or *Fusarium*.

Infection takes place in June and July when the soil temperature is high. At this time, although the fungus is present in the roots, a well-grown plant may show no signs of disease, but after it has produced five or six trusses of fruit, and is consequently reduced in vigour, signs of root trouble appear. Thus, unless the conditions are exceptional, the outward signs of the disease do not appear earlier than the middle of August. Considerable financial losses, however, are incurred through the disease, which prevents the plants from continuing to bear fruit to the end of the season and causes their premature death. It has been calculated that between twenty and twenty-five per cent of the total yield per plant is lost when it is attacked by this fungus.

Causal Organism.—The disease is caused by a fungus *Colletotrichum tabificum* Pethybridge. The actual hyphæ are difficult to distinguish on the plant, and occasionally very small spores or conidia are produced. Typical resting bodies or sclerotia are formed, which are at first white in colour, but finally turn dark brown or black and become covered with dark brown bristles or setæ. The fungus ramifies through the wood, and produces sclerotia inside the large wood vessels, and in any hollows inside the stem. Generally sclerotia are not produced until the plant is almost dead.

Control.—The disease organisms develop most rapidly in soils rich in organic matter, and thrive in manure heaps and any straw or woody material. In the laboratory the fungus has been cultivated successfully on wood and straw. It is thus obvious that clean cultivation by removing such materials is an important factor in the control of the disease.

Watering the soil round the plant roots with a solution of "Cheshunt Compound" has been found to prevent the disease from spreading. Sterilization with steam or by baking will destroy the disease organisms in the soil.

Root Rot of the Carnation.—The first sign of this disease is the yellowing of the leaves. Generally the entire plant is affected, but in some cases only a shoot or two may show the yellowing. Later, when the fungus is firmly established in the plant, wilting during intervals of intense sunlight may occur. The disease is caused by *Rhizoctonia solani* Kuhn, which confines itself mainly to the roots and lower parts of the plant, where a brown rot may develop. High temperatures, over-watering, excessive feeding, and deep planting favour the disease. Control methods are similar to those described on page 60.

Root Rots of the Sweet-pea. Rhizoctonia Root Rot.—This is much the same disease as already described for the carnation, but it is more serious than in the latter.

BULB ROTS

Sclerotium Disease.—This disease, due to *Sclerotium tuliparum* Klebahn, is found on tulip and other bulbs. Towards the end of the flowering period the plants assume an abnormally unhealthy appearance, and on lifting the bulbs small black sclerotia may be seen in the scales, and especially on the inner side of the outer ones. Affected bulbs become desiccated and finally die (Fig. 12).

The disease has been investigated by J. K. Ramsbottom (40). Infected soil may be sterilized by means of steam, while a dressing of flowers of sulphur has frequently proved beneficial.

Botrytis Rot.—This disease, which shows itself by the development of the typical grey *Botrytis* mould upon the leaves and bulb scales (Fig. 13), and the consequent rapid decay of the diseased tissue, is largely connected with bad cultural conditions. Hot, moist conditions, accompanied by imperfect circulation of the air and injudicious watering, are favourable to the disease. For a description of the fungus and method of control, see page 64.

Fusarium and Penicillium Rots.—Certain species of *Fusarium* and the common blue mould *Penicillium* produce a bulb rot of the hyacinth, narcissus, and tulip. The rot commences from the base of the bulb, and is typically a storage rot. Unsuitable conditions at the time of harvesting and imperfect drying of the bulbs are the main factors connected with the disease. Diseased bulbs are frequently planted because external signs of rot are absent. The disease organisms attack the base of the bulb and work up into the centre, where the flowering shoot may be destroyed.

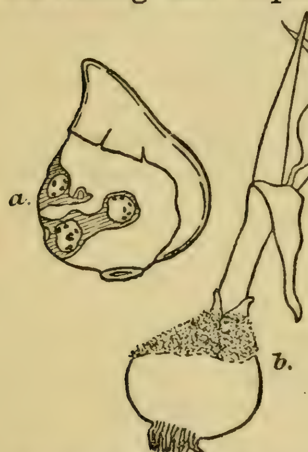

FIG. 13. *Botrytis* disease of the tulip: (*a*) bulb showing black sclerotia, (*b*) fungal growth on the bulb.

Such bulbs rarely flower, no new bulb is formed, and the old one is converted into a powdery mass.

Attention to the conditions operative at harvesting and during storage so as to ensure that the bulbs are perfectly dry, and the elimination of rotten bulbs from which infection may spread, are the best ways of preventing the disease.

CHAPTER IV

DISEASES DUE TO FUNGI—*Continued*

2. Wilt Diseases

"Sleepy Disease" or wilt disease is common to most plants, and is indicated by a wilting of the leaves followed by a yellowing and desiccation which usually ends in the death of the individual. Obviously any root injury, if sufficiently drastic, will cause such symptoms, but the true wilt diseases are due to a reduced functioning or complete stoppage of the vascular system, which comprises the water- and food-conducting tissues of the plant.

Massee (31) first described the Sleepy Disease of tomatoes in Britain and attributed it to *Fusarium lycopersici* Sacc., an organism with two developmental stages—the *Diplocladium* and *Fusarium* stages. Investigations at the Cheshunt Experimental Station (10) demonstrated that these two stages are separate fungus species, each of which under definite conditions can produce wilt. The *Diplocladium* form is *Verticillium albo-atrum* Reinke and Berthold, and the pathogenic *Fusarium* form is *Fusarium lycopersici* Sacc. There are therefore two wilt diseases of the tomato in Britain—the *Verticillium* wilt and the *Fusarium* wilt—and other workers have shown that many other cultivated plants are susceptible to these two wilt diseases.

VERTICILLIUM WILT OF THE TOMATO

Verticillium wilt is widely distributed throughout the British and Channel Islands where tomatoes are grown, and is responsible for considerable financial losses to the industry. In normal years it first appears about the middle of April and increases in intensity up to the second and third week in May, when it reaches its maximum. In normal summer temperatures the attacks die down during the second half of June, July, and August, but reappear at the end of September, when the plants die prematurely.

Disease Symptoms.—Diseased plants are usually stunted, but not invariably so, while the internodes, especially the younger ones, are badly developed. When the conditions of temperature and light are most favourable to the fungus, the disease symptoms appear quite suddenly and the plant wilts while the leaves are still green. The plants may recover their turgidity at night, but wilt again as the morning advances. The leaves wither from the base of the plant upwards, adventitious roots emerge from the stem, and the plant dies. The process of death is much slower when the conditions are less favourable to the fungus: yellow blotches appear on individual leaflets on the lower leaves, and these leaflets either wilt and wither or wither without wilting. Under conditions least favourable to the fungus the leaves do not wilt, but gradually desiccate from the base of the plant upwards. Finally death ensues. On cutting open the stem of a diseased plant the wood is seen to be discoloured practically to the top of the plant—the colour varying from light to dark brown. The discoloration of the stem may be followed to the root, and the place of entrance of the fungus into the plant may be distinguished by the intense browning at that point. The disease-causing organisms hibernate in the soil or compost from season to season and infect the young roots as they develop. Entrance to the plant is assisted by wounds, but experiment has shown that such are not essential for infection, *Verticillium* having the power to invade roots absolutely free from wounds. The fungus destroys the cortex at the point of entrance, and, entering the wood,

FIG. 14. *Verticillium* wilt of the tomato. Old diseased tomato stem showing the fungal outgrowth at the base.

a *b*

FIG. 15. *Verticillium* wilt of the tomato: (*a*) Wilted plant six weeks after inoculation with *V. albo-atrum*, (*b*) control plant

[*Facing page 74*

passes up into the stem. Here it is found solely in the woody parts. When the plant dies, the fungus leaves the vessels and, penetrating the cortex, forms at the base of the stem a white external growth (Fig. 14). This is the active fruiting stage, and the spores are readily blown about, enabling the fungus to spread rapidly. Occasionally the fungus may penetrate the fruit, causing a soft rot. Infection rarely takes place in the seed-boxes or pots, but almost entirely after the plants have been placed in the houses.

TABLE 2.

Type of Plant Used.	Mean Diameter of Stem Base in cms.	No. of Plants.	Age in Weeks.	Date of Inoculation.	Average No. of Days between Inoculation and First Symptoms.	Average No. of Days between Inoculation and Total Wilt.
"Comet" soft growth ..	0·8	12	6	4/4/20	21	39
Do. do. ..	1·05	12	8	4/4/20	21	47
Do. do. ..	1·20	12	10	18/4/20	21	53
"Comet" hard growth ..	0·45	12	6	4/4/20	10	24
Do. do. ..	0·7	12	8	4/4/20	8	29
Do. do. ..	0·75	12	10	18/4/20	8	37
"Comet" starved growth	0·45	12	6	4/4/20	8	20

The Causal Organism.—*Verticillium albo-atrum*, to which this disease is due, produces its spores characteristically at the tips of short branches arranged in whorls or verticils around the main conidiophore. The spores, which are produced in quantity at the base of every plant killed by the fungus, are extremely light, and are readily blown about in the air. They settle upon the soil or plant debris and germinate, producing a white mass of hyphæ. If sufficient food is available, the hyphæ produce a crop of spores, and so infection is abundant. After a time the mass of hyphæ produces innumerable small sclerotia or resting bodies, by means of which the fungus tides over the winter or other adverse conditions. Such sclerotia may be produced in the dead remains of a diseased plant, or generally in the soil humus. In the spring, the sclerotia germinate and produce hyphæ able to infect young healthy plants. Susceptibility to the disease is influenced by the character of the plant, as indicated in Table 2 (p. 75), giving the results of inoculating plants in different stages of growth and of varying degrees of hardness and softness of growth.

It is a general experience with most diseases that plants developing rapidly and producing quantities of soft, sappy growth are the most susceptible to disease, but in this case the above table indicates the reverse effect, for plants of "hard" growth with a thin stem, or plants obviously starved, most readily succumb to the disease.

TABLE 3.

Date Inoculated.	No. of Days after Inoculation that Symptoms Appeared.	Pathological Symptoms.
27/3/19	15	Complete wilt with slight yellowing
26/4/19	14	Complete wilt, no yellowing
25/5/19	10	Do do
27/6/19	No wilt in 10 weeks	Lowest 9 leaves turned yellow and partially dried up.
25/7/19	Do. do	Lowest 3 leaves desiccated
25/8/19	53	Complete desiccation of leaves from base upwards
22/9/19	40	Bottom 4 leaves desiccated
22/10/19	26	Complete wilt with practically no yellowing

Temperature Relations.—If different sets of tomato plants are inoculated with *V. albo-atrum* each month throughout the year, striking results are obtained. In such an experiment twelve tomato plants were inoculated each month, and were grown under similar conditions throughout the year except for such alteration as was caused by seasonal variation. The results given in Table 3 (p. 76) indicate that the conditions during the months of June, July, and August are unfavourable to the rapid progress of the fungus in the plant.

These results indicate the probability that temperature is an important factor in relation to the disease.

As a series of glasshouses where different temperatures could be constantly maintained was not available, inoculated plants (*hypocotyl stab*) were placed in different

TABLE 4.

———	Frame.	Corridor.	Tomato House.	Cucumber House.
Average temperature ° C.	13·5°	16·6°	20·0°	25°
Absolute minimum ° C.	5·6	11·1	12·2	20·6
Absolute maximum ° C.	20·6	22·2	27·8	33·3
Date of inoculation	14/4/20	14/4/20	14/4/20	14/4/20
No. of days after inoculation	21	21	21	21
Ratio of wilted to total leaves	0 : 10	6 : 12	8 : 12	0 : 12
Height of discoloured wood above stab ..	15 cm.	26 cm.	28 cm.	9 cm.
No. of days from inoculation to complete wilt	49	28	28	No wilt after 80 days

positions in the experimental houses, corridors, etc., under different average temperature conditions. Twelve plants were placed in each position, and the average temperatures were calculated from readings taken twice daily from maximum and minimum thermometers placed beside the plants. The final observations, shown in the Tables 4 to 7, were taken twenty-one days after inoculation, and where figures are given they represent the average obtained from twelve plants.

While the results obtained are open to criticism because of the wide range of temperature to which the plants were submitted in any one position, certain facts emerge which have been fully confirmed by observations on commercial nurseries. Chief among these are the beneficial effects which shade and temperatures above 24·0° C. have upon plants suffering from wilt. Table 4 (p. 77) shows that average temperatures of 16·6° C. and 20·0° C. are favourable to the rapid progress of the disease, that of 12·5° C. is unfavourable, while that of 25° C. practically inhibits it. It will be seen that the organism has travelled most rapidly up the stem, as indicated by the browning of the wood, at 16·6° C. and 20° C. and at these temperatures, also, complete wilt occurred most rapidly. The results shown in Table 5, while confirming the temperature relations shown in the preceding table, also show the beneficial effect of shade. While plants in the unshaded house readily wilted, those in the shaded house did not wilt although the temperature was favourable to the disease.

TABLE 5.

———	Frame.	Tomato House.		Cucumber House.	
		Un-shaded.	Shaded.	Un-shaded.	Shaded.
Date of inoculation	14/4/20	14/4/20	14/4/20	14/4/20	14/4/20
No of days from inoculation ..	21	21	21	21	21
Average temperature ° C. ..	17	22	20	26·3	25
Ratio of wilted to total leaves ..	6 : 10	3 : 10	1 : 10	0 : 10	0 : 10

General observations have also shown that temperatures between 15·6° C. and 24° C., with an optimum of 21·1°–22·8° C. are favourable to the rapid progress of *Verticillium* wilt, which below 15·6° C. and above 24° C. is exceedingly slow, while suitable shading counteracts the effects of low temperatures.

A series of experiments were next arranged in which

FIG. 16. This photograph shows the wilted plant in Fig. 15 after being submitted to shade and an average temperature of 25°C for thirty days. The wilted leaves have fallen off, but the plant has recovered and made good growth in the top.

FIG. 17. Sweet pea, showing right-hand branch wilted as the result of inoculation with a pure culture of *V. albo-atrum.*

[*Facing page 78*

wilted plants were transferred to high temperatures to ascertain if they would recover and if such a recovery would continue when the plants were returned to lower temperatures. The results which are shown in Table 6 indicate that wilted plants recover when the average

TABLE 6.

No. of Wilted Plants.	Length of Time in Shaded Cucumber House. Average Temp. 25° C.	Effect of High Temperature.	Length of Time after Returning to Average Temp. 20° C. before Plants again Wilted.
12	1 day	Recovered	15 hours
12	2 days	Do.	15 hours
12	7 days	Do.	2 days
12	14 days	Do.	3 days
12	30 days	Do.	16 days
12	75 days	Do.	30 days

temperature is raised to 25° C. and they are shaded (Figs. 15 and 16). When such a temperature is operative for a short time the effect is not a lasting one for the plants rapidly wilt again when the temperature

TABLE 7.

No. of Wilted Plants.	No. of Days Wilt has been Visible prior to Experiment.	Per Cent Recovered in Shaded Cucumber House. Average Temp. 25° C.	Per Cent Recovered in Unshaded Cucumber House. Average Temp. 25° C.
20	2	100	100
20	7	100	100
20	14	100	100
20	21	100	90
20	30	100	80

is lowered. Longer exposure to the high temperature produces a more lasting result, for after 75 days at 25° C. the plants remained turgid for 30 days at a temperature favourable to wilt. Table 7 compares the percentage of wilted plants which recover when transferred to a shaded house at an average temperature of 25° C. with that of similar plants transferred to an unshaded house at the same average temperature.

Plants in different stages of wilt were used, from a series where the wilt was just appearing to a series in an advanced stage after thirty days' wilting. All the plants recovered in the shaded house, but only a percentage recovered in that which was not shaded. The plants which did not recover in the unshaded house, being badly wilted ones, were probably desiccated before they had a chance to recover.

These observations appear to justify the conclusion that temperature is a most important factor, while shading is valuable because it assists the plant by reducing transpiration. The minimum, optimum, and maximum temperature for growth in pure culture of the strains of *Verticillium albo-atrum* utilized for the inoculations were 4·4° C., 23·3° C., and 30° C. respectively. It will be seen, therefore, that the optimum temperature for infection coincides approximately with the optimum temperature for growth in pure culture. *Verticillium* wilt is distinctly a disease of low temperature, and is most severe in spring and autumn.

Shade.—Shade, as we have seen, has a beneficial effect upon the resistance of the host to the disease. Probably this is due to retarded transpiration and consequently to the decreased rate of conduction of the water in the vessels, so that the toxic products excreted by the fungus are not carried up the plant in such large amounts.

Soil Factors.—Experiments carried out with soils of different types show that *Verticillium* wilt is not restricted to any particular soil.

Generally speaking, plants on soils which contain a large amount of humus yield a greater amount of disease than those growing on soils of a poorer nature.

Clay soils, in virtue of their greater water-holding capacity, are cooler than sandy soils, and plants grown upon them are more prone to wilt than those grown on the latter.

Control—Cultural Methods.

Cultural methods for the control of the wilt have been devised and have been tested with promising results.

It is commonly held by pathologists that plants exhibiting hard growth are more resistant to disease than the more succulent types, but observations on wilt disease show in this case the reverse to be true, the harder growing varieties succumbing more readily than the more succulent ones. The only variety, Manx Marvel, which so far has proved highly resistant to *Verticillium* shows a distinctly free growth with thick stems and large leaves.

It has also been specially noted that plants, starved in the early stages, or having suffered from a severe check, are highly susceptible. It has been mentioned previously that the average temperature of the air and soil are limiting factors in the incidence of the disease. The disease is first seen in spring, when the temperature is low, but with the coming of the higher summer temperature the wilted plants recover, and the percentage mortality of the plants infected in the spring depends upon the length of time the cold weather lasts.

The incubation period for the disease varies from eight to twenty days under favourable conditions, and complete wilt and death occurs in from six to eight weeks after the first symptoms appear, if conditions are favourable for the fungus. Should the temperature be sufficiently raised before the plant dies it will recover and produce a satisfactory crop during such time as the temperature remains high. Once the temperature drops in the autumn wilt reappears and the plant dies prematurely. Early summer temperatures, therefore, enable the plants to resist the fungus. It will at once be evident that good results may be obtained by artificially shortening the period of low temperature, and in glasshouses this may be done by increasing the boiler heat and closing down the houses in the middle of the day.

The following cultural methods for controlling the disease have yielded satisfactory results. As soon as the wilt appears and it is proved that *Verticillium albo-atrum* is the pathogen, the average temperature of the houses should be raised above 25° C. by suitably increasing the boiler heat, regulating the ventilation, and by closing down the houses from two to four hours in the middle of the day. A light dressing of whitewash on the glass makes the conditions still more favourable for the plants. As little water as possible should be given to the roots, as heavy watering merely aggravates the wilting, but a light overhead damping helps the wilted plants to recover. The plants should be encouraged to make fresh roots above the original diseased ones by placing fresh soil round the base of the plant.

In one case 68 per cent of the plants in a nursery were showing symptoms of wilt disease before the above methods were enforced, but a fortnight later only 10 per cent remained wilted. In view of the fact that low spring temperatures are favourable to infection by *Verticillium*, some advantage might be gained by planting later than normally, so that the higher summer temperatures may arrive by the time the plants have reached a stage suitable for infection.

Examination of the effect of soil type upon the incidence of the disease has shown that soils rich in humus yield a higher percentage of diseased plants than those of a poorer nature. Results obtained on the experimental plots at the Experimental Station, Cheshunt, confirm this, the greatest percentage of *Verticillium* wilt occurring on the plots receiving complete artificials with large amounts of dung.

Soils infected with *Verticillium* may be cleansed by sterilization with steam or formaldehyde.

VERTICILLIUM WILT OF THE CUCUMBER AND MELON

This disease is in every way similar to that of the tomato. The first symptoms are the wilting, yellowing, and desiccation of the lowest leaves, followed by similar effects upon successive leaves from the base of the plant to the top. Finally the whole plant hangs limp and dies. On cutting open the stem the wood is seen to be a yellowish-brown, which discoloration extends up the plant practically to the growing point, and *Verticillium albo-atrum* is readily isolated.

The disease is one of early spring and autumn, when the temperature is low, and is most destructive in cold houses and beds. Recommendations for the control of *Verticillium* wilt of the tomato are equally effective in the case of the cucumber and melon.

VERTICILLIUM WILT OF THE SWEET-PEA

During recent years growers who cultivate winter sweet-peas as a catch crop between the tomato seasons have been troubled by a wilt attributable to *Verticillium albo-atrum*. As in the case of other plants, the lowest leaves are first attacked—the fungus working rapidly up the plant, until the entire leaf surface is in a state of wilt, yellowing, and desiccation (Fig. 17). The wood is browned and the roots are in most cases entirely destroyed. The disease spreads rapidly, and the entire stock of plants may be destroyed within three weeks of the first appearance of the disease. In this case the disease progresses so rapidly in the plant, and the conditions of flowering are so restricted, that, except in special cases, the cultural methods of control advised for the tomato may have no value.

When the disease is slight it may frequently be checked by an application of "Cheshunt Compound," but in bad cases the soil should be sterilized by steam before planting.

Other Hosts of Verticillium albo-atrum.—Recent work has shown that *V. albo-atrum* attacks a wide range of plants, many of which are of interest to the commercial glasshouse grower. The writer has isolated this fungus from the following plants during the last three years: potato, tomato, cucumber, melon, sweet-pea, antirrhinum, and elm. Cross inoculations have demonstrated that the fungus from any one of these plants will infect all the others. Inoculations of cotton, egg-plant, capsicum, and sycamore with *V. albo-atrum* from the tomato have yielded positive results.

It is thus apparent that many external sources of infection exist, and these must be carefully guarded against if glasshouse crops are to remain healthy.

FUSARIUM WILT OF THE TOMATO.

While a number of soil *Fusaria* are frequently found causing rotting of tomato roots, having gained entrance through wounds made by soil insects and small animals, the true *Fusarium* wilt, due to *Fusarium lycopersici* Sacc. is comparatively rare in England. It occurs only at the height of the summer, when the soil temperature is sufficiently high to enable the parasite to function. The relatively low temperature of glasshouse soils in this country is suited to development of *Verticillium albo-atrum*, which grows best at a mean temperature of 21°–22° C., but is too low for *F. lycopersici*, which requires a mean temperature of at least 28° C. before it can do much damage. In America, however, the soil temperature in the chief tomato-producing regions is generally too high for *Verticillium* wilt, but is suitable for *Fusarium* wilt. American reports show that *Fusarium* wilt is well distributed over the southern states, extending up to Illinois, Indiana, Ohio, and New Jersey. North of this it is found only occasionally.

Symptoms of the Disease.—The external symptoms of *Fusarium* wilt are indistinguishable from those of *Verticillium* wilt. There is the same wilting, yellowing, and desiccation of the lower leaves, and the progression of these symptoms from the base of the plant upwards. Diseased plants have a stunted appearance, but the shortening of the internodes is more marked at the top of the plant than at the base, presumably because the low temperature which prevailed while the lower parts were developing kept the fungus in check. The root of the plant is affected by *Fusarium* wilt to a much greater degree than is the case with *Verticillium* wilt, and during the last stages of the disease the roots may be completely destroyed. Another distinguishing feature between this and *Verticillium* wilt is the colour of the infected wood inside the plant. In *Verticillium* wilt the light brown colour of the affected wood extends practically to the growing point, while in *Fusarium* wilt, the colour usually ends at least a foot below, and in most cases does not extend so far. The colour of the wood in *Fusarium* wilt is a much darker brown, and in the root is almost black. The fungus passes from the main stem, through the leaf traces into the leaves, and occasionally reaches the fruit. No fungus growth appears outside the stem until the plant is dead, when a pink growth forms round the basal parts. A similar outgrowth appears in the case of *Verticillium* wilt, but the colour is white at first. It is not always possible to distinguish between the two diseases in this way, as saprophytic *Fusaria* often produce a pink growth over that of *Verticillium*.

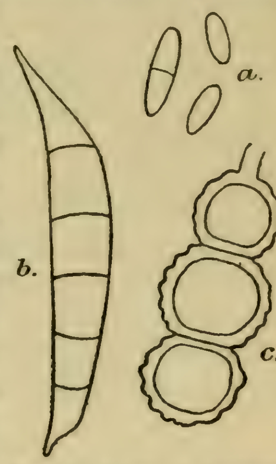

FIG. 18. Spores of *Fusarium vasinfectum*: (*a*) microspores, (*b*) sickle spores (*c*) chlamydospores.

Causal Organism.—The disease is due to *Fusarium lycopersici* Sacc., which name was first given by Saccardo to a fungus he found growing upon decaying tomato fruits. The genus *Fusarium* produces three kinds of spores or conidia (Fig. 18). One kind are very small microspores, others are larger and sickle-shaped with three or four cross walls, while the third type consists of thick-walled chlamydospores, or resting spores, which enable the fungus to exist through unfavourable conditions.

Fusarium lycopersici is able to live as a saprophyte in the soil, and while it is known to have remained there for three or four years in the absence of a tomato crop, there is no reliable data as to limit of its saprophytic existence. It has long been known that heavy dressings of caustic lime tend to produce a considerable reduction in *Fusarium* wilt.

Temperature Relations.—Inoculation experiments conducted under different temperature conditions have demonstrated that temperature is a limiting factor in this disease, just as it is in the case of *Verticillium* wilt. Infection is most successful, and the disease develops most rapidly at a soil temperature of 29° C., while little infection occurs if the temperature remains constantly much below this.

Control of the Disease.—In a climate like ours, which is unfavourable to the disease, it may be controlled by reducing the temperature of the soil and the air, but in favourable climates control is dependent upon efficient soil sterilization by heat or formaldehyde or the raising of resistant varieties of tomato plants.

FUSARIUM WILT OF THE CUCUMBER AND MELON

The temperatures of the soil and atmosphere in which these plants are cultivated are more favourable to *Fusarium* wilt than those of a tomato house. In consequence this disease is not uncommon in this country.

The symptoms are much the same as in the previously described wilts. In slight cases of the disease, when the plant possesses high resistance, the symptoms may be that of stunted growth and a reluctance "to break" on the part of the laterals; but as these symptoms can be due to unsuitable physical conditions of the bed, this stage of the disease may frequently be overlooked. Later, the lowest leaves become affected and soon the entire plant wilts. On cutting open the stem the wood is seen to be of a reddish-brown colour.

The disease is due to *Fusarium vasinfectum* Atk., var. *niveum* Sm. (4). At the present time no treatment is known whereby infected plants may be induced to recover their turgidity. Elimination of infection is important if the disease is to be controlled, and infected soil should not be planted again unless it has been sterilized by heat or with formaldehyde. In cases where occasional plants are attacked they should be removed immediately, taking up at the same time all the root and a ball of soil a foot in diameter. The hole should be filled with a mixture of five parts soil and one part lime and replanted. Watering with "Cheshunt Compound" at the time of planting is an extra precaution which has proved beneficial.

CHAPTER V

DISEASES DUE TO FUNGI (*Continued*)

3. Stem, Leaf, and Fruit Diseases

(*a*) STEM DISEASES

Sclerotinia Stem Rot.—While this disease appears regularly every year, it ranks as one of the least important of the diseases of glasshouse plants. *Sclerotinia sclerotiorum* Massee (30) is the cause of the disease, and attacks a wide range of host plants, including beans, cabbages, carrots, chrysanthemums, cucumbers, melons, petunias, potatoes, sweet-peas, turnips, and zinnias. Plants are generally attacked at the soil level, where a white mould develops on the stem and also spreads into the soil. The fungal hyphæ grow rapidly into the plant, choking up the conducting vessels and disorganizing the softer tissues. The pith is destroyed and a hollow cavity produced. Rotting of the stem progresses steadily up the plant until some six inches may be involved. Diseased plants show all the common symptoms of wilt, and soon die. Following the decay of the stem, small, soft, white bodies may be found embedded in the white mould. These vary in size from a sixteenth of an inch to a quarter of an inch in diameter, and eventually dry, becoming hard and black (Fig. 19). Such bodies, which are the sclerotia or resting forms of the fungus, are found within the hollow stem as well as on the outside. Tomato and cucumber stems are frequently attacked high up from the ground, especially on the angles between the leaves and the stem, which hold moisture, and so provide

FIG. 19. *Sclerotinia sclerotiorum* on the cucumber, showing typical sclerotia. [*Facing page 88*

suitable conditions for the growth of fungus reproductive bodies which may settle there. All diseased plants should be removed and burned, for if they are allowed to lie and decay in a heap or on the ground the sclerotia will fall out of the stems into the soil. In the following spring the sclerotia give rise to several brown funnel-shaped structures with long slender stems. These ascophores, as they are called, produce innumerable spores, which if carried by the wind to a susceptible host plant will cause disease. The cucumber is more susceptible to this disease than is the tomato, and in the case of the latter crop a virulent outbreak is a sign that something is wrong with the physical factors in the plant's environment. In bad cases sterilization of the soil will destroy the disease organisms, but generally it is sufficient to water the soil with a solution of "Cheshunt Compound" before planting. When the disease appears the base of the affected plants should be watered with this solution, as also should the neighbouring healthy plants.

Stem "Canker" of the Tomato.—This disease became of serious importance to the tomato industry during the early part of the present century. It was at first attributed to a fungus, *Mycosphærella citrullina* Grossenb., described as the cause of a stem disease of the melon in America. Brooks and Searle have recently shown that the fungus was incorrectly identified and is really *Diplodina lycopersici* Cooke, Holtos emend., Brooks and Searle (13).

About 1909 the disease had reached its maximum virulence, and was extremely dangerous, but since then it has decreased in power, until at the present time it exists only in isolated places. Attention is first drawn to the disease by the wilting of the affected plant. Examination of the base, where the fungus infection commences, shows the tissues to be waterlogged and pale in colour. Later the affected portions become grey and finally black. The diseased stem becomes shrunken, cracked, and generally exhibits a canker-like appearance (Fig. 20). Innumerable minute black pimples may be seen on the surface of the lesions. These are flask-like vessels called pycnidia, which contain many tiny spores, by means of which the disease is able to spread.

During its most destructive years the disease was extremely virulent. Affected plants died quickly and infection spread with alarming rapidity. Diseased plants should be at once removed and burned, and of recent years a solution of "Cheshunt Compound" has proved useful in preventing the spread of the disease from plant to plant. Sterilization of the soil by means of steam has proved successful in eliminating the disease from infected nurseries.

A similar disease of the cucumber and vegetable marrow has been reported in this country, and Massee demonstrated that the fungus from the tomato was able to infect these plants also.

Botrytis Stem Rot.—This disease is common to many plants grown under glass, and is especially important in the case of the tomato. Under conditions of excessive humidity *Botrytis* sp. attacks badly pruned leaf bases of the tomato and, gaining strength by feeding on this half dead matter, works into the healthy stem tissues, destroying the cortex, vascular ring, and pith in turn, and by cutting off the water supply to that part of the plant above the point of attack causes it to wilt.

The first signs of disease are the appearance of grey, sunken areas on the stem, generally round a ragged wound or half dead leaf base. The lesion slowly enlarges and may finally extend from six to twelve inches along the stem and girdling it (Fig. 21). Once the stem is attacked the plant can be saved, but only by cutting out all the browned tissue and rubbing the wound thus made with a moistened lump of liver of sulphur or a crystal of copper sulphate.

The disease may be prevented by careful pruning,

FIG. 20. Tomato stems showing "cankers" made by *Diplodina lycopersici.*

FIG. 21. *Botrytis* stem rot of the tomato, showing typical lesions at *a* and *b.*

[*Facing page 90*

defoliation, and regulation of the atmospheric humidity by efficient ventilation. When removing side shoots and unwanted leaves, the cuts should be clean, and made close to the main stem, when they will rapidly heal over. If stumps are left, these do not heal over, but shrivel and die, affording suitable places of entrance to the fungus. When the fruit has been picked from the lower trusses the plants should be defoliated from the base to the lowest unpicked truss to allow the air to circulate freely through the plants. In bad cases it may be necessary to spray the stems with a 2 per cent solution of calcium bisulphite to destroy the spores of the fungus and so lessen the risk of infection. Carnations, chrysanthemums, and roses under glass are subject to this disease, the conditions of infection and control being the same as in the case of the tomato.

Stem Canker of the Rose.—The symptoms of this disease are large, cankered wounds frequently found on rose stems. The lesions are brown in the centre, with a black border, usually surrounded by a reddish zone. The disease, caused by *Coniothyrium Fuckelii* Sacc., first appears as small, reddish patches on the young wood. Later, cracks develop at the infected points, and increase in size, becoming extended and distorted by the production of callus until the typical canker is produced. Examination with a lens readily shows the presence of minute black bodies scattered over the surface of the canker; these are the pycnidia or fruit bodies of the fungus. Infection takes place on the tender shoots or through wounds made in older parts of the plant. All infected parts should be removed and burnt at once if the disease is to be controlled.

Rose Graft Disease.—Recently a rose graft disease, caused by *Coniothyrium rosarium*, has been described by Vogel (51) in America. The disease attacks the scion at the union, and speedily causes wilt and death. The lesions are light yellow water-soaked areas at first, turning dark brown later. The epidermis becomes loosened and changes from dark brown to a light brown colour. Minute black pycnidia are produced on the light brown areas. In some cases only one side of the graft is attacked and the plants do not appear to have suffered, but when taken into rose houses they are instrumental in spreading the disease. If possible, resistant varieties should be grown.

(b) LEAF DISEASES

Leaf Diseases of the Cucumber.—Under the name " Spot Disease " the commercial cucumber grower groups all the leaf diseases of that plant. The most important of these in this country are those caused by *Cercospora melonis* Cke., and *Colletotrichum oligochætum* Cav., while under conditions of abnormally high humidity *Cladsporium cucumerinum* E and A may be a destructive parasite. In spring *Alternaria Brassicæ*, var. *nigrescens*, may damage the lowest leaves, and *Erysiphe polygoni* D.C. may be destructive at low temperatures.

Cercospora Leaf Spot.—During the years 1896 to 1907 *Cercospora melonis* appeared in the Lea Valley in this country and caused considerable destruction, but the advent of the immune variety, Butcher's Disease Resister in 1903, and the application of methods of soil sterilization, led to its ultimate disappearance. At the present time the *Cercospora* disease exists only in isolated parts of Great Britain.

Instances are recorded of the entire crop in houses one hundred feet long containing ninety-six plants per house being completely destroyed in four to six days after the disease made its first appearance.

The first sign of the disease is the appearance on the upper surface of the leaves of tiny pale green, water-soaked spots. These rapidly increase in size and number and coalesce, turning grey at first and afterwards becoming an ochreous-brown colour. The spots are definite in outline, irregular in shape, and may be distinguished readily from other leaf spot diseases. Frequently the entire leaf withers within the space of forty-eight hours after infection.

An examination with a pocket lens of the upper surface of a "spot" shows the presence of brown erect fungal filaments, bearing conidia at their tips. These conidia are comparatively large, cylindrical in shape, but narrowed towards one end, and each possesses seven to nine cross walls (Fig. 22). Infection spreads rapidly, the conidia being easily blown about the house, as well as being transported by the workers, insects, and by the process of overhead damping.

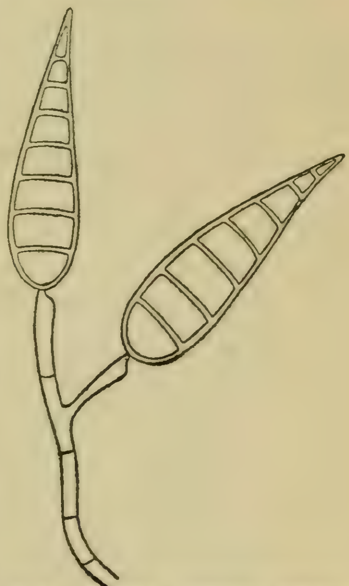

Fig. 22. Spores of *Cercospora melonis*.

The disease can only attain epidemic proportions under conditions of high temperature and humidity, but rapidly growing, sappy plants are more susceptible to attack than slow growing plants with harder tissues. It has been observed that the tops of badly diseased plants grow away clean if by any chance they pass through the ventilators into the open air. Similarly, cucumbers grown under frames or in the open air are not attacked by this disease.

The control of the disease depends very largely upon the humidity of the glasshouse atmosphere, and efficient ventilation readily checks it by drying out the moisture from the house. All diseased leaves should be at once removed and burnt, for if these fall upon the damp earth they become covered with a fungal growth bearing innumerable spores, and so constitute a constant danger as a source of infection. Spraying with a solution of liver of sulphur and flour paste is recommended as a means of control in severe cases.

Colletotrichum Leaf Spot or Anthracnose.—In its commonest form this disease first attacks the leaves, and may appear at any time during the life of the plant. It has occasionally been observed during the propagating period, but generally it does not appear until March or April, when the plants are well established in the house and some fruits have been cut. The time at which the plants are attacked bears no relation to their age, but is determined by the presence of suitable sources of infection. On the leaves the spots are washed into the hollows of the leaf surface by the process of overhead damping. The lesions commence as pale green water-soaked spots, barely distinguishable by the untrained eye, but quickly assume a characteristic appearance, becoming dry and reddish-brown in the centre with a yellowish water-soaked surrounding zone (Fig. 23). The lesions vary in shape from an almost circular spot in areas untouched by any large vein to irregular amœboid patches where they form over a vein. The spots frequently crack in the centre, and the desiccated tissue may not infrequently be beaten out by the daily overhead damping. The spots increase rapidly in size, become more circular and blotch-like, finally coalescing, and the leaf dies. At the final stage the leaves have a scorched appearance and are covered with spots. Microscopic examination shows the presence of numerous minute acervuli bearing spores and setæ on the upper surface of the leaf.

As the disease advances lesions develop on the leaf petioles and stems, showing as sunken, water-soaked areas at first, but rapidly becoming dry and powdery. At first they are usually linear in shape, but may spread round the stem, and under glasshouse conditions it is not

FIG. 23. Cucumber "leaf spot" caused by *Colletotrichum oligochætum.*

FIG. 24. *Colletotrichum oligochætum* growing on cotton-wool, straw, and wood.

[*Facing page 94*

uncommon to see the soft tissues of the stem completely destroyed, leaving the vascular bundles exposed as dry fibres, and causing the death of the plant above the point of attack. On stem and petiole lesions, sporulation is abundant, a pinkish colour being produced, which turns black with age.

The lesions on the fruits appear as pale green water-soaked, sunken areas, the surface of which, owing to abundant spore production, become pink in colour and finally black. The tissues under the lesion are destroyed and a cavity is produced, and this is exposed by the cracking of the surface above. When the leaves are attacked the health of the plant is impaired only by the serious reduction of leaf area, but lesions on the stem are more serious and may cause the rapid death of the plant by destroying the tissues.

The cause of the disease is a fungus, *Colletotrichum oligochætum* Cav., which has been shown by experiment to thrive upon such materials as new and rotten wood, straw, cotton wool, and paper, provided these are kept suitably moist (Fig. 24). Further tests have proved that following a severe outbreak of the disease the causal organism may tide over the winter by a saprophytic existence in various parts of the glasshouses. As the result of investigation (7), the following main conclusions have been arrived at:

(1) The present methods of cleansing glasshouses during the winter months are not sufficient to exterminate centres of infection of *Colletotrichum oligochætum*, which may exist from a previous diseased crop.

(2) Infection is more abundant immediately after the diseased crop has been removed than after the period of winter rest, but sufficient survives to carry the disease over from one season to another.

(3) The fungus may live occasionally in the debris which collects in the overlap between two panes of glass, but except in old houses this does not form an important source of infection.

(4) The fungus may carry on a saprophytic existence in rotten wood in the house and in paper used for blocking holes, and these constitute important sources of infection.

(5) Straw manure removed from beds in infected houses was found invariably to harbour the parasite, and when allowed to remain unburnt in a heap outside the houses is a centre for the spread of the fungus.

(6) The examination of "flats" was unsuccessful in obtaining positive evidence of their transmission of this fungus, but observations upon the incidence of this disease in commercial nurseries indicate the probability that it may frequently be carried in this way.

(7) Manure fresh from country farms has proved to be free from infection with this organism.

(8) Heaps of manure placed adjacent to those of decaying cucumber remains have been found to be infected.

(9) Manure direct from town stables has in some cases been found to be infected.

Other important sources of infection are the water supply and the clothes of workers in the infected nurseries, the latter having been found to be a most important method of disease transmission in the Lea Valley.

As in the case of the *Cercospora* disease, humidity of the atmosphere has proved to be an important factor in the progress of the disease, which is considerably more rapid at humidities about 90 per cent than at those below 60 per cent.

During the fallow season the fungus is known to hibernate in various parts of the houses. This being so, the efficient cleansing of the houses forms an important part of the control of the disease. Fumigation by burning sulphur has not proved efficient in this respect, and it is necessary to wash down the structure with emulsified cresylic acid, as explained in Chapter IX.

Of the many spray fluids tested, those of liver of sulphur or lime sulphur have yielded the most promising results. One essential quality of first-class fruit is the presence of a perfect "bloom" on the surface, and in consequence commercial growers hesitate to use any spray which destroys this "bloom" or spots the fruit.

Copper compounds have a tendency to do this, and cannot be recommended.

The foliage of the cucumber is difficult to wet thoroughly with ordinary aqueous solutions, and the addition of an efficient spreader is necessary. Flour paste has proved satisfactory in this respect and is therefore recommended. Liver of sulphur and flour paste or lime sulphur and flour paste, the preparation of which is described in Chapter IX, have proved satisfactory for checking the spread of the disease during the growing season. To be quite effective they should be used in the early stages of the disease, before the fungus has attacked the succulent petiole and stem tissues. Generally one or two plants are first attacked, and it is better to sacrifice these than to endanger the rest of the plants by allowing the diseased individuals to remain untreated.

When the disease first appears the plants should be thoroughly sprayed with either of the mixtures recommended, and on the next day every "spotted" leaf should be cut out and burned. This process of spraying and removing the diseased leaves should be repeated again at weekly intervals, but generally two applications are enough if the fungus has not entered the petioles or stems. Spraying should be carried out only in the cool of the evening, and the next morning the plants should be thoroughly sprayed with water to remove any surplus spray liquid that may have remained on them, and a little ventilation should be allowed. Care should be taken to see that the houses are well shaded, as after this treatment direct sunlight may give rise to scorching. The effect of the spray on cucumber plants is slight if careful attention is given to the above precautions. Occasionally the spray burns a newly opened leaf or tendril but rarely does any appreciable damage. If the fungus is allowed to get a strong hold upon the petiole or stem tissues it is increasingly difficult to check the disease permanently. Its spread may be stopped for a time, but as only the spores and spore-bearing hyphæ on the outside of the plant are killed the hyphæ within the stem grow out in time and produce masses of spores which are rapidly carried about the house and the disease again appears. In these cases it is advisable to take out the diseased individuals and replant the house after thoroughly cleaning it.

The latter may be done by means of a cresylic acid emulsion, after which cleansing planting must be deferred for a fortnight; or else by a solution of liver of sulphur at the rate of 6 lbs. in 100 gallons of water, or lime sulphur at the rate of 3 pints per 100 gallons. When liver of sulphur or lime sulphur is used the house may be replanted in twenty-four hours.

Dusting with sulphur powders has been proved to check the disease, but a complete control has not been obtained by this means.

Much can be done to prevent and control the disease by providing the best cultural conditions for the plants. The disease assumes its worst form, and spreads most rapidly, when the atmosphere of the house is badly ventilated and saturated with moisture, and also when there is a marked difference between the day and night temperatures in the houses. The conditions which best enable the plants to resist the disease may be summarized as follows:

Plants should be grown steadily from the beginning, without any attempt at forcing, and a little air should be given whenever outside conditions will allow. The atmosphere of the houses should never be stagnant or saturated with moisture for long periods, and efficient circulation of air should be encouraged by suitable ventilation. The beds should never be cold or sour, and careful attention should be paid to the maintenance of constant day and night temperature.

Cladosporium Leaf Spot.—Cladosporium cucumerinum

E and A., described later (page 117) as the cause of a disease of cucumber fruits, has been found to cause a spotting of the leaves under conditions of exceptionally high humidities constantly maintained for long periods. Innumerable, small, light-brown, irregular spots are produced on the leaves, which are ultimately destroyed.

Usually the disease does not attack the leaves, but on the rare occasions when it is present the attack may be checked rapidly by reducing the amount of moisture in the atmosphere.

Alternaria Leaf Spot.—This disease, caused by *Alternaria Brassicæ*, var. *nigrescens*, not infrequently appears during the early part of the season. The lowest leaves are attacked, and dead, reddish-brown spots, circular in shape, are produced on the leaves. Such spots frequently possess faint concentric growth rings, and are not unlike the spots produced by *Colletotrichum*.

Powdery Mildew.—This disease, caused by *Erysiphe polygoni* D.C., is not infrequently found in cucumber houses, but it rarely reaches a serious stage. It appears as small, greyish, water-soaked spots, on the upper surface of which fungal growths soon appear, giving them a white, mealy appearance (Fig. 25). Under suitable conditions the isolated spots rapidly extend until the whole surface of the plant may be covered with a white powdery, fungal growth. Excessive watering, insufficient ventilation, and irregular temperatures, combined with insufficient light, provide favourable conditions for the disease. In this country the disease appears chiefly in winter and may be controlled by providing suitable ventilation so as to dry out the atmosphere of the house, reducing the water supply, and improving the conditions of lighting. Dusting with sulphur powders is of considerable assistance in controlling the disease.

Downy Mildew.—This disease, at present unknown in this country but important in America, is caused by *Pseudoperonospora cubensis* (B and C) Rost. When the air is very moist and warm the disease appears on the leaves as ill-defined yellow spots, which rapidly run together and cause the leaves to turn yellow and die. At low temperatures the progress of the disease is considerably less rapid. The disease attacks the old leaves first, but rapidly spreads over the entire plant, which produces only a few small, misshapen fruit.

When the disease appears all overhead damping should cease and the foliage should be kept dry. Spraying with Bordeaux Mixture is recommended in America as being an efficient means of control.

Tomato Leaf Mould.—The most important leaf disease of the tomato in this country is that caused by *Cladosporium fulvum* Cke., and variously named "mildew," "rust" and "leaf mould" (Fig. 26). The term "mildew," which is most commonly used, is unfortunate, as most mildews are whitish in appearance, and the most suitable name would seem to be "leaf mould," for diseased leaves possess a typical mouldy appearance.

The first sign of the disease is the appearance of a pale olive-buff, downy growth in local spots on the under surface of the leaf. A little later the top surface of the leaf immediately above the diseased spot turns a pale yellow colour which merges gradually into the green colour round the spot. As the disease progresses, the yellow colour of the top surface turns a deep ochre-yellow, finally becoming reddish-brown when the leaf tissue is killed.

The fungus growth on the lower surface of the leaf changes colour as the disease progresses. From the original pale olive-buff it becomes tawny-olive and finally purple when the leaf tissues are dead. The infected areas soon begin to die, and the fungus growth covering the dead tissues assumes a violet-purple colour.

As the first infected parts of the leaf are the first to

FIG. 25. Powdery mildew of the cucumber.

FIG. 26. Tomato "mildew" caused by *Cladosporium fulvum*, showing the fungal masses on the underside of the leaf. [*Facing page 100*

die a very pretty effect is frequently seen on the under surface of the leaves where violet-purple areas are surrounded by the tawny-olive zones of the later infections. The fungus spreads rapidly over the leaf, which soon shrivels up and hangs as dead tissue covered with a fungus growth producing innumerable spores. In bad attacks the spores are so numerous and so easily dislodged from the leaves that by shaking the plants the air may be filled with them. It will readily be seen that infection may be both abundant and rapid. Generally the disease does not appear until July or August, but under specially favourable conditions, which are largely climatic in origin, it has been observed as early as April. Under normal conditions the older and more succulent leaves are first attacked, the disease passing from the lower parts of the plant to the top, but in severe attacks even the young leaves are attacked almost as soon as they are unfolded. The fungus occasionally attacks the flowers and young fruit, and while large fruit are uninjured those below the size of a pea have frequently been found to contain the filaments of *C. fulvum*. In severe cases the entire flower may be attacked and destroyed. Infection takes place by means of the stomata, through which the germ tube from the spore passes into the interior of the leaf.

The effect of the disease upon the plant varies with the extent of the disease, which is again dependent upon the atmospheric conditions of the glasshouse. In slight attacks the old leaves only are attacked, and as these are being continually removed in the cultural process of defoliation, little injury is done to the plant. In severe cases the reduction in leaf area resulting from the action of the parasite is so great that the plants are weakened to a considerable degree, fruit production ceases, and the plants die prematurely.

The extent and progress of the disease varies with the conditions of light, humidity, and temperature of the glasshouses. Light is unfavourable to the rapid development of *C. fulvum*, laboratory experiments having shown that the rate of growth is much slower in well-lighted conditions than in the dark. The minimum growth temperature is approximately 9° C., the maximum temperature 30° C., while the most favourable temperature lies between 20° C. and 25° C. The fungus also grows best when the atmosphere is rich in moisture. Such facts are confirmed by observations in commercial nurseries, where outbreaks have generally occurred after periods of dull, humid weather. Also, those parts of a house or block of houses where the heat and water vapour tend to accumulate are notable as places where the disease first appears and spreads most rapidly. Thus a block of houses without dividing partitions, if built on a severe slope, develops leaf mould first at the highest level, where the heat and moisture accumulate. This can be obviated by interposing dividing partitions at intervals through the block. The disease also appears first at any spot in a house where the air tends to be stagnant and moisture accumulates. Any departure from a uniform level of the soil surface by the formation of hollows and depressions provides sufficiently moist conditions for *C. fulvum* to develop.

The disease is best controlled by providing a dry atmosphere for the plants, efficient ventilation and circulation of the air being important factors in this respect. It is equally important to trim the plants so as to allow the air to circulate freely between the leaves. Spraying with liver of sulphur and lime sulphur have been recommended as a means of control, but under commercial conditions it is practically impossible to do much good by spraying, for the dense foliage and height of the plants render a complete wetting of the plant surface an almost impossible process.

Dusting with sulphur powders helps to keep the disease in check, but is by no means a cure for it. Under commercial conditions the most convenient method of checking the progress of "leaf mould" is to vaporize with sulphur at regular intervals by means of a mechanical vaporizer and to provide efficient ventilation.

Leaf Spot Disease of the Tomato.—This disease, due to *Septoria lycopersici* Speg., is described as being a serious one in America, but fortunately it has not yet appeared in this country. It can easily be recognized by the appearance of numerous spots with light grey centres and dark margins. Levin (28), who carried out a careful investigation of this disease, describes the symptoms as follows:

"The earliest indication of the disease is a water-soaked spot which can be distinguished with a hand lens on the underside of the leaf. There is no noticeable discoloration of the tissue at the outset. As the spot grows larger it becomes more or less circular in outline and shows a definite margin. The affected tissue darkens, becomes shrunken, and later appears hard and dry. The colour of this spot may vary from black to greyish-white. The spots may vary in shape and size from a small circular spot of pin-head size to a large irregular spot of about 2 cm. in diameter. Not infrequently the spots coalesce. While the tissue is shrinking three to ten small, black, glistening pycnidia appear in the spot. Finally, yellowish mucilaginous masses can be seen exuding from the pycnidia. Upon microscopic examination these are found to be masses of long, filiform spores. The number of pycnidia are well defined, visible with the naked eye, and separate. Pycnidia may occur on the underside of the leaf; usually, however, they occur on the upper side. At this point it must be noted that not all spots contain pycnidia when the leaf dies. This point will be taken up in detail later.

"About the time of spore exudation the green tissue of the leaflet contiguous to the fungous spot begins to turn yellow. This yellowing increases, eventually involving the entire leaflet. Then the fungous spots which have been so far pliable become dry and brittle. The leaflets gradually droop and dry on the stalk, which later also shrivels up but remains attached to the stem until broken off by a slight jar. On tomatoes which are staked the disease is sometimes confined to the lower leaves. Where the plants are allowed to trail at will the disease may cause almost complete defoliation of the plant, the small tufts of young terminal leaves alone escaping.

"The disease is commonly found on the stems. It is manifested by small, slightly elongated, dark spots containing pycnidia. These spots are not so clearly defined as those on the leaf. The damage to the stem is slight; these spots do not enlarge to form cankers and are not serious except in so far as they produce spores for further infection.

"Small spots, more or less elongated, occur on the calyx, and take a form intermediate between those on the leaves and stems."

It may be remarked that the difference in form of the spot are doubtless due to the texture of the host.

A moist atmosphere and temperatures of 25° C. to 30° C. are favourable to the disease. The fungus will not grow at a temperature of $37\frac{1}{2}$° C., and ten days' exposure to this temperature has been found to prevent any further growth even when the temperature has been reduced to the optimum. Control measures recommended include efficient ventilation, spraying with Bordeaux Mixture, and the enforcement of strict sanitary conditions.

Carnation Rust.—This disease, which is probably one of the commonest diseases of the carnation, is caused by a fungus, *Uromyces caryophyllinus* (Schrank) Wint., and has been known in Europe for more than a century. Rust is easily recognized by the blisters or sori which are produced on the leaves and stem (Fig. 27). These are at first covered by the epidermis of the leaf, but this is eventually ruptured, and masses of brown spores are exposed. The disease begins at the lowest leaves, but under favourable conditions it spreads rapidly over the entire plant. Affected leaves turn yellow round the diseased spots and ultimately curl and die. While few glasshouses are entirely free from rust it only becomes a serious trouble when the temperature is excessively high and the plants are over-watered. When the leaves at the base of the plant are continually moist ideal conditions for spreading the disease are produced. Thus

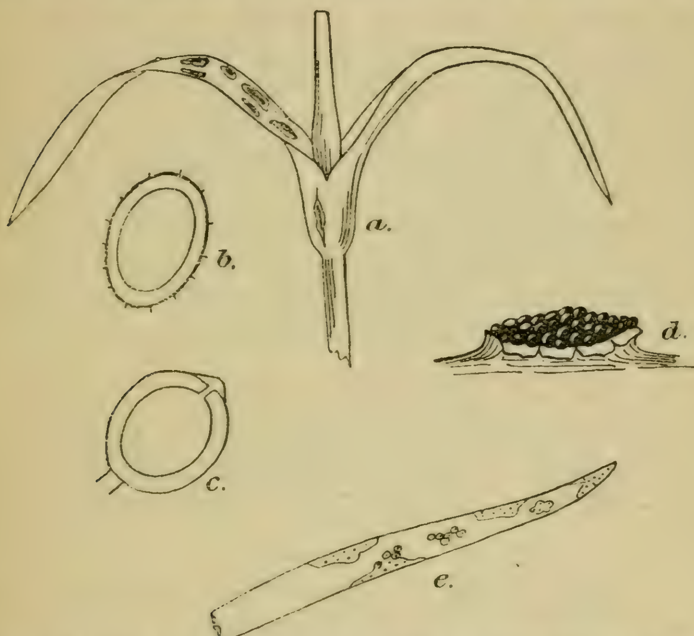

FIG. 27. (*a*) Rust of the carnation, (*b*) uredo-spore, (*c*) teleuto-spore, (*d*) spore mass, (*e*) stigmonose of the carnation.

where rust is prevalent it is advisable to keep the lower foliage off the ground by wire netting supports, bent in the shape of an inverted V, placed between the rows.

Rust is spread each year by means of cuttings taken from diseased plants, and in consequence it is necessary to propagate from healthy plants only. Sponging the leaves with a solution of potassium permanganate has been recommended as a means of checking the disease, while spraying with liver of sulphur and flour paste solution has proved useful in severe cases. Careful attention to cultural conditions and an avoidance of high temperatures and excessive watering, combined with careful selection of cuttings, are usually sufficient to prevent the disease from reaching abnormal conditions, so that spraying should not be necessary.

Septoria Leaf Spot of the Carnation.—This disease is caused by *Septoria dianthi* Desm., which produces light brown areas on the leaves and stem of the carnation. Most commonly the lower portion of the leaves, especially the sheathing base, is attacked, and this causes the leaves to bend downwards. Diseased leaves also frequently become much shorter and curl longitudinally. Diseased areas on the stems are generally found between the nodes. When the tissue has died as the result of the fungus attack, numerous tiny black spots may be seen scattered over the surface. These are the pycnidia or fruiting bodies, which contain masses of long, narrow, septate spores.

Under normal glasshouse conditions the disease is rarely serious, being checked by efficient ventilation and careful watering. Spraying with liver of sulphur or dusting with sulphur powders is recommended as a means of control.

Leaf Mould of the Carnation.—The symptoms of the disease, which is caused by *Heterosporium echinulatum* Berk., are recognized by the production on the leaves of small, pale grey spots about an eighth of an inch in diameter. The spots become covered with a dense mat of fungal growth, which assumes a grey and finally a light brown colour. Numerous olive-coloured spores covered with tiny warts are produced on the spots. The method of control recommended is the same as for "leaf spot."

Macrosporium Leaf Spot of the Carnation.—Some varieties of carnations suffer from a disease of the leaves and stems due to *Macrosporium dianthi* Stevens and Hall. Pale grey, circular or elongated spots, the centres of which are covered with a black fungal growth, are produced, and may cause the death of the leaves and even the stem, but usually only the leaves are attacked.

Low temperatures and an excess of moisture in the air should be avoided. All diseased leaves should be removed and burned. Spraying with Bordeaux or Burgundy Mixture is recommended as a means of control.

Powdery Mildew of the Carnation.—Occasionally this disease, due to a species of *Oidium*, is found on carnations in this country. White, powdery patches appear on the leaves, also the calyx and corolla of the flower. Good cultural conditions are sufficient to control this disease in the early stages, but in severe cases dusting with sulphur powders or spraying with liver of sulphur may be necessary. Mercer (34) reports Alington, Bridesmaid, and British Triumph as being specially susceptible varieties.

"*Die Back*" *of the Carnation.*—Frequently badly cut stems and flower stalks do not heal but die from the cut end towards the main stem (Fig. 36, facing p. 132). Affected portions first turn a pale yellowish-green, then become yellow and die. A fungus belonging to the genus *Fusarium* is responsible for the disease, having gained entrance through the wound. Soft, rapid growth; overcrowding; and high temperatures favour the disease. Care should be taken to make clean cuts, and overhead spraying should be performed in the morning so that the foliage may be dry before night. All diseased portions should be cut away at a point in the healthy tissue at least two inches away from the apparent dead parts. The removed pieces should be burned immediately.

Rust of Chrysanthemums.—This is a very common trouble with chrysanthemums, and is similar in nature to the rust of carnations. Small blisters are produced beneath the epidermis of the leaf, and with age the epidermis bursts and breaks away leaving a mass of tiny rust-brown spores (Figs. 28, 29). Thus typically infected leaves are densely spotted with tiny rusty pustules, the majority of which are formed on the underside of the leaf. At one time it was thought that the rust of chrysanthemums was the same as that which attacks a large number of plants of the same family, but Arthur has shown that it is not so, and that the chrysanthemum rust will not attack any other plant. This disease is caused by *Puccinia chrysanthemi* Roze.

It is carried from season to season by means of cuttings and old stock plants, and it is important that cuttings should be made solely from healthy stock. Dusting with sulphur powders is generally practised as a means of keeping the disease in check. Under glass it is rarely serious, and in fact need not be feared by careful growers, as attention to ventilation, careful watering, and selection of stock is sufficient to effect a control. The disease is frequently imported on new stock, which should be carefully examined for signs of it. Miss Clay Frick (white), Niveus (white), W. Duckham (pink), and W. H. Lincoln (yellow) have proved to be highly susceptible to rust. Cheshunt White, Heston White, Ivy Gay (mauve-pink), Kathleen May (red), Mrs. Henneage (yellow), Nagoya (yellow), Mlle. R. Pancouche (white), Romance (yellow), and Winter Cheer (pink) are moderately susceptible. Baldock's Crimson, Gladys Lane (bronze), Hortus Tolosanus (bronze), Mme. R. Oberthur (white), Tuxedo (bronze), The Favourite (white), and Winter Gem (yellow-bronze) have proved highly resistant.

Chrysanthemum Leaf Blight.—This disease, caused by *Cylindrosporium chrysanthemi* E. and D., makes rapid progress once a plant is attacked. It is not common in this country, but when it occurs serious damage results. Large dark brown patches are formed on the leaves. The tissues round the patches turn yellow and the leaves

FIGS. 28 and 29. Chrysanthemum rust, showing the dark spore masses.

[*Facing page 108*

soon die and hang down the stem. Tiny heaps of spores are produced on the diseased areas on both sides of the leaf. Control is a difficult matter, and infected plants should be destroyed immediately. Spraying with a copper fungicide is recommended as a means of protecting the healthy plants.

Powdery Mildew of the Chrysanthemum.—Chrysanthemums grown under glass frequently suffer from this disease, due to *Oidium chrysanthemi* Robh. The leaves become covered with a white, powdery, fungal growth. The presence of the disease is conditioned by a moist atmosphere, and attention to ventilation and the massing of the plants so as to encourage an efficient circulation of air will do much to limit its development. Dusting with sulphur powders or spraying with liver of sulphur and flour paste has proved successful in checking its rapid spread.

FIG. 30. *Septoria* leaf spot of the chrysanthemum: (*a*) diseased leaf, (*b*) a pycnidium, (*c*) spores.

Chrysanthemum Leaf Spot.—*Septoria chrysanthemella* Cav. (Sacc.) causes a leaf spot disease of the chrysanthemum (Fig. 30) which is distinguished by the presence of small dark brown spots, bearing pycnidia or fruiting bodies which show as minute black points. The spots grow rapidly and coalesce, causing the leaves to curl at the edges and to fall prematurely. Leaf spot is not a common disease in this country, although it has been recorded several times. In America and Europe it is well known to growers. Diseased leaves should be removed and burned, and the plants sprayed with liver of sulphur.

Downy Mildew of the Rose.—This disease, while common on glasshouse roses, is somewhat difficult to detect. Frequently young plants appear to lack vigour for no obvious reason, but a careful examination of the leaves reveals the presence of minute fungal filaments. The causal organism, *Peronospora sparsa* Berk., is capable

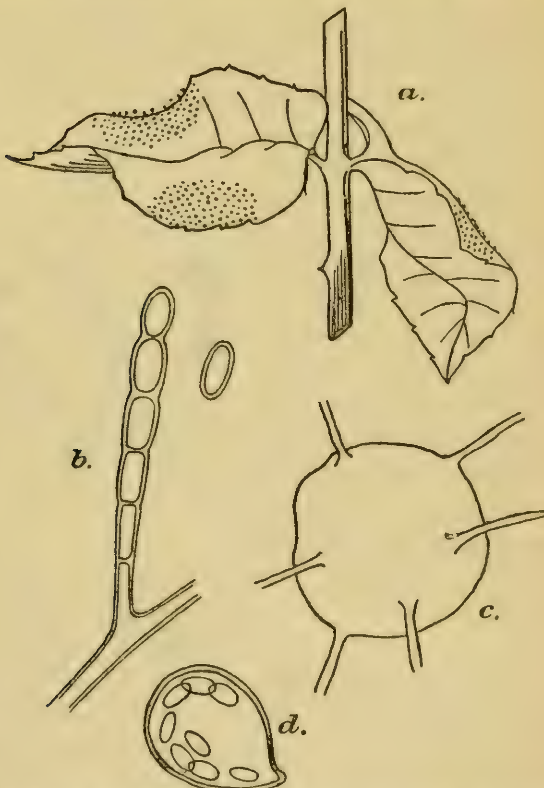

FIG. 31. Powdery mildew of the rose: (*a*) Diseased leaves, (*b*) summer spores, (*c*) a perithecium, (*d*) ascus containing eight ascospores.

of attacking all leaves and young shoots. The first symptom of the disease is the sudden flagging of young, vigorous leaves, which readily fall off the stem if it is shaken gently. The shoot itself droops and dies. Diseased leaves and shoots possess reddish-purple patches bearing a fungus growth. Gradually the disease develops until all the green tissues are destroyed.

All infected material should be removed at once and burned. Spraying with liver of sulphur and flour paste has yielded promising results and vaporizing with sulphur is also recommended.

Powdery Mildew of the Rose.—This disease, caused by *Sphærotheca pannosa* (Wallr.) Lév., may cause serious trouble under glasshouse conditions.

On the leaves appear white powdery patches consisting of innumerable spores (Fig. 31), while dense white growths, producing comparatively few spores, develop on the fruits and shoots of the plant. These latter patches give rise to the perithecia or resistant fruiting bodies which carry the disease over the adverse conditions of winter. The mildew covers the leaves, especially of the young shoots, causing the former to fall, and frequently deforming the more sappy stems. Usually the disease appears in two distinct attacks. One occurs in spring, shortly after the leaves have unfolded, while the second occurs towards the beginning of July. The former attack injures the plant, but does nothing towards producing resistant bodies capable of perpetuating the disease over the winter. These are, however, produced during the second attack, which is therefore the more serious. Some roses are more susceptible to mildew than others, but in every case moist, crowded conditions are most favourable to the disease. Careful attention to temperature and ventilation are therefore necessary. Dusting with flowers of sulphur at intervals of ten days is generally sufficient to control the disease. Liver of sulphur and ammoniacal copper carbonate are also effective, while vaporizing sulphur in the houses for two hours twice a week is also recommended.

Rose Leaf Blotch.—This disease, caused by *Actinonema rosæ* Lib., is second only to powdery mildew in destructiveness and frequency. More or less irregular purplish spots with a characteristic fringed border are produced on the upper surface of the leaves, varying in diameter from an eighth of an inch to patches covering half the leaf. (Fig. 32). The tissue round the spots turns yellow, and, as the spots become old, minute dark pycnidia or fruiting bodies are distributed over the surface. Ultimately the leaves fall, and as the diseased plants lose their foliage they become weakened and stunted blooms are produced.

On the diseased areas conidia are produced in great abundance during the summer and autumn months, and in consequence any new foliage is quickly infected. Infected leaves may remain green through the winter and so carry the infection over to the next season. Mrs. Alcock (1) has shown also that in this country the fungus may hibernate on the young wood of the previous season. On such parts she found discoloured areas, which on examination proved to contain abundant mycelium, and compact fungal masses bearing innumerable spores of the leaf blotch parasite.

FIG. 32. Rose leaf blotch: (*a*) Diseased leaf, (*b*) spore cluster, (*c*) spores.

This discovery is of considerable importance as affecting methods of control for this disease. Not only must all infected leaves be removed from the tree or collected from the ground at the base and burned, but attention must be paid to the fungal patches occurring on the new wood. These should be removed by pruning, but the operation must be conducted judiciously, in accordance with the requirements of the variety. So far as is known, the old pustules on two-year-old wood do not bear spores, and therefore attention need be paid only to the wood of the previous season.

To be effective, spraying or dusting should be conducted early in the season, before the fungus has gained entrance to the leaves. In America repeated dusting with a powder composed of 90 parts finely ground sulphur and 10 parts powdered arsenate of lead has proved effective in controlling the disease.

Spraying with Bordeaux Mixture or lime sulphur (1 in 50) has also proved effective, but both these sprays disfigured the trees, and therefore they can only be employed before the blossoming period begins.

Downy Mildew of the Sweet-pea.—This is practically the only important leaf disease of the sweet-pea under glass. It is caused by *Peronospora trifoliorum* De Bary. The disease first appears when the young plants are barely three inches high, but it is not uncommon to see older plants affected. As in the case of the rose, but little is seen of the causal organism, typical signs of the disease being the yellowing and dying of the foliage. The delicate fungal filaments may be seen readily, when diseased leaves are submitted to microscopical examination. Under exceptionally moist conditions, however, a delicate grey mould develops. Attention to cultural conditions constitutes the best way of controlling the disease. All diseased parts of plants should be at once destroyed to prevent further spreading of the trouble.

(C) FRUIT DISEASES

"*Buckeye*" *Rot of Tomato Fruits.*—This is mainly a disease of the first or lowest truss of fruit of the tomato, but it has been found occasionally on the second, where it has come into contact with a diseased truss below. It is known by different names, such as ' bad-penny," " black rot," " water rot " or " buckeye rot." Affected fruit may be recognized by the appearance of discoloured patches, varying from grey to reddish-brown in colour, frequently arranged in alternating zones of colour so that the whole lesion resembles the eye of a large animal (Fig. 33). Thus the term " buckeye rot " aptly describes the appearance of the disease.

The main cause of the disease is a fungus, *Phytophthora parasitica* Dastur., which is synonymous with *Ph. terrestria* Sherbakoff, but occasionally *Ph. cryptogea* Pethybridge and Lafferty has been found as the cause.

Fruits become infected by touching the soil in which the disease organisms live, or, on the other hand, careless watering may splash infected particles of soil on to the truss as it hangs near the ground. The infection is held in a film of water between the fruits, and readily attacks them. The cold, moist conditions operative in the neighbourhood of the bottom trusses are especially favourable to this disease, and if the fruit becomes infected the disease makes rapid progress and spreads from fruit to fruit through the entire truss. Finally the fungus may work back along the truss and attack the main stem, when the entire plant dies rapidly. The diseased fruits remain quite hard and firm except when bacteria are present, when a soft watery rot ensues. Under moist conditions the fungus grows out into the air and the fruits become covered with a dense white fungal growth. Innumerable spores are produced and the infection spreads rapidly in the process of watering.

The disease may be prevented by early mulching with straw to cover up the infection and prevent it being splashed on to the fruit. In this respect, however, the mulch must not be applied until the soil has become properly warmed, as the mulch, placed over cold soil, prevents it from becoming warm, and so the rate of growth of the plant is much reduced. Where the disease has been abundant in previous years the soil may be watered after planting with a solution of " Cheshunt Compound," applied at the rate of four to eight pints per square yard.

FIG. 33. "Buckeye" rot of tomato fruits.

a b

FIG. 33a. "Foot rot" of the melon due to *Bacillus carotovorus*: (*a*) inoculated plant, (*b*) control.

[*facing page 114*

Spraying the bottom trusses and soil with this compound may also be performed if the disease becomes serious. Trusses touching the soil should be staked or tied up so as to keep them as far off the ground as possible. It is also advisable to remove some of the bottom leaves from all plants to allow the air to circulate freely and so keep the fruit as dry as possible. All diseased fruit should be removed at once and burned.

As the infection may be introduced by a contaminated water supply, only clean water should be used.

Rhizoctonia Fruit Rot of the Tomato.—This rot, caused by *Rhizoctonia solani*, is similar in appearance to "Buckeye rot," but the zone lines are much closer together, and the affected portions are sunken. It is by no means as common as "buckeye rot," and can be controlled by similar methods.

Botrytis Rot of Tomato Fruits.—Towards the end of the season, especially in unheated houses, which lie cold and damp in consequence, a soft rot of green tomato fruits due to a species of *Botrytis* is frequently found. Such fruits become soft water-bags, which for a time show no signs of fungal growth and no apparent wound through which infection has taken place. The first sign of the disease is the appearance of a pale, water-soaked area, which is not confined to any particular part of the surface, although frequently it occurs at the blossom end, and indicates a probable infection through the style in such cases. The affected area increases in size until the whole fruit is involved, and ultimately the fungus grows out into the air, when the fruits become covered with a typical grey, velvety mould of *Botrytis*. Not infrequently infection takes place at the calyx end, when the ensuing rot causes the fruit to fall to the ground.

Infection is easily produced by means of wounds, but the fact that a diseased fruit will infect an adjacent healthy fruit which it touches, indicates that under suitable conditions a wound is not necessary for infection.

The rot may be prevented by careful attention to the heating and ventilation of the houses, to ensure that the fruit do not remain covered with moisture for long periods.

Careful pruning of the foliage to expose the fruit to the sun and air is also advisable. It is probable that sucking and biting insects carry the disease to healthy fruits, and these should be eliminated as much as possible.

A similar disease of the cucumber appears under abnormally moist conditions. Infection occurs at the flower end of the fruit, and an abundant growth of *Botrytis* develops, which works rapidly over the entire fruit. Control measures are the same as for the tomato disease.

Rhizopus Rot of Tomato Fruits.—A soft rot of minor importance caused by *Rhizopus nigricans* Ehrenbg. is found occasionally towards the end of the season.

Fruits may be attacked while still on the plant in the green condition, and in the first stages of infection soft, watery patches resembling bruises are noticeable. This rot develops rapidly, the epidermis bursts, and the fungus grows out.

The fungal growth, which appears on the outside of the fruit, is very marked in character, showing as a dense mass of strong, erect filaments, each of which bears a tiny black sphere at the end. These tiny spheres burst and liberate numerous spores whereby infection is spread.

Experiments have shown that the fungus is a wound parasite and cannot penetrate the uninjured skin of a healthy tomato. Wounds made by insects, or the natural splitting of the fruits under unsuitable conditions, assist the disease, while warm, moist conditions favour its progress. Diseased fruits should be destroyed at once, as these become soft and are easily broken, scattering infection over the plant.

Penicillium and Fusarium Fruit Rots of the Tomato.—Frequently various species of *Penicillium* and *Fusarium* are found in tomato fruits, showing hard, brown diseased patches. These have been isolated and shown to produce a rot of healthy fruits.

In nature, however, attacks by these fungi generally follow " blossom end " rot which is not due to parasites. The lesions of this disorder are very attractive to insects, and it is probable that spores of *Penicillium* sp. and *Fusarium* sp. are introduced into the affected tissues by this means.

The control of the rot due to these fungi is largely to be obtained by eliminating the insect carriers.

Other Tomato Fruit Rots.—Besides the rots previously discussed a number of others have been reported in this country, but as they are of minor importance and exist mainly on tomatoes grown in the open, it is unnecessary to describe them. The fungi causing these rots include species of *Phoma*, *Glœosporium*, *Colletotrichum*, and *Diplodina*.

Other fruit rots caused by *Macrosporium solani*, *M. tomato*, and *Phytophthora infestans* are discussed later.

" *Gummosis* " *of Cucumber Fruits.*—This is a common disease of cucumbers under glass, caused by *Cladosporium cucumerinum*. Commonly it appears towards the end of the season, but under favourable conditions it may appear much earlier. The first sign of the disease is the appearance of small, sunken spots, mainly on the concave side of the fruit. These rapidly extend and the skin ruptures, when a small drop of amber-coloured, gummy liquid exudes. This hardens and has the appearance of a small globule of gum-arabic. Finally the fungus grows out and the whole lesion becomes covered with a dark olive-green velvety growth bearing numerous spores (Fig. 34). The lesions frequently crack, exposing the white flesh.

The malady is most destructive under excessively moist conditions, and may be checked by drying the atmosphere by means of suitable ventilation.

Dusting with sulphur powders, accompanied by efficient ventilation, will generally effect a control. In

FIG. 34. Gummosis of the cucumber caused by *Cladosporium cucumerinum*: (*a*) Leaf lesions, (*b*) fruit lesions, (*c*) hyphæ and spores, (*d*) spores.

bad cases spraying with liver of sulphur and flour paste is recommended, and in any case diseased fruits should be removed and burned.

GENERAL SURFACE DISEASES

Potato Blight of Tomatoes.—The disease of tomatoes caused by *Phytophthora infestans* (Mont.) De Bary, universally known as the cause of the late blight of the potato, rarely attacks tomatoes grown in glasshouses in this country. It is, however, a common disease of outdoor tomatoes, and one may successfully predict its appearance if abundant rain falls in July or August. Indeed, so serious is this disease in wet seasons that the outside tomato crop is frequently ruined, unless regular spraying with Bordeaux or Burgundy Mixture is adopted. Thus under cool, moist conditions the disease assumes considerable importance. The first symptoms of the disease is the appearance of black, water-soaked spots on the stem and mature leaves. The lesions rapidly increase in size, causing the death of the leaves and a rotting of the stem tissues. The malady can easily be distinguished from other tomato diseases, for the entire plant appears to be suffering from the effect of frost and in bad cases turns completely black and dies. Discoloured sunken areas varying from grey to black are produced on the fruit. Such lesions are mainly produced at the stem end of the fruit, where the water drips collect.

An examination of the under surface of diseased leaves reveals a white, downy fungal growth, similar in appearance to that present on diseased potato leaves. This is the spore-bearing portion of the fungus, which enables its rapid spread.

Under normal glasshouse conditions the disease is unimportant, and where it has appeared a ready control has been effected by increasing the temperature and reducing the amount of moisture in the atmosphere. In old, leaky houses and out of doors continuous spraying with either Bordeaux or Burgundy Mixture is necessary to check the disease.

The Macrosporium Disease of the Tomato.—As in the case of the preceding disease, that due to *Macrosporium solani*, which also causes the early blight of the potato, is confined mainly to outside tomatoes or to those grown in cold, leaky houses, although it is occasionally found on the last fruits of the season, when these are picked green from the plants and laid on benches to ripen.

The fungus attacks the leaves, producing brownish-black angular spots and blotches, but is chiefly found on the fruits, where sunken brownish-black areas are produced chiefly at the stalk end. These lesions enlarge and become covered by a black, velvety mass of spores.

Under glass this disease is rarely of sufficient importance to warrant special precautions being taken to combat it, and can be controlled readily by keeping a normal temperature and regulating the moisture conditions. In the case of outdoor tomatoes spraying with Bordeaux or Burgundy Mixture may be necessary to effect a control.

"*Nailhead*" *Spot of Tomatoes.*—Another *Macrosporium* disease of the tomato, caused by *Macrosporium tomato* Cke., is that commonly known as "Nailhead Spot." This disease, while common in America, is unknown as yet in this country. It receives its name from the typical more or less circular, reddish-brown spots, resembling the head of a nail, which occur on the leaves, fruit, and stems of tomato plants suffering from the disease. Sometimes the spots possess peculiar ridged lines which give them a target-like effect. Spraying with Bordeaux Mixture is recommended as a means of control.

CHAPTER VI

DISEASES DUE TO BACTERIA

ANOTHER class of micro-organisms which cause plant diseases are the bacteria. Plant bacteria are generally rod-like in form (Fig. 35), varying from one thirty-thousandth to one ten-thousandth part of an inch in length, and about a third of that in diameter. They multiply by dividing across the middle, each half becoming a separate bacterium. This process takes place so frequently that in a short time many millions of bacteria are produced from one original parent. Certain bacteria may divide once every twenty minutes, and at this rate the progeny of one bacterium would exceed sixty-four thousand million in twelve hours, were all the offspring to remain alive. Most disease-producing bacteria possess a number of tiny "tails" or flagella, by means of which they are able to swim in water. Some types of bacteria produce within their bodies hard, resting spores, capable of withstanding abnormal conditions, but bacteria causing diseases of plants are not known to do this.

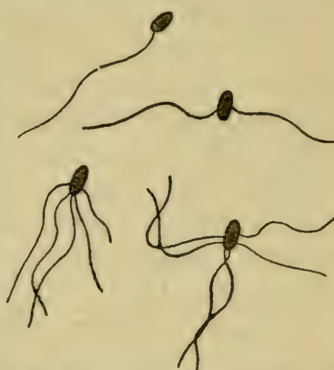

FIG. 35. Typical appearance of bacteria pathogenic to plants.

Bacteria are carried from plant to plant by wind, rain, insects, and animals, including man. Once on the plant they may enter the inner tissues by means of the stomata, or by wounds, and in this process they are assisted by a film of water on the surface of the plant. Unless they gain a speedy admittance the rays of the sun and dryness of the atmosphere will soon kill them. Frequently bacteria are carried on the mouthpieces or suckers of insects, and by these are placed in direct contact with wounded tissues, into which they rapidly spread.

Once inside the plant tissues the bacteria feed and rapidly multiply, producing millions of new organisms in an incredibly short space of time.

Wilt Disease of the Cucumber

The symptoms of the bacterial wilt disease of the cucumber are very similar to those produced by fungi. Plants moderately resistant to the disease, or those in very favourable conditions, may wilt during the day and recover at night, and such plants are frequently stunted in comparison to their healthy neighbours. As a general rule, however, cucumbers are so susceptible to the disease that death is exceedingly rapid, and usually occurs within two or three weeks after the appearance of first symptoms. A yellowing of the foliage may accompany the wilting, but generally this is not so, the leaf-laminæ wilting while still green. This takes place quite suddenly, and the plant presents a curious appearance of having its leaf surfaces wilted and hanging limp from turgid petioles and stems. The leaves soon wither up and die, being followed in this respect by the petioles and stems, until the whole plant hangs limp. Frequently no destruction of the root is evident, but upon cutting across a diseased stem a white bacterial ooze emerges from the cut ends of the vascular bundles. This is so sticky that if the finger is pressed against the cut surface and slowly taken away the bacterial ooze sticks and may be drawn out in fine cobweb-like strings. The oozing of the bacterial mass is most evident if cut pieces of stem are placed with one end in a basin of water under a glass jar. Microscopic examination of diseased stems shows the large vessels of the wood to be completely filled with an incalculable number of bacteria, and the wilting is thus brought about by the choking of the conducting system.

The causal organism was first described by Dr. E. F. Smith (46), who named it *Bacillus tracheiphilus*.

The disease is by no means common in this country, but spasmodic outbreaks have occurred with serious results. In America the disease is widespread, and attacks cantaloupes, cucumbers, pumpkins, and squashes, but not water melons, the cucumber being by far the most susceptible of these plants. The disease has been found to occur in varying intensity from season to season, at times only an occasional wilted plant being reported, while at others 70 to 95 per cent of the crop has been destroyed. Rands and Enlows (41) found that the percentage infection and the rate of progress of the disease were not determined by weather conditions, but were related intimately to the vigour of the plant and to the prevalence of cucumber beetles present at the time. They demonstrated that the bacteria do not winter in the soil in America, and found no evidence that they were carried by the seed. Infection does not take place through the stomata or breathing pores of the plant, but depends upon the introduction of the causal bacteria into the inside of the plant by some suitable agency, which might well be of the nature of an insect.

In America the striped cucumber beetle (*Diabrotica vittata*) and the twelve-spotted cucumber beetle (*D. duodecimpunctata*) have been shown to carry the disease from plant to plant during the growing season, and are probably the only means by which the disease is spread under natural conditions. Under glasshouse conditions in this country it is probable that the cucumber wood-louse is instrumental in disseminating the disease. It has invariably been found that plants which have received a check either by reason of a prolonged spell of cold damp weather or some fault in crop management are the most susceptible to the disease, but otherwise temperature or shade have apparently no determining effect upon the incidence or progress of the disease. Control measures, thus, must be related to the growing of plants physiologically robust, and to the control of biting insects which transmit the disease from plant to plant. The bacteria are readily carried on the hands and tools of the workers. After cutting a diseased plant, tools should be sterilized by wiping on a rag dipped in a two per cent solution of lysol or other disinfectant. Bacterial wilt is most serious at low temperatures, and raising the temperature of the houses until the average of day and night approximates to 90° F. has been found to check the disease.

Foot Rot of the Cucumber and Melon

A common disease of melons and cucumbers is that which is commonly called "canker" by the practical man. It appears at the soil level, and is typically a rotting of the outer tissues of the stem at this part. These outer tissues soften, turn brown, and a rot begins, which spreads down into the roots as well as upwards along the main stem. Mainly it is confined to a region not more than six inches above soil level. The rot extends deep into the stem tissues and the disease organisms enter the wood vessels, ultimately causing the death of the plant (Fig. 33*a*). Under suitable conditions melons and cucumbers are so susceptible to the disease that the whole crop may be imperilled. Usually the disease does not show until the plants are eight to ten weeks old and are fruiting, but occasionally quite young plants are affected.

The causal organism has been isolated and found to be *Bacillus carotovorus*, which causes a soft rot of many plants.

It has been ascertained that the disease is intimately connected with moisture conditions operative round the base of the plant. When the soil is kept uniformly damp at the surface, the disease may readily be induced by spraying the base of the plant with a water suspension of the organism. If the soil is dry at this part the bacteria may be pricked into the stem tissues, without causing serious trouble. It is thus apparent that any serious development of this disease is the result of very wet conditions of the soil at the stem base. Alternate periods of dryness and extreme dampness are still more conducive to the rot, while plants, especially the cucumber, which are physiologically weakened through bearing a heavy crop of fruit, are most susceptible.

The control of the disease is a simple matter if the correct conditions are imposed. It is essential to keep the base of the plant as dry as possible, and the indiscriminate pouring of water directly on to the stem must be avoided. The young plants should be planted out in the beds in metal collars about the size of a forty-eight pot or else in pots with the bottoms knocked out. When the plants are watered no water should be allowed inside the collar, but it should be applied to the bed around it. The roots readily grow out through the bottom of the collar into the beds, and thus gain access to moisture, but the base of the plant remains dry. Under these conditions the disease makes no progress. If the disease has commenced under normal conditions of cultivation, but has not gone too far, it may be checked by dusting the base of the plant with a mixture of lime, copper sulphate, and sulphur. Ten parts of dry slaked lime, two or three parts of finely ground copper sulphate, and two or three parts of flowers of sulphur are intimately mixed and may be applied from a tin box with a perforated lid, or simply by sprinkling by hand. It is sometimes necessary to continue the treatment through the season, and in any case fresh applications should be made when top-dressing the beds. Growers of melons need no convincing as to the importance of the disease, but in the case of the cucumber it is not so obvious. At the same time those who cultivate the cucumber must have noticed each year that the base of the stem is the weak part of the plant towards the end of the season, and that given a healthy base there is no reason why the plants should not continue to produce fruit for a longer period than they do.

Angular Leaf Spot of the Cucumber

This disease, due to *Pseudomonas lachrymans* Sm. and Bry. (47), is characterized by brown, angular spots on the leaves. These begin as dark, watery spots, and examination in the early morning shows the presence of a watery bacterial exudate which collects in drops on the lower surface of the spots. Later, this watery material dries up and leaves a white chalky deposit. The spots, which are rarely more than a quarter of an inch in diameter, dry up and, becoming brittle, the centre falls out, leaving a ragged hole in the leaf. In consequence, affected leaves possess a very ragged appearance. The disease rarely attacks the fruit, but where it does the outer skin is ruptured and an amber gummy exudate comes out, which dries up and becomes white. Secondary infection by soft rot producing organisms frequently occurs and spreads deep into the centre, which in a short time becomes soft and watery. This gummosis should not be confused with that caused by a fungus, *Cladosporium cucumerinum*, in which the gummy lesions become covered with a velvety olive growth.

Young plants have been observed to be so badly injured by the disease that they have become much stunted in growth, and consequently the yield is much reduced. In this country the disease is rarely serious in normal, well-conducted nurseries, but in America it ranks as one of the most important diseases of the cucumber. The organism has been shown to enter the inner tissues of the leaf by means of the stomata, and as they are open during the day and generally closed at night, the greater part of infection occurs during the day. Much the same process takes place on the fruit, and the small, circular spots turn white in the centre and crack. The lesions themselves are quite shallow, but the cracking of the surface opens up wounds for the entrance of other organisms, and a rapid soft rot frequently occurs. The disease organisms are disseminated by the workers, currents of air, overhead damping, and probably by insects. Conditions of high humidity above 80 per cent, such as occur during the early morning, are conducive to the rapid progress of the disease, and under these conditions the bacterial exudate beneath the spots becomes abundant. Carsner reports that there is substantial evidence that the disease may be transmitted by the seed ; and while the shallow nature of the fruit lesions would indicate that seed is rarely infected under natural conditions, the present-day methods of seed extraction encourage such infection. No one variety of cucumber has proved more resistant to the disease than any other.

Control.—The causal organisms have been found upon the seed, sheltering chiefly in the micropylar opening. Carsner recommends sterilizing the seed in 1-1,000 mercuric chloride for five minutes as the best method of control.

In this country dusting with sulphur powders or spraying with liver of sulphur and flour paste has provided a convenient method of checking the rapid spread of the disease.

"Stripe" Disease of the Tomato

The disease of tomatoes known to the nurseryman as "stripe" (see Frontispiece) is characterized by brown, longitudinal markings or stripes on the stem, by shrivelling of the leaves, and by sunken, irregularly shaped pits usually of a brown colour on the fruit (36). It is a specific communicable disease due to a bacillus which has previously been described as the cause of a very similar disease of the sweet-pea.

So far little is known concerning the geographical distribution of the disease, but it is very common on tomatoes grown under glass in this country and in the Channel Islands.

In many cases the disease is not of a very serious nature. By most nurserymen it is regarded rather as a nuisance than as a disaster, for, with care, a moderate crop of fruit can be obtained from plants which have been attacked. At times, however, the disease may be so prevalent as to ruin the whole crop. Sometimes, during the first years of a nursery, plants have shown a considerable amount of disease, but this has gradually diminished until only a small percentage of the plants has been attacked in the later years. Conversely, cases are known where "stripe" has appeared and gradually increased after some ten or twelve years, during which time no sign of the disease has been observed.

The disease may appear in the seed-boxes, producing rapid destruction of the young plants and compelling fresh sowings to be made; it is not uncommon to find the first symptoms of the disease while the plants are still in the small pots (sixties), or again after these have been planted out in the houses for a fortnight or so. Usually, however, the disease first appears about May, when the earliest fruit is ready for picking, but frequently no signs appear until the tops are allowed to develop, when these often become badly attacked.

There is a distinct connexion between soft and rapid growth and the incidence of disease; plants growing rapidly in the early stages are more liable to "stripe" than others of a hardier nature. In one case observed at Cheshunt the plants were so badly attacked that it seemed impossible for the crop to recover. The conditions were then altered so as to induce a slower rate of growth, with the result that the plants completely "grew out" of the "striped" condition, showed perfectly clean tops, and yielded a good crop of sound fruit.

During previous seasons observations have been made in the houses at Cheshunt Experimental Station to ascertain the relation between manurial treatment and crop management to the incidence of the disease. The results are indicated below in Tables 8, 9 and 10.

TABLE 8

The Effect of Different Manurial Treatments on the Incidence of "Stripe" Disease.

Variety.	Treatment.	Total No. of Plants.	Diseased Plants.			
			1919.		1920.	
			No.	Per Cent.	No.	Per Cent.
Comet	[1]C.A. without potash	120	78	65	105	88
Do.	Untreated	,,	50	42	68	57
Do.	[1]C.A. with dung	,,	45	38	50	42
Do.	[1]C.A. without phosphates	,,	41	34	51	43
Do.	[1]C.A.	,,	40	33	41	34
Do.	[1]C.A. without nitrogen	,,	34	28	50	42
Do.	[1]Double C.A.	,,	34	28	34	28
Kondine Red	[1]C.A. without potash	120	33	28	96	80
Do.	Untreated	,,	30	25	48	40
Do.	[1]C.A. with dung	,,	33	28	38	32
Do.	[1]C.A. without phosphates	,,	28	23	31	26
Do.	[1]C.A. without nitrogen	,,	19	16	27	23
Do.	[1]Double C.A.	,,	14	12	31	26
Do.	[1]C.A.	,,	13	11	31	26

These tables show clearly the differences in the relative susceptibility of the varieties tested, and point to the selection or breeding of a resistant variety as one means of controlling the disease. They also show that

[1] Complete Artificials.

a soft, rapid growth, such as is produced by liberal dressings of nitrogenous fertilizers accompanied by high temperatures, renders the plant more susceptible to "stripe" than does a hard, slow growth accompanied by suitable additions of potash. Overhead damping

TABLE 9.

The Effect of "Damping" on the Incidence of the Disease.

Variety.	Damped.		Not Damped.	
	Total Plants.	No. Striped.	Total Plants.	No. Striped.
Comet	260	124	260	110
Fillbasket	260	112	260	95
Kondine Red	260	112	260	82
Ailsa Craig	260	95	260	34

TABLE 10.

The Effect of Forced and Slow Growth on the Incidence of the Disease.

Variety.	Forced Growth.		Slow Growth.	
	Total No. of Plants.	No. of Diseased Plants.	Total No. of Plants.	No. of Diseased Plants.
Fillbasket	100	58	100	44
Comet	100	38	100	26
Kondine Red	100	24	100	14
Ailsa Craig	100	24	100	16

also favours the disease. These observations are fully confirmed by inoculation tests carried out on plants grown in pots. Increased applications of nitrogen were found to favour the disease, and suitable dressings of potash to reduce it.

As stated above, the most usual mode of infection would appear to take place underground, young attacked plants showing on examination a brown discoloration of the root cortex. The occurrence of disease in the seed-bed suggests that the seed from infected fruit may also be infected or carry the causal organism externally, though so far, no actual proof of this has been obtained. Observations in nurseries and large scale experiments have shown that the disease may sometimes spread downwards; successful "prick" inoculations have been made on the upper parts of plants and indicate that insects may produce infection of these parts. It is also fairly certain that the pruning knife is a potent factor in spreading the disease. In one house it was observed that this disease had spread from one end on both sides of the house, while in another it had spread a certain distance down one side only. In the former case it was found that the pruning had been across the house from left to right, while in the latter the pruning had been down one side and up the other.

Symptoms of the Disease.—The stem of an attacked plant shows the earliest symptoms of disease as light or dark brown to black, sunken patches of irregular shape, varying from small spots to long furrows and "blazes." The blazes are often three or more inches long, and frequently extend over the entire length of an internode. In slight cases these markings occur intermittently along the stem, while in bad cases the typical furrows can be found throughout the whole length of the stem and on the leaf and truss stalks.

On the leaf the disease first appears as yellow blotches near the mid-rib and the main veins. Later, these turn brown and extend so that finally the greater part of the surface becomes browned and much distorted by the shrivelling of the diseased areas.

The fruits show light or dark brown sunken patches with round or irregular outline. They vary from a few spots developed near the calyx to many scattered promiscuously over the surface of the fruit. They greatly reduce the market value, and in bad cases the fruit is rendered quite unsaleable, being almost covered with these pock-like depressions.

Attacked plants become very brittle and are easily damaged by the workers. In the worst cases the whole plant becomes covered with lesions and finally dies.

Lesions in the pith and cortex are the characteristic internal features of the disease; the walls of the attacked tissues are strongly browned, so that the patches are readily seen on splitting the stem with a knife. In older stems which have become hollow, small brown patches occur in the remains of the pith and in the cortex, but at the nodes, where the pith is close and moist, the patches are much larger.

The roots are often found to be diseased only in the upper portion, and infection can usually be traced to some wound or insect puncture just below the ground level; the tissues of the lower roots are in these cases white and apparently healthy. In some cases, however, no wound can be discovered but the cortex is found to be browned to a considerable depth below the soil level, and microscopic examination shows the presence of the bacillus in the tissue. It would seem either that penetration of the root may occur without the aid of a wound or that the latter has escaped observation, or, on the other hand, that the disease has spread down to the root from an aerial infection.

The disease is due to *Bacillus lathyri* Manns and Taubenhaus, described as the cause of "streak" disease of the sweet-pea, red clover, soya bean, etc. It has been shown that the organism from the tomato can cause a number of "stripe" or "streak" diseases of other plants. Positive results have been obtained with the following plants: sweet-pea, garden pea (Fig. 37), red clover, broad bean, lucerne, lupin, vetch, sainfoin, and potato. The symptoms of the disease upon these plants bear a strong resemblance to those on the tomato. The lesions are in the form of dry brown or black sunken spots, blotches, or furrows.

The knowledge that "streak" disease of the above-

FIG. 36. "Dieback" of the carnation caused by *Fusarium* sp.

FIG. 37. "Streak" disease of the pea.

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mentioned plants and "stripe" disease of the tomato are caused by the same organism is of considerable importance to commercial growers. It is now possible to explain why certain nurseries have been badly attacked by "stripe" in the first year of their existence—a fact which has hitherto been inexplicable. It is highly probable that the land had previously held a leguminous flora suffering from "streak" disease which had been overlooked. Already we have proved this to be true in a number of nurseries where "stripe" has just started. The previous diseased crop was clover in three cases and vetches in two. It is advisable, therefore, when choosing a site for a new nursery, to have the advice of a plant pathologist to ascertain if the existing crop is free from "streak" disease.

Control.—As the disease is intimately connected with soft, rapid growth, induced by an excess of nitrogen and a deficiency of potash in the soil, manuring with the latter has proved an efficient method of combating it.

Affected plants will grow away clean if top-dressed with sulphate of potash. A suitable dressing is five hundredweights to the acre which in severe cases may be repeated after an interval of a month to six weeks. Generally the most convenient method of treatment is to dissolve half a pound of sulphate of potash in fifty gallons of water, and apply the solution at the rate of a pint per plant to the diseased plants each week until they show a clean new growth. The cutting away of a diseased stem and allowing a lateral to develop will often give a clean plant. As the disease is spread from plant to plant by means of the pruning knife, workers should be taught to leave the diseased plants until all the healthy ones have been attended to, and before passing to a healthy plant, after pruning a diseased one, the knife should be cleaned by wiping the blade with a rag soaked in two per cent lysol or other disinfectant.

Wilt of the Tomato

The brown rot or wilt of the tomato is a disease common to many members of the important plant group, the *Solanaceæ*. As is the case in other wilt diseases, the plant may wilt suddenly while the leaves are still green, or the leaves may turn yellow and slowly wither unaccompanied by wilting. Young plants show the former symptoms and old woody ones the latter. Finally the stems droop and the softer parts of the plant collapse and shrivel. On cutting across a diseased stem the vascular system is seen to be stained brown, and a greyish-white or brownish-white bacterial slime oozes out of the bundles. Unlike the cucumber wilt, this slime is not sticky and cannot be drawn out in fine strings. The brown discoloration is not confined entirely to the wood, but may be seen in the pith and sometimes in the bark. In the young, rapidly growing shoots the discoloration may frequently be seen through the more translucent tissues. Under favourable conditions the interior of the pith is reduced to a soft, watery mass teeming with bacteria. Generally no lesions can be seen on the exterior of the plant to account for the wilt, and it is necessary to cut open the stem. The disease, due to *Pseudomonas solanacearum* E. F. S. has been submitted to an exhaustive investigation by Dr. Erwin F. Smith (44), to whom we are indebted for the larger portion of our knowledge of bacterial diseases of plants. It attacks a very large number of plants, among which may be mentioned the potato (*Solanum tuberosum*), tobacco (*Nicotiana tobacum*), egg-plant (*Solanum melongena*), black nightshade (*Solanum nigrum*), thorn apple (*Datura stramonium*), *D. metelloides*, *Physalis crussifolia*, *P. philadelphica*, *Petunia* sp., and *Nasturtium* sp.

While there is little doubt that this disease occurs in England, it is probable that the temperature conditions are not favourable to it, and no serious case has come within the author's experience. It is a serious disease, however, in the United States and causes much destruction annually.

Control.—As there is evidence to show that the organism enters the plant by means of wounds, every care should be taken to prevent injury to the roots, and in this respect the possible effects of attacks by wireworms, woodlice, and eelworms should be borne in mind. Excessive moisture, both of the air and soil, favours the disease and should be avoided. Diseased plants should be removed and burned immediately they are noticed. In badly diseased land, sterilization should be resorted to, and reinfection from susceptible host plants should be prevented.

Grand Rapid's Disease of the Tomato

This disease was first described by Dr. E. F. Smith (45), who attributed it to a micro-organism, *Aplanobacter michiganense* E. F. S.

It has been confused with the wilt or brown rot of the tomato, although differing from it in a number of ways. The symptoms described by Smith are as follows: The leaflets do not wilt, but slowly shrivel one after another, and longitudinal cankers are produced on the stem petioles, through which the bacteria come to the surface. In consequence there is an abundance of infective slime on the outside of the diseased plants. The disease spreads rapidly, and plants may be infected through the stomata, wounds, or broken roots. There are also indications that it may be seed-borne. The tissues within the plant become disorganized and brown, and the entire pith may be hollowed. The disease has not yet been reported in this country.

A Tomato Canker

Miss Doidge (18) has described a disease of the tomato, to which she applies the term "tomato canker," due to *Bacterium vesicatorium* Doidge. Numerous dark green, semi-translucent, water-soaked spots appear on the under surface of the leaves. These increase in size, until they become 2 mm. in diameter, and may be either round or irregular in shape. They are slightly sunken and frequently coalesce to produce discoloured streaks. Finally the affected portions dry up and break away from the rest of the leaf. Affected leaves become twisted and distorted. Similar spots appear on the calyces, laterals, etc. Cankers are produced on the stems, especially the older parts, where the tissues have been injured by friction. These are corky in appearance, " raised and roughened with numerous small, longitudinal cracks." The disease is apparently superficial and does not penetrate into the wood. On the fruit a " minute green or brownish blister is the first indication of infection." Later the spots become " hard and scabby in texture and usually slightly convex." " The epidermis ruptures in the centre, showing whitish-brown over the discoloured tissues, like the broken edges of a blister." Rarely are the individual scabs more than 5 mm. in diameter, but by coalescence, large, scabby areas several centimetres in extent may be produced. The cracks produced in the scabs permit secondary infection, and a soft rot may take place. The disease is not considered serious, but by disfiguring the fruit its market value is reduced.

Tomato Fruit Diseases

Two of these are attributable to bacteria, namely, a soft rot and a brown rot.

(*a*) *Soft Rot.*—This is typically a disease of green tomato fruits, and usually appears towards the end of the season. A pale green, water-soaked spot can be noticed at first, which enlarges rapidly, while the tissues beneath collapse and the surface of the fruit becomes flattened. Finally the entire flesh of the tomato is converted into a soft, watery mass, held by the tough skin. These water bags may hang for a time, but soon burst and scatter the bacteria-infested contents over the leaves below. The watery mass is very attractive to insects, which are instrumental in spreading the disease.

The disease is caused by the common soft rot-producing organism, *Bacillus carotovorus* Jones.

Investigations undertaken by the author indicated that the disease may be controlled most efficiently by limiting insect life about the plants. At one nursery where the disease attained epidemic proportions a deep ditch, filled with vegetation and eminently suitable as a breeding place for insects, ran alongside the houses. Sucking insects allied to the mosquito group abounded in the houses, and were observed to feed on the disrupted rotten tomatoes. The ditch was cleaned out and covered in, and with the consequent disappearance of the insects soft rot of the fruits ceased to spread and finally disappeared also.

(*b*) *Brown Rot.*—This disease may be identified by the appearance of hard, dark brown circular patches, smooth at first, but afterwards becoming wrinkled. Later the tissues become disorganized and a soft rot results, the fruits becoming mere water bags. This rot, due to an unnamed bacillus, may be distinguished from that caused by *B. carotovorus* by the brown colour which is assumed by the affected tissues. The methods of transmission and control are similar to those described in the disease caused by *B. carotovorus*. The organism has frequently been isolated from "blossom end rot" lesions, which appear to be very attractive to insects, which cause a secondary infection by introducing the bacillus in question.

Soft Rot of the Arum

For a great many years cultivators of the arum or calla lily (Richardia) have been troubled by a disease which threatened to exterminate their entire stock.

On some nurseries its hold became so strong that it was impossible to grow arums, and the whole of the stock had to be burnt. Only after an interval of several years was it possible to cultivate this plant again. The disease generally shows itself about January, after the first lot of blooms has been gathered. First symptoms consist of a withering of the leaf apex and a desiccation of the entire margin. The desiccation spreads as blotches from the margin and the diseased leaves die prematurely. The plants come to a standstill, do not readily produce more flowers, and do not react to feeding.

FIG. 38. Arum disease caused by *Bacillus carotovorus* showing diseased corm and roots.

An examination of the roots shows them to be brown, soft, and watery. The rot spreads from the roots back into the pseudo-corm (Fig. 38), becoming worse as the season advances. Quite commonly the foliage appears to recover, but soon goes back to the diseased appearance. This recovery corresponds to the production of clean roots, but as these are attacked in turn so the foliage suffers.

The disease is of bacterial causation, and isolation has yielded a bacillus indistinguishable from *B. carotovorus* Jones. Townsend has also described a soft rot of the calla in America due to *B. aroideæ*, which is closely related to *B. carotovorus*, but our isolations appear to differ from *B. aroideæ* Towns.

Certain methods of control have been devised which up to the present have yielded satisfactory results (7). The general method is as follows: After the plants have been allowed to "dry off" they are shaken out of the pots and all soil removed. The adventitious roots are scraped off, all decayed parts cut out, and the corms well scrubbed with water, using a fairly strong brush. The prepared corms are next steeped, taking care to keep as much of the foliage out of the liquid as possible, in a 2 per cent solution of formaldehyde (1 part 40 per cent formaldehyde in 49 parts of water) for four hours. After this time they are removed and immediately potted up in disease-free soil and sterilized pots.

The treated corms rapidly produce a supply of clean, white roots, and have every appearance of health, while the untreated controls quickly show all the symptoms of the disease. This method has been tested on a large scale at a commercial nursery, and so far the plants have remained healthy.

The chance of secondary infection in nurseries where the disease has been epidemic is exceedingly great, and special care must be taken to prevent it. Disease-free soil and pots are essential, and the treated corms must not be replaced in infected houses unless these have been sterilized previously. Should the well from which the water supply is drawn be a shallow surface one with faulty brickwork, there is every possibility that it has been infected by surface drainage. Expert advice should be obtained on this point, for a clean water supply is imperative.

CHAPTER VII

MOSAIC DISEASES

In previous chapters an account has been given of two big groups of diseases caused by fungi and bacteria respectively. Considerable progress has been made in the study of these, but there is a third large group of diseases the cause and nature of which, although studied by investigators in all parts of the world, remains largely unknown. This is the group of Mosaic Diseases, or Virus Diseases, as they have latterly been named. Of profound interest, and of great and perhaps increasing economic importance, the solution of their main problems would probably constitute one of the most important events in the study of plant diseases of modern times.

The name "Mosaic Disease" (*Mosaikkrankheit*) was first applied by Mayer (33) in 1886 to a disease of the tobacco in which the leaves assumed a mottled, distorted appearance. To-day the name is applied to several diseases the cause of which is unknown, but which all possess two very definite characters. The first is a mottling of the plant, in which light yellow patches alternate with others of a dark green colour. Also the various parts of the plant may be distorted, giving rise to blistered, irregular leaves and flowers. The second character is the highly infectious nature of the plant juices, even after filtration through porcelain vessels.

Practically one hundred different species belonging to widely separated genera are known to be susceptible hosts, and as these include many of the food plants of the world, the economic importance of the disease cannot be over-estimated. Growers of glasshouse crops are mainly interested in the fact that tomatoes and cucumbers are susceptible to this disease, but it must be very clearly realized that infection may be introduced from diseased plants of other species, such as certain common hedge and field weeds, and therefore that a wide knowledge of the disease as a whole must be obtained if complete control is to be effected.

General Symptoms of the Disease

The chief symptoms of mosaic disease consist of a mottling and abnormal development of the leaves, flowers, fruit, etc. While diseased plants generally possess both symptoms, they may have one or the other separately, or indeed both may appear on the same plant at different times in accordance with the conditions to which it is exposed.

Mottling.—Mottled leaves develop irregular, pale green or yellow patches alternating with patches of dark green. The mottling may be so slight as to be almost indistinguishable, or it may be strikingly evident. Under certain conditions the light areas turn brown and wither, but frequently the tissues remain alive. Mottling of stems, flowers, and fruits also occurs.

Abnormality.—This may include curling, blistering, and distortion of the leaves, flowers, and fruits, and a dwarfing of the stem. Curling of the margin of the leaf is a common occurrence in the case of the clover, cucumber, lettuce, potato, raspberry, tobacco, and tomato. Where blistering occurs, small, raised islands or blisters of dark green show up in striking relief to the rest of the surface, which is flat and light green in colour. This type of symptom is especially noticeable in the case of the cucumber, petunia, tobacco, and tomato.

Distortion.—The effect of the disease upon leaf growth also shows itself by a reduction in size of the leaf blade, with a consequent alteration in the position of the veins, and the assumption by the edge of the leaf of a fantastic form. This is especially noticeable in the case of the tomato, where filiform and fern-like leaves are common. Among growers, plants affected in this way are said to be suffering from "sweet-pea disease," because the leaf blades are often reduced to such an extent that only the mid-ribs remain, and the resemblance to sweet-pea tendrils is obvious.

Similar effects have been noticed in the case of the petunia and tobacco. Distortion of the symmetry of the leaf is a common symptom, produced by retarded growth at certain parts of the margin. In some cases as many as 43 per cent of the tomato flowers have been observed to fall from diseased plants, the fall from healthy plants under the same conditions being 2 per cent. In other cases abnormal fruits have been observed, and a considerable reduction in the number of viable seeds in each fruit.

Other symptoms connected with mosaic disease in general are a dwarfing of the plants and a general paling of the foliage. Many investigators have examined the roots of diseased plants, but have been unable to determine any definite root symptoms.

Symptoms of Tomato Mosaic Disease

The appearance of tomato plants infected with mosaic disease varies considerably, according to infection having taken place in the early or late stages. Plants infected when quite young develop typical symptoms in all parts. They are generally stunted in growth and paler in colour than normal plants. Those infected later in life show typical symptoms only on those parts which develop after infection.

In respect of the foliage, five main types of symptoms

FIG. 39. Mosaic disease of the tomato.

FIG. 40. Mosaic disease of the cucumber, showing the distorted leaves.

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exist, and may be found singly on individual plants or together on the same plant. The first type consists of a simple mottling of the foliage without distortion of any kind. Pale green areas appear between the veins, and in process of time these turn yellow, with an indistinct margin. The second type resembles the first somewhat, but the spots produced appear very quickly without any gradual transition from pale green, and are distinct in outline and deep yellow in colour, like the variegations of *Aucuba Japonica.* This type is probably similar to the aucuba-mosaic of the potato described by Quanjer (39). The third type shows a distorted leaf margin, but without blistering or mottling.

In the fourth type blisters are produced on the leaf surface, and the leaf margin is more or less distorted. There is no mottling (Fig. 39). The fifth type, or tendril type, is distinguished by a reduction of the lamina and the production of fern-like or tendril-like leaves. Mottling is absent.

While a considerable amount of investigation is necessary before the full facts are available, it would appear that these symptoms are manifestations of the same disease, their appearance being governed by a number of factors, chief of which are the environmental conditions under which the host plant is grown and the degree of resistance exhibited by it. Thus, most varieties of tomato plants inoculated in February and March develop distorted, blistered leaves without mottling, but as the season advances these symptoms are gradually replaced by mottling and distortion. Towards the end of the year the new leaves develop blisters and become distorted, but mottling is rare.

The type of symptom exhibited by the host may vary with the variety, even when the conditions are uniform. Thus in the case of Manx Marvel and Invincible mottling of the foliage occurs later in the year than it does in the case of other varieties like Kondine Red, Blaby, and Comet. The flowers of tomato plants suffering from mosaic disease are frequently abnormal, cohesion and twisting of the various parts being fairly common. The anthers are sometimes quite small and sterile, and many flowers drop from the pedicels at an early stage. Some workers claim that the fruits are frequently mottled, but this symptom has not proved to be common in this country. The stems are often marked with streaks of a paler colour, and occasionally small, thin, brown streaks are present.

The total effect on the plant of all these abnormalities is to reduce the weight and quality of fruit produced. Plants physiologically weak are more severely attacked than those more robust, but in commercial nurseries the worst results are seen after the plants have been "stopped." "Stopping" consists in cutting away the growing point of the main stem just above the leaf above the fifth truss, in order to encourage the fruit to mature. Side shoots are then allowed to develop and produce what are known as the "tops." If an exceptionally heavy crop has been produced by the lower five trusses the "tops" may grow away weak and spindly, and if infected with mosaic disease at that stage the effect is extremely bad. Mottling, distortion, and desiccation of the leaves follow rapidly and the yield becomes negligible.

Symptoms of Cucumber Mosaic Disease

Mosaic disease of the cucumber may easily be recognized, and two types have been observed in this country. One resembles the aucuba type of the potato and tomato, and is marked by localized yellow patches of distinct outline. Curling and distortion of the foliage is rare in this type, which apparently does little damage to the plant. The second type is characterized by mottling, wrinkling, and blistering of the leaves and dwarfing of the plant (Fig. 40). Infection takes place at an early stage and may lead to complete "blindness' of the growing point. As a general rule only a small proportion of infected plants go "blind," the majority continuing to produce foliage bearing typical lesions throughout the season. It has been observed that infected plants may produce normal foliage after a time, but they cannot be said to have recovered because their juices are still infectious. Infected plants continue to bear fruit during the season, but the crop is considerably less than that from healthy plants. The flowers of diseased plants are frequently smaller and paler in colour than normal flowers, and mottling of the fruits may occur in advanced stages of the disease.

As in the case of the tomato, the resistance of the host plant and its environmental conditions are important factors in determining the severity of the external symptoms. Thus the variety Butcher's Disease Resister grown in this country shows only slight symptoms in comparison with other varieties commonly cultivated. The temperature of the soil and air, as will be shown later, are also important factors influencing the progress of the disease.

Pathological Anatomy of Diseased Plants

A critical microscopic examination of the tissues of plants suffering from mosaic disease reveals several interesting facts. Woods (50) in 1902 was the first to observe structural differences between the light and dark green parts of mosaic-infected leaves. He found that the palisade cells of the lighter areas did not develop normally but were cuboidal in shape, being only a third or half as long as the palisade cells from the dark areas. Also, the cells from the lighter areas contained an abnormal amount of starch. Recently Dickson (17), working with rapidly growing leaves of highly infected plants of different varieties, obtained interesting results. He found that the thickness of the light areas of the leaf was in the majority of cases only two-thirds that of the dark areas, whilst the dark green areas were rarely thicker than normal leaves. He confirmed the previous findings concerning the abnormality of the palisade cells, and noted the degeneration of cell contents. Slightly affected cells differed from healthy ones in that the chloroplasts were a paler green than usual. Increased effects were accompanied by a reduction in the number and in the depth of colour of the chloroplasts, and in severe cases they coalesced to form irregular green masses. Finally, the latter broke up into small hyaline bodies, at which stage the cell contents were observed to move very rapidly, and he concluded that the rapidity of movement of the granules was greater than could be accounted for by ordinary protoplasmic streaming. In the dark green areas the cells were generally larger than usual and contained more chloroplasts, which were of a darker green than is normally the case.

The Infectious Nature of the Disease

In certain plants, more especially the tomato, a mottling or variegation of the leaves frequently occurs, and this apparently results from malnutrition induced by unsuitable soil conditions. This state, which is generally known as "chlorosis," may be confused with true mosaic if the basis of comparison is solely a macroscopic one, but the two disorders differ materially in one important respect, namely, the infectiousness of the plant juices. The investigations of Iwanowski in 1892 led to the discovery that the extracted juices of a tobacco plant infected with mosaic disease are capable of infecting a healthy plant when pricked into the tissues, even after passage through a Chamberland filter. His results were confirmed by Beijerinck (11), in 1898.

This fact has now come to be recognized as a critical character of mosaic disease, and distinguishes it from non-infectious disorders of the "chlorosis" type. True mosaic disease, therefore, is of an infectious nature, and is readily spread from plant to plant by natural and artificial agencies. The expressed juices have been carefully examined for the presence of a micro-organism likely to cause the disease, but without success.

In the past many theories have been propounded to account for the disease. The first suggested that it was of a bacterial nature, and this was supported by Mayer (33), Iwanowski (25), Hunger (24), and Boncquet (12). Iwanowski states that in the cells of tobacco leaves from a diseased plant he found bacteria, amœba-like bodies, colourless lamellæ, and waxy crystalline deposits.

The enzymatic theory next found favour with investigators, among whom may be mentioned Woods (49), Chapman (14), and Freiberg (22). They considered the cause of the disease to be an excessive development of oxidizing enzymes, which prevented the production of the green colouring matter. In this respect the later work of Allard in 1916 is interesting. He showed that it is possible to destroy the oxidase by hydrogen peroxide without destroying the infectiousness of the juice, and that on destroying the virus without changing the oxidase no infection is obtained.

The virus theory, which is most generally accepted to-day, is the outcome of Beijerinck's theory (8) of a *contagium vivum fluidum.* Although he first favoured the bacterial theory, he later suggested that the infective principle is soluble in water. The term " virus " as used to-day includes the existence of an ultra-microscopic organism or an infective principle of an unknown type in the expressed juices of an infected plant.

Of late years a new theory—the amœba theory—has been expounded by Matz (32) and Kunkel (27). In their published results they suggest the presence of amœba-like bodies as the cause of mosaic disease of the sugar-cane and maize.

Many attempts have been made to isolate the causal organism in pure culture on artificial media by methods well known to bacteriologists, but without success.

Properties of the Virus

The infectious virus has been studied critically by Allard (2) and others, who have made important deductions. It was found that the virus of tobacco mosaic retained its infectivity after passing through Berkefeld, Chamberland, and Kitasato filters, but was non-infectious after filtration through filters with fine pores, such as the Livingstone atmometer cup or a layer of powdered talc seven-eighths of an inch in thickness. Thus 91 per cent of the plants inoculated became infected after the virus had been passed through a Chamberland filter, 63 per cent when a Berkefeld filter was used, and 40 per cent with the Kitasato filter. The cucumber mosaic virus has been found to pass a Berkefeld filter but not a Chamberland. The virus may be destroyed rapidly by treatment with 80 per cent alcohol or 4 per cent formaldehyde. The virus is destroyed in thirty-one days when treated with formaldehyde of a strength greater than 1 in 800. Carbolic acid and mercuric chloride have little effect on the infectivity of the virus. When heated to boiling point the infective principle is quickly destroyed, but lower temperatures are only doubtfully effective. The virus may be diluted to 1 in 1,000 without losing its infectivity, and it is claimed that infection has been obtained with dilutions as low as 1 in 10,000. The juice has been kept for fifteen months and has retained its infectivity, although in an advanced state of putrefaction.

Experiments with the virus of cucumber mosaic have shown it to be less resistant to killing agents than is that from the tobacco. Heating to a temperature of 70° C. and treatment with 0·5 per cent solution of copper sulphate, formaldehyde, or phenol has been found to destroy its infectivity, as has a 0·5 per cent solution of mercuric chloride.

Transmission of the Disease

The researches of previous workers have shown that once the infectious principle has been introduced into a susceptible host the disease spreads rapidly through the plant, and juice taken from all parts is found to be infective if introduced into a healthy plant. It has been shown also that the disease is very easily spread, it being sufficient to transfer a minute quantity of juice from an infected plant to the wounded tissues of a healthy one to render it diseased. The infection has been transmitted by such delicate operations as cutting the leaf hairs of a diseased plant with a pair of scissors and then cutting those of a healthy plant.

Under conditions of cultivation the disease may be spread by such processes as defoliation, picking, pruning, "stopping," and tying. Transmission by means of insects has been proved to take place in many instances and is now an accepted fact. In this respect aphides are especially dangerous, and experiments conducted by the author indicate that the white fly (*Aleurodes vaporariorum*) is an important factor in the spread of mosaic disease of the tomato under glass.

Experiments with tobacco mosaic were conducted by Allard to determine if the disease is transmitted in the soil, and his results lead him to conclude that infection does not take place in this way, but there is evidence that the active virus may be carried over the winter in the roots of susceptible perennials.

The importance of seed transmission has attracted much attention to this phase of the problem, but except for isolated cases it has not been proved to occur. Dickson (17) claims that seed transmission occurs in the case of the pea (*Pisum sativum*), certain clovers (*Trifolium pratense* and *T. hybridum*), and the sweet clover (*Melilotus alba*). Doolittle has found also that it takes place in the cucumber. No records of seed transmission are known for the petunia, potato, tobacco, and tomato.

Cross Inoculations

The question of the host range of any disease is always important to its control, and experiments with mosaic disease have shown that it contains a number of separate diseases, each of which has a limited host range. Thus tomato mosaic may readily be transmitted to the petunia, tobacco, bittersweet, and black nightshade, and with difficulty to the potato. It is also possible to cross-inoculate any of these from the others. The mosaic disease of the cucumber has not been transmitted experimentally to any of the above plants.

Carrier Plants

Inoculation experiments conducted with large numbers of plants have added facts of considerable value to our knowledge of this disease. It is frequently observed that a limited number of plants remain apparently healthy. They do not develop characteristic lesions, and one might expect them to be healthy. When, however, the juice from such plants is extracted and pricked into healthy plants the latter frequently become diseased. This phenomenon has been examined critically, and it has been shown that plants may become infected without showing any outward signs of the disease. In other words, " carrier " plants exist—a fact which has also been observed in susceptible weeds, such as the black nightshade. The identification of sources of infection thus become increasingly difficult, and their complete elimination impossible.

The Effect of Environmental Conditions

The influence of environmental conditions upon the incidence of other disease has proved to be considerable, and it is not strange to find that the same occurs in the case of mosaic disease. The temperature of the air is important in this respect, the development of the symptoms being retarded by low temperatures and increased by higher ones, in proportion to the extent to which the rate of growth is decreased or increased. Thus in the case of the tomato the development of the symptoms is slow during the spring, when low temperatures prevail and plant growth is retarded, but rapid during the higher summer temperatures, when the plant is growing quickly. Indeed, as noted before (page 143) the character of mosaic symptoms at these two periods may vary considerably.

Similar facts have been proved for the tobacco, where the incubation period for the disease is shortest at temperatures between 28° C. and 30° C. The optimum temperature for cucumber mosaic has proved to be 30° C., infection failing below 20° C.

Light may also have an effect upon the development of symptoms, as shown by the researches of Lodewijks (29) and Chapman (15). The latter showed that when tobacco plants inoculated with the mosaic virus were exposed to blue light they developed slight symptoms of the disease, although the expressed juice was infectious. Dickson (17) has shown that this effect is due to the modified conditions of growth occurring in plants exposed to this light.

The Control of the Disease

Mosaic disease appears to be attaining serious proportions, and its control becomes of great economic importance.

Four main lines of control may be considered, as follows:

(1) The determination and elimination of infection centres.

(2) The determination and elimination of agents by which the disease is transmitted.

(3) The determination of the environmental conditions which will induce a high resistance in the host plant.

(4) The breeding of immune varieties.

The Determination and Elimination of Infection Centres. —This involves a knowledge of all host plants of the particular strain of mosaic disease to be combated. Neighbouring weeds as well as cultivated plants must be taken into consideration. Growers should make a careful examination of weeds and other plants growing in the immediate vicinity of the nurseries, and any plants bearing symptoms suggestive of mosaic disease should be dug up and burned. No suspected plant should be given the benefit of the doubt. In relation to tomato mosaic it is now known that certain solanaceous weeds like the black nightshade (*Solanum nigrum*) and the bittersweet (*Solanum dulcamara*) are susceptible hosts, and should be eliminated from the neighbourhood of tomato nurseries, as they may act as centres for the spread of the disease. Similar dangers exist in the petunia and potato, and manure harbouring potato tubers should not be used, as, if these contain the virus of mosaic disease, infection may spread from the diseased shoots when these develop.

Alternative hosts for cucumber mosaic in this country have not been discovered, and it is somewhat difficult to understand from whence the infection comes, unless one accepts the statement which observation on commercial nurseries seems to support—that the disease is transmitted in the seed. There are no indications that tomato mosaic is carried in the same way.

In the case of sporadic infection of plants in a nursery during the early days of the season, care should be taken to remove immediately the affected plants before the disease can spread. In the case of mid-season infection, no useful purpose would appear to be served by removing infected plants. The difficulty which presents itself when an attempt is made to effect a control by eliminating centres of infection is that these are not always easy to identify when the symptoms are slight, and in the case of "carrier" plants showing no outward signs of the disease identification by simple means is impossible.

The Determination and Elimination of Agents by which the Disease is Spread.—The chief means by which the disease is spread from plant to plant are by insects and by the workers.

The complete elimination of insect carriers is almost impossible, but much can be done by reducing the number to a minimum. The white fly pest of tomato houses may be effectively controlled by hydrocyanic acid gas or tetrachlorethane, while aphides, when present, are easily controllable by many simple insecticidal fumigants.

By careful education of the workers, the rate of spread of the disease by this means can be reduced. They should be made to understand that merely crushing a diseased leaf with their fingers and then bruising a healthy plant, thus conveying infected juices to it, is sufficient to transmit the disease. It is imperative in cultural operations that all diseased plants should be left alone until the healthy plants have been treated, and in no case should a healthy plant be touched immediately after a diseased one. It is claimed that infection is spread by the clothes rubbing against a diseased plant and then a healthy one, but this does not appear to have been confirmed experimentally. After handling a diseased plant it has been shown that the infection can be removed from the hands by washing with soap and water. Pruning knives, after contact with a diseased plant, should be wiped on a rag moistened with some disinfectant like lysol.

The Determination of Cultural Conditions necessary to Increase the Resistance of Susceptible Plants.—As yet but little information in this respect is available, and investigations should yield important results.

The Breeding of Immune Varieties.—Many attempts have been made to breed varieties immune to this disease, but while satisfactory results have not been obtained, there are indications that success will eventually be forthcoming. In the case of cucumber mosaic the variety Butcher's Disease Resister is highly resistant.

CHAPTER VIII

GENERAL REFLECTIONS AND CONSIDERATIONS ON DISEASE TREATMENT

Soil and Water Sterilization

THE practice of soil sterilization is now an accepted method of increasing the fertility of infertile soils and of ridding them of diseases and pests.

When soils are heated, they undergo a process of change, the extent and form of which varies with the increase of temperature and length of time it is operative. Even slight increases of temperature are important as affecting the functions of roots and the behaviour of soil organisms as well as the chemical reactions occurring in the soil. When, however, soils are heated until the temperature becomes approximately 97° C. (207° F.) important changes take place and the soil becomes "partially sterilized." Partial sterilization has a beneficial effect upon soils, which is most marked in infertile or "sick" soils. Complex chemical compounds, unavailable as plant foods, are split up by the heat, and the simple compounds thus set free are either directly available as plant foods or rendered so in a short time by the bacteria present in the soil. The high temperature affects the living organisms of the soil in a differential manner, those which possess thin walls and are not specially adapted to resist abnormal conditions being killed, while others survive in virtue of possessing resistant spores and other reproductive bodies. Thus the non-sporing bacteria are destroyed, while those possessing spores which are resistant to abnormal temperature conditions are able to survive. The result is a specially clear field of action for those organisms which remain because of the destruction of enemies which in normal soils restrict their development. Among the spore producing bacteria which remain after partial sterilization are the ammonia producing organisms, which are thus enabled to spread rapidly and carry out unrestricted operations. After partial sterilization there is an immediate drop in the number of bacteria present in the soils, when there is a rapid increase which continues for several days, after which the number decreases slightly and then remains constant for a considerable period. Similar effects are shown in the amount of ammonia produced. This ceases immediately after heating, but increases suddenly, drops slightly, and remains approximately constant following a curve similar to that of the bacterial numbers. As might be expected this increased ammonia production has a beneficial effect upon plants, as is shown by a comparison of those grown in sterilized and unsterilized soil.

Partial sterilization effects a reduction in the extent of disease, but this varies with the nature of the disease organisms. The vegetative hyphæ and thin-walled spores are readily destroyed, but not so the thick-walled resistant spores and other bodies which, like the bacterial spores, are able to withstand such conditions. For the purpose of eliminating disease the soil must be heated to a greater extent than is required for increasing fertility. Generally, however, a temperature of 200–205° F., maintained for an hour, is sufficient to eliminate most fungus diseases. Complete sterilization or over-sterilization is a possible contingency which must be guarded against, for when this takes place the soil is rendered unable to maintain plant growth until reinoculated with fresh soil and sufficient time allowed for the introduced organisms to permeate the original soil and restore fertility.

In practice, the aim of sterilization is to restore soil fertility and to effect the complete eradication of harmful soil organisms, including fungi, bacteria, amœbæ, insects, and small animals. It is achieved by steaming or baking the soil, or treating it with some special chemical compound.

Steam Sterilization

This is effected by continuously passing into the soil large quantities of steam at a high pressure, until the soil temperature becomes sufficiently high, when it is maintained there for a definite time.

(*a*) "*Box and Grid*" *Method.*—A trench about six feet wide and one foot deep is made across one end of the house, and the soil thus removed is taken to the other end. The subsoil at the bottom of the trench is forked up and if necessary a light dressing of lime may be given. Four boxes, six feet square, or of some size to suit the position of pipes in the house, and without bottom or top, are placed in position over the trench, the house being 27 feet wide. One box fits between the wall flowpipe and the return on each side of the house, and two in the middle of the house. The boxes average 5 feet 6 inches square at the top and 6 feet square at the bottom, the sloping side being about 18 inches in depth. A "grid" for distributing the steam is passed under one side of each box and laid on the subsoil. The grid resembles a large digging fork, and is made of perforated hollow pipes (Fig. 41). Two grids are connected, by means of a steam barrel T-piece fitted with two control valves, to a length of best flexible hose, which in turn is connected to the steam barrel leading to the steam boiler. When the boxes and grids are in position another trench 6 feet wide and 1 foot deep, adjacent to the line of boxes, is dug and the soil thrown into the boxes. It is important here to fill the boxes evenly, and in no case must the soil be firmer in one part than another, for steam always takes the line of least resistance, and the result will be that it will rush through the loose parts and leave the firm parts untouched. The soil is next packed well round the sides of the boxes to prevent any escape of steam. It is always advisable to remove the

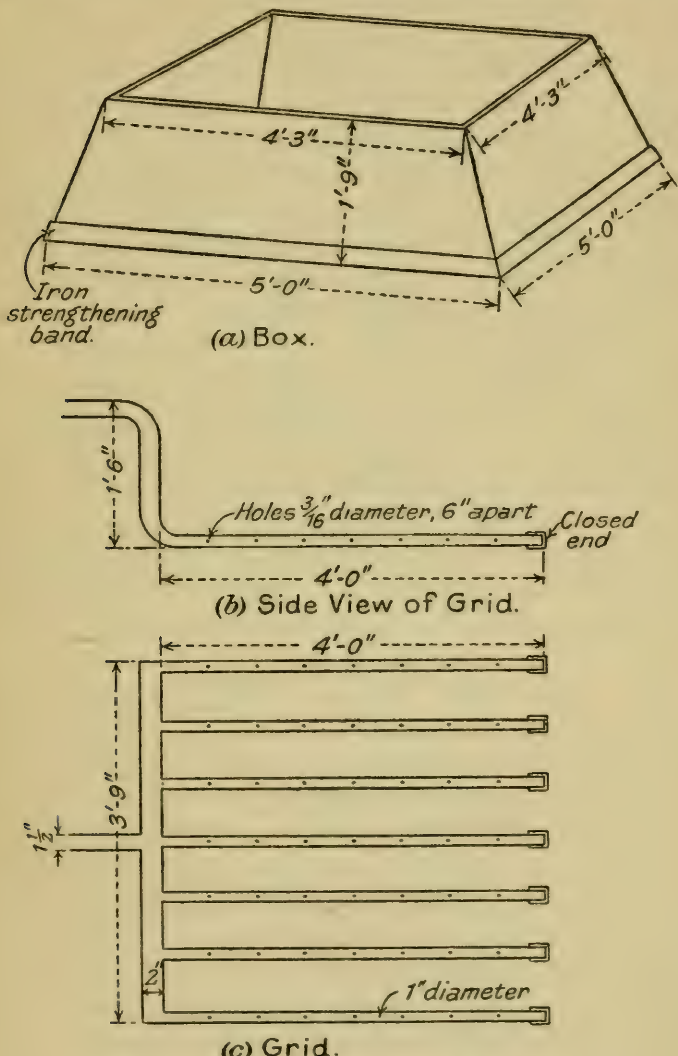

FIG. 41. "Box and grid" for steam sterilization.

soil used for packing, before lifting off the box, as it is rarely sterilized, and is a source of contamination. It should be thrown into the next box for sterilization. When the boxes are filled they are fitted with lids and tarpaulins thrown over the top. The steam is supplied from a portable steam boiler of 12 to 30 horse power (Fig. 43), and maintained at 60 to 90 lb. pressure per square inch. Steam is passed through the grids for 30 mins., which under normal conditions is sufficient to raise the temperature of the soil to 200° F. Any leaks of steam round the sides of the boxes must be stopped by packing with earth. The passing of steam is continued for another 20 to 30 minutes, and the box left on for still another 30 minutes. To facilitate operations six boxes and four grids should be employed. With a suitable head of steam two boxes may be steamed at a time, while two are being prepared and two previously steamed are cooling. The grids, however, may be pulled out as soon as the steam has been turned off. The boxes, being smaller at the top than the bottom, are easily lifted off the soil—a process performed by two men with lifting irons—and the grids being shaped like forks are easily pulled out from underneath. A house 250 feet by 26 feet can be steamed in 70 hours continuous working.

(*b*) "*Small Grid*" *Method.*—An adaptation of the grid system has proved useful in some places (Fig. 42). The apparatus, which resembles a comb, is made of 1-inch iron tube from 8 to 10 feet long to suit the size of the plot to be treated, and to fit the spaces between the pipes and walls, etc. The "teeth" are each 2 feet 6 inches long, fixed at intervals of 10 inches to 12 inches along the "back" of the grid. Holes a quarter of an inch in diameter are made slightly on the lower side of the laterals or "teeth," and are placed alternately on either side at intervals of three inches, so that holes on the same side are six inches apart. The end of each lateral is sealed, and the last hole should be made exactly on the under side of the pipe to allow any condensation water to run out. A short connexion of 1-inch iron tube

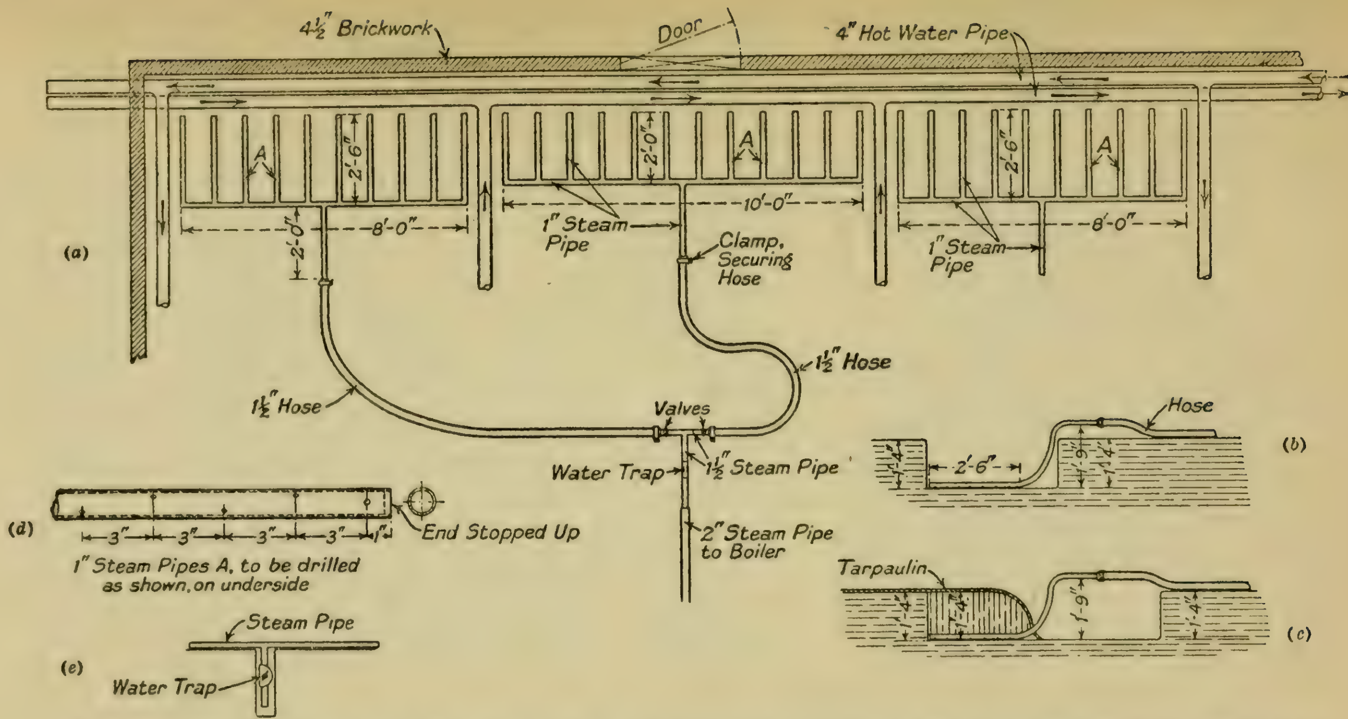

FIG. 42. Steam sterilization by the "small grid" method: (*a*) diagram showing apparatus in position, (*b*) section illustrating the method of placing the grid in the trench, (*c*) section showing the soil in position ready for steaming, (*d*) portion of grid showing position of the holes, (*e*) water trap.

bent like the handle of a plasterer's trowel placed on the opposite side to the laterals serves to connect the grid to a length of $1\frac{1}{2}$-inch best flexible hose piping fitted to the main 2-inch steam barrel leading to the boiler. A trench 30 inches wide, 6 feet long, and 16 inches deep is made and the soil wheeled away to the other end of the bed to be sterilized. The grid is placed in the bottom of the trench and a second trench is dug similar to the first, and immediately behind it. The soil from this trench is thrown into the first and covers the grid. When the trench has been filled, a tarpaulin is thrown over the top and steam passed for 10 to 15 minutes. The grid is then pulled out and back into the empty trench, which is filled up and steamed as was the first. By working a pair of these grids one man can be fully employed.

The success of this method of steaming depends very considerably upon keeping the pipes and grid free from condensation water. Any quantity of water lodging in the pipes will cause failure by checking the proper flow of the steam. The holes in the laterals, being placed low down near the soil, prevent any condensation water from filling the pipe, and the end hole, being made at the bottom of the tube, allows the water to drain away. When the actual steaming is done some distance away from the boiler, and consequently a considerable length of 2-inch steam barrel has to be used, there is a tendency for condensation water to lodge in the pipes. This is overcome by placing a steam trap at the end of the steam barrel just in front of the T-piece connected to the hoses. In the absence of a steam trap a valve slightly opened can be fitted as shown at Fig. 42 (*e*). This allows the condensation water to drain away, but does not affect appreciably the steam pressure.

(*c*) "*Tray*" *Method.*—In this method the soil is well dug one spit deep, so as to assist the penetration of the steam, and it is important that the soil should be moder-

FIG. 43. Steam Boiler.

FIG. 44. Tray method of steaming, showing trays and pipes ready to place in position.

FIG. 45. Trays down ready for steaming to begin. [*Facing page 160*

ately dry. If it is too wet the steam condenses before it has penetrated very far into the soil, and its latent heat is lost. Furthermore, it tends to pass quickly through the soil in certain definite channels, and the correct general diffusion of steam between the soil particles is prevented. The result is imperfect sterilization and money wasted.

In the "tray" system the steam is passed into inverted shallow trays placed on the soil and from them diffuses down into it (Fig. 44). The trays are designed to combine lightness with efficiency, and generally are made of match-boarding lined with zinc to make them air tight. A better type of tray can be made of galvanized sheet iron reinforced with "T" irons and "angle" irons. They vary from 6 to 9 inches in depth and are made in various sizes suited to the house to be treated, having regard to the position of pipes, purlins, stays, etc. The trays are placed on the soil and the steam fed from suitable pipes introduced at one side. These pipes are laid in shallow trenches a few inches deep, and serve to connect one tray with another or with the main steam supply pipe. The number of trays treated with steam at one time depends upon their size and the amount of steam available. Frequently when more than two trays are employed at a time it is necessary to pass the steam for a long period. The pipe introducing the steam into the tray extends to the centre of it, and it is an advantage to place a brick close to the end to assist in dispersing the steam as it issues from the pipes. Trays 8 feet by 4 feet may be steamed in pairs joined by a T-piece, the left half of the top of the T-piece passing under one tray, the right half passing under the other, and the pipe being connected to the main pipe. When the pipes and trays are in position, the latter are pressed down into the soil, well packed round the edges and pipe junctions with earth (Fig. 45), and covered with tarpaulins. Steam is then turned on, and $1\frac{1}{2}$ hours is usually necessary before the soil at a depth of 6 inches is raised to a temperature of 200° F.

From observations taken by the author when using trays (9 feet by $2\frac{1}{2}$ feet by 5 inches) in pairs, it was found that by passing steam at 60 lb. pressure into moderately heavy soil for $1\frac{1}{2}$ hours the temperature $\frac{1}{2}$ hour after the steam was cut off was 210° F. at 6 inches depth, 190° F. at 9 inches depth, and 150° F. at 15 inches depth. The general practice is to pass the steam for 2 hours, thus allowing 30 minutes after the desired temperature is reached, and then to leave the boxes in position for $\frac{1}{2}$ hour after the steam has been shut off. The governing factor to the man in control must be the actual soil temperature obtained. This should be not less than 190° F. at a depth of 6 inches.

(*d*) *Tank Method.*—For this method a galvanized tank of about 100 gallons capacity is employed (Fig. 46). A

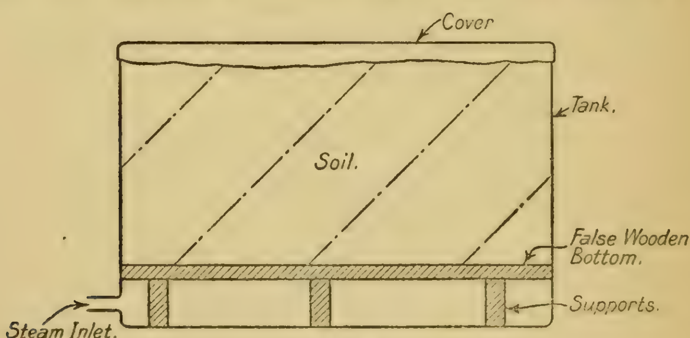

FIG. 46.

false bottom consisting of wooden boards supported on bricks is placed about 6 inches from the bottom and a piece of steam barrel fitted into it, so that steam may be introduced into the space between the true and the false bottoms. When the tank is almost full of soil a lid is fitted and a tarpaulin thrown over the top. Steam is then passed for half an hour, after which time it is shut off and the tank emptied. This method has the advantage that every piece of soil is removed and sterilized and there is little chance of any being missed.

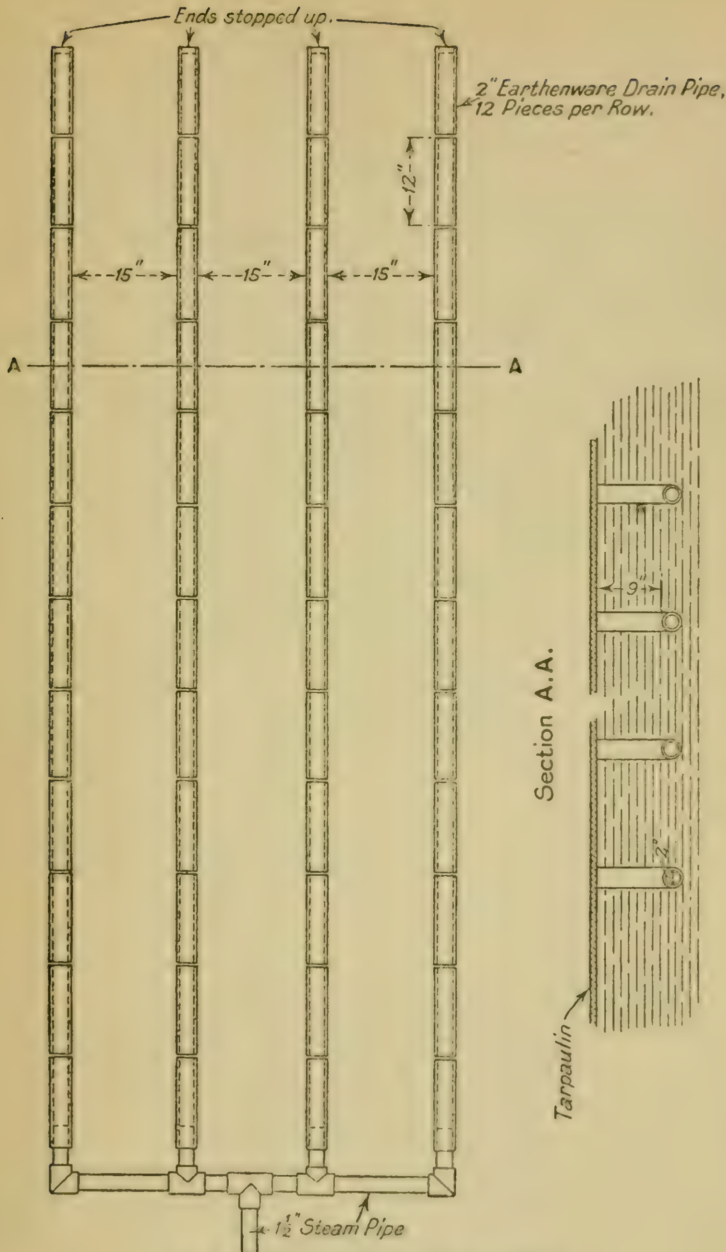

Fig. 47. Drain-pipe method of steaming.

(*e*) *Drain Pipe Method.*—Where trays are unobtainable or too expensive to use, steam may be passed through a buried system of pipes (Fig. 47). For this purpose 2-inch agricultural tiles may be used. These are laid at a depth of about 9 inches in rows 15 to 18 inches apart, each row consisting of 12 tiles, the far end of each row being stopped up. It is convenient to steam four rows at a time, the steam being introduced by a hollow four-branched tube of steam barrel, the branches of which fit into the four rows to be steamed. It is advisable to dig the soil first, and in covering the pipes the soil must be compacted uniformly to enable the proper diffusion of steam. The surface of the soil should be covered with a tarpaulin or steam-proof sail-cloth, and then the steam may be turned on. Four rows of 12 tiles with 18 inches between the rows will steam 72 square feet of soil surface. Steam should be passed for 1 hour in order to heat the soil sufficiently to a depth of 18 inches. It is advisable not to disturb the soil before it is quite cold in order to obtain the maximum benefit from the steam, and so an extra supply of tiles should be obtained to allow the work to proceed continuously. Two men can be constantly employed in laying and removing tiles, making up beds, and attending to the steam boiler for each set of tiles. It is a saving to employ several sets of tiles simultaneously.

Surface Sterilization with Hot Water

The ground is first well dug and broken up; and in this respect a mechanical cultivator is helpful. It is sufficient to run the cultivator over the ground once, as by repeating the process the soil is broken up to such a fine state that it pans badly. Boiling water is applied freely, and temperatures of 180° F. at 3 inches depth, 140° F. at 6 inches depth, and 120° F. at 9 inches depth are usually reached.

A special hot water boiler can be obtained to deliver

1,500 gallons of boiling water per hour. It takes 130 hours to treat one acre of land, in the course of which approximately 200,000 gallons of water are applied.

Deep Sterilization with Hot Water

In this process the normal winter dressing of caustic lime is first applied to the soil. Drills are next made across the house and as close together as possible; generally they are a foot apart and 6 inches deep. Three drills are treated at a time, and these are filled with boiling water three times. During the process extra heat is provided by the rapid slaking of the lime, which "explodes" all over the ground, and, with the repeated filling with boiling water, produces a temperature of 150° F. at a depth of 9 inches. Three floodings are sufficient to level the soil and the next three drills are then filled up three times and so on.

By this method, 180,000 gallons of boiling water are applied to each acre, or 37 gallons per square yard. Using a boiler delivering 1,500 gallons of boiling water per hour, and working 10 hours per day, the process takes 12 days.

The Boiler Tray Method

In this method soil is heated in a shallow tray placed on the top of an ordinary heating boiler. The tray, made of galvanized iron, 8 feet long, 3 feet wide, and 1 foot deep, is made to fit over the top pipes of an ordinary horticultural tubular boiler. The tiles and brickwork of the flues, etc., are made to fit round the tray in such a manner that the boiler may be used for ordinary heating purposes at the same time. Suitable brickwork is made to prevent the weight of the tray and soil being borne solely by the top pipes, as otherwise there is a risk of causing the ring joints of the castings to leak. Moist soil to a depth of 12 inches is placed in the trough, which is then covered with wood and waterproof sheeting.

Each lot of soil is heated for 24 hours, the heat being evenly distributed throughout the mass by means of the moisture, and after some time a temperature of 180° F. is obtained throughout. It is important that the soil should not be too dry or the heat will be imperfectly distributed and the bottom layers overheated.

In sterilization by the "tank" and "boiler tray" methods it is easy to over-sterilize. For this reason these methods should be performed in the summer, at least three months before using the soil. The soil should be mixed with clean stable manure and allowed to recover before using.

The main principles governing the practice of sterilization by heat have been given, but growers may have occasion to alter the small details to suit their own houses and convenience. Thus, in the tray method of steaming, the size of tray is optional and may be adjusted to conform to the structure and size of the house. Galvanized iron is often useful for constructing small trays to fit into narrow places between pipes and walls, etc. Modifications in size and shape of grids and combs may also be devised to suit individual requirements.

Sterilization by Baking

When sterilizing small quantities of soil for propagation purposes it is often inconvenient to employ steam. In such cases the soil may be sterilized by baking. In this method damp soil is placed in a suitable oven (of which there are a number on the market) and heated until the temperature at the interior of the soil mass is between 205° F. and 210° F. This should be maintained from 60 to 120 minutes and the soil removed from the sterilizer to a suitably covered position, where there is no danger of reinfection.

Our experience has indicated that for satisfactory work it is necessary to have a factory thermometer fitted through the side of the oven, with the bulb in the soil mass, otherwise there is danger of over-heating the soil, especially if it is too dry. Investigations with regard to the temperature details are now in progress at Cheshunt Experimental Station. Even with the crude methods at present in practice satisfactory results are generally obtained. In any case, it is advisable to bake the soil six weeks ahead of using it, and in the interval the heap should be well worked and watered to bring the soil into a suitable physical state for cultivation.

Sterilization by means of Chemical Compounds

The researches of Sir John Russell and his colleagues at Rothamsted Experimental Station have elucidated many problems of soil sterilization and led to the knowledge that soil treatment with chemical compounds produces partial soil sterilization effects. The intrinsic value of any method of soil sterilization depends upon the ease of application, thoroughness of sterilization, and the cost. Chemical treatment of soils has proved to be slightly cheaper and easier of application than that of heat treatment by steaming or baking; but while the compounds at present on the market have proved successful for certain purposes, there is need for a more efficient and cheaper compound than is at present available to the practical man.

Investigations conducted at Rothamsted indicate that such compounds will be available in the future. Caustic lime and cresylic acid are the only compounds used extensively in practice. Heavy dressings of caustic lime of from four to ten tons per acre are employed in the glasshouse industry with beneficial results.

Sterilization with Cresylic Acid

Pale straw-coloured "carbolic" acid, composed of a mixture of ortho-, meta-, and para-cresols of 97 to 99 per cent purity is used, one gallon being poured into a barrel containing 39 gallons of water. On light soils the

40 gallons of diluted acid is applied to 9 square yards, but on heavy soils the same quantity is applied to 12 square yards. The original method was to apply the acid in two half-strength dressings with a fortnight's interval, and wash each into the soil by copious watering. The present plan is to spread the diluted acid over the soil, so as to saturate the top inch or so, and at once dig the ground, so as to leave the saturated layer of soil a foot below the surface. By so doing the vapours permeate the top foot of soil and sterilize it.

Probably the best way of applying the acid is to absorb it in a quantity of dried soil containing gypsum, which is then well mixed with the soil by digging. Cresylic acid has proved useful in increasing soil fertility, but while it reduces certain diseases to some extent it does not eradicate them completely.

Sterilization with Formaldehyde

Formaldehyde has proved eminently satisfactory for bringing about the destruction of some disease organisms in the soil, but the present cost prohibits its extended use on a large scale. For sterilizing a few tons of soil intended for propagation the excellent results obtained more than compensate for the expense. A 2 per cent solution prepared by adding 1 gallon of 40 per cent formaldehyde to 49 gallons of water will effectively sterilize most soils. To sterilize each ton of moderately heavy soil 1½ gallons of 40 per cent formaldehyde or 75 gallons of the diluted solution is used. A suitable place to perform the operation is first chosen, and this should be fairly flat and if possible protected by an overhead covering to keep off the rain. The ground should be beaten flat and damped with formaldehyde. The soil to be sterilized is laid out in a layer not more than 6 inches deep and saturated with the diluted formaldehyde. Another layer of soil is placed on top and saturated in turn, until the whole of the soil has been treated. The heap is then covered with tarpaulins or sacks sprayed with formaldehyde, and left so covered for 48 hours, after which time the covering is removed and the heap opened out to dry. This is accelerated by constant turning, but all instruments should be sterilized with formaldehyde to prevent reinfection of the heap. When the soil ceases to smell of formaldehyde it is ready for use.

Benches, staging, boxes, and pots may also be sterilized by thoroughly wetting with the solution, stacking, and covering for 48 hours, and then allowing to dry. Where stable manure is suspected of carrying infection formaldehyde offers the best method of sterilizing it.

At Rothamsted many chlorine and nitro-derivatives of benzene and the cresols have been tested with excellent results. Among these may be noted dichlorcresol, orthonitrochlorbenzene, and chlordinitrobenzene, but these have not been tested yet on a commercial scale, and large quantities are not yet on the market. The grower may look forward with confidence to the future, when thoroughly efficient chemical sterilizers will be available.

Sterilization by Drying

The fact that some soil organisms can resist desiccation to a greater degree than others is responsible for the fact that the drying of soils produced effects similar to those of partial sterilization. Under normal conditions of cultivation, however, it is possible that glasshouse soils are never sufficiently dry to benefit from this process.

The Effect of Different Methods of Soil Sterilization upon Plant Growth

Sterilization of the soil results in the liberation of plant foods previously locked up in unavailable forms and in an increased production of ammonia. Plant growth, therefore, is stimulated in much the same way as by the addition of nitrogenous fertilizers. The extent to which the plant is stimulated depends upon the method of sterilization employed.

Heat is the most active in this respect, and liberates large quantities of plant foods, while chemical sterilizers, like cresylic acid, liberate considerably less. Again, the amount of food liberated and ammonia produced varies with soil type, being small in light sandy soils and large in heavy soils rich in organic matter. When soils have been sterilized by heat it is not advisable to give a base dressing containing nitrogen, but to wait until the plants develop, when nitrogen may be given as a top-dressing if necessary. Many a grower has regretted disregarding this principle when his crop has developed a soft, sappy growth which could only be corrected by excessive dressings of potash and phosphates. On some soils, therefore, sterilization encourages a soft, sappy growth if accompanied by normal base treatment, and thus the safest procedure is to give the normal quantity of potash in the base manure and to omit all nitrogenous manures. Phosphates may be added at the grower's discretion. This applies especially to steam sterilization on all but the poorest soils, and to cresylic acid sterilization on heavy, rich soils.

The presence of large quantities of ammonia in the soil has an inhibiting effect upon plant growth, which is especially noticeable in young seedlings. Generally, seeds sown in sterilized soil exhibit a retarded germination in comparison with those sown in virgin soil. After a time, however, those grown in sterilized soil forge ahead and become much better plants than the controls. The amount of ammonia produced is dependent upon a number of factors, such as the richness of the soil, method of sterilizing, and duration of the sterilizing processes. It is greater in rich soil than in poor soil, in heated soil than in chemically treated soils, and in soils heated for a long time than in those heated for a short time. The growth

TABLE 11

Soil Sterilization Experiments

		TOTAL, 1922.				1921.				1920.				1919.							
TREATMENT.	Plot No.	Lbs. per Plant.	Tons per Acre.	Relative.		Lbs. per Plant	Tons per Acre.	Relative.		Lbs. per Plant.	Tons per Acre.	Relative.		Lbs. per Plant.	Tons per Acre.	Relative.		Average lbs. per Plant.	Average Tons per Acre.	Relative.	
SERIES 1																					
Steam	1	3·98	31·8	124	129	4·01	32·1	104	113	3·99	31·9	100	100	4·29	34·3	114	116	4·07	32·5	110	114
Steam	5	4·30	34·4	134		4·70	37·6	122		4·06	32·4	101		4·44	35·5	118		4·38	35·0	118	
Carbolic	6	4·26	34·1	133	121	5·07	40·6	132	124	4·48	35·8	112	102	4·44	35·5	118	117	4·56	36·5	123	115
Carbolic	8	3·46	27·7	108		4·43	35·4	115		3·66	29·2	91		4·36	34·9	116		3·98	31·8	107	
Formaldehyde	3	4·07	32·6	127	129	4·82	38·6	125	124	4·55	36·4	114	103	4·43	35·4	118	117	4·47	35·8	121	118
Formaldehyde	7	4·20	33·6	131		4·71	37·7	122		3·72	29·7	93		4·44	35·5	116		4·27	34·1	115	
Untreated	2	3·48	27·8	109	100	4·02	32·2	104	100	4·12	32·9	103	100	3·87	31·0	103	100	3·87	31·0	105	100
Untreated	4	2·93	23·4	91		3·68	29·4	96		3·89	31·1	97		3·64	29·1	97		3·54	28·3	95	
SERIES 2																					
Steam	2	5·56	44·5	152	151	5·04	40·3	130	129	3·89	31·1	118	116	4·77	38·2	131	128	4·82	38·5	133	131
Steam	6	5·48	43·8	149		4·81	39·3	127		3·73	29·8	114		4·51	36·1	124		4·63	37·3	129	
Carbolic	5	3·93	31·4	107		4·38	35·0	113		3·25	28·0	107		4·15	33·2	114		3·93	31·9	110	
Formaldehyde	8	4·20	33·6	115		4·03	32·2	104		3·27	26·2	100		4·03	34·2	118		3·88	31·6	109	
Hot Water	4	3·81	30·5	104	111	3·99	31·9	103	108	3·40	27·2	104	107	3·70	29·6	102	109	3·73	29·8	103	109
Hot Water	7	4·33	34·6	118		4·38	35·0	113		3·61	28·9	110		4·18	33·4	115		4·13	33·0	114	
Untreated	1	3·58	28·6	98	100	3·92	31·3	101	100	3·10	24·8	95	100	3·57	28·6	98	100	3·54	28·3	98	100
Untreated	3	3·78	30·0	102		3·81	30·5	98		3·46	27·7	105		3·70	29·6	102		3·69	29·5	102	

inhibiting factors may be removed by thoroughly soaking the soil with water and allowing it to drain, or by leaving the soil to weather under cover for three or four weeks before using. Of all methods employed for sterilizing the propagating soil that of formaldehyde has proved to produce the best plants. Occasionally tomato seedlings raised in baked soil have turned a dark blue-green colour and refuse to grow. This is generally due to the soil having been over-sterilized, and a slight top-dressing of virgin soil is usually sufficient to restore normal conditions in a short time.

The table on p. 171 indicates the effect of different methods of sterilization upon crop yield, and is drawn up from the results of experiments conducted on a commercial tomato nursery in the Lea Valley.

The Effect of Sterilization upon Plant Disease

One of the most important functions of the sterilization of soil is the eradication of the disease organisms which inhabit it, and numerous investigations have shown that diseases may be prevented by sterilization by steaming, baking, or with formaldehyde and other chemical compounds.

It is necessary to bear in mind, however, that sterilization to be completely satisfactory must be very thoroughly done. If patches of untreated soil remain in corners, under pipes, etc., infection rapidly spreads into the adjacent sterilized parts, and after a year or so the whole of the soil may be reinfected. It has been shown that disease organisms spread more rapidly through sterilized soil than through virgin soil—a fact which is easily understood, as the enemies and competitors of the parasitic fungi, which restrict their growth in normal soils, have also been destroyed by sterilization.

An experiment performed by the author is instructive in relation to the fact. Two troughs 8 feet long, 18 inches wide and 2 feet deep were filled, one with steam sterilized soil and the other with virgin soil, and six tomato plants were planted at equal distances apart in each trough. Five pounds of soil copiously infected with *Verticillium albo-atrum* was introduced at one end of each box, and the temperature maintained as near as possible to 65° F. The tomato plant nearest the point of inoculation in the sterilized soil was the first to show signs of wilt, which appeared in twenty days. In six weeks all plants in the sterilized soil, but only two in the virgin soil, were infected. This indicates clearly that the fungus in question spreads more rapidly in sterilized soil than in unsterilized soil, and provides a reason for the fact that diseased soil may be more heavily infected two or three years after sterilization than it was before treatment. In sterilizing soil, therefore, every possible means to avoid reinfection should be taken. It is a good plan to sterilize with formaldehyde all brickwork under the ground and a foot above it, and any soil that cannot be treated by steam.

Water Sterilization

It has been shown previously (3) that the water supply of modern nurseries may be so highly contaminated with disease organisms as to form a continuous and important source of infection to glasshouse plants. In considering the elimination of this form of infection the grower is faced with two alternatives: he may either discard the contaminated well and construct a new one upon such lines as to ensure its freedom from pollution, or he may endeavour to cleanse the old one. The former plan will appeal to growers as being the most satisfactory in the end. The best wells are made by boring into the subsoil to a depth of 100 feet or more, and should be well bricked in for the top 10 to 20 feet, to prevent the entrance of surface drainage, by which means contamination enters. All deep artesian wells have proved practically free from fungi and should be used wherever possible.

Complete cleansing of a polluted well is by no means simple. The first thing is to clear away the surface scum and as much of the growth round the sides as possible. When the water is thick with decaying plant materials it may be cleared by precipitation with alum and sodium carbonate, added at the rate of 18 lb. potash alum and 5 lb. sodium carbonate for every 25,000 gallons of water. Perchloride of iron at the rate of 9 lb. per 25,000 gallons of water is also a useful clarifying agent. After precipitating the organic matter in the water the well may be pumped low and cleaned out as much as possible. When the well has filled up again the water should be "chlorinated" to destroy disease organisms, and a convenient method is to add 50 gallons of "Chloros" for each 100,000 gallons of water. After this treatment the well should be left alone for a week before using. Complete sterilization of the water can only be obtained by boiling, and this may be accomplished by arranging the pipes leading to the tank in such a manner that they are heated by passing through the boiler. The treated water is then stored in a tank adjacent to the boiler. While it may not be so necessary to supply the more mature plants with disease-free water it is advisable to sterilize the water used in the stages of propagation when the plants are most susceptible to disease.

CHAPTER IX

GENERAL REFLECTIONS AND CONSIDERATIONS ON DISEASE TREATMENT—*Continued*

Spraying and Dusting

The value of spraying has long been recognized by the potato and fruit growers, the more progressive of whom regard it as an essential cultural operation—almost as a form of insurance. The glasshouse owner, however, has not yet learned to regard it in the same light, and many of those who have attempted to spray against fungus diseases have been disappointed by the results, mainly because they have not understood the rationale and function of the process.

Spraying consists of the application of fungicidal and insecticidal fluids to the surface of a plant as a protection against pests causing diseases.

Some fungi and most insects live on the surface of the leaves and stems and may be destroyed directly by contact when a suitable spray is applied. On the other hand, the majority of parasitic fungi and bacteria spread deeply into the plant tissues, and therefore cannot be touched by spray fluids, which are external. In such cases the application of a fungicidal spray destroys the fruiting parts of the fungus, which are produced on the outside of the plant, but does not prevent the further development of the deeply buried parts, which in course of time are able to grow out into the air and produce new fruiting bodies.

The true function of a fungicidal spray is protective, not curative; and realization of this fact will lead the grower to a better understanding of the effects of spraying and perhaps prevent undue disappointment. This protection is obtained by covering the entire plant surface with a thin, poisonous coating able to destroy any fungus spores which may settle on the plant. Spraying efficiency is governed by a number of different factors, each of which must be taken into account if success is to follow.

In the first instance it is necessary to determine correctly the cause of the disease. This is important because different organisms are more sensitive to one poison than to another, and what is a certain cure for one disease may not affect another in the slightest degree. Thus spores of *Botrytis* are extremely sensitive to calcium bisulphite, being rapidly killed by a two per cent solution, which is quite innocuous to spores of *Cercospora melonis*.

Having, however, determined what organism is causing the trouble, a suitable spray liquid may be chosen ; but it is necessary to remember that complete protection of the plant tissues depends upon every part of the surface being covered by the poisonous film. Some plants are easily covered by watery solutions, but others, such as those possessing waxy or hairy surfaces, offer considerable resistance. This is overcome by adding a " wetting agent " or " spreader " to the liquid, which assists it to wet the entire surface. Further, any new growth which develops after spraying has been carried out is of course unprotected, and so at critical periods the spraying operation must be repeated at frequent intervals.

Because the work of the spray is to protect the plant by destroying any fungus spore which happens to fall on its surface it is necessary to spray only immediately prior to and at the time when the spores are being shed and blown about in the air. Spraying at other times, when spores are not being produced and therefore do not exist in the air, is merely wasted time, money, and energy. This being so, a knowledge of the life-history and methods of growth of the disease organisms is important, so that spraying may be conducted at the right time.

The method of applying the spray is a matter of considerable importance, for no matter how destructive to the disease organisms the liquid may be, or how perfectly it may wet the surface, it is of no avail if not directed in the proper direction or with the required force from suitable machines.

It must also be remembered, however, that under certain conditions the cure may be worse than the disease, and consequently the effect of the spray upon the health and growth of the plant must be taken into consideration in choosing a spray liquid. In this respect physical conditions of the environment at the time of spraying and for some days afterwards are important. Thus a spray which is perfectly harmless to the plant under cool, moist conditions may scorch it beyond remedy when the air is hot and dry.

Fungicides

A fungicide is a chemical compound which is poisonous to fungi and which, when correctly applied to the surface of the living plant, serves to protect it from attack by fungus parasites. A good fungicide should be extremely poisonous to the pathogen against which it is directed, but harmless to the plant to which it is applied; it should completely wet the plant surface and adhere strongly once it is applied; and finally it should be cheap and easy to use.

The discovery of Bordeaux Mixture by the Frenchman Millardet in 1883 may be said to mark the commencement of fungicidal treatments. Since that time scientific investigations have produced a large number of preparations of proved fungicidal value.

Bordeaux Mixture

The discovery of the fungicidal value of Bordeaux

Mixture was entirely the result of an accident. In order to prevent loss by thieving, the vineyard owners near the city of Bordeaux were in the habit of sprinkling the vines near the roads with verdigris to make them look as if they had been poisoned. Later a mixture of lime and copper sulphate was used to replace the verdigris on account of cheapness. Downy mildew, caused by *Peronospora viticola*, was introduced accidentally from America, and it soon became apparent that the vines sprinkled with lime and copper sulphate were less affected by the disease than those untreated. Bordeaux Mixture is prepared by mixing a solution of copper sulphate and lime in varying proportions in accordance with the disease and kind of plant to be sprayed.

Standard Bordeaux Mixture is made of 6 lbs. copper sulphate, 4 lbs. of lime and water to make 50 gallons. The copper sulphate should be fully 98 per cent purity and the lime should be freshly burnt stone lime of good quality. The copper sulphate should be dissolved in 40 gallons of water in a barrel, and the lime slowly slaked in another vessel. This is best done by adding as much water as the lime will absorb, but no more. The remainder of the water, making 10 gallons in all, should be added gradually to the slaked lime, taking care to stir thoroughly at the same time. The 10 gallons of lime and water are then added to the 40 gallons of copper sulphate solution, stirring all the time. No matter what quantity of the mixture is being prepared it is necessary to strain the materials through a sieve, the best type being made brass wire having 18 to 20 meshes to the inch. Correctly prepared Bordeaux Mixture possesses a brilliant sky-blue colour, but the improperly prepared mixture generally has a greenish colour, and is dangerous to use as it will injure the foliage. The following precautions must be observed in preparing the mixture:

(1) Only pure 98 per cent copper sulphate and freshly burnt stone lime should be used. Air slaked lime is useless.

(2) The copper sulphate solution must not be placed in vessels of tin, iron, or zinc, as it corrodes them and loses its strength.

(3) Concentrated solution of copper sulphate and lime should never be mixed.

(4) The lime and water should be added to the copper sulphate solution and not vice versa.

(5) Hot water should not be used in the preparation.

(6) The mixture can only be used when freshly prepared, as it loses its fungicidal powers after standing 12 hours.

(7) Bordeaux Mixture must be strained before transferring to the spraying machine, and constantly shaken or stirred during use.

The action of the lime on the copper sulphate is to produce compounds called basic copper sulphates, which possess valuable fungicidal powers. If insufficient lime is used to combine with all the copper sulphate (which happens when the lime is not up to standard), a certain amount of the latter will remain free in the solution and will scorch the foliage when the solution is applied. It is important, therefore, to make quite sure that enough lime has been added and that no free copper sulphate remains, as shown when the yellow prussiate of potash test is applied. A 10 per cent solution of yellow prussiate of potash, which may be secured from any chemist, is used. If a drop of this solution be allowed to fall on to the surface of the mixture after thorough stirring the drop will turn a reddish-brown colour should any unchanged copper sulphate be present. If this happens more lime must be stirred in until the brown colour fails to appear when a drop of the test solution is added.

As a rule, the normal mixture is used upon plants with strong foliage grown in the open, but plants under glass are generally more sensitive, and a modification of the mixture is used.

For very tender plants 3 lb. of copper sulphate, 6 lb.

of lime, and 50 gallons of water are employed. This is called the 3—6—50 formula.

For less delicate plants the 4—4—50 formula, or 4 lb. copper sulphate, 4 lb. lime, and 50 gallons of water, may be used, while on occasions it may be necessary to employ the 5—5—50 formula.

Burgundy Mixture

This is a modification of Bordeaux Mixture and was devised for use where good freshly burnt lime is unobtainable. In this mixture washing soda is used instead of lime. The normal mixture is prepared from 4 lb. copper sulphate, 5 lb. washing soda, and 40 gallons of water. In practice, the copper sulphate is dissolved in 5 gallons of water, which is then made up to 35 gallons. The washing soda is dissolved in 5 gallons of water, and when solution is complete is added to the 35 gallons copper sulphate solution, stirring thoroughly all the time. When prepared correctly the mixture is bright blue in colour, and the fine precipitate it contains remains in suspension for a considerable time. If the colour is greenish the mixture has not been correctly made, and if the precipitate settles rapidly it will not adhere to the foliage. It is important to procure pure materials, and both copper sulphate and washing soda should be fully 98 per cent purity. The mixture must be used fresh and certainly not more than ten hours after preparation.

On most plants correctly made Burgundy Mixture has a greater tendency to cause scorch than correctly made Bordeaux Mixture.

Just as Bordeaux Mixture containing an excess of lime is less likely to scorch foliage than the normal mixture, so the same effect is produced in Burgundy Mixture by an increase in the proportion of washing soda. In cases where normal Burgundy Mixture has caused scorch, the 4—6—40 mixture, in which the washing soda is increased from 5 lb. to 6 lb., should be used. Both Bordeaux and Burgundy Mixtures have a high fungicidal value, but when freshly burnt lime is easily obtained the former is advised.

Ammoniacal Copper Carbonate

One objection to Bordeaux and Burgundy Mixtures is that they stain the leaves and fruit, and when this is an important factor, ammoniacal copper carbonate is employed, for this, upon drying, deposits practically no stain. This compound, however, possesses less value as a fungicide, and plants susceptible to injury by Bordeaux Mixture are more likely to be injured by ammoniacal copper carbonate. It is prepared from 5 ozs. copper carbonate, 2 to 3 pints strong ammonia (·880), and 50 gallons of water. As copper carbonate is more soluble in dilute ammonia than in the strong solution it is necessary to dilute it. The copper carbonate should be rubbed down to a thin paste with a little water, and then 1 pint of the ammonia diluted to 1 gallon with water, poured over it. The mixture should be shaken well and then allowed to settle, when the clear blue, supernatant liquid is poured off. A further quantity of diluted ammonia is added to the residue and well shaken, pouring off the clear liquid after standing. This process is repeated until the whole of the carbonate is dissolved, but care should be taken to use no more ammonia than is necessary to do this. After adding the remainder of the water the solution is ready for use. It should be used immediately, for it rapidly loses ammonia and its fungicidal value becomes reduced.

Sulphur Fungicides

Sulphur in various forms has long been used as a fungicide. Apart from the pure "flowers of sulphur," which are employed as a "dust" and will be considered later, the best known compound is "liver of sulphur," or potassium sulphide. This is dissolved in water at the rate of 3 to 10 ounces per 10 gallons of water for spraying purposes, but it is important to obtain a guaranteed pure sample, as some samples have been found to be highly caustic and cause injury to delicate foliage. For general purposes a solution of ½ ounce to 1 gallon of water will be found most suitable. The solution should be used immediately it is prepared as it loses value upon standing.

Lime sulphur prepared from freshly burnt stone lime, flowers of sulphur, and water has valuable fungicidal properties. The finished product is a deep amber-coloured liquid, and while it can be made at home its preparation requires a considerable amount of skill, and it is advisable to procure the ready-made article from a reliable commercial firm. The manufactured article is sold at different concentrations, which are indicated by the specific gravities marked on the label. Generally the specific gravity is 1·3, but it is necessary to know this, so that suitable dilutions may be made for spraying purposes. The solution deteriorates upon standing and should be used immediately.

Of recent years ammonium polysulphide has come into use as a fungicide as the result of investigations by Professor Salmon and Dr. Eyre. It has proved extremely valuable in controlling many diseases, and will probably have a wide application in the future. Concentrated ammonium polysulphide is of a dark red colour in bulk, becoming yellow in dilution. It is extremely pungent and smells strongly of ammonia. It should be stored in a cool place in tightly stoppered vessels, and the vapours should not be inhaled, as they are harmful. The diluted solution, however, is harmless. The compound can be obtained in two concentrations, namely, "A.P.S. 1918" and "A.P.S. 1919," the latter being approximately twice as strong as the former.

For spray purposes 1 gallon of "A.P.S. 1918" or

½ gallon "A.P.S. 1919" is diluted to 100 gallons by the addition of water. Saponin at the rate of 2 ounces per 100 gallons of spray should be added, and two sprayings are necessary at a week's interval. Solutions of colloidal sulphur are now on the market and should prove valuable aids in the combating of plant disease, but at present little can be said about them.

Spreaders

It is a matter of some difficulty to wet thoroughly the foliage of some plants if only aqueous solutions are being used. In order to overcome this difficulty "spreaders," which increase the wetting power of the spray solution, are added.

The first known spreading agent to be used was soft soap, but this has now been replaced by other and more suitable compounds. Of these saponin, calcium caseinate, flour paste, and certain resin mixtures are the most important. Saponin at the rate of 2 ounces per 100 gallons may be added to most fungicides with beneficial results. In the case of Bordeaux and Burgundy Mixtures it increases the wetting power and helps to keep the precipitates in suspension for a longer time than would otherwise be possible.

Certain plants, such as the cucumber and carnation, are only imperfectly wetted, even with the addition of saponin, but this may be overcome by using flour paste, which imparts an efficient wetting power to the solution. In the Lea Valley it was first used with "liver of sulphur" and "lime sulphur" as a means of combating the *Colletotrichum* leaf spot of the cucumber, for which the following sprays are recommended:

Liver of Sulphur and Flour Paste—

5 lb. flour.
4 lb. potassium sulphide (liver of sulphur).
100 gallons water.

Smaller quantities may be made up at a time by taking proportional parts of these quantities. Thus for two gallons of spray the quantities are as follows:

$1\frac{1}{2}$ ounces flour.
$1\frac{1}{4}$ ounces potassium sulphide.
2 gallons water.

Two gallons of spray are prepared in the following way: Fourteen pints of water are placed in a bucket and $1\frac{1}{4}$ ounces of liver of sulphur added, which will completely dissolve while the flour paste is being prepared. A very little water is added to $1\frac{1}{2}$ ounces of ordinary wheat flour and the mixture carefully rubbed into a smooth paste. Water to 2 pints is then added till the mixture is as thin as milk and free from lumps. This is next boiled, with constant stirring, until it froths up, when it is added to the solution of liver of sulphur and mixed thoroughly. The spray is then ready for use.

Lime Sulphur and Flour Paste—

5 lb. flour.
2 pints lime sulphur (specific gravity = 1·3).
100 gallons water.

For $2\frac{1}{2}$ gallons of spray the following amounts are necessary:

2 ounces flour.
1 fluid ounce lime sulphur (specific gravity = 1·3).
$2\frac{1}{2}$ gallons water.

Two and a half gallons of spray are prepared in the following manner: Two ounces of flour are mixed and boiled in 3 pints of water in the manner described above, and added to 17 pints of water in a bucket. One fluid ounce of lime sulphur, the specific gravity of which is 1·3, is then added to the liquid in the bucket and thoroughly stirred.

The spray compounds described above constitute the most important fungicides in general use. They have been widely used and their value has been proved repeatedly. Other spray compounds have been devised for special purposes, but as they have not proved of special value under glasshouse conditions there is no need to discuss them here.

The Process of Spraying

Having determined the spray compound best suited to control the disease in question care should be exercised in its preparation. Only the purest ingredients should be obtained, and the method of preparation should be carefully studied and followed to the smallest detail. Any doubts or difficulties which arise should be discussed with an expert who is familiar with the details. Hurried carelessness in preparing the spray compound invariably leads to disappointing results.

Spraying should follow immediately the fungicide is ready. The ultimate aim of the process is the covering of the entire plant surface with a uniformly thin film of the fungicide, and in attempting to spray this should be kept constantly in mind. Sufficient liquid must be applied to do this, but an excess must be avoided, otherwise a deposit of irregular blotches will result. To obtain the best results the fungicides should be applied to the plants as a very fine mist, and many excellent spraying machines have been designed for this purpose; these are fitted with nozzles especially designed for the purpose. The amount of pressure used is important, for while high pressures assist in the production of a fine mist spray, low pressures with the same nozzle produce a much coarser spray.

It is thus apparent that an efficient machine must be employed and used correctly if the process is to be successful. All spray fluids must be strained through a wire sieve before placing in the machine, otherwise clogging of the pipes and nozzles will result, with loss of time and patience. Most machines are fitted with suitable strainers. It is important to clean thoroughly the machine immediately after using, otherwise its efficiency will be impaired for the next operation.

In small nurseries a small portable machine holding about 12 gallons of spray will be found most convenient. These may be taken into the houses, and a short length of hose will enable one of the operators to work along the rows of plants while another works the machine. On larger nurseries a motor driven machine placed outside the house is convenient. The spray is delivered through two or more long hoses taken into the house. To be efficient the spray must be carefully applied to each plant, and should be directed towards the lower surfaces of the leaves before spraying the upper surfaces. If the upper surface is sprayed first the leaves tend to drop and it becomes increasingly difficult to spray the lower surface. At the best, spraying plants in glasshouses is a difficult and somewhat unsatisfactory process, because of the difficulty of reaching every part of the plants when they are close together and the foliage is dense. It is of considerable assistance if the foliage can be suitably thinned out before spraying, especially in the case of cucumbers and tomatoes.

It must be remembered that spraying does no more than destroy the fungal parts on the outside of the plant and prevents further infection through the poisoned surface. It does not destroy those parts of the fungus within the tissues which later grow out and produce new spores. Where plants such as the cucumber are growing rapidly, new leaf areas unprotected by the fungicide are continually being produced, and may be infected by any spore which may settle there. This state of affairs may only be prevented by spraying at exceedingly short intervals. As this is undesirable and may be impracticable, special methods must be adopted. These consist of spraying and next day removing all infected leaves. About a week later the spraying and removal of diseased leaves should be repeated. This is generally sufficient to check a normal attack, but in severe cases it may be necessary to repeat the process again.

The Effect of the Spray on the Plant

One of the properties connected with a satisfactory fungicide is that it shall be of a composition and strength which will be non-injurious to the plant to which it is applied. This, however, cannot always be determined precisely, for under different meteorological conditions the injurious action of a fungicide may vary considerably. Bordeaux Mixture may be perfectly harmless to apple foliage under one set of conditions and ruinous to it under different conditions. Generally, the atmospheric conditions of glasshouse cultivation are unfavourable to fungicidal treatment, and special precautions are necessary to prevent undue damage to the plants. Too strong a fungicide, or one applied under unfavourable conditions, produces damage to the foliage, which may vary from a slight scorching of the tender shoots to the entire destruction of the leaves and the defoliation of the plant.

In order to reduce to a minimum the possible harmful effects under glass due observation must be paid to the following rules:

(1) In the absence of expert advice or previous experience no new fungicide should be applied to the main body of plants in a house before a preliminary test has been made upon a small number.

(2) Spraying should be done in the cool of the evening, and never before the sun has ceased to shine directly on the houses or whilst the temperature is above 70° F.

(3) After spraying with copper compounds the foliage should be kept as dry as possible, as surface moisture increases the amount of scorching.

(4) Before spraying cucumber plants with liver of sulphur, lime sulphur, or ammonium polysulphide, care should be taken to see that the houses are sufficiently shaded, otherwise scorching will result. The morning after spraying with these compounds the ventilators should be opened to allow the escape of the hydrogen sulphide given off from the fungicidal compounds.

(5) Cucumbers, tomatoes, and other plants with heavy masses of foliage should be trimmed before spraying to allow the fungicide to be applied thoroughly, but the spraying must follow immediately after completion of the trimming to prevent infection from the spores which have been distributed over the leaves by the disturbances of the foliage.

Soil Fungicides

While spraying the aerial portions of plants for purposes of disease control has long been in practice, but little attention has been given in the past to the treatment of diseased soils in which plants are growing. The general view has been that any compound capable of destroying the disease organism would injure the plant at the same time. In consequence, any treatment directed towards the destruction of disease in the soil has been applied at a time when no plants were being grown. Recently, while investigating "damping off" of the tomato, a soil drench was devised which, while causing no injury to the living plant, possesses fungicidal powers. This compound, which for convenience has been named "Cheshunt Compound," has already been described on page 61. The treatment was devised to control "damping off," but has given satisfactory results against other fungal diseases originating in the soil.

Dusting

Of recent years the practice of dusting plants with dry powdered fungicides and insecticides has been introduced to replace spraying. The process, which is largely due to the initiative of Professor H. H. Whetzel, of Cornell University, is still in its infancy, but the excellent results obtained have earned for it considerable praise by both scientific and practical investigators.

To be entirely satisfactory the dust should take the form of an impalpable powder, for in this state it may be easily and thoroughly applied. In this country dusting with flowers of sulphur has been practised for many years, and recently the so-called "green sulphur" has gained many supporters among glasshouse cultivators because of its ease of application.

Progress along the lines of dusting seems inevitable, and should lead to the preparation of a dust possessing high fungicidal powers combined with a sufficiently fine state to render application very easy.

In America, dry preparations containing lime, sulphur, and various copper salts have been tested extensively against liquid fungicides and have compared favourably with them. So much is this the case that special mechanically driven machines able to emit dense clouds of dust are employed for dusting on a large scale. In this country, however, dusting has barely passed the experimental stage, but there is little doubt that its importance as a factor in disease control will soon be recognized.

Cleansing Glasshouses

Since it has been shown that certain fungi may live from season to season in decaying wood, paper, etc., it is obvious that very careful cleansing methods must be adopted during the winter in any nursery where disease has occurred. Fumigation with sulphur has not proved entirely satisfactory in every case, and it is advisable after vigorous attacks of disease, or in old houses, to adopt some method of cleansing the houses with an emulsion of cresylic acid and soft soap. Such an emulsion is prepared in the following manner: Pale straw-coloured cresylic acid 97 to 99 per cent purity and pure potash soft soap are placed in a bucket at the rate of 1 gallon of the former and 8 lb. of the latter. The bucket is then heated over a brisk fire until all the soap is completely dissolved, the process taking about ten minutes to complete. The strong emulsion is used at the rate of about 1 part in 50 parts of water, i.e., 1 pint in 6 gallons.

It will mix properly without agitation, it being sufficient to place it in the tank of the sprayer and run in the correct quantity of water. The diluted emulsion is best applied by means of a strong power sprayer, and should be carefully directed into every part of the woodwork, soil, etc. Special attention should be paid to any rotten part of the structure.

The ventilators should be left open while the spraying is in progress, so that they may be thoroughly treated, but must be closed down when the spraying is finished, in order to retain the strong vapours. The houses should remain closed for four days after treatment, and then opened to allow the vapours to escape. Fourteen days afterwards the house may be planted if necessary. The operators should wear goggles while spraying, as the liquid causes the eyes to smart, and rubber gloves should be worn to protect the hands. In high houses it is advisable to fit bamboo lances to the hoses, so that the nozzle may be held close to the woodwork and the spray forced into the cracks and crevices. One hundred feet of house, 13 feet wide and 8 feet to the ridge, requires about 100 gallons of spray, which takes about four hours to apply. As a final precaution every cavity in the woodwork should be filled up with putty and painted over.

Breeding

It is a matter of common observation that among large colonies of plants exposed to infection from disease organisms some are completely destroyed, others only slightly diseased, while an occasional plant remains unaffected and continues to function in a normal manner. Such phenomena are attributed to varying degrees of susceptibility and disease resistance possessed by the individual plants. Disease resistance in a plant may be defined, therefore, as the ability to develop normally when exposed to conditions of infection under which normal plants of the same variety are unable to function. Many reasons have been brought forward to account for disease resistance, but with these the practical man, in the present state of our knowledge, is unconcerned. It is sufficient for him to know that such phenomena do exist, and to realize the great possibilities of disease control which they open before him. Resistance is variable in extent—some individuals being slightly resistant, others completely resistant. Plants belonging to this latter class are commonly said to be immune. Plants which are resistant to one disease are not necessarily resistant to another. This is well known to farmers, who find that certain varieties of potatoes immune to wart disease are yet susceptible to blight caused by *Phytophthora infestans*. While this is disappointing it should not prevent us from taking full advantage of the benefits to be derived from the existence of resistant varieties, even though these are limited in the scope of their resistance.

All growers of plants, and especially those of glass-house plants, have long since experienced the difficulties connected with disease control, and many have voiced an opinion that the control may be worse than the disease, for it requires infinite care and patience before it is effected. Moreover, many diseases are only imperfectly controlled by any known means, and the production of resistant varieties in such cases would solve the problem satisfactorily. The use of resistant varieties is becoming more and more important, and in the future the production of such varieties must become one of the most important problems of the pathologist and grower.

The chief means by which disease resistant varieties can be obtained is by selection or by hybridization.

Selection

By this method plants are grown under conditions which expose them to a considerable amount of infection from the disease in question. Where the disease is controlled through the roots they are grown in highly infected soil, while if the disease attacks the aerial portions of the plants they may be grown in normal soil and artificially inoculated by spraying with a suspension of spores of the disease. Among these plants, the majority of which become diseased, a few remain healthy and are selected for seed. From this seed plants are again grown under similar conditions and healthy plants again selected. Out of the original number only one or two healthy plants may be obtained, but after many generations of selection the entire batch may be found to be healthy and a strain immune to the particular disease may be obtained. A necessary detail of the process is the exposure of each generation of selected plants to copious infection of the disease to resist which the plants are being cultivated.

The selection method has been successfully employed in America, where varieties of cotton, cabbage, and tomato have been selected which are highly resistant to wilt disease due to various species of *Fusarium*.

Recently Egerton (19) has elaborated a system of selecting in the seed-bed varieties which are resistant to attacks of *Fusarium lycopersici*. Selection has proved to be an easy way of obtaining resistant varieties, but in this country there is need for much investigation in this line, especially in relation to glasshouse plants. Practically the only resistant variety of any glasshouse plants produced in England is Butcher's Disease Resister cucumber, which was selected during an epidemic of the leaf spot disease due to *Cercospora melonis*, and which so successfully resisted attacks by the fungus.

Hybridization

This process consists in raising a disease resistant variety by means of cross-breeding, but is more laborious and less certain than that of selection. Usually it is resorted to when selection is impossible because the first slightly resistant plant is unobtainable.

Wilt resistance has been shown by Orton (35) to be of a heritable character by his creation of a wilt resistant edible water melon. For this purpose an inedible form of melon, *Citrullus vulgaris,* known as citron or stock melon, which was resistant to wilt, was crossed with the Eden variety of melon. The first generation resulting from this cross proved to be extremely vigorous and productive. From the second generation ten fruits from 3,000 or 4,000 plants were selected for resistance and quality, and the seeds from them were planted in infected soil. Continued selection in this manner resulted in a resistant variety of good quality fruit.

At Cheshunt Experimental Station a similar investigation is being carried out in an endeavour to produce a tomato resistant to *Verticillium* wilt, and of good quality and productiveness.

For breeding investigations large areas are necessary, but any expenditure is amply rewarded if a resistant variety is ultimately obtained.

CONCLUSIONS

The ultimate end of investigations upon plant diseases must be an effective control, and in conclusion it is fitting that the general principles governing disease control should be recited briefly.

General principles must come under three main headings : plant hygiene ; spraying, dusting, and sterilizing ; resistant varieties.

Plant Hygiene

(*a*) *The Elimination of Centres of Infection.*—This process has been exploited extensively in the control of human diseases, and the resultant success may readily be seen when one compares the death-rate due to disease during the last war with that during previous wars.

Similar benefits result when hygienic methods are applied to glasshouse work, and it is in the interests of the grower and the whole country that cleanliness should prevail in every nursery and market garden. Contaminated soil, manure, water, seed, imported plants, and weeds are important sources of infection, as are also contaminated buildings, market baskets, workers, visitors, and insects. It is important to realize this, for in every case a little knowledge before the event is better than a good deal more afterwards. Often growers are reluctant to spend time and money in destroying weeds outside the houses, but it is always worth the expenditure, and where centres of infection are known to exist no pains should be spared in their elimination.

(*b*) *Cultural Methods.*—The wise grower has learned by experience, often dearly bought, that plants which are grown strong and vigorous, without any tendency to soft, sappy growth, are often resistant to many diseases. So obvious is this fact to the observant grower and pathologist that no study of a particular disease can be complete unless a study of the effect of different cultural conditions upon it has been made. The rapid forcing of glasshouse produce so that early markets and high prices may be captured often ends in producing plants susceptible to disease, while a healthy growth, developing uniformly, often produces plants upon which disease can make no headway. Cultural details are vastly important, and there is an immediate need for investigation, so that when a particular disease appears the best conditions for assisting the plant in its struggle for health and life are known and can be applied.

Spraying, Dusting, and Sterilization

In cases where the disease has got the upper hand and cultural means are ineffective or unknown, the above devices must be resorted to, but they require careful application, and frequently are difficult to carry out.

All available information should be obtained and every detail followed minutely.

Resistant Varieties

The employment of such varieties as are highly resistant to disease is the simplest way of guarding against it, and where disease is rampant these varieties should be grown when possible. Unfortunately the number of resistant varieties of cultivated plants is very limited, but it is in the interests of the country that no money should be spared in obtaining a great many more. The usual criticism against employing resistant varieties is that such are lacking in quality and productiveness. This fact must be borne in mind by every hybridist, so that resistant varieties of high commercial value may be produced.

Finally, a word to pathologists and students of disease problems, the outcome of much experience in commercial nurseries. First learn to grow your plants so that they may pass the most critical examination for health, quality, and productiveness by practical commercial growers, and then experiment upon the healthy plant. It is useless to base detailed knowledge of any disease or the method of its control on experiments conducted on half-starved, physiologically weak plants grown in tiny pots.

APPENDIX I

TOMATO DISEASES COMMONLY FOUND IN ENGLAND

Name	Causal Organism
"Damping off" of seedlings	(*a*) *Phytophthora cryptogea* Pethybridge and Lafferty; (*b*) *Phytophthora parasitica* Dastur; (*c*) *Rhizoctonia solani* Kuhn
"Foot rot" or "Blackleg" of young plants	(*a*) *Phytophthora cryptogea* Pethybridge and Lafferty; (*b*) *Phytophthora parasitica* Dastur
Fusarium root rot	*Fusarium* spp.
Colletotrichum root rot	*Colletotrichum tabificum* Pethybridge
Verticillium wilt or "sleepy disease"	*Verticillium albo-atrum* Reinke and Berthold
"Stripe"	*Bacillus lathyri* Manns and Taubenhaus
"Mildew" or "leaf mould"	*Cladosporium fulvum* Cke.
Botrytis stem rot	*Botrytis* sp.
"Buckeye" rot of the fruit	*Phytophthora parasitica* Dastur
Fusarium fruit rot	*Fusarium* spp.
Botrytis fruit rot	*Botrytis* sp.
Rhizopus fruit rot	*Rhizopus nigricans*
Penicillium fruit rot	*Penicillium* sp.

Name	Causal Organism
Bacterial soft rot of the fruit	*Bacillus carotovorus* Jones
Blossom end rot	Physiological causes
Mosaic	Cause unknown
Potato disease	*Phytophthora infestans* (Mont.) De Bary

TOMATO DISEASES FOUND OCCASIONALLY IN ENGLAND

Fruit rots resembling "Buckeye" rot	(*a*) *Phytophthora cryptogea* Pethybridge and Lafferty (*b*) *Rhizoctonia solani* Kuhn
Sclerotinia stem rot	*Sclerotinia sclerotiorum* Massee
Fusarium wilt	*Fusarium lycopersici* Sacc.
Macrosporium blight	*Macrosporium solani*
Stem canker	*Diplodina lycopersici* (Cooke), Hollos emend. Brooks and Searle
Fruits rots	(*a*) *Phoma* sp. (*b*) *Glœosporium* sp. (*c*) *Colletotrichum* sp. (*d*) *Diplodina lycopersici*

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