CHAPTER 10

Cultural Practices in Disease Control

RUSSELL B. STEVENS

Department of Botany, The George Washington University, Washington, D. C.

I. Introduction
II. General Considerations
   A. Nonpathogenic Diseases
   B. Basis of Cultural Control
   C. Economic Considerations
   D. Obstacles to the Adoption of Cultural Measures
   E. Desiderata
III. Elements of Cultural Control
   A. The Diseased Plant
   B. The Pathogen
   C. The Diseased Population
IV. Intrinsic Measures Directly Affecting the Individuals Comprising the Host Population
   A. Cultural and Related Practices
   B. Genetic Resistance
   C. Physiologic Changes
V. Extrinsic Measures Indirectly Affecting the Individuals Comprising the Host Population
   A. Practices Involving Number of Host Plants
   B. Practices Involving Position of Host Plants
   C. Practices Involving Timing
   D. Practices Affecting Sequential Relationships
VI. Measures Affecting Elements Other than the Host Population
   A. Affecting Inoculum
   B. Affecting Hosts Other than the Primary Crop
VII. Summary and Prognosis
References

I. Introduction

If we are to be completely honest with ourselves, and at the same time willing to depart from the rules of orthodox journalism, the boundaries of this chapter must be defined in the negative. Inevitably, one must include all those means of disease control not clearly reserved to other, more specifically delimited, categories. "Cultural" must then be inter-
interpreted in the broadest possible terms, to include measures involving
agricultural cropping practices, harvesting and storage methods, tillage,
crop rotation, soil management, resistant varieties, land-use planning and
all of like nature. One must seek to bring order within a miscellany—and
we are encouraged to think that this can be accomplished.

Plant disease, that is, pathogenic plant disease, is three—perhaps
four-dimensional. One dimension is represented by the pathogen—virus,
bacterium, fungus, nematode—and forms the subject matter of Volume
II of the present treatise. A second dimension, the host plant, is treated
in Volume I. The complex of diverse factors comprising the environment
represents the third dimension—and it can be argued effectively that by
introducing a time factor (disease development or epidemiology) it
achieves a fourth.

Disease control, it may now be perceived, interestingly parallels the
above concept. Traditionally, the popular means of combating patho­
genic diseases have been: (1) application of agricultural chemicals to
foliage, seeds, and soil, and (2) adoption of resistant crop varieties. The
one aims almost entirely at the pathogen; the other concerns itself as
exclusively with the host. Cultural control, our immediate consideration
in this chapter, has these same facets, but centers chiefly about the
environment—the environment as it affects crop and pathogen, the in­
teraction of crop and pathogen, and their interactions through time.
Chemical control and disease resistance thus tend to become essentially
one-dimensional, monolithic problems; cultural control often becomes
three- and four-dimensional. Small wonder that the issues are less clearly
drawn and that, as a general rule, it enjoys less popular understanding
and support.

Having these considerations in mind we should be willing to accept
the fact that cultural measures cannot be dissected with the conceptual
cleanliness of other approaches. Indeed, too rigorous an attempt to do
this may lead to unsought and unwanted difficulties. We deal with a
sort of network, and just as a net is distorted when a single cord is
arbitrarily drawn into a straight line, yet forms a pleasing symmetry in
its undisturbed whole, so the consideration of cultural control measures
cannot be on a strictly one-at-a-time basis. Rather, in the discussion to
follow, it is primarily the viewpoint, not the basic maneuver itself, which
changes as the outline unfolds.

II. GENERAL CONSIDERATIONS

Cultural control is not without its rationale, its useful generalizations,
its problems, and its promise. Recognition and understanding of these
form a foundation upon which a consideration of specific measures can
most surely rest.
A. Nonpathogenic Diseases

Cultural measures directed against pathogenic diseases operate indirectly through effects on host or pathogen; against nonpathogenic, abiotic, or physiologic diseases they directly alter the environment. And the over-all importance of the nonpathogenic diseases must not be underestimated. Deficiencies or excesses of soluble materials, irregularities and extremes in such factors as temperature, moisture, and light, and toxic gases in soil and atmosphere decrease by a very large factor the health and productivity of crops, forests, and ornamental plants. Considering disease to be "any impairment of structure or process of sufficient intensity or duration noticeably or permanently to affect the normal development of the plant (Stevens and Stevens, 1952)," we cannot easily establish just what proportion of plant disease is attributable to nonpathogenic causes, but it can scarcely be less than half. Stakman and Harrar (1957, pp. 49-64) present a useful summary of what they term "inanimate" causes, to which the interested reader is referred, although they make no attempt to establish the relative importance of these several factors or their total effect.

More often than not, once the cause or causes of nonpathogenic diseases are established, the sort of measures needed to alleviate them are self-evident. The relationship is direct, even in those cases where other considerations—technical or economic—preclude their implementation. In short, the problem is how to modify the environment so as to minimize the damage done to the plant species in question. Final action is almost always predicated on assessments of cost, feasibility, secondary effects on other species, and related management problems.

All too often the causes of diseases thought to be of inanimate nature are imperfectly known. Some, such as the brown root rot of tobacco, later prove to be pathogenic (in this case one of the root-invading "meadow" nematodes). Others, such as "frenching" in tobacco, prove to be the immediate result of inanimate, nutritional imbalance, but linked in turn to the activities of the soil microflora. Still others, such as a form of "soil sickness" common in greenhouses, are controllable through measures worked out by strictly empirical means, while the cause continues to elude the pathologists concerned (Mader, 1947). It has been found that the gradual decline of greenhouse-grown plants may be halted if the "sick" soil is thoroughly drenched with dilute sulfuric acid and that—provided the plants are protected by asphalt-coated collars—it is not even necessary to remove them from the bench during treatment. Yet every indication to date has failed to show that cultural practices, pathogenic organisms, or nutrient supply are responsible for the situation, and sterilization of the affected soil is to no avail.
B. Basis of Cultural Control

1. Environment and Disease

Environment, the third dimension in the complex biological phenomenon we call pathogenic disease, is now recognized as critically important. This has not always been so, for its full realization awaited the investigations of the late 18th and early 19th centuries, which clearly established the pathogenic nature of many plant maladies. The pendulum thereafter swung, as is so often the case, overly far in emphasizing the causal organism. By the mid-30's the importance of environment in disease development was coming into its own, as attested by Foister's early review article and later supplement (1946), Wilson's bibliography of nearly four thousand titles (1932), and similar publications. Interest continues unabated to the present, and environment is now a fully established element of all serious studies of epidemiology and disease development, be it microorganism (Allen, 1954) or virus (Bawden and Pirie, 1952), and extends through the entire spectrum of extrinsic and intrinsic cultural control measures (see Sections IV and V).

Because environment is demonstrably the most powerful controlling factor in pathogenic disease, alteration of the environment is equally the most potent weapon available to man in his efforts to obtain for himself the maximum productivity from his crops. And attention to the environment is but another term for cultural control. His problem is to identify the environmental factors which most profoundly affect the disease in question and to develop techniques which can be employed to ameliorate these factors. That this is often not easy, and at times unattainable, does not lessen the cogency of the argument.

2. Direct and Indirect Effects

As noted earlier, cultural practices aimed at alleviating nonpathogenic diseases are characteristically direct. Many of those employed against pathogenic diseases are equally so, particularly as they pertain primarily to the diseased host plant—roguing, sanitation, eradication, storage management, heat therapy, and shifts to resistant varieties; or primarily to the inoculum—disease-free seed, certification of propagating material, indexing, soil sterilization, flooding, eradicant sprays, and disinfectants. But others are more or less indirect—vector control, nutritional and other soil amendments, dispersal, isolation, crop rotation, elimination of alternate and reservoir hosts, and establishment of trap and buffer crops. In these last instances, the grower seeks, by manipulating one or more factors in the chain of events and circumstances, to
retard the development of disease and lessen its eventual impact. By
destroying the vector of bacterium, virus, or fungus, he seeks to inter­
cept the movement of inoculum. By soil amendment he seeks sometimes
to abet host resistance, sometimes to inhibit pathogen growth. By dis­
persal, isolation, or barrier crops he seeks to prevent the juxtaposition
in time and space of susceptible crop and virulent pathogen. Measures
such as these are often effective, sometimes dramatically so, but they
are indirect, and thus inherently more difficult to identify, develop, and
administer.

Disease control by cultural measures is not only frequently indirect,
even obscure, but it is very likely to involve more than one operation, to
require the joint application of two or more practices. Thus attention
not to seeding rates alone, but to seeding rates, timing, and depth of
sowing are required for results to be satisfactory. Care in storage avails
but little unless preceded by care in harvest. Vector control must often
be supplemented by destruction of weed hosts and sanitation within the
crop. In our discussion of specific measures later in this chapter we
attempt to focus on each of many possible approaches one by one, but
with the full realization that, in practice, they do not operate in a
vacuum and that crop production, by whatever combination of means
proves practicable, is the ultimate goal.

It is perhaps not an unwarranted oversimplification to say that the
basic approach in cultural control is to invoke every aspect of cropping
practice which will promote crop growth; inhibit or otherwise obstruct
the pathogen; avoid, delay, or lessen the impact of disease, should it
ensue—and rigorously to discover and eliminate any and all practices
which operate in the opposite direction. To the extent that these steps
can be knowingly instituted, so much the better, but it is a rare indi­
vidual indeed who does not, wittingly or unwittingly, employ certain
practices calculated to control disease.

3. Cultural vis a vis Other Methods

In public and private favor, two methods of disease control stand
out head and shoulders above all others (see N. E. Stevens, 1940). First
rank must clearly go to application of fungicidal (and bactericidal)
chemicals to foliage, seeds, and soil; next most popular is the develop­
ment and introduction, through plant breeding and selection programs,
of disease-resistant varieties. These two approaches have little in com­
mon, it is true, being directed at different facets of the crop-pathogen­
environment complex, and finding their greatest popularity in different
sectors of the agricultural structure. But in the aggregate they dominate
the time, attention, resources, and enthusiasm of growers, professional
plant pathologists, and the lay public. What, then, is the status of cultural measures as contrasted to the "big two"?

It is instructive here to turn to the experience of entomologists concerned with forest insects (Graham, 1951). Some, at least, recognize that to accomplish "preventive control" it is always necessary to manipulate factors of "environmental resistance," and that the interrelations between forces of production and resistance are more often than not highly complex. Graham insists that even with DDT available in large quantities and application methods both cheap and efficient, prevention is still less expensive in the long run and more effective than direct control. He warns us lest in our enthusiasm for chemicals we blind ourselves to the fact that although the current crop of organisms can be poisoned, conditions favoring outbreaks cannot be thus directly changed to our advantage, that never will all the individuals of a species be killed nor can harm to other species be always avoided. After all, we must agree that whether it be a population of insects or of plant pathogens, it can be held in check only when destructive forces at least equal reproductive capacity and when the situation is stabilized at a relatively low population level, such that damage is not unduly severe. With but slight modification these strictures apply directly to our use of fungicidal sprays or dusts.

It is, likewise, no disservice to the recognized contribution of the plant breeder and to the importance of disease resistant varieties to remind ourselves that each new achievement in this direction wins but a temporary skirmish in the never-ending war with plant pathogens. Ceres wheat, Victoria oats, and a host of less publicized varieties stand as monuments to the ability of the pathogenic species to mutate, multiply, and survive. We are needlessly risking our welfare if we rely solely on chemicals and resistant varieties, alone or in concert, and ignore the third and fourth dimensions—environment and disease development—and the cultural practices by which matters in these dimensions can be turned to our advantage.

Chemical treatments to control disease are furthered or hindered by cultural practices, and resistant varieties vary in success, depending on how they are managed in the field. There is no necessary conflict between cultural and other measures, and the wisest course lies in a well-informed, objective welding together of all possible offensive and defensive aspects into a coordinated, integrated whole.

No association is more inextricably close than that between cultural measures and biological control (see Chapter 13). In many instances we are not yet even certain whether the ultimate effectiveness of a given practice is the one or the other, particularly when available evi-
ence suggests that the immediate result is so to alter the environment that growth of nonpathogenic organisms is accelerated at the expense of pathogenic forms.

Finally, when other, more orthodox methods fail, grower and pathologist turn, if only for interim relief, to the diverse measures of cultural and environmental nature.

C. Economic Considerations

In every aspect of disease control economic considerations come to bear importantly, none more so than in the application of cultural measures. As N. E. Stevens (1938b) pointed out some years ago, outside the field of ornamentals, control should cost demonstrably less than losses from the disease are likely to be. "However much we may enjoy experimenting with seemingly impracticable problems and solutions, we owe it to our profession not to urge the use of any control method unless it meets this economic test." He suggests that to make this possible we need much more accurate information on the actual cost of disease and insect losses. He regards some of the dollar estimates of losses from plant diseases and insects published earlier as "little short of fantastic," which did plant pathologists very little good with the public or with their colleagues in other fields of biology. "In their zeal for demonstrating their ability to solve difficult problems of disease control, plant pathologists seem a little like the old time volunteer firemen who were more interested in beating the other outfit to the fire and putting on a good show there than in saving the building. Pathologists seem sometimes to forget that the real purpose of agriculture is not to control plant diseases but to grow profitable crops. For growing profitable crops, disease prevention is often better than disease treatment."

Informative discussions of the economic aspects of plant disease losses are to be found in a recent monograph by Chester (1950) in the classic bulletin published some years ago by a committee of the California State Agricultural Experiment Station on plant quarantine problems (Smith et al., 1933) and Brooks' (1935) sound treatment of botanical aspects of food storage and marketing.

1. Criteria

Because the relationship between outgo and income, as it pertains to cultural control, is more obvious than in the case of better-known alternative measures, it is far more likely to be taken directly into consideration. Not only does this prove true, but one suspects that rather more stringent criteria of economic feasibility are applied to cultural practices than to chemical control measures or the use of resistant
varieties. It is not uncommon to find sprays and dusts recommended, and applied, in situations where the economic soundness of the program is not clearly demonstrated—if, indeed, considered at all. But only rarely do we see cultural procedures undertaken until there has first been serious thought given to whether it will "pay off" in increased crop value.

Naturally, those cultural measures which are synonymous with, or only a slight modification of, practices and programs already being carried out in the routine planting, tillage, and management of crops will cost little, if anything, and can be instituted without undue concern for their economic outcome. In a word, there are instances when, as the saying goes, "it doesn't cost anything to try." Our chief point is that, when it does cost something to try, the probable gain must be rather clearly shown before the grower can be persuaded to take the suggested steps. We will have more to say on this point shortly.

2. Crop Value

Granted that cultural control is forced, to a degree not encountered elsewhere, to meet the criterion of economic feasibility, we find a number of factors influencing the final decision. Not the least of these is the consideration of crop value. Understandably, the higher the basic worth of the crop, the greater expenditure of time, effort, and money becomes justifiable in its defense. Other things being equal, one can wisely expend more upon a perennial than upon an annual crop, more upon ornamentals than other commercial crops, more upon horticultural than agronomic varieties. Forest stands, traditionally, are not subjected to measures having a high per acre cost. When they have been converted into processed materials, they (like all market produce) attain minimum volume and maximum value, and can be protected by the more expensive measures characteristic of storage and market pathology. Each case must be judged and decided upon its own merits—weighing crop value, control expense, and predicted benefits. Sometimes the answer will be a clear affirmative, sometimes negative—and too often in the uncertain intermediate gray zone. The obligation to make an honest assessment is inescapable.

3. Cost, Liability and Responsibility

Who, then, bears the cost of cultural control, once it has been undertaken? We can agree that it is the producer who must nearly always make the effort and foot the bill, however surely the costs will eventually be passed along to the consumer.

This is in sharp contrast to the situation as regards fungicidal control and adoption of resistant varieties. In the case of fungicides and other
agricultural chemicals the cost of development (variously estimated at between $1,000,000 and $2,000,000 for each new spray, dust, or insecticide) has already been borne by society before the grower makes his initial purchase, in the form of research and development establishments, experiment station facilities, and professional manpower. Even more strikingly, virtually the whole cost of developing disease-resistant varieties is underwritten by public and private funds before the seed or propagating stock is ever made generally available for sale.

While it might be argued that costs are in the last analysis the liability of the producer, the point to remember is that the grower is aware of paying only a tiny fraction of the full cost of resistant varieties, a somewhat larger proportion of the costs of chemical control, and is likely to feel the full burden of cultural practices. To him, then, the last may well seem disproportionately expensive and correspondingly unattractive. Thus, while in actuality they are often the cheapest available control, cultural measures may and often are judged the most dear—even in those cases where total costs are reduced by combining one or more practices with each other or with agricultural programs unrelated to disease control.

Responsibility for instituting cultural controls is often, but by no means always, to be laid at the feet of the producer. In those instances where the immediate cropped area is affected, the grower may come to a decision with only his personal interests in mind. Vector control, on the contrary, almost always depends ultimately upon the attitude of a group of growers, and the individual has an obligation to cooperate which goes beyond his immediate prejudices. When weeds act as sources of inoculum, it may be necessary for governmental agencies to take action (Broadbent, 1957). Fixing responsibility, in the special instance where eradication of incipient infections is carried out as an adjunct to plant quarantine, becomes an interesting and difficult question of property rights. Smith et al. (1933) provide a particularly penetrating analysis of this situation in pointing out the important difference between requiring a grower to control a pest or disease which otherwise continually threatens his neighbor and requiring him to eradicate it. They argue that if a reasonably effective control is available at moderate cost, it can be assumed to be to the mutual advantage of all to adopt these measures and that the individual can be held liable if incidence on his property reaches a state which menaces others. He is not, however, fairly held responsible for the occurrence of disease or pest organisms on his property above and beyond ordinary methods of control, and ought to be compensated for any considerable cost in excess of this or for any destruction of property involved in eradication. In their opinion,
compulsory control is a proper function of the police power, but com-
pulsory eradication, since it deprives the grower of valuable property
for the benefit of society, is an altogether different matter, and should
be fairly compensated.

In countries whose resources are less than adequate or where indus-
try and scientific agriculture are as yet underdeveloped, economic con-
siderations operate to stress cultural control practices. In primitive
agricultures throughout the world, what little disease control effort is
made is entirely based on cultural measures; they are the first and the
last resort of the producer who is unaided by public or private support
and who farms without benefit of modern experimental research. Even
in large nations such as the USSR, a survey of published literature
clearly indicates above-average interest in cultural control, although
this undoubtedly stems from lack of information and general unavail-
ability of more orthodox materials and procedures rather than a special
appreciation of the full potential of cultural methods.

D. Obstacles to the Adoption of Cultural Measures

A number of obstacles to the more widespread adoption of cultural
control measures are implicit in the foregoing discussion. Two deserve
further emphasis.

1. Problems in Research

All too frequently our research methods must be empirical, and
progress is seriously hampered by the multiplicity of variables encoun-
tered—more, by far, than beset those who work with more generally
recognized approaches. The latter research, too, is largely empirical,
but demonstrable results are more easily come by, and much of the
collected data less complex. In case after case the investigator of cultural
techniques finds himself hampered in trying to see his way to a clear
analysis, and is distressingly unable to duplicate his experimental results.
This is not an inherent weakness of the research man, but a measure of
the sheer complexity of the material circumstances with which he deals.

2. Problems in Application

Several problems arising in the application of cultural control meas-
ures further hinder their more widespread adoption. The impact of
popular fashion is certainly paramount among these. Control by chem-
icals or by the use of resistant varieties has become so firmly fixed in
the minds of pathologist, producer, and public that any alternative
method is handicapped from the start. A thread of oppressive con-
servatism runs conspicuously through the whole fabric of agricultural
research and practice, and militates against departure from orthodox and long-established procedures.

Application—demonstrably successful application, that is—very often requires cooperative action, and the achievement of this ranges from the difficult to the impossible. The grower who chooses to apply chemical substances to his crops, seed, or soil may—provided he exercises the most rudimentary safety precautions—do so with impunity and on his sole initiative, encouraged by the assurance that at least some direct benefits will accrue whether his neighbor on either side chooses to act accordingly or not. He may plant seed of resistant varieties or employ disease-resistant propagating material and confidently hope for some improvement in his situation whether or not his colleagues follow suit. But very often, as will be shown later, the whole success of an unorthodox measure rests upon its simultaneous, conscientious application by a group of individuals. This cooperation must often be initiated by law and bolstered by public opinion, for, as Racicot (see Stevens and Stevens, 1952, p. 176) has phrased it in referring to eradication programs, "without adequate legislation, a goodly number of people believe that in this free country of ours it is their duty to do as they please and others put it off until it is too late. The result is frequently failure."

Basic to the normal application (not necessarily the experimental study) of disease control procedures, but most conspicuously in the case of cultural methods, is the absence of rigid controls. It is very like taking medicine or not taking medicine, going to bed or refraining from it when afflicted with the common cold virus. For any particular instance or individual it is impossible to do both—and impossible to show, therefore, what would have occurred had the rejected alternative been adopted. The same is true of cultural control of plant diseases as applied to the farm, backyard, or forest. There is just no possible way, in most instances, of assessing how different the eventual outcome may be because of cultural measures undertaken. This inherent indecisiveness is highly prejudicial to the popularity of unorthodox practices among men who very humanly wish to see, or to think that they see, tangible gain for their efforts.

The far greater complexity of cultural control situations stands as an obstacle to adoption of these techniques because there is the ever present danger of worsening the existing damage. Spraying and dusting may not be the sinecure they are commonly held to be, but rarely are matters made worse (except perhaps by insecticides, where instances of unfavorable side effects are well publicized). The maximum loss is customarily no more than of money and labor. In the same sense, adoption of resistant varieties is, by and large, a thoroughly "safe" proce-
dure, despite such dramatic failures as of the Victoria oat lines, which fell before a hitherto unknown *Helminthosporium* pathogen. But, in the web of interacting variables within which cultural measures must operate, it is not at all uncommon to encounter practices which have led to a harmful, rather than helpful, outcome. Adjusting the environment, which is in the last analysis the basis of cultural control, is at best a risky business. The wise and able producer, the one best able to understand and apply these special measures, is well aware of the hazards just pointed out and rightly reluctant heedlessly to risk them. The implications of this state of affairs for the professional research pathologist and extension worker are obvious.

Finally, many cultural control measures are by their very nature necessarily instituted well in advance of the appearance of disease. They do not, therefore, lend themselves as readily to use against diseases of the sporadic type as does chemical control, which can often be delayed until forecasting systems detect a specific threat. Economies in time and labor made possible by disease forecasting are not possible in relation to cultural control.

**E. Desiderata**

We have painted, thus far, a somewhat dismal picture of disease control by cultural methods, stressing the overwhelming complexities involved, the general reluctance of those concerned to think and act in this area, and the obstacles standing in the way of more widespread adoption. This pessimism has been wholly intentional, of course. At the same time we have tried to give some indications of future promise and have hinted at some of those aspects wherein cultural methods can and do compete very favorably with orthodox programs. If these promises are to be realized, what further work needs doing and what further information is essential?

1. **Biological Information**

Graham (1951) has given us, with specific reference to forest insects, to be sure, convincing evidence of the absolute indispensability of sound and thorough knowledge of the biological basis of disease as a prelude to cultural control and an indication as to the frame of mind in which this information must be sought. He points out, for example, that the white-pine weevil was for many years studied only where it was abundant, until it eventually dawned on someone to look in those areas where it was normally scarce. This new lead soon showed that where the trees grew from infancy in dense stands a good crop was invariably produced, whereas scattered plantings were always severely injured or worthless,
and that pines growing intermixed with hardwoods were practically never attacked. This all pointed to obvious ways by which forest management could materially reduce damage.

A second major insect menace, the spruce budworm, is estimated to have destroyed, in a 10-year period, enough timber to have operated the then existing pulp mills for 40 years—a volume sufficient, piled as cordwood, to have encircled the globe at the equator 10 times. This problem also proved solvable through the same basic approach when it was shown that spruce-fir stands having, in the upper crown, less than 50% balsam were seldom killed because the newly hatched young, contrary to popular opinion, enter almost immediately into a period of hibernation. The balsam appears to serve as an ideal site for their survival. It was shown, further, that the pine form of the insect led to outbreaks only when the proportion of twigs bearing staminate cones was in excess of 20% of the total twigs on the tree. This proportion, in turn, depends on the root-to-crown ratio and is based on the relatively greater amounts of carbon than of minerals in large-crowned individuals. Once the complex interdependencies were established, control needed to be no more involved than the cutting out of scattered, large-crowned trees.

Satisfactory progress in the identification, development, and application of cultural control measures will be achieved only through similarly meticulous and persistent researches on the biology of disease in plants, coupled with close observation of the effects of empirical field tests and a genuine willingness to evaluate objectively the long-established, tradition-based practices of the commercial producer. Along with these studies it will be necessary to make major improvements in our ability to recognize and evaluate disease losses and, in pushing toward this goal, to accept every new technique which presents itself—such as, for example, aerial color photography (Colwell, 1956).

2. Historical Information

History, long neglected, might provide us with priceless keys to disease control, particularly by cultural measures, if we were to seek them diligently enough—history not of disease control; or of the identification, nomenclatural vicissitudes, or laboratory studies of the pathogen; but history of diseases per se. Plant pathology does not have, to its great detriment, any such monographic study of disease development, epidemic spread in prior times, geographic origins, and the like, as is to be found in the magnificent volumes on human medicine brought out by the Geomedical Research Station at Heidelberg (Rodenwaldt, 1952–1955). Plant pathology faces the same challenges as does public health, but plant pathologists neglect to use some of the tools in the hands of the
public health specialists. Contemporary experimentation plus observation of current field incidence cannot always discover the circumstances in the host-pathogen-environment complex which can lead to disease development. If we were to make careful studies of the origin, spread, and fluctuations of diseases as entities—much as one would chronicle the rise and fall of human civilizations and societies—against a background of weather, crop varieties, farming methods, etc., we might find new and highly promising leads toward effective control. After all, in looking at past outbreaks we would at least know that the peculiar set of circumstances necessary to produce them had existed at that particular time and place. Our problem would be to find out what factor was common to many epidemics and thus of proved importance. Large (1940) has done something of this nature for potato late blight, but the whole approach is virtually unexplored and we shall be handicapped until it is attended to.

3. Cooperative Action

Cultural control in many situations is best carried out as a joint venture—if large geographic areas are involved it must always be so handled. Valleau (1953) has given us a good example of this in reference to the blue mold of tobacco (*Peronospora tabacina*) in the eastern United States. As he says, any informed tobacco grower can with comparatively little labor, be certain that his farm does not originate an epidemic. The joint efforts of a majority of tobacco growers in the region could reduce losses to the vanishing point. In the over-all picture, by eliminating the pathogen from Georgia, where it survives the winter on living plants and as oospores, we could prevent the spore showers to which tobacco in the Carolinas and Virginia are subject and, hopefully, engineer the gradual disappearance of the disease in those more northerly regions. Here is the extreme case of joint action, wherein success in disease control in one area would be totally dependent on the efforts—and joint efforts at that—of growers in a far distant sector.

A somewhat similar suggestion has been made with a view to reducing cereal rusts in the Indian plains by arbitrarily limiting plantings in the nearby highlands (see Section V, C, 1). Neither of these plans has been tried, and either might be challenged on biologic, economic, or political grounds, but the principle of cooperative action is still valid.

III. ELEMENTS OF CULTURAL CONTROL

The diseased plant, the pathogen, and the diseased population form the framework of this treatise and the point of view emphasized, in turn, by each of its three volumes. Save in the exceptional case of individual
ornamental plants, disease control measures are directed toward the
diseased population, but they may operate primarily in relation to the
host plant, the pathogen, or the environment. Pathogenic disease is not
an entity in itself—it is the sum of innumerable specific interactions
between individuals of the pathogen population and individuals of the
host population. Control of pathogenic disease is the net effect of the
particular measures involved upon these specific interactions, a gen­
eralization which holds as true for the cultural approaches to disease
control as for the more orthodox endeavors. The effect is general, the
mechanism specific.

A. The Diseased Plant

N. E. Stevens (1949) has tabulated certain data in an effort to
establish, with respect to ornamentals, the characteristics which lead to
freedom from, or propensity for, disease damage. Disease-free forms
are found to be predominantly of foreign origin, to have no near relatives
within the native flora, and to be of no more than minor commercial
importance, at times even decidedly rare. Disease-prone forms, by con­
trast, are characteristically native to the area, vegetatively propagated.
and found in great abundance. Similar generalizations could be estab­
lished for crops species, and forest plantings.

1. Epidemiological Aspects of Host Defense Devices

Chapters 11, 12, and 13, Volume I are especially pertinent to a con­
sideration of cultural control. The reader is directed particularly to such
matters as disease escape, the influence of environment on histological
mechanisms of defense, hypersensitivity, the acquisition of apparent
immunity to invasion by virus proteins, and the development in the
host of tolerance to the presence of the pathogen (Hart, 1949). In the
laboratory, greenhouse, and experimental plot these are problems in the
physiology of host-parasite relations; in the field they become attributes
of population dynamics and of disease control by cultural measures. As
noted earlier in this chapter (see Section II, E, 1), it is of this basic
stuff of biology that effective control must be compounded.

Cultural control, when it is specifically directed to the plants of the
host population (see Section IV) works through the agency of host
defense—be it histological (cuticle, work formation, lignification, hyper­
sensitivity, etc.), avoidance, degree of receptivity, habit of growth, rate
of maturation, or sheer fortuitous escape—and seeks so to alter the
environment as to maximize the net effectiveness of these host defenses
from the standpoint of the entire population.
2. *Host Predisposition in the Diseased Population* (see also Volume I, Chapter 14)

Mineral nutrition, temperature, moisture, light, soil reaction—these and related factors of the environment prior to inoculation act to predispose the host to invasion by pathogen or to minimize the likelihood of its becoming established, although Gäumann (1950, p. 362) insists that in general "disease proneness" is less markedly affected by external influences in plants than in man and that the pathogen therefore dominates plant pathological thought. In any event, whatever effect there is, is upon individual and specific plants, not upon the population. Only when attention is fixed on practical application does the emphasis shift from the biology of the individual plant and pathogen to the over-all effect of management practices upon that relationship. For example, water congestion and the role of guttation droplets in facilitating the entry and establishment of pathogens (Eide, 1955) is a problem, and a very stimulating one, in plant physiology; transferred to disease control, it becomes a problem in soil and air temperature, rainfall, humidity, wind, selection of varieties, cropping practices and, often, manipulation of irrigation water.

3. *Therapeutic Measures in Disease Control* (see also Volume I, Chapter 15)

The concept of therapy assumes that the pathogen has become established and that disease exists; therapy seeks to remove the affected portion or to exorcise the invader in such a way and in such good time that the host plant will resume essentially normal growth. Excision, pruning, chemotherapy, heat treatment, are representative measures directed to this end.

The distinction here between the biology of the individual plant and the control of disease in a population is one only of degree. The research investigator applies his techniques to one or to a small number of host plants; the grower attempts to find means whereby these same measures can, perhaps by simplification and mechanization, be imposed on large numbers of plants within a diseased population. For once he does not operate primarily through the environment, but, like his professional colleague, directly upon the individuals of the host population.

### B. The Pathogen

Volume II examines plant disease from the standpoint of the pathogen. Control by cultural methods has its parallel aspects wherein the chief target is the inoculum (see Section VI) and where techniques are
designed to take advantage of any vulnerable spots in the biological role of the disease-producing organisms: their reproduction, pathogenicity, or dispersal.

1. **Reproduction** (see also Volume II, Chapters 3–5)

   Virus multiplication, the reproduction of bacteria, fungi, and nematodes, and seed formation by parasitic flowering plants contribute ceaselessly to the fund of inocula threatening host populations. Reproduction potential is reflected in the epidemic pattern of disease. Inoculum production is, in turn, much conditioned by environmental factors, especially of the microclimate and of the soil, and is, therefore, subject to alteration by cultural measures.

   Individual cases differ. Some foliage diseases, serious when hosts are crowded and humidity in the immediate vicinity of the leaf surfaces is high, can be favorably altered by reducing the seeding rate. Others, such as the aphid-transmitted peanut rosette virus, are made worse by dry weather and can be partially controlled by sowing more thickly. In any event, plants requiring much moisture, if it be supplied by irrigation, do not normally suffer from pathogens requiring high humidity (Hunt, 1946).

   Spore germination, viability, survival and longevity, resistance or sensitivity to extremes of light, temperature, drought—all these elements of the pathogen are in the last analysis influenced by the environment and hence affected by cultural practices.

2. **Pathogenicity**

   Volume II of the treatise, particularly Chapters 6–8, treats of the mechanical and chemical means whereby pathogens invade their host species and of the interactions of pathogen, soil, and other microorganisms. Here, too, environmental factors play a part, and cultural control measures have a rightful place.

3. **Production and Dispersal of Inoculum**

   Pathogen reproduction is a manifestation of the biology of an individual organism—virus, bacterium, fungus, nematode, or flowering plant. Inoculum production is the cumulative result of reproduction of a given population of a pathogenic species and as such is reserved to Volume III (see Chapter 2). Data on spore discharge and movement is part of the biology of the fungus pathogen and properly belongs in Volume II; inoculum dispersal is a problem in epidemiology and its consideration as rightly appears in Volume III (see Chapters 3–6). Reference to those chapters will show the impact of the physical environ-
ment upon the amount of inoculum produced; on dispersal by insects, air, and water; and the importance of the biotic environment, as exemplified by alternate hosts, symptomless carriers, reservoir hosts, vector species, and the like.

4. Inoculum Control

Efforts to control the inoculum may be directed at the source (biological control, Chapter 13; or chemical soil treatment, Chapter 11), during the process of dispersal (through quarantines, Chapter 9), or at the site of the newly contacted host plant (chemical protection of foliage and seeds, Chapter 12). Cultural and related special measures, insofar as they operate against inoculum, lie mostly in a transitional zone not yet sharply delimited. Sometimes they aim primarily at the site of production, sometimes at the site of invasion, sometimes at both. In the detailed enumeration to follow, this variability will be clearly evident. Strategy and efficiency differ, and must be separately evaluated for each host-pathogen situation.

C. The Diseased Population

While it is entirely proper to consider a single plant as diseased, it is only when a population of plants is damaged to an appreciable extent by some agent or circumstance that disease, as the word is customarily thought of, exists. When this damage results from the interaction of two populations (host and pathogen), the study of their interaction is epidemiology, which van der Plank has treated in Chapter 7. Epidemiology, in its best established and most reliable form, leads to prediction and the benefits of forecasting (see Chapter 8).

The epidemic characteristics of a disease complex, whether swift moving or slow, whether of sporadic or regular occurrence, whether of relatively uniform or sharply fluctuating severity, influence greatly the extent to which cultural control measures prove practicable or (better said) whether a particular cultural control measure will prove practicable.

IV. INTRINSIC MEASURES DIRECTLY AFFECTING THE INDIVIDUALS COMPRISING THE HOST POPULATION

Of the cultural measures employed for disease control, some act primarily by direct action on the individuals of the host population. They are applied, in almost every case, to the diseased crop as a whole, but the effect is to alter in some physical, genetic, or physiologic way, the plants themselves.

Intrinsic measures are not always devoted exclusively to disease control—often this is an ancillary aspect. The following discussion can
be extended to include, however, only the plant pathological implications of the subjects covered irrespective of whether they are primarily or incidentally devoted to that end.

A. Cultural and Related Practices

"Cultural" as used in the title, and thus far throughout this chapter, has been accorded the broadest possible meaning. As noted earlier, it incorporates all control measures other than imposition of quarantines, application of chemicals to soil, seed and foliage, disease-resistant varieties, and biological interference. In the present section, however, the word is employed in a much more restricted sense to refer to those management, tillage, and handling practices which relate to disease and disease control. We are attempting thus to see, in a few examples, how the often routine practices of the grower—what he does or doesn't do—are of importance in the eventual pathology of the crop in question. Oftentimes, disease control is only incidentally related to the procedure discussed; oftentimes it is not yet clearly understood why the observed results are obtained. That there can be a consistent, significant effect is pretty well established.

Growth habit, for instance, natural or as altered by pruning, influences the disease propensities of the host plant. Gäumann (1950, p. 258) reminds us that, in general, erect bean plants are less subject to anthracnose than squat, drooping varieties; what he refers to as "standard" roses are less troubled by black spot than bush roses; and potato varieties with open habit are less damaged by late blight.

Avoidance of heart rots of orchard, shade, and ornamental trees is largely a matter of preventing wounding, treating promptly such wounds as do occur, and stimulating growth to promote rapid healing (Wagener and Davidson, 1954). In the important area of market pathology of perishable fruits and vegetables, care in handling, all the way from harvest to eventual sale, is of first-rank importance (see Section 4, below).

Soil characteristics and tillage practices are among the factors involved in crop culture in the restricted sense used here. Gäumann (1950, p. 423) mentions the influence of heavy- and light-textured soils on potato tuber infection with late blight, and comments on the widely recognized importance of soil reaction and humus content. Fischer and Holton (1957), discussing wheat bunt, underscore the advantage of fall plowing of summer fallow, which has the effect of turning the smut spores to a depth below the usual placement of seed.

Soil, soil management, and cropping procedures have been convincingly implicated in the matter of root rots, a category of disease
which has been long recognized as of major importance, but one only recently subjected to carefully controlled experimental research. Results have been disappointingly hard to come by, largely because a multiplicity of variables is inevitably encountered, but some very useful leads have been struck and the outlook for the future is encouraging. “Take-all” of cereals, particularly of wheat, is made worse by continuous cropping, by weed competition, and by low soil moisture (resulting in low fertility) primarily because diseased roots cannot be replaced rapidly enough. A dry topsoil seems particularly unfavorable (Simmonds, 1953). Irrigation can, of course, profoundly alter the entire pathology of a crop (Chester, 1947, p. 477).

Silvicultural methods can be enlisted in campaigns for pest and disease control. Graham (1956) discusses the regulation of insect populations through planned forest management, aimed chiefly at reducing the amount of land occupied by what he terms “hazardous” forest types, but with due regard for economic considerations and in harmony with efforts to control pests by chemicals. Much study has gone into the matter of dwarf mistletoe infestations as encountered in conifer stands of the southwestern United States. As noted earlier, the economy of standing timber largely precludes control measures other than those which can be instituted as an integral part of the over-all silvicultural program. Except in a relatively few cases, chemical control of forest diseases is prohibitively expensive and technically difficult, and the peculiar problems of forest tree breeding have seriously postponed the development of resistant varieties, even assuming that the bulk of our forest lands will eventually be occupied by set trees rather than naturally reseeded. According to Kuijt (1955) mistletoe infestation is most favored by selective cutting and least by clear cutting. He recommends: (1) cutting infested blocks first, where the block system of cutting is in vogue; (2) selection of seed trees free of the parasite; (3) removal of infested trees first in thinning operations; and (4) where possible, cessation of logging and pruning operations during the parasite fruiting season.

Burning has proved valuable in scattered situations as a means of reducing disease damage, wholly aside from its routine use in seedbed soil sterilization. As N. E. Stevens (1938a) pointed out in a review some years ago, destruction of diseased plant parts by burning in order to reduce inoculum has been very often recommended, although perhaps less generally practiced. A 5-year study of the brown spot needle blight of longleaf pine seedlings by Paul Siggers has shown that a single fire greatly reduces the disease for a season or two, and that, once the seedlings are established, controlled winter burnings at three-season intervals is effective as a control in areas devoted to timber.
More recently, Hardison (1948) has recorded control of blind-seed disease of perennial rye grass (caused by *Phialea temulenta*) in Oregon for at least 1 year by burning straw and stubble. He does not recommend this as the only action. Indeed, a complex of measures is indicated: (1) elimination of badly diseased fields through inspection of seed samples; (2) where possible, ageing of seed for 2 years; and (3) planting seed to a depth of \( \frac{1}{2} \) inch or more, completely covered, to prevent emergence of the apothecia.

Tobacco blue mold or downy mildew furnishes another good example of control, largely cultural, achieved by joint employment of a considerable number of individually unrelated measures (McGrath and Miller, 1958). Current recommendations include: (1) selection each year of a new seedbed site, with a view toward adequate air drainage, ventilation, and surface water runoff; (2) sterilization by steam, burning, or chemicals of seedbed sites when new ones are not available; (3) destruction of holdover plants; (4) watering, when necessary, in forenoon only; and (5) field sanitation, i.e., removal and destruction of diseased plants and plowing under or cutting down of all plants remaining after harvest.

Seldom, if ever, are cultural control measures encountered which are entirely independent of other practices; often they are part of a whole fabric of activities which, in the aggregate, suffice to produce a dependable crop. We cite the above examples not as special instances but as illustrative of the normal state of affairs; similar relationships hold, even though unspecified, in most that is to follow.

1. Removal of Plants

Roguing, so-called, or the systematic removal of diseased individuals from a host population is an obvious and often practiced control procedure. Because it is characteristically a hand operation, it involves, on any extensive scale, undeniably high labor costs. While frequently recommended, roguing has fallen rather out of favor with the advent of control measures which are more specific and supported by more experimental evidence. Of itself, it is doubtful whether roguing ever achieves a degree of control which would be fully satisfactory. This is in part because by the time disease symptoms are so conspicuous as to indicate removal of the plant, inoculum will have spread to nearby healthy individuals. By far the most appropriate use of this device is as an adjunct to other practices, as in the production of virus-free propagation stock, as a preliminary to chemical disease control in small plantings, and in combating diseases of forest and shade trees.

Akin to roguing is the removal of volunteer plants, usually hold-
overs from the crop of the preceding season. These serve not infrequently as a source of inoculum threatening the new host population, importantly as a means whereby pathogenic organisms survive the unfavorable environment of the winter season, as a bridge for nutritionally fastidious organisms between successive cropping periods, and as a site for the development of viruliferous vector populations. In many—but not all—ways, volunteer plants play the same role as do weeds and other reservoir hosts (see Section VI, B, 1), and their consideration overlaps somewhat the discussion of sanitation and eradication (see below, subsection A, part 5).

2. Physical Alteration of Host Individuals

At times a physical alteration of the host plant, rather than its removal, is indicated as a means to disease reduction or control. Among these treatments are girdling, poisoning, root severing, desiccation, and defoliation.

Root rots of woody species furnish interesting examples. Berkeley, in a 1944 review which covers control by varietal resistance, crop rotation, biological interference, fertilization, soil disinfection, green manuring, etc., recounts how the *Armillaria* root rot of tea in Nyasaland is reduced by ring-barking trees before they are felled in the process of land clearing. This prevents passage of carbohydrate from leaves to roots and—to be most effective—should be carried out just before trees break into leaf, thus accelerating the rate at which roots die. Trees which die slowly should be felled 1 year after ringing. Similar advantages have been gained in Ceylon as a protection for tea against *Poria* in jungle clearings, and in Nyasaland for tung plantations. The efficacy of these steps can be further enhanced by injecting stumps with sodium arsenite, which hastens decay and invasion by saprophytic fungi at the expense of pathogenic fungi—in some sense, therefore, a biological control measure.

Wagener and Davidson (1954) argue that methods of control of decay feasible for forests must usually be applied to stands of trees rather than to individual trees. This follows from the fact that forests are not sufficiently valuable to justify the kind of care usually given other woody perennials. At first glance, this would seem to rule out physical alteration in forest stands, but selective thinning and related silvicultural measures can prove effective, and rot can be much reduced by thinning hardwood sprouts before a bridge of heartwood forms at the base. Low-origin sprouts and those from small stumps should be retained rather than those of high origin and from large stumps. Wagener and Davidson advise pruning of crop trees while the branches are still small, which—aside from improving timber quality—reduces decay in young conifer
stands by fungi such as *Polyporus aniceps*, which enter through dead side branches.

Colonization of stumps by butt rot fungi entering through roots (which may then lead to invasion of adjacent living roots) may be prevented by girdling and exhausting food supplies. Experiments on artificial colonization of stumps by saprophytic-decay fungi holds promise, and early infection of conifers may be reduced by setting the roots at planting time in such a way that taproot formation is hindered. But these workers conclude that, for some conditions, "conversion to mixed stands is probably still the most practical means" and that the reasons for the natural arrestment of decay and the natural dying out of infections need to be better understood.

Forest tree diseases have frequently aroused much public interest in the United States, none more so than oak wilt. For some years it has been observed to progress slowly through local groves of oaks and to spread over greater distances in a most erratic fashion. The cumulative efforts of workers at a number of experiment stations have established that tree-to-tree spread is accomplished in large measure by vascular transport of inoculum across root grafts and that overland spread is due to the activities of certain beetles and is associated with formation by the fungus of what are called "mats" beneath the bark. The former has been controlled in experimental areas by poisoning a strip of trees immediately surrounding the infected individuals and (more interestingly perhaps) by passing a large, subterranean, tractor-drawn knife between diseased and adjoining healthy trees in an effort to sever the root connections (Kuntz and Riker, 1950). Mat formation by the oak wilt fungus—and consequent overland spread—is substantially reduced by early felling of the wilted trees, by deep girdling (preferably in the first part of the summer), or by application of sodium arsenite to a band of exposed heartwood (Gillespie et al., 1957; Morris 1955).

Resort to destruction, defoliation, and desiccation as adjuncts to disease control has in the main awaited the development of special-action chemicals and of means for their cheap and effective application. Thus, as N. E. Stevens and Nienow point out (1947), under certain conditions a major portion of infection of tubers with potato late blight occurs at the time the potatoes are dug, chiefly, if not solely, if the tops of the plants are green at that time. It has been long recognized that little or no rot occurs in storage when the potato plants are completely killed by blight prior to digging. With this in mind, and particularly since better control of both disease and insects have in recent years materially prolonged the period during which the foliage remains actively growing, methods have been worked out whereby the above-ground
parts are killed by an herbicide and allowed to dry out thoroughly before the crop is harvested. One has only to visit the potato-growing sections of Long Island, New York, or Aroostook County, Maine, to observe the widespread adoption of this highly successful procedure in the spectacle of field after field of dead brown plants in an otherwise green and luxuriant landscape. As presently carried out, destruction of potato vines is thought not only to prevent infection of tubers by the late blight fungus but to reduce spread of virus diseases. It is not routinely done, however, in the Far West, where the vines are allowed to remain alive in order to shade the soil and reduce losses from heat injury (Addicott and Lynch, 1957).

Defoliation is of demonstrated value in reducing disease and pest damage. In cotton culture, defoliation by calcium cyanide seems to induce lodged plants to return to an erect position, and to reduce boll rot and the injuries of leaf-feeding insects. When the leaves of nursery stock being dug preparatory to storage or shipment are defoliated, diseases normally associated with foliage are reduced. Several means are available: (1) hand beating; (2) application of ethylene gas to stored stock, either from tanks or by including a bushel of apples for every 400–500 cubic ft. of the chamber; or (3) in the case of California roses, by allowing sheep to graze prior to lifting (Addicott and Lynch, 1957).

Field defoliation has been advocated as an aid in bacterial canker of stone fruits, which invades the host through freshly exposed, incompletely healed leaf scars. The procedure of choice is to defoliate the trees in mid-autumn and then protect them with a single spray application until leaf scars are completely healed.

3. Sanitation and Eradication

Sanitation has been advocated repeatedly as a means of reducing the amount of inoculum to which the host population is exposed. In this sense its consideration might be postponed to Section VI, but, while the final aim is inoculum reduction, the sought-after result is achieved through actions immediately involving the host plant proper. Sanitation as a direct means of disease control and as an adjunct to use of chemicals can be summarized in the following terms (Stevens and Stevens, 1952, pp. 166–167):

"One of the simplest of all these means is, of course, removal and destruction of diseased plants or plant parts. In the home garden, especially the ornamental garden, and in the greenhouse, this is of far greater utility than is generally realized. In fact, the very obviousness of the method is one of its greatest weaknesses—it is not exciting; it is not expensive; and makes no appeal to the imagination. Sanitation is also of
utility in the orchard, primarily for such diseases as black rot of apple, and some stone fruit viruses.

"The effectiveness of this type of sanitation in the home garden is due to the fact that infection is almost always heaviest in the immediate vicinity of a source of infection [see also Wilson and Baker, 1946]. Falling off in concentration of spores or other inoculum is at first very rapid. At greater distances the rate of falling off is much slower, but the concentrations are so much lower that this is of less practical importance.

"As sanitation is the simplest of all methods of attempting disease control it may well have been one of the first attempted.

"In many cases sanitation is of unquestioned utility as an aid to disease control by spraying. If the amount of inoculum can be markedly reduced by relatively inexpensive sanitation procedures the likelihood of achieving commercially adequate control by spraying is vastly enhanced. There are many instances of this well known to growers and to plant pathologists. Perhaps there is no better example than black rot of grapes. Given reasonably favorable conditions this disease is readily controlled by standard spray schedules. As a matter of fact it serves as an unusually satisfactory subject for demonstrating the efficacy of spraying. However, if the disease has been severe in the previous season such control is usually possible only if, when the grapes are pruned, adequate precautions are taken to remove and destroy dead portions of the vines which bear fruiting bodies of the black rot fungus. This involves destruction of all mummies and dead branches. Tendrils, even, must be removed from the wires; a step most easily accomplished by burning.

"The same general principles apply to apple blotch and black rot, and to brown rot of stone fruits. Keitt's work on eradicant sprays (see also VI, A, 3) for the control of apple scab is essentially an attempt to cut down the amount of inoculum present during the period of rapid growth of the host plant."

Sanitation takes many forms; sometimes the removal of infected plant parts and sometimes the removal of the body or reproductive parts of the pathogen, as the apple rust galls from cedar, conks of wood rot fungi, leafy mistletoe, and corn smut galls (Chester, 1947, p. 480). It may be cleanliness in the literal sense, as the avoidance of dissemination of tobacco mosaic virus on the hands of workers through use of disinfectants (Chester, 1947, p. 477); or "housekeeping" care, as when leaf mold and surface litter, in wet seasons, are removed from tea plantations to prevent the spread of the Rosellinia pathogen (Berkeley, 1944). It may be employed directly in the control of smut diseases, as by the burning of diseased stubble against flag smut in Australia, reduction of corn and
sugar cane smuts, excision of infected buds in combating anther smut of carnations, or mechanical removal of bunt spores from seed grain by special machines (Fischer and Holton, 1957); or indirectly as an adjunct to other cultural control measures for the production of virus-free cabbage seed in western Washington (Pound, 1946). It may be achieved by routine, self-evident techniques, or by such unique procedures as that cited by Stevens and Nienow (1947) in connection with Sclerotinia on lettuce. In this last instance, lettuce harvesting methods in the Salt River Valley of Arizona leave obviously diseased heads, bearing their abundant sclerotia, in the field. At least part of the time sheep are allowed to pasture on these fields—with the result that the vast majority of the inoculum is consumed and digested.

Eradication differs from sanitation only in the matter of degree; it aims at the complete removal of diseased plants or infective material. Summarizing the situation several years ago, Stevens and Stevens (1952) said: "The earliest successful eradication campaign of which the writers have found record is that against the Colorado potato beetle in Germany in 1875. . . . A very limited area was given such a drastic clean-up that the pest never reappeared. A second introduction was reported in 1934 and the insect again eradicated at a cost which appeared trifling when compared with the value of the German potato crop.

"The first apparently entirely successful eradication campaign conducted on a large scale in the U. S. A. was that against citrus canker. Of this work Fawcett says, 'the eradication of this disease in Florida and other Gulf states and in South Africa, after it had become well established on susceptible varieties and in spite of great difficulties, is perhaps one of the most remarkable achievements in the history of plant disease control. In Florida citrus canker was found at various times on 515 properties scattered through 26 counties . . . it was necessary to destroy 242,502 grove trees and 2,740,850 nursery trees.

"Complete eradication of at least two other tree diseases has also been achieved in the U. S. A. These are larch canker which was recently introduced into New England and eradicated by destruction of all infected trees, and witches' broom on Japanese cherry eradicated from the District of Columbia and adjacent Maryland.

"On the other hand there have been three major attempts at eradication of tree diseases in the U. S. A. which were abandoned as impracticable. Accounts of the campaigns against the chestnut bark disease, and the Dutch elm disease will be found in a recent edition of texts in plant pathology published in the United States of America. Less emphasis was placed on eradication of white pine blister rust by this means, and attention soon concentrated instead on removal of the currant species."
Eradication of incipient infections as a means to increase the importance of plant quarantine is considered by Smith et al. (1933), who in so doing emphasize that quarantine is only a part of the machinery required for the prevention of permanent disease establishment and that it may often be unnecessary to discover the last individual pathogen and destroy it.

Yarwood, in a recent review of the powdery mildews (1957), cites several instances where a sort of eradication has been invoked as a control measure: of the lower leaves of tobacco in Southern Rhodesia; removal of apple shoots in Switzerland; elimination of *Rosa banksia* in control of apricot mildew; and the “clean-digging” of raspberries. In the last instance (Peterson and Johnson, 1928) powdery mildew is controlled in wide-row propagative plantings by digging all canes in the row each fall and permitting new rows to come up from the underground parts in the inter-row space. In this way rows are alternated each year and there are no above-ground plants in which the pathogen can overwinter. Fruit plantings, on the other hand, can be benefitted by pruning tips and by removing stunted and late-season growth.

4. Harvest Practices

As harvest time nears, whether it be the approaching end of the annual growing season or the last few years of a maturing forest stand, it becomes increasingly important to be vigilantly attentive to the welfare of the produce. Not only is it too late to make adequate substitution in the event of disaster, but the investment represented is second only to that of the harvested item. After all, “of all losses caused by plant diseases those which occur after harvest are the most costly, whether measured in monetary terms or in man hours. Even a crop like corn or potatoes which is harvested on a large scale by machinery has cost society measurably more in storage than in the field. By the time a crop, particularly a highly perishable crop, has reached a city consumer its cost has multiplied. The consumer’s apple, for example, is the producer’s apple plus the cost of picking, packing, shipping, storing and handling, as well as sales cost, allowance for spoilage, and profits” (Stevens and Stevens, 1952, p. 191).

Preharvest inspection can provide information on the pathology of a given crop as it completes its growth and maturation and enters into the harvest phase. Particularly when coupled with experimental tests, reliable forecasts of postharvest conditions are attainable; this has been conclusively demonstrated by N. E. Stevens in relation to fruit rots of the cultivated cranberry.

Handling procedures and the care with which they are executed have a great deal to do with the ultimate welfare of agricultural commodities,
particularly as they relate to the more perishable fruits and vegetables. "This is one of the simplest methods to explain and to understand. It is also one of the most difficult of all to maintain at a really effective level. So in everyday plant disease control it is easier to sell patented processes, machinery and appliances than to convince each of ten thousand (or even ten) strawberry pickers that he should keep his fingernails trimmed" (Stevens and Stevens, 1952). Studies in a number of regions and for a number of commercial fruits and vegetables leave no doubt that decay can be very substantially reduced by exercising care during harvesting. Some well-organized industries seem better aware of this situation than others, taking every precaution to insure minimum injury and introducing special methods for the express purpose of cutting down on loss of produce during shipping and storage.

Care in harvesting is of proved benefit in a number of situations. Strawberries picked early are less subject to fruit rots because the tissues, when cool, offer more resistance to mechanical injury (N. E. Stevens, 1938a), whereas vacuum cooling, presumably because it results in minor injuries, leads to high percentages of loss (DiMarco and Davis, 1957b). In Britain dry rot of potatoes (Fusarium) has been found to be worse following mechanical grading, which necessitates agitation on bare wire screens, and in the United States the better insect control achieved with DDT is partly offset in late-maturing varieties by an increased tendency to harvest immature tubers and consequently greater damage from bruising. Threshing of dry flax is considered injurious to seed coats, producing cracks so small as frequently to be invisible to the unaided eye, but leading to poor quality seed (Eide, 1955). Gaskill (1950) emphasizes the value of prompt removal of harvested sugar beets from the field, showing that if they wilt in the field before storage not only are respiratory losses increased but also, very sharply, loss from rotting. All of this strengthens the argument in favor of mechanical harvesting—with either direct loading from the harvester or immediate pickup from the windrows.

A number of food articles are subjected to immediate postharvest treatments prior to storage or shipment. Black rot of sweet potatoes, for example, is effectively controlled by a momentary dip in 1% borax solution (Martin et al., 1949). Bratley and Wiant (1950) list a considerable number of preshipping treatments, most of them chemical in nature: (1) borax; (2) addition of hypochlorite and free chlorine to the wash water; (3) painting stems of watermelons with copper sulfate and of pineapples with benzoic acid; and (4) application of sulfur dust for control of brown rot in defuzzed peaches. DiMarco and Davis (1957a) have demonstrated substantial reduction in Botrytis and Rhizopus rot of straw-
berry by adding mycostatin to the cooling water and of brown rot and *Rhizopus* rot of peaches with mycostatin and Dowcide as a postharvest dip (DiMarco and Davis, 1957b).

Citrus, a crop on which much research time and effort has been expended, furnishes instructive information on prestorage treatment (Miller, 1946; Hopkins and Loucks, 1948). Benefits of “curing” or exposure to CO\(_2\) may be due to an accelerating effect on certain processes before the fruits enter low temperature storage. It has been discovered that in the early part of the season, when fruit is being held 60-70 hours for coloring, stem end rot (caused by *Diplodia natalensis*) is high, but that when coloring is discontinued later, there is a sharp drop in end rot and a marked increase in *Penicillium* mold. The latter can be avoided by inserting a curing period in place of the degreening, at a cost far overbalanced by the advantages gained.

Reports by Graham (1951), Wagener and Davidson (1954), and Verrall (1945) are representative of a very extensive literature on the relation of harvest and prestorage handling on quality of timber and forest products, and provide convincing evidence of the critical importance of this phase of operations. In general, heart rots are reduced by a preliminary light sanitation cut, which permits a rapid removal of defective trees, it having been shown that even when sporophores are formed on felled trees, they are less dangerous than when the hosts remain standing. Adjustment of cutting age, special salvage cuts in fire or storm-damaged stands, protection against fire and wounding, clear cutting where otherwise practicable, and, in species with an age-decay relationship, logging practices designed to minimize risk and to harvest the crop before heavy losses occur—each of these contributes to the eventual quality and quantity of the final product. Handling methods that permit treatment before infections become deep-seated are a useful adjunct to chemical control of fungi in air-seasoned lumber. Storage in water proves effective, provided the entire log is kept wet, although prolonged immersion may remove certain water soluble toxic extractives and increase susceptibility to fungus pathogens. Contributory measures are: quick utilization of logs, minimum delay between milling and chemical treatment, reduction of bulk-piling periods to a minimum, and good air-drying conditions—all of which become more important as the proportion of sapwood in the timber increases.

5. Storage Management and Market Pathology

Fully adequate coverage of postharvest pathology is not possible within the space limitations of this discussion. It has always been (more's the pity) a study apart from the body of plant pathology, but
is particularly pertinent to a treatment of cultural control methods. Shippers and dealers are understandably reluctant to apply chemicals in appreciable quantities to a commodity that will soon be consumed—the very produce whose perishability poses troublesome market pathology problems. Thus deprived of one convenient approach to control, the pathologist, shipper, middleman, and retail merchant turn to cultural techniques.

General summaries of market pathology are available in varying detail in Stevens and Stevens (1952, Chapter 19), Stakman and Harrar (1957), Bratley and Wiant (1950), and Pentzer and Heinze (1954). Discussing transit losses, Stevens and Stevens (1952, p. 190) summarize Bratley and Wiant as follows: "In this paper is presented for the first time a summary of the losses as they occurred in a true random sample of all rail shipments of various commodities unloaded in a great terminal market. This was made possible by an agreement between a group of produce dealers in New York City and the U.S.D.A. whereby all car lots of produce received by members were inspected on arrival by a federal inspector. Of those commodities that were included in the study, 14 were fruits, and 31 were vegetables.

The average decay per carload ranges from 0.6% in a few cars of nectarines to 2.9% in over 3,000 carloads of apples. Among the vegetables, the lowest average per cent of decay is for green corn, 0.1% of the relatively few cars inspected to well over 11% average decay in endives and lettuce. Perhaps only those who have actually worked in terminal markets will appreciate either the high accuracy of the certificates used in the study or the very large amount of work involved in this preparation. The writer's conclusion that on the basis of the figures given, 'decay of these forty-five commodities during rail transit to New York City totalled nearly 3,000 carloads annually' cannot fail to arrest the attention of anyone who is seriously interested in the national food supply."

This same report (Bratley and Wiant, 1950) lists blue mold, gray mold, Rhizopus, and bacterial soft rots as leading the transit and marketing phase; brown rot and apple scab as representative of pathogenic troubles originating prior to harvest but continuing into postharvest situations; blossom end rot of tomatoes, bitter rot of apples, and scald as major nonpathogenic problems; and bruising, freezing, and heating as the most common environmental injuries. Stakman and Harrar (1957) reduce nonpathogenic diseases to three classes: (1) suboxidation—black heart of potatoes, brown heart of apples, internal browning of citrus; (2) accumulation of aromatic esters; and (3) unfavorable temperature and humidity. They consider two categories of pathogenic
10. CULTURAL PRACTICES IN DISEASE CONTROL

storage diseases: (1) those attacking dry, bulk materials (chiefly stored grains); and (2) those affecting succulent fruits and vegetables.

Pentzer and Heinze (1954) in their review of postharvest physiology of fruits and vegetables first remind us that some maladies, such as water core and cork spot of apples, are really not true postharvest troubles, and then set up three categories: (1) functional diseases related to volatile emanations, lack of oxygen, etc.—the most publicized of these, apple scald, once thought to be caused by ethylene, can be prevented or minimized by allowing fruit to become riper or by accelerating removal of volatile substances with oiled wraps, air movement, intermittent warming, etc.; (2) chilling injury; and (3) problems arising out of the use of growth substances. These last-named materials are used in a rapidly increasing variety of ways: to maintain the “buttons” of pineapples longer in a green condition, thus reducing Alternaria rot; to control fruit drop or hasten maturity of orchard fruits which may affect storage; to prevent abscission and conserve color and moisture in snap beans; and to increase rate of ripening in banana, with subsequent accelerated spoilage. In a related situation, increased use of sprout inhibitors in storage bins, which delays suberization of cut surfaces and formation of wound cork, seems to aggravate dry rot of potatoes.

Control of market and storage diseases involves a large and diverse list of measures. Modified atmospheres of several types are used: sulfur dioxide, nitrogen trichloride, ozone, ethylene oxide, and methyl bromide, in a variety of techniques. Nonvolatile substances, oiled wraps, copper-impregnated materials, etc., prove useful in certain instances. Probably the most widely adopted of all preventive measures is temperature control, ranging from precooling to transit refrigeration and cold storage. Optimum temperatures for different commodities vary, and it is necessary to establish specific conditions for each group of fruits and vegetables. In the special area of stored grains, damage is minimized by the use of fungicides, by storage under toxic or inert gases such as CO₂, and—most of all—by drying to the point where no portion of the mass is moist enough to support the growth of fungi (Christensen, 1957).

Special methods are introduced from time to time with limited success. Radiations of various types—ultraviolet, high energy electrons, gamma radiations, ultrasound—have been tried (Morgan, 1948; Imshenetskii and Nazarova, 1937; Metlitskii and Soboleva, 1936). In the case of perishable foods, the major objective is the economy of storing and transport without refrigeration. As yet these techniques have not been approved by federal agencies for treatment of edible items.

The expedient but otherwise unfortunate schism between plant pathology and economic entomology extends into commerce and the
market place. But the problems are much the same, as evidenced by Parkin’s review (1956) of several years ago, and the gap between knowledge and practice is just as great. He bemoans the fact that application of knowledge lags sadly behind the scientific advances of "stored product entomology" in all but the most highly developed countries, and in plant pathology we find instances where the crudest sort of conditions lead to postharvest damage. In Greece, for example, because apples are simply piled in the orchards for some time after picking, sunburn becomes a significant problem (Krochmal, 1956).

Market pathology introduces basic problems in the physiology of mature tissues (Smock, 1944). Studies of respiration in deciduous fruits show marked fluctuations which can be related to maturity at time of picking, temperature, size, presence of mechanical injuries, and composition of the atmosphere in the storage chamber. Intentional adjustment of the gas content of the atmosphere, by introducing CO₂, oxygen, ozone, or nitrogen, is undertaken with the avowed purpose of favorably affecting the rate of respiration and other metabolic activities in stored produce (Miller, 1946; Bratley and Wiant, 1950; Schomer and McColloch, 1948). Transpiration rate, also, significantly affects the quality of produce, and depends on maturity at picking, size, vapor pressure deficit, air movement, and wax coatings—if any (Smock, 1944).

B. Genetic Resistance

Without exception, practices included in the immediately preceding discussion of "cultural" control, in the restricted sense, result in no fundamental change in the host plant nor are they effective for succeeding generations. As we have indicated, they are mainly physical alterations—sometimes complete removal or destruction—of the individuals of the host population or, not infrequently, measures subsidiary to routine agricultural practices.

The use of disease- and pest-resistant (Snelling, 1941) crop varieties on the contrary, takes advantage of genetically based, permanent changes in the host individuals. Chapter 14 of this volume is devoted to the problems of the plant breeder and the genetics of disease resistance. It would be inappropriate to dwell further on this subject here.

It will be recalled, further, that in the first three sections of this chapter considerable emphasis was put upon the relative popularity and advantages of cultural control on the one hand as opposed to use of chemicals and resistant varieties on the other. We seem now, by including resistant varieties as but one of a host of cultural control measures, to be contradicting ourselves. As a matter of fact, the selection and use of disease-resistant crop varieties is just another weapon
available to the grower from a very large and diverse arsenal. But be-
cause it is so exceedingly popular, because it is so nearly independent
of other measures and so often employed alone—without the support
of any other cultural control, and because research and development
in this direction require considerable special information and training,
genetic resistance has come to deserve consideration as a topic in itself.

Exploitation of disease resistance in the great majority of instances
involves little more than a choice of established resistant varieties, either
as seed or propagating material. It need not always be thus simple and
direct, and some interesting complications arise from time to time.

"In the past greater attention has been given to breeding for dis-
ease resistance among field crops than among those usually considered
horticultural. This difference is concretely shown by the publications
of comparable societies in the U. S. A. There are several fairly obvious
reasons for this difference. Cereal crops are almost entirely annuals;
many of the fruits are perennial. Moreover, among cereals the per acre
returns are usually not sufficient to permit any known form of disease
control other than modified culture, seed treatment, or breeding. On the
other hand it is among the fruits that disease control by spraying has
been most generally economically practicable. Vegetable crops occupy
an intermediate position" (Stevens and Stevens, 1952, p. 180).

The basis for resistance, whether mechanical or chemical, may have
in any particular instance been identified, but is often obscure. It may
be direct, in the sense that the host resists in some way or ways the
establishment or spread of the pathogen; it may be indirect, as when
the host is repellent to an insect vector (Walker, 1941). It may be
highly specific, as in the hypersensitive reaction so welcome to the plant
breeder; it may be relatively nonspecific, resulting in an ill-defined but
often very desirable "field" resistance. Field resistance of potatoes to late
blight in Mexico, for example, limits blight in years when weather is
only moderately favorable, and makes for easier fungicidal control (Eide,
1955). These less specific types of resistance are effective against a
broader range of pathogenic races than is resistance based on hyper-
sensitivity.

In the special case of woody perennials we find situations wherein
useful resistance need not involve the entire individual. To nematode-
resistant peach understocks, for example, any number of named varieties
may safely be budded (Groves, 1958). A more complex situation involves
"double-working" or multiple grafts, a technique which has been adopted
in several cases, most spectacularly in combating the South American
leaf blight of Hevea rubber, which was earlier responsible for the
destruction of the industry on that continent. As finally developed, a
high latex-yielding variety is first grafted to a selected rootstock, and, to it, somewhat later, a blight resistant clone which develops into the leafy crown. The resulting tree has roots of one genetic make-up, a trunk selected for productivity, and a top having genetic resistance to the blight pathogen.

There is considerable literature dealing, directly or indirectly, with the complications arising from the introduction of disease-resistant varieties, among these a brief treatment by N. E. Stevens (1942). Stakman and Harrar (1957, p. 30) point to an instance of the often contradictory results of attempts to use resistant varieties wherein tristeza or quick decline of citrus has wrought havoc on trees budded to sour orange stocks, but is relatively harmless to those on sweet orange stocks. This has reversed the shift from sweet orange to sour orange stocks which had stemmed from the susceptibility of the former to fungi. “The choice had to be made between two evils, and these evils have been very disruptive of an important agricultural industry and have been a heavy tax on producer and consumer alike.”

C. Physiologic Changes

A third and final category of intrinsic measures includes those where the conspicuous effect on the host is not anatomical, does not include removal or destruction, and has no relation to the genetic make-up of the plant, but is chiefly a temporary alteration in some functional or physiological property of the host. Other than this general resemblance there is no convenient uniformity about the measures included here, and all too often their mechanism of action is unknown. Generally, they involve an alteration in the environment with a view to increasing the disease resistance of the host, reducing its vulnerability to disease establishment, or ridding it of associated pathogens.

1. Nutritional and Related Soil Amendments

Conventional soil treatment, wherein the primary objective is to reduce inoculum, is discussed in Section VI; at this point we are concerned with those measures whose most significant effects are, or seem to be, upon the host plant.

The January, 1946, issue of “Soil Science” was entirely devoted to soil-plant disease relationships, a series of eleven commendable papers which, although now more than a decade old, are very well worth careful study. Those by Sanford on soil-borne diseases in relation to the microflora associated with various crops and soil amendments, by Walker on soil management and plant nutrition in relation to disease development, and by Daines on control of plant diseases by use of
inorganic soil amendments are especially germane. Additional thoughtful comment has been contributed by Hart (1949), who reminds us that, exceptionally, nutrients exert their effect directly on the pathogen and influence its growth and multiplication within the host plant—witness the relation of nitrogen in tracheal sap to the growth of the corn wilt bacterium, *Phytomonas stewarti*.

A few generalizations may be hazarded: (1) that the influence of nutrients and other soil amendments is usually through their effect on the host plant; (2) that secondary soil factors governing availability of nutrient elements are at times as important as total nutrient content; (3) that imbalance, as well as the absolute amounts of each element, must be taken into consideration; (4) that the form in which a substance is applied (e.g., as ammonia nitrogen versus nitrate nitrogen) affects the final outcome; (5) that the type of disease under consideration, the weather, and other environmental factors are importantly significant; and (6) last but not least, that the results of laboratory research can by no means always be transferred to field conditions.

Most writers (for example, Wingard, 1941; Stakman and Harrar, 1957; Coons, 1953) agree that, by and large, high levels of nitrogen predispose toward disease, whereas increases in potassium and phosphorus, particularly the former, render plants more resistant. They are equally in agreement that there are many exceptions to the rule. *Sclerotium rolfsii* rot of sugar beet, for example, has been markedly reduced by applications of nitrogenous fertilizers (Cooley, 1946; Berkeley, 1944). Stakman and Harrar deal effectively with the whole problem and distinguish between the situation as it affects diseases caused by facultative saprophytes, which show the relationship just noted, and those caused by obligate parasites, where vegetative vigor of the host is generally favorable for disease development. However, extensive experiments with cereal rusts lead to the cautious conclusions that "fertilizers had relatively little effect on stem rust except as they affected density of stand and consequent moisture retention; lodging and its direct and indirect effects; and rapidity of ripening, either premature or delayed, depending on temperature and moisture conditions. There are other data that indicate strongly that environmental factors such as moisture and temperature affect rust development in the field far more than any direct predisposing or protective effects of nutrients. . . . The percentages of leaf rust, *Puccinia rubigo-vera* var. *tritici*, were affected somewhat more by fertilizers than was stem rust, but the differences were mostly in degree rather than in kind."

Fertilizers in relation to smut control are discussed by Tapke in a review put out in 1948. Bunt is increased by potassium and phosphoric
acid, reduced by nitrogen, increased by potassium chloride in two very
different soils, reduced by calcium cyanamide. Stalk smut of rye is
decreased by solutions high in potassium and phosphorus and low in
calcium nitrate and magnesium sulfate; the reverse situation tends to
increase damage.

The influence of soil reaction on plant disease is widely recognized.
In some instances its effect is known to be primarily upon the pathogen
and inoculum; at other times it may act indirectly as it affects nutrient
availability; in still other cases the mechanism is a combination of effects
or is unknown. Berkeley's review (1944) of root rots in noncereal crops
recognizes not only that soil reaction is important in disease incidence,
but that it is related to the temperature range at which infection takes
place. According to him, soil reaction is related to the accumulation of
certain toxic substances that may be absorbed by the plant. As a result
of this, it becomes more susceptible to attack, a correlation which has
been demonstrated between absorption of aluminum and root rot of
corn and sugar cane.

In all likelihood, the benefits derived from incorporation of organic
manures far more often results from a biological interference with the
pathogen (see Chapter 13) than from any physiological effect on the
host population.

It is only fair to include, in a consideration of nutritional relations
and fertilizer applications, a reminder that there are not only formula­
tions newly available for soil amendment (e.g., liquid ammonia) but
new techniques, particularly foliar feeding, the disease control implica­
tions of which have not yet been fully investigated.

2. Heat Therapy

N. E. Stevens, two decades ago (1938a), summarized a number of
instances of heat treatments of seeds and other plant parts for control
of fungi, nematodes, and virus diseases. In this review he pointed out
that heat (usually hot water or steam) has been used for many years
against pathogens in seeds and bulbs. An ingenious modification of this
has been employed in India, where seed grain is exposed either to the
sun in a blackened iron vessel filled with water or, after being moistened,
directly to the sun. Similar results were obtained in Nigeria in attempts
to free cotton seed from the bacterial wilt organism. Hot water has been
used successfully against nematodes infesting strawberry, chrysanthemum,
violet, and begonia, and against the mycelium of mint rust and
brown rot of tomato fruits. Finally, great interest has been developed
over the possibilities of inactivating the viruses of potato, sugar cane,
stone fruits, and the like.

More recently, Fischer and Holton (1957) on the subject of heat
treatment of seeds for smuts insist that increases of 65-70% in the water content of the embryo are essential to effective action against dormant smut. When soaked seed is held under anaerobic conditions (see Section VI, A, 1), smut is eliminated. On the amount of water absorbed may depend the temperature necessary to destroy the smut mycelium.

Virus diseases, of course, still occupy the forefront among those diseases against which heat therapy is regularly employed. Kassanis (1957) has furnished us with a recent summary of the effects of changing temperature on plant virus diseases, on susceptibility to infection, incubation period, symptoms, and virus multiplication. He contends that heat is the only therapeutic treatment known which has proved consistently effective in freeing plants from many different viruses—an attribute particularly essential when the entire stock of some valuable clonal line is virus-infected. Among the better established uses of heat therapy is the preparation of planting stock of sugar cane threatened with such diseases as sereh, chlorotic streak, or Ratoon stunt. In Queensland, Australia, a steam-heating apparatus has been developed employing tanks capable of handling 3 tons at a time, or 12 tons in an 8-hour shift. Using these, one establishment can prepare enough healthy stock to plant an area yielding 10,000 tons of clean “seed” for the ensuing season (King, 1953). Wire baskets, which cool more rapidly than bags, seem to enhance germination and to be generally preferable.

In special situations normal atmospheric temperatures have been sufficient to inactivate viruses within host tissues. Peach yellows in the southern United States and potato leaf roll in India (until such time as the crop came to be raised from tubers in cold storage) apparently belong in this category (Kassanis, 1957). It will be apparent, too, that foliage pathogens are subjected to leaf temperatures which reach maxima well above that of the surrounding air.

Much of the importance of heat therapy, it will have become obvious, derives from its contribution to production of disease-free seed and propagation stock. Rather than divorce this from other means of achieving the same end, it is treated in Section VI, A, 1, to which the reader is referred.

3. Other Physiologic Measures

Vernalization has been shown to affect smut incidence, although not always in the same direction. Gäumann (1950, p. 383) points to disease reduction following vernalization, possibly because the growth of the seedlings is accelerated and outdistances the infection. Aberg (1945) in experiments with barley stripe found that vernalization for 38 days favored development of the disease.

There has been some difference of opinion, too, over Chester's sug-
gestion that disease can be reduced if acid-delinted cotton seeds are separated into light and heavy fractions on the basis of their specific gravity in water. Arndt (1945) feels that the improvement observed depends upon the characteristics of each lot of seeds and that the general applicability of the procedure is questionable.

In the highly specialized area of medical mycology, where man is the host, dermatophytes are commonly treated with a fungicide plus a keratolytic agent to induce peeling of the infected skin layers. Deeper mycoses require surgical drainage, X-ray therapy, medication with potassium iodide, desensitization, and improvement of the general condition of the patient (Emmons, 1940).

Careful consideration of the various current uses of chemicals in the control of plant growth will uncover several possible and probable applications to disease control. Avery and Thompson (1947) list the following: rooting of cuttings; blossom thinning of fruits; control of pre-harvest drop, manipulation of fruit set, and production of seedless fruits; an antidote to the effect of fungicides in seed treatment; regulation of time of flowering and of fruit ripening; in weed control; and in breaking or prolongation of dormancy.

Whether or not practical advantage can be taken of cross-protection reactions in plant viruses in much the same way as immunization in human pathology is debatable. The phenomenon of cross protection itself is well established, even in viruses of the insect-transmitted group (Kunkel, 1955). Suggestions along this line appear from time to time in the literature. Gäumann (1950, p. 350) notes that in potato an apathogenic form of the X-virus will be transmitted to progeny and will exclude more virulent forms, but that resistance to frost may be lowered and that the virus may mutate to a more severe form or that another group of viruses, e.g., Y and leaf roll, may be worse. Stout (1950) suggests that a mild form of the peach mosaic virus from normal-appearing shoots protects against the severe form of the virus found in the remainder of the tree. Stakman and Harrar (1957, p. 367) feel that the most effective control of tristeza will be obtained by using virus-free scions on tolerant rootstocks, although they recognize the suggestion that susceptible hosts might be inoculated with mild strains of the pathogen.

On the basis of preliminary experiments a few years ago, in which TMV virus was subjected to ultrasound, Newton (1951) makes the interesting suggestion that we thus have available an exclusively physical method for reducing the virulence of plant viruses without affecting their antigenic properties, with obvious implications for the preparation of virus vaccines.

Finally, N. E. Stevens (1938a) and Stevens and Nienow (1947) cite
several unique methods of disease control that might fairly be termed physiologic.

1. Freeing of tomato seed from the organism causing bacterial canker by submitting the fruit pulp to fermentation for from 3 to 6 days at approximately room temperature.

2. Prevention of heat injury to forest tree seedlings by inclining the trees slightly toward the south at time of transplanting; reduction in smothering by sowing black soil on the snow over seedling plots to hasten snow melting in the spring.

3. Prevention of leaf drop in cranberries, resulting from lack of oxygen, by withdrawing the water from the frozen bogs in winter and allowing the sheet of ice to rest directly on the vines or by freezing the vines into the ice itself.

4. Restoration of trees girdled by Phytophthora rot by banking soil about the base and stimulating the formation of new roots.

5. Injection of chemicals into host plants—chemotherapy.

V. EXTRINSIC MEASURES INDIRECTLY AFFECTING THE INDIVIDUALS COMPRISING THE HOST POPULATION

Primary attention in the foregoing section (Section IV) centered upon those measures wherein some actual change in the host plant was achieved, ranging from its complete removal or destruction, through physical, physiological, and genetic alteration. In the discussion to follow, so far as possible, emphasis will be placed upon practices which elicit their effect without producing any immediate change in the individuals of the host population. These are instances in which the host population continues to occupy the center of interest, but without there being any attempt, either permanently or temporarily, to alter it.

A. Practices Involving Number of Host Plants

Stevens and Nienow (1947) contend that although overplanting as a means of obtaining a crop despite seedling diseases is probably of common occurrence, it seems only rarely to be spelled out in technical literature. It was resorted to in an effort to obtain satisfactory stands of sweet corn in New York and New England during the outbreaks of bacterial wilt in 1932 and 1933. Pool, somewhat earlier, had called attention to a similar means of reducing losses from Fusarium stem rot of sweet potatoes in New Jersey; and in the Carolinas it has been the custom, ever since the first outbreak of blue mold, to increase the size of seedling beds to double the size formerly used.

Recommendations on seeding rates are often made with reference to cereal diseases, usually as part of general instructions including rate,
timing, and depth. Severity of root rots in wheat seems often to increase with increases in seeding rate (Greaney, 1946), as does bunt or stinking smut (Tapke, 1948), whereas both very wide or very close plantings, particularly the former, should be avoided if leaf rust is to be kept at a minimum (Chester, 1946).

Gäumann (1950, p. 256) demonstrates that dense stands of rye, with consequent limited tillering, tend to flower simultaneously and thus suffer less secondary infection from "honeydew" conidia of the ergot fungus, while more widely spaced plants lead to increased infection. Chester (1947, p. 477) comments in regard to rate of seeding that fungus diseases favored by high humidity are most destructive under excessive rates of seeding (cereal rusts, powdery mildew, damping-off) but that heavy seedling loss from disease of crops such as cotton may be compensated for by increased seeding rates.

B. Practices Involving Position of Host Plants

1. Placement

Important effects upon disease may result from the proximity of host plants to each other. The microclimate, rather than the over-all meteorological conditions, most influences the rapidity with which many kinds of diseases develop. By microclimate is meant the conditions of moisture, temperature, and air movement of the atmosphere in the immediate vicinity of the host plants. Close spacing, however arrived at, tends to raise the atmospheric humidity, encourage sporulation of pathogenic fungi, and reduce air circulation (Gäumann, 1950, p. 482). Growth habit, whether luxurious and dense or sparse, contributes to or reduces the effect of spacing on microclimate. Thus, in France, the Early Rose variety of potatoes is as susceptible to late blight as Saucisse, but less receptive, since its aerial parts are not luxurious enough to provide favorable microclimate (Foister, 1946). And the so-called pink disease of rubber, caused by Corticium salmonicolor, which may be serious in wet seasons, can be reduced by providing for air circulation, drainage, and access of sunlight, and by proper location and spacing of trees (Hubert, 1957).

Placement as related to disease includes the selection of planting site. Always, albeit sometimes without conscious effort, the grower chooses a planting site with attention to the general welfare of the projected crop. Usually this concern includes matters of disease hazard. In Chester's (1946) monograph on cereal rusts we find these recommendations given on choice of planting site: well-drained, somewhat
exposed upland; elimination of volunteer grain by tillage; separation of fields of winter and spring varieties or location of spring wheats to windward.

In its extreme form, "placement" control need be no more elaborate than a very local adjustment in farming practice. Good results in control of sugar beet damping-off have been obtained by growing the plants on ridges with furrows on either side, thus facilitating soil drainage in the immediate vicinity (Berkeley, 1944). According to Dobromyslov (1932) nonridged plantings are more favorable to bunt in the early stages than are ridged furrows.

2. Dispersal

It is unquestionably true that as man developed an agriculture and as that agriculture became more and more specialized, there has been an increasing tendency to concentrate large numbers of host individuals in contiguous plantings. It is likewise unquestionably true that disease hazards are thereby increased.

"The greatest need for plant disease control is in connection with those crops that are artificially cultivated. When several hundred human beings dwell within a single square mile, the area is said to be crowded, and great care is taken to prevent the development of serious public health problems. In comparison, one acre of wheat may contain approximately a million individual plants, all more nearly identical than individuals in any group of human beings; and the plant pathologist is concerned with the fact that the crowding together offers optimum conditions for the development of epidemic diseases. This crowding is a deliberate modern agronomic technique designed to promote maximum agricultural production through the use of improved varieties and soil management, but it provides highly favorable conditions for the devastating attacks of plant pathogens. Thus, agriculture takes the form of plant urbanization in which tremendous populations are abnormally concentrated in a relatively small area, and in a sense each cultivated field becomes a gigantic culture medium for pathogens. Every successful effort to improve yield by adding to the carrying capacity of the soil intensifies disease problems which must be met if agriculture is to progress" (Stakman and Harrar, 1957, pp. 3-4).

In view of these trends in modern agriculture, one finds very little if any material in the literature recommending dispersal as a means of disease control. Yet within the very severe practical and economic limitation imposed, it is an obviously desirable move, to be taken advantage of whenever possible, and stands as one of the few compensating features of primitive agriculture.
3. Physical Barriers

Quite naturally, Smith et al. (1933) in their outstanding examination of the basis for quarantines deal with the role of physical barriers to the spread of disease. True, barriers act primarily to interrupt the movement of inoculum, but because they often directly affect the choice of planting site or otherwise impinge on the host plant, they will be dealt with here. Barriers, according to the committee, may be topographic (high mountains, large bodies of water, deserts), biological (absence of host plants or vectors, territory occupied by competitors), or climatic (meteorologically unsuitable areas). Absolute barriers can be traversed only through the agency of man. As evidence of the effectiveness of natural barriers, they cite only one disease of importance to California, asparagus rust, which appears to have entered the state by natural means.

On a much smaller scale, trenching has been used to stop the advance of soil fungi. It is apparently the only known method for controlling the fairy ring caused by Psilocybe agrariella vaccinnii in cranberry bogs (N. E. Stevens, 1938a). Trenching was also recommended for control of Armillaria and Rosellinia (Berkeley, 1944). Cotton root rot has been confined not only with trenches but with artificial barriers such as galvanized iron and by mixing into the soil various substances such as oil, sulfur, acid, copper sulfate, etc. At least one effect of the addition of sulfur is to lower the pH very sharply in the 4–6 inch barrier of treated soil. Kuijt (1955) refers to a 60 ft. mistletoe-free zone surrounding stands infested with this parasite; and Hunt (1946) cites marked reduction in incidence of pupation disease of oats in Russia by providing barriers 2 meters high between sown fields and weed-grown fence rows.

4. Geographic Location

Many important cultivated plants have a more extensive geographic range than their pathogens. Stakman and Harrar (1957, p. 431) suggest several instances wherein it is possible to grow crops in areas free of their principal pathogens: e.g., the production of coffee in the Western Hemisphere, where coffee rust does not occur; and of rubber in Southeast Asia, which is free of the South American leaf blight. They add that, occasionally, disease can be avoided by planting out of season; in Mexico, both potatoes and wheat are commonly grown during the dry season under irrigation to avoid destructive attacks from late blight and rust, respectively.

These same authors summarize (Stakman and Harrar, 1957, pp. 304–305 and 313–314) the effects of temperature and moisture on the geo-
graphic incidence of disease, pointing out that temperature is often the limiting factor in seasonal and regional incidence and that latitude and elevation can be very important in determining temperature extremes. Diseases commonly associated with cooler northern climates will thus be found during the winter season in more southerly latitudes or at higher altitudes during the high temperatures of the tropical summer. Pathogens vary with regard to their optimum temperature ranges, and this must be taken into account in developing effective cultural control measures.

Seasonal and geographic distribution of disease is alike conditioned by moisture—particularly distribution of rainfall during the year—and the frequency and intensity of fogs and dews. The practice of producing disease-free seed in arid regions (see also Section VI, A, 1) takes advantage of the moisture dependency of the pathogen.

Baker and Snyder (1950) list a number of diseases which normally cause serious loss in regions of high rainfall but are generally absent from California: bean anthracnose, bean bacterial blight, black rot of cabbage and cauliflower, Septoria leaf spot of tomato, anthracnose of watermelon, angular leaf spot, and scab of cucumber. Tapke (1948) believes that the floral infection smuts are usually scarce in sections of the country where humidity of the air is low at flowering time; in California, for example, damage is too slight to be of economic importance because the dry season is near at hand when cereals are heading. Yarwood (1957), discussing powdery mildews, on the other hand, attributes the absence of Sphaerotheca from hops on the west coast of the United States and Canada, as compared to the eastern United States and Europe, and of Oidium from rubber in the Americas, as compared to Malaya and Central Africa, to the fact that they have not been introduced rather than to any basic incompatibility of environment and pathogen.

To be informed about the geographic range of host and pathogen does not constitute per se a control measure. The foregoing discussion is intended, of course, to focus attention on the possibility of employing this kind of data in trying to select, most wisely, optimum areas for a given crop or the most promising crops for a given area, as the case may be. N. E. Stevens (1938b) has made specific recommendation to this end in suggesting the preparation of "disease hazard" maps based on information some of which is already in the hands of the professional pathologist and entomologist. He bolsters this argument by pointing to a number of instances where agricultural enterprises have been undertaken in ignorance of disease and pest threats, only to fail entirely or to provide only very meager returns for the investment of time and energy.
He argues that the preparation, or at least an effort to begin the preparation, of maps of regions considered extra hazardous because of unusual risks from crop pests is well within our scientific capabilities, provided we are willing to attempt it. Wood and Miller (1949) add strength to the argument favoring some such effort in reporting a questionnaire which they sent out several years ago (as a follow-up of a much earlier one distributed by N. E. Stevens) to collect data on the effects of disease losses on crop industries and farm life. Of greatest interest are those cases where disease has forced the abandonment of what otherwise appeared to be promising enterprises.

Geographic location, in a very much more limited sense, is employed whenever plantings are isolated for the express purpose of disease control. Such a technique as this is most promising for diseases caused by pathogens that do not give off aerial spores, and is not often employed in connection with seedling production and seed-increase plots. Because the total area thus isolated is relatively modest, it becomes possible to utilize fungicides on crops where economic considerations preclude their use under ordinary field conditions. Thus small quantities of seed from wheat and barley affected with loose smut are first treated with hot water or by some similar technique, and this supply then increased in plots isolated by a few hundred yards from any commercial grain fields which might be a source of contamination, often under the supervision of selected growers.

Crops to be set out in the field as seedlings are first sown in isolated beds, particularly when one or more of the common diseases is primarily a seedling problem. The widespread practice of isolating tobacco seed beds as an anti-blue mold measure is a case in point. Pound (1946) provides us with a less widely known example in his discussion of control for virus diseases of cabbage in the Pacific northwest. Because cabbage is a biennial, no crop-free period is possible, and strict sanitation becomes imperative. The vector, a cabbage aphid, has proved difficult to control and is best avoided by isolation of the plant beds, since wild cruciferous hosts and other weeds do not appear to be, as a general rule, responsible for more than scattered appearances.

C. Practices Involving Timing

1. Noncoincidence of Host Population and Inoculum

The precision with which host and pathogen must synchronize and the span of time over which successful infection and establishment are possible vary greatly from one disease to another. More often than not, pathogen spores germinate only during a limited period or under given
environmental conditions. If, in addition, the possibility of host infection is limited to a particular phase of development or to certain, often transient, plant organs or parts, the chances of disease are greatly reduced. The principle of disease control involved here remains the same; it is an effort to upset this timing and to produce a crop in spite of the presence of pathogenic organisms and of host varieties susceptible to them. A considerable variety of such instances are of record, some few of which will suffice in illustration.

It was some time ago recognized that early-maturing varieties of crop plants will complete their growth before the threat from disease has materialized. Varieties of cowpeas are known, for instance, which mature before the season for wilt and root-knot development arrives; certain varieties of potatoes commonly mature before the appearance of late blight, although they succumb quickly enough if planted later in the season (Wingard, 1941).

Noncoincidence stems also from topographic and climatic factors. In India, for example, some 2,000,000 acres of grain at lower elevations is annually threatened by leaf rust coming from less than 4,000 acres in the nearby highlands (Chester, 1946). It has been suggested that sowing in April and June be suspended and that it be delayed in areas of secondary foci of infection or, more drastically, that culture be entirely stopped for a period of 2 or 3 years at altitudes of 3,000 ft. and above where the pathogen survives the hot season. Because of differing governmental jurisdictions and other practical considerations, this has not yet been tested as an actual control step. In parts of Russia small patches of winter wheat serve as sources of infection for very much greater acreages of spring wheat. Noncoincidence could, in this instance, be very readily achieved.

Without resort to earlier maturing varieties, or relying upon peculiarities of terrain and climate, the grower still may benefit by selecting the most favorable seeding time. Most reports in this area refer to cereal grains although Gäumann (1950, p. 482) speaks of the possibility of accelerating potato crops by sprouting the tubers prior to planting, and Hunt (1946) indicates that the beet leaf hopper, key to curly top incidence, does not thrive if beets are large enough to cast considerable shade and produce increased humidity before the time when insects abandon native weeds and migrate to beet fields.

Fischer and Holton (1957) recommend that winter wheat be seeded early when temperature and moisture are unfavorable for germination of bunt spores and infection of the seedlings—with the result that the seedlings get beyond the susceptible stage before smut is active. Incidence of infection in the Pacific northwest is high for fields sown in the
A 4-week period from mid-September to mid-October, low for fields sown before and after that time. In Pakistan early seeding at temperatures above 28° C. reduces flag smut. Similar relationships between sowing time and disease incidence are noted by Tapke (1948) for bunt of wheat in Kansas, Missouri, Australia, Siberia, and Italy, and for stalk smut of rye. Simmonds (1953), discussing root rots of cereals, advises seeding spring wheat early, when soil temperatures are low, to avoid common root rot; his testimony is corroborated by Greaney (1946). Chester (1947, p. 477) says that time of seeding, usually directly related to the influence of temperature, has an important bearing on disease control, dry-land foot rot of wheat being practically controlled by selecting a proper date for sowing. Early spring seeding may be effective in dealing with diseases such as root knot or Texas root rot, which are common only in the hot summer months.

Hunt (1946) lists three diseases which may be substantially reduced by seeing to it that seedlings are not in a susceptible stage at the time environmental conditions are favorable for infection: flag smut of wheat, pupation disease of oats, and flax rust. He contends that if corn is planted early enough to be nearly mature before vectors become prevalent after mid-summer, it will suffer very much less damage from the virus of wallaby ear.

The advantages sought in choosing a planting time may be antithetic. Bunt and scab (Gibberella) on wheat, for example, are favored by, respectively, slow and rapid growth (Gaumann, 1950, p. 482). Perhaps the best-known research in explanation of apparently contradictory results is that by Dickson on Gibberella (see Brown, 1936), which showed that wheat is attacked at high temperatures, corn at low. When soil temperatures are low, rapid hydrolysis of wheat starch produces seedlings rich in sugar, having thick cell walls, and consequently reduced susceptibility; protein formation and tissue growth are accelerated at higher temperatures—with consequent increase in susceptibility. In corn, on the other hand, walls of unmodified pectic materials are formed at low temperatures, and more resistant, suberized walls at higher temperatures; hence the greater damage to seedlings of this crop at low readings.

Rarely, drastic measures are recommended in order to achieve non-coincidence of host and pathogen, such as the crop-free period recounted by Chester (1946) in connection with leaf rust in India. Just such a crop-free period has been put to the test in California and has proved an effective control of Western celery mosaic (Stevens and Nienow, 1947; Milbrath, 1948). This plan was voluntarily established by growers in 1943 to break the continuous culture of celery and adopted
by the state legislature the following year. Within a very short time yields returned to the levels commonly reached before virus inroads had become serious.

Depth of sowing, in the literal sense, refers to position, not timing, but the net effect is primarily to determine the interval required for the seed to germinate and the resulting seedling to emerge and begin maturing. The usual result of deep sowing is to prolong the seedling stage; it thus bears the same relation to disease incidence as late sowing. Rye, therefore, sown deeply, takes longer to appear and is in direct contact with the soil for an added period, materially increasing *Fusarium* invasion (Gäumann, 1950, p. 256), whereas in favorable weather shallow sowing encourages germination and shortens the susceptible phase. Increased depth of seeding is directly correlated with increase in bunt of wheat (Tapke, 1948), and shallow planting of potatoes is known to reduce *Rhizoctonia* (Stakman and Harrar, 1957, p. 433). Small seed size, when it is correlated with slow emergence and increased exposure to infection, leads to high incidence of barley stripe, *Helminthosporium gramineum* (Gäumann, 1950, p. 255).

Comparison of grain-sowing methods in Egypt affords convincing evidence of the importance of seeding depth to disease losses (Fischer and Holton, 1957; Tapke, 1948; Stevens and Nienow, 1947). Several systems are in common usage, but evidence indicates that seed sown on moist land and then plowed in (germinating at an average depth of 8 cm.) shows the highest incidence of smut; seed sown on dry land, then harrowed and immediately irrigated (average depth 4 cm.), consistently less damage; and broadcast sowing 1 hour after flooding (surface planted), the least. Wheat bunt, covered smut of barley, and millet and sorghum smuts respond in similar patterns.

2. Age, Life Span

Cultural practices involving timing include those situations where the grower takes advantage of age or life span of the host in avoiding serious disease damage. A number of instances are of record which demonstrate that the age of the host materially affects the likelihood that it will become diseased. To every generalization there are exceptions, but seedlings are often more susceptible than mature plants—as mature or moribund leaves are more likely to be invaded than those less aged. Perennial plants have, with respect to flowers, fruit, and foliage, a cycle of growth from youth to senescence each year while the remainder of the plant tissues gradually age. It is reasonable, therefore, to speak of "old" trees in describing the greater root rot damage in long-established orchards or in stands of mature trees (Cooley, 1946).
Gäumann (1950) discusses at some length the problem of susceptibility as it relates to the stage of development of the host plant in three classes of cases: (1) where the pathogen has a store of inoculum available only after a given time (e.g., late blight); (2) where the host has a susceptible growth period for only a limited time (e.g., *Rhizoctonia* on potato); and (3) most commonly, in which the availability of pathogen inoculum and susceptibility of host are both limited (e.g., stem rust). He examines also, with special emphasis, the ontogenetic or developmental changes in the host as they affect susceptibility and resistance, and spread of disease within the host plant, citing a number of specific examples in documentation of the thesis.

Papers dealing with the relationship between host age and disease damage are much more readily located than are specific recommendations for cultural control based on these established facts—much less records of measures actually employed in commercial agriculture. The application of these principles is, however, a direct one and is probably, for all practical purposes, frequently in operation.

Life span refers to the length of time necessary, here restricted to annuals or biennials, for a crop plant to develop from seed to harvest. Both age and life span are special aspects of noncoincidence, a topic dealt with more extensively in the preceding section. Life span could signify the length of time required to get safely past a particularly susceptible stage, but is more usefully thought of as the total time needed to "make a crop." From the viewpoint of its importance to disease control, consideration of life span leads, usually, to the adoption of early-maturing varieties (Walker, 1941) which, in one way or another, avoid the severest inoculum threat. Sometimes the advantage can be compounded by coincidentally slowing down the pathogen, as by deep plowing the stubble of foot-rotted cereals (Gäumann, 1950, p. 254). Care must be exercised whenever varieties developed and adapted for one geographic region are introduced into another lest differences in photoperiod or other factors unfavorably alter the time of maturity and harvest.

If life span can, in effect, be arbitrarily shortened by early harvest, without at the same time introducing new and equally troublesome pathogenic and agronomic problems, disease will be reduced. This maneuver has been instituted in the case of seed potatoes, in an attempt to avoid tuber invasion by viruses which have been introduced into the foliage during the current growing season. Cooperative, simultaneous early harvesting by all growers in a contiguous area could materially reduce bacterial ring rot and several virus problems (Schultz et al., 1944). Chester has suggested early harvesting as a means of salvaging severely rusted grain fields.
3. Longevity of Inoculum

Just as the age and life span of the host are special aspects of non-coincidence of host and pathogen, focusing attention on attributes of the host, so longevity of inoculum is a special aspect of noncoincidence which focuses attention on an attribute of the pathogen. Persistence of inoculum is so directly pertinent to a consideration of crop rotation and nonchemical soil treatments that it will be referred to later from those points of view (see Sections V, D, 2 and VI, A, 2). For the moment we are concerned with the special situation wherein host material may be freed from associated pathogens simply by allowing sufficient time to elapse.

When seed of crop plants is held beyond the customary length of time in order that inoculum borne therein may be eliminated or reduced, the grower takes advantage of the greater longevity of the host species. Several cases of this are on record; perhaps the best-known instance relates to cotton seed invaded by the anthracnose organism (N. E. Stevens, 1938a). Arndt (1946) has studied the effect of storage conditions on survival of Colletotrichum gossypii on cotton seed, and finds that at moisture levels from 8 to 16% there is a reduction in the number of seedlings infected with each successive increase in seed moisture. Hardison (1948) cites blind seed disease of perennial ryegrass as one that can be eliminated by aging seed 2 years. Benefits from routine chemical treatment are apparently in no way reduced when seed are held in storage for an additional season (Miles, 1939).

D. Practices Affecting Sequential Relationships

As we have seen, number, position, and timing can be turned to advantage by the grower who seeks to hold disease to a minimum. Lastly, certain practices can be identified which emphasize the particular sequence in which different crops occupy a given plot of ground.

1. Specific Crop Sequences and Associations

By all odds the best-known and most widely adopted cultural control based on host sequence is crop rotation. This will be taken up presently. Rotation deals in generalities and seeks primarily to avoid crops with peculiar susceptibilities by substituting any of a wide selection of other types; the key to the problem immediately before us is the specificity of the relationship. The mechanism by which the effect is achieved may be toxic, nutritional, biological, or as yet unknown, but to be fairly included here it must be a demonstrated crop-to-crop influence.

Coons and Kotila (1935), Coons (1953), and Buchholtz (1944)
have published extensively on crop sequences affecting sugar beets, and
demonstrate that damping-off is increased when the crop follows legumes,
decreased when it follows corn, soybeans, or small grains. This effect
seems to be tied in with the higher nitrogen levels reached in the former
situation and may be avoided by careful timing of the several agronomic
steps involved. Tip rot in Iowa, which is very widely distributed in those
soils and which is built up to damaging proportions through successive
cropping to sugar beets, can be substantially reduced by a prior crop of
alfalfa. Other diseases and other primary crops might be cited in sup­
port of the basic thesis. Chester (1947, p. 458) lists scab, wilt, and
Rhizoctonia, troublesome to Nebraska potatoes on virgin soils and in
some rotations, as diseases which can be reduced to a minimum when
alfalfa immediately precedes the principal crop. And the pathogen so
controlled need not be a bacterium or fungus—the brown root rot of
tobacco, now known to be primarily due to the invasion of meadow
nematodes, seems generally to be favored by previous crops of timothy
and corn (Berkeley, 1944).

Plant residues cannot always be assumed to be the cause of the
reaction observed in succeeding crops, but there is convincing evidence
that this is often the basis of the relationship. Cochrane (1949) feels
that, at least part of the time, residues exert a direct toxic effect on the
roots of susceptible plants, probably aggravated by the action of sec­
ondary rot-producing microorganisms. Actively growing roots of walnut
and other species are known to secrete toxic materials—with the result
that surrounding plants are visibly harmed; other root interactions are
traceable to nutrient relations, pH, alterations in soil texture, and so
on (Loehwing, 1937).

Woody perennials, like field crops, can be affected by species which
occupied the land immediately before planting, a fact which can be put
to good use in choosing an orchard site. Cases are known where all
ornamental shrubs planted on stumpy land, in the immediate vicinity
of the stumps themselves, have been killed by white rot; presumably
they were invaded by pathogens remaining in the roots of the original
trees (Cooley, 1946). Replanting of peach after peach often intensifies
survival problems even where no disease seems prominently present,
whereas peach after other prunus rootstocks or fruit varieties do not suf­
fer appreciably. The explanation seems to lie in a toxic microbial
degradation and decomposition of amygdalin, which cannot be alleviated
by soil fumigation (Groves, 1958).

Reduction in disease following specific crops does not result solely
from the absence of a susceptible variety, as noted. Ophiobolus graminis,
for example, disappears more rapidly from soil under a nonsusceptible
crop than in fallow because of the depletion of nitrogen reserves (Simmonds, 1953). Similar gains derive from coincident plantings of two varieties. According to Simmonds, there is very little take-all of barley when undersown with trefoil, which makes luxuriant growth after the barley is cut. On the other side of the ledger, Groves (1958) points to the greatly increased probability of *Verticillium* troubles in stone fruits when a susceptible species is used as an intercrop. The same holds for nematode injury to peach when aggravated by the presence of a susceptible cover crop. Destructiveness of *Sclerotium rolfsii* on apple is influenced by the nature of the cover crop, susceptible legumes such as lespedeza tending to intensify the hazard to nurseries and young orchards (Cooley, 1946).

Admixtures of rye with wheat result in increased damage from wheat bunt in proportion as the content of rye increases; damage is greater following peas than following wheat and highest on soil newly broken from grass and alfalfa (Tapke, 1948). Hunt (1946) explains the interrelations of sugar cane and corn in respect to downy mildew under Australian conditions by pointing out that the pathogen forms large numbers of short-lived conidia on corn but not on sugar cane and that, therefore, corn plantings are necessary if disease is to spread rapidly during the growing season.

An interesting suggestion of admittedly limited applicability comes from Chitwood and Oteifa (1952). Based on the fact that a particular level of invasion of the proper species of nematode is sometimes stimulatory to certain host varieties, they propose that this effect might be stabilized by growing perennials in conjunction with a moderately resistant plant serving to maintain a proper inoculum balance.

2. *Crop Rotation*

Diseases caused by soil-borne pathogens are usually the targets against which crop rotation is brought into play. Stakman and Harrar (1957, p. 439) point to a few nonsoil pathogens—certain cereal rusts, late blight, banana leaf spot, and virus diseases—which are usually more destructive where continuous cropping is practiced, due in most instances to increased amounts of overwintered inoculum or to increased vector populations. They admit, of course, that “monoculture” is at times dictated by economic or other considerations—bananas in Central America; sugar cane in Cuba; pineapple in Hawaii; rice in Japan—but insist that where done it is despite heightened disease hazard, and then only on the basis of high cash value, cheap hand labor, mechanization, or especially effective chemical control measures.

“The efficacy of rotation as a disease control measure lies in the fact
that, in the absence of susceptible crops (i.e., in the presence of non-susceptible crops), the population of a given pathogen materially decreases. Other pathogens, those to which the alternate crop or crops are susceptible, must as surely increase; but by rotating crops subject to widely different pathogens, effective control is often achieved" (R. B. Stevens, 1949).

Literature on crop rotation is extensive; only a tiny sample is included in the bibliography to this chapter (for example, Stakman and Harrar, 1957; Hunt, 1946; Berkeley, 1944; Leighty, 1938). It is a very old and very widely adopted cultural measure. Leighty, for example, lists twenty-four diseases of seventeen crops controlled solely or mostly by crop rotation and the list could be much increased. Throughout, one finds general agreement on the two factors which, when encountered, constitute the chief obstacles to success in disease control through crop rotation: (1) pronounced longevity of the inoculum; and (2) wide host range. Longevity may stem from the existence of resistant resting spores or sclerotia, or from the ability of the pathogen to exist as a saprophyte. However explained, if it requires a decade or more to disappear from agricultural soils (e.g., flax wilt, cabbage yellows), then crop rotation loses its point. If, on the other hand, a very large number of possible hosts are vulnerable (e.g., Agrobacterium tumefaciens; Phythium debaryanum; Rhizoctonia solani; or Phymatotrichum omnivorum), it becomes very nearly impossible to establish a favorable rotational pattern.

Economic considerations loom large in weighing the advantages and disadvantages of rotations. It is not feasible, whatever the gain in disease control, to set up a rotation with too few and too infrequent cash crops. Neither can soil fertility, erosion problems, and maintenance of desirable soil structure be ignored. At best, disease relations are but one of several factors to be kept in mind in establishing agricultural crop series.

R. B. Stevens (1949) has suggested a means whereby, in his opinion, the principles and advantages of crop rotation and resistant varieties (see also Section IV, B, 1) can be simultaneously achieved and, at the same time, some of the continuing problems of plant breeding minimized. His argument, which relates most specifically to nonsoil diseases of cereal crops, runs as follows: "Why not practice a rotation of host varieties, rather than of distinct, often widely divergent, crop species? While focusing our attention on the striking and often disturbingly rapid increase in ‘new’ races or species of pathogens in the presence of newly emphasized host varieties, we should not forget that some, at least, of the ‘old’ races are correspondingly decreasing. There is likely as significant a decrease in the inoculum of hitherto prevalent
pathogens as there is increase in hitherto rare ones! This, coupled with the very possible fact that the old host varieties well may be resistant to the new pathogens, leads to our main thesis: that varietal rotation should be studied as a means of disease control.

"The simple fact that a pathogen is new stands as direct evidence that the older varieties were highly resistant to it, and that it was therefore formerly rare. After five or ten years of widespread plantings of a new host type, it may well be that formerly well-known species or races of pathogens will have become scarce, and that older host varieties can be replanted with profit. By selecting for a given crop, such as wheat or oats, several commercially desirable varieties of widely differing susceptibility, it should be possible to work out a type of rotation which would hold disease losses at a low level."

To our knowledge this suggestion has not yet been proved in actual practice; neither has it been shown invalid.

VI. MEASURES AFFECTING ELEMENTS OTHER THAN THE HOST POPULATION

Repeatedly, throughout this chapter, we have pointed out that the ramifications of cultural control are such that no one item can be clearly dissected from all others. The outline upon which we have based our discussion does not pretend to be either completely logical or entirely free of inconsistencies. Each successive section or subsection represents primarily a new point of view, but we are entirely conscious that facts and instances are partially duplicated from time to time. In Sections IV and V the center of interest was upon actions taken with reference to the host plant. Whatever the particular aim of the control measure discussed, and whatever the specific medium through which that aim was achieved, it was the host plant that was manipulated. Often it was desired to affect the inoculum as well, but the host plant itself was the factor principally involved.

In this, the final section, a full turn about is contemplated. We are concerned now with measures which involve elements in the disease complex other than the host—pathogen or other hosts, as the case may be. Objectives often parallel those recounted in earlier sections; the point of view and emphasis are new.

A. Affecting Inoculum

Chapters 11, 12, and 13 present the case for chemical and biological control of inoculum. It remains here to see what cultural measures there are which have this same objective.
1. Disease-Free Seed and Propagating Material

Chester (1947, p. 466) distinguishes two categories of "noninfested" seed: (1) uninfested (from uninfested areas, from protected seed blocks, indexed material, cleaned or selected seed, certified seed and registered propagating material); and (2) disinfested (by chemicals or heat). This seems an acceptable organization and suggests some of the diversity of ways in which the objectives are sought.

Stevens and Nienow (1947), among others, recount instances of the production of disease-free seed, particularly that of legumes (beans and peas) in semi-arid areas of the western United States. This device is effective against such pathogens as those of anthracnose, bacterial blight, and Ascochyta, which are seed-borne and which cannot be destroyed by any currently practicable seed treatment. Because the spread of these diseases in any particular growing season is strictly dependent upon atmospheric moisture, the pathogen does not develop under arid conditions, even when the original seed used is contaminated. The net result is, of course, that seed certified free of the pathogen in question can be made generally available for planting in commercial producing areas.

In an earlier section (IV, C, 2) we referred to heat therapy as one way of ridding seed and propagating material of pathogenic inoculum; chemical seed treatment is discussed in Chapter 12. A few related and miscellaneous techniques deserve mention at this point, most importantly perhaps some recent developments in seed treatment for the blossom-infection loose smuts of wheat and barley. For many years the accepted practice has been a modified hot water treatment, designed to kill the contained mycelium without undue damage to seed and reduction in germination. It now appears (Tyner, 1953; Arny and Leben, 1955; Leben et al., 1956; Tandon and Hansing, 1957) that the same result can be achieved, with much less trouble, by simply soaking the seed in water, a technique which is enhanced if the seed be held in an air-tight container, after soaking, for, say, 48 hours at 80°F. This method has come to be known as the "anaerobic" method, and is both simple and effective. Laboratory studies point to the presence of certain volatile acids (formic, acetic, butyric) produced by the moist seeds as responsible for the disinfecting action and show that spores of several of the pathogens involved do not germinate well under anaerobic conditions and at the pH levels reached (Leben et al., 1956). Addition of various chemicals to the water in which the seeds are placed is thought by some to be an advantage (Tyner, 1953). Others recommend germination tests as a precaution against possible sharp reductions in viability (Arny and Leben, 1955).
Pathogen-free propagative material of ornamentals and orchard crops is much sought after, for reasons that will be self-evident. A number of examples come to mind, some few of which can be cited here. In a recent paper, Baker and a committee (1956) summarize efforts to prepare disease-free items for a number of plants: chrysanthemums, carnations, gladioli, roses, foliage and succulent plants, geraniums, stocks, zinnias, nasturtium. Soaking plum budwood in solutions of streptomycin has been reported successful as a means of ridding it of the bacterium Phytomonas pruni (Brown and Heep, 1946).

Sooner or later, if the crop or disease in question has appreciable economic importance, represents a significant portion of the agriculture of a given political unit, or extends over a relatively large area, some kind of governmental regulatory machinery usually comes into operation. This machinery varies greatly in its complexity, and in most cases develops gradually over a period of time, becoming more exacting and effective as the advantages of clean stock become increasingly apparent, and, with this, picks up added public support. In its simplest form, provision for producing disease-free budding and propagating stock consists in an inspection of source trees or nurseries and the selection of only those individuals that seem free of viruses or other undesirable pathogens (Stout, 1950; Boyer, undated; Hildebrand, 1953). Inspection need not be a once-only affair nor cursory; bramble fruit nursery stock in Michigan has been the subject of a careful inspection program for some years (Boyer, undated), involving two inspections so timed as to minimize aphid transmission and to avoid the hotter months when symptoms are masked. Low tolerances are in force, roguing is carried out at time of inspection, and all systemic pathogens are included in the survey.

Regulations governing production and sale of plants and propagating material usually involve a certification system of some kind—the word can be extended, of course, to cover seeds as well and to refer to properties other than freedom from disease, but our usage here is in the more limited sense.

Levy (1948) outlines the development of fruit plant certification in England under the Ministry of Agriculture. Black currant material must be produced under a compulsory system. Strawberry plants, on which great emphasis has been placed since World War I (Demaree, 1948), come either under an “A” or ordinary certificate, which is compulsory, or under a “special stock” certificate introduced in 1945, which is voluntary. The latter is ordinarily only for growers specializing in production of “runners” and hence likely to qualify. Presently, four varieties are included in this certification system, which sets very high standards for
care in propagation and allows only very low disease incidence. Raspberry certification is voluntary and confined to certain varieties; while the fruit tree scheme is mostly aimed at accurate naming.

Strawberry certification in California (Mather, 1952) covers yellows, crinkle, nematodes, and red stele. It was first officially sanctioned in 1941 and the present program adopted in 1949 at the request of the growers. Fees adequate to make the program self-supporting have been set. Features of the system include: low tolerances on the pests and diseases named; intensive pest control, roguing, isolation, and plant indexing. There are four field inspections during the first year, before plants can be set in an increase field; three inspections are made in the second year. Provision was made in 1951 for a registry of foundation stock actually indexed and found to be virus-free. Otherwise, this newer program parallels the certification system except for the additional requirement that the source plants first be proved virus-free by 1 year in an index bed. Indexing is to *Fragaria bractata*, a suitable indicator plant.

In the eastern United States (Demaree, 1948) strawberry yellows and related viruses can be avoided, on a stop-gap basis, by using only vigorous plants, but more certainly by indexing the more desirable varieties to Marshall or other good indicator. Demaree suggests that each state experiment station undertake to handle the comparatively few varieties grown commercially within its geographic region. Maintaining virus-free stocks in the West has been very difficult, due to the wide distribution and common occurrence of principal insect vectors.

The technique of indexing, just mentioned, is often employed in programs to develop certified stock when the pathogen is a virus. It involves grafting material from the plant to be tested to a selected host, known to produce consistent and recognizable symptoms, and makes possible confirmation of the presence or absence of virus even when systemic symptoms on the original host are masked or uncertain. A large number of indexing procedures are now available and many suitable test plants identified. As a general rule, each virus of stone fruits (Hildebrand, 1953), strawberries, etc., must be indexed separately, although at times more than one virus can be checked in a single operation. A very common technique is to index a systemic virus on a host which produces local lesion reactions.

Propagating methods in several ways influence for better or worse the spread of disease in vegetatively increased crops and ornamentals. Dimock (1951b) tells how when nurserymen abandoned the practice of grafting roses to imported stocks (*Rosa manetti*) in favor of buying plants already budded to understocks grown on the Pacific Coast,
Verticillium difficulties were augmented; the pathogen in the majority of cases is introduced with the plant and not acquired from infested soil in the area where planted. Christie (1942) points out that in vegetative propagation of chrysanthemums, foliar nematode injury can be held to a minimum if cuttings are taken from the tips of new growth on old crowns rather than by breaking off lateral shoots. Only this simple change is needed to avoid hot-water treatment. Dissemination of nematodes in deciduous fruit trees seems to be favored by the layering propagation method commonly used in multiplying clonal apple rootstocks (Groves, 1958).

Elimination of red stele from valuable strawberry stock by a curious cultural technique has been effected by Vaughan (1956). His procedure takes advantage of the fact that the fungus does not invade the crowns and stolons, even in susceptible varieties, that it grows poorly at temperatures above 65° C., and that it does not thrive in adequately drained soil. Special sterilized flats with wire bottoms were prepared, sterilized, and the whole apparatus set at a level above the soil of potted plants. New runners forming on these plants were kept physically free from the soil in which the mother plant grew, glass wool was employed to prevent splashing, and, when long enough, the new runners pegged down to the surface of the clean flats. As soon as possible after rooting, the new plant was cut free and later checked for freedom from disease by growing under conditions favorable for development of red stele symptoms.

Finally, a special instance of propagation which reflects unusual ingenuity is called to our attention by Stout (1950). In this case certain citrus viruses are avoided by the propagation of "nucellar" seedlings, which technique permits vegetative propagation (and thus retention of varietal characteristics) without danger of virus transmission, since virus does not enter the seed itself.

2. Soil Treatment Other than Chemical

In Chapter 11 are recounted all those techniques whereby inoculum resident in the soil is got rid of or at least where attempts are made to reduce it by the action of chemical agents. Possible alternatives open to the commercial grower or other practicing agriculturist are by no means limited to a choice among chemicals and methods for the application thereof. At several points in our discussion we have alluded more or less specifically to the soil as a source of inoculum and to cultural methods whereby this threat can be lessened; we have reached the point now where these matters are of central interest.

Chester (1947, p. 457) makes the same distinction relative to non-
infested soil as he had made in connection with noninfested seed, i.e.: (1) uninfested soil (new land, save in those instances where the native flora harbors pathogens which will invade the first crop; land freed of pathogens through crop rotation; and land "sanitized" through avoidance of undesirable crop residues, infested manure, and contaminated tools, or by the erection of trenches and other physical barriers); and (2) disinfested soil (by heat, or by fumigation). Other breakdowns could be made, but this one is useful and the distinctions might profitably be kept in mind when examining cultural measures.

Except for chemicals, heat is probably the most commonly employed means for achieving complete or partial sterilization of the soil. There are several important ways of doing this: with steam, hot water, dry heat, and so on. The effect of soil heating, regardless of how it is accomplished, is often to destroy the beneficial nitrifying bacteria, which are nonspore forming species, but to allow ammonifiers to escape (Newhall, 1955). Soluble salts are frequently liberated as a result of heat treatments and colloids destroyed, which latter event can lead to deterioration in soil structure and to loss in capillarity and water-holding capacity.

Steam heat, a method of long standing, has been employed against nematodes chiefly, but can render other kinds of inoculum impotent as well. As a technique, it has the advantage of being very easily learned and understood. Furthermore, live steam is dissipated almost immediately after application ceases, leaving no undesirable residues, although re-invasion by fungi is often rapid. Newhall (1955) lists several means whereby steam may be introduced into the soil under field conditions: inverted pans, buried perforated pipe or tile, steam harrow or rake. For very limited volumes of soil, autoclaving is an effective procedure.

Less widely applicable means of heat treatment of soil include: (1) hot water, which is less effective than steam; (2) firing, as when sites for seed beds are prepared by first burning quantities of wood on the area, when natural and other existing vegetation is deliberately set afire or, in limited situations (control of Sclerotium rolfsii in India), when flame throwers are utilized; or (3) electrical sterilization, relying either upon the resistance set up by the soil itself or upon some form of heating apparatus containing resistance units (Newhall, 1955).

Rarely, soil temperatures in warm latitudes rise to levels that inactivate contained pathogens. In Texas, at times, larvae of the root knot nematode are unable to survive in the top 3 inches or so of the soil, and it is therefore feasible to destroy high percentages of the population by the simple device of plowing 3 times at 7–10 day intervals during hot weather. In some instances, greenhouses can be successfully rid of pests and soil borne diseases if they be tightly closed in mid-summer sunlight.
and the heating systems turned on. Needless to say, this can be done only if the plants therein are either removed or sacrificed.

In the review above cited, Newhall includes a summary of disease control by flooding, and notes its use in the last century against the *Phylloxera* threat to French vineyards. Other pests have been attacked in this manner: wireworms in California, root knot nematode, garden centipede, etc., but the two most publicized examples at present are in connection with the Panama wilt of cultivated banana in Central America and *Sclerotinia sclerotiorum*, affecting truck crops in Florida (Moore, 1949; Stoner and Moore, 1953; Stevens and Nienow, 1947; Stevens and Stevens, 1952). It has been demonstrated that soil inoculum of the *Fusarium* responsible for banana wilt can be materially reduced by several months' inundation of the soil and that it will not again reach troublesome levels for perhaps 6 years. Subsequent experience soon showed that second cycles were not nearly so effective as the first and that considerable inoculum persisted in the upper few inches of soil. This was got rid of by one or both of two means: (1) by plowing and reflooding; and (2) by chemical treatment. Flooding for control of banana wilt was an outgrowth of earlier experience with silting of diseased areas.

From 3 to 6 weeks' flooding suffices to kill the sclerotia of *Sclerotinia sclerotiorum* in Florida soils, and it does not seem to matter much whether it be marl, muck, or sand nor whether the water be held continuously or flooded and drained at 3-day intervals—sclerotia do not, however, deteriorate at all rapidly if subject only to prevailing rainfall in nonflooded fields (Moore, 1949). Stoner and Moore (1953), more recently, have pointed to an economically attractive possibility for cultural control of *S. sclerotiorum* through summer plantings of lowland rice. Not only are the sclerotia rotted under the conditions normally maintained for lowland rice growing, but destruction is completed in a period as short as 20 days, some 2 weeks sooner than in "static" flooding. By fitting rice into an acceptable crop rotation, valuable winter-vegetable land can be profitably occupied in summer.

It must be perfectly clear that flooding associated with rice growing is in this instance directed against diseases of crops (mostly vegetables) in the rotation other than rice itself. The general approach is also practicable as a pest and disease control measure even when the primary crop is flooded in the course of its normal agronomic or horticultural management. Cranberries, bog-grown plants, are often flooded for the express purpose of reducing diseases and pest damage. Perhaps the greatest drawbacks to wider use of flooding are: (1) the sheer physical impossibility, in the majority of places, of getting adequate water sup-
plies and establishing the necessary grading and ditching; and (2) the
danger of spreading some unsuspected pathogen other than the one
against which the measure is invoked.

One or more forms of tillage is almost invariably involved in agri­
cultural crop production; certain sod-grown orchard crops, forage crops,
and forest trees are the only obvious exceptions. The literature of plant
pathology contains occasional reference to tillage as related to reduction
in soil-borne inoculum, consisting usually of recommendations that
surface inoculum be plowed under to such depth that fruiting is pre­
vented or reinvasion of the upper layers delayed (Simmonds, 1953;
Hardison, 1948). Such difficulties as result are largely in doing a suf­
ficiently thorough job, without which much inoculum remains on or in
the surface layers.

Darpoux and Vuittenez (1949) discovered, experimentally, that pear
scab (Venturia pirina) could be reduced sharply by "digging in" the
fallen, ascospore-producing leaves. It is questionable whether this would
be a practicable measure in commercial orchards or whether it would
prove superior to eradicant sprays for the same purpose.

Chinn and associates (1953) report a curious means for reducing
common root rot of wheat which does not fall clearly into the class of
soil amendments (Section IV, C, 1) or of antibiotics (Chapter 13).
They indicate a drop in infection following the addition of soybean
meal to soil, but insist that this is not related to any increased activity of
soil microflora. Instead, it appears that whereas conidia of the fungus
(Helminthosporium sativum) remain dormant in natural soils, the soy­
bean meal stimulates germination, whereupon lysis ensues and the
organism is destroyed.

Soil-borne pathogens differ from each other widely in respect to the
pH levels which they find optimum. This fact has long been recognized
and taken advantage of by pathologists and others interested in disease
control. One can find in the literature lists of organisms favored by
relatively acid soils and others favored by alkaline soils. Adjustments of
soil pH are regularly made within the tolerances of the host itself.
N. E. Stevens (1938a) points to a special instance of pH manipulation
worked out by Eddins in Florida against a bacterial pathogen causing
brown rot of white potato. Both extremes in pH were combined into a
regular yearly alteration wherein soil was rendered acid for an interval
sufficient to reduce the population of the organism and then returned to
alkaline conditions during the period necessary to grow the crop.

For additional useful, readily available summaries of cultural soil
treatments, the interested reader is referred again to the January, 1946,
symposium issue of the journal "Social Science."
3. Antisporulants, Eradicant Sprays

By all odds the greater portion of the chemicals used against plant disease, more specifically against inoculum, are used in the form of fungicides and related materials applied to the soil, seed, and foliage (see Chapters 11 and 12). There are special situations, however, where fungicidal substances are employed in a somewhat different manner or where materials not commonly classed as fungicides are used in disease control.

First and foremost are eradicant sprays, at one time treated experimentally for control of overwintering ascospores of the apple scab fungus, 90% of which were eliminated by spraying the orchard floor with Elgetol (sodium salt of dinitro ortho cresol). The remaining inoculum was sufficient to produce scab abundantly however. More recently 5% Puratized (phenyl mercury triethanol ammonium lactate) has been applied to young leaves, flowers, and fruits with greater effectiveness (Goldsworthy et al., 1949). Eradication can, at times, extend to the elimination of pathogens already established in the living host. The striking eradicative action of actidione (cycloheximide) on cherry foliage invaded by the leaf spot fungus (Coccomyces hiemalis) is coming to be regarded a classic example (Stout, 1950). Yarwood (1945) gives us a much less well known instance wherein copper sulfate or other soluble coppers, plus a spreader, almost completely eradicated the powdery mildew of beans. At the other extreme, Dimock warns us that phytopathogenic spores in viable condition may be disseminated by fungicides as sprays, thus aggravating rather than improving the situation (Dimock, 1951a), although unpublished studies by Waggoner indicate that this occurs but rarely under field conditions.

Several miscellaneous citations, summarized below, will serve to indicate the very considerable diversity of cultural disease control employing fungicides and fungicide-like substances:

1. Lear and Mai (1952) describe the use of methyl bromide for disinfecting burlap bags, tools, and equipment against spread of the golden nematode. The material is effective between 50–80°F., and, by employing vinyl resin coated covers, can be used to fumigate trucks and other comparable farm vehicles.

2. Ayers and Lambert (1955) report that bacterial blotch, soft rot of "pinheads," Verticillium spot, and mycogone disease of mushrooms can be controlled by chlorinating the water used for wetting the beds at approximately 50–200 p.p.m., applied when mushrooms begin to appear in the beds. It had apparently been mistakenly thought for some years that this treatment could be used only locally, not as an over-all drench.
Chlorination is, of course, a common way of preventing fungus growth in pulp circulation systems and in other industrial processes.

3. Stevens and Nienow (1947) make reference to a paper by Yarwood to the effect that a spray of water under pressure will check growth of a considerable number of powdery mildews, apparently because, once dislodged, the mycelia cannot regenerate from haustoria.

4. If we can judge from Katznelson’s review (1937), control of plant disease by bacteriophage is as yet largely in the experimental stage.

5. Bawden (1954), considering inhibitors of plant viruses, makes the interesting suggestion that such materials as ribonuclease and glycoprotein from *Phytolacca*, if used with a sticker, might prove an effective protectant and a far less irritating substance with which to disinfect the hands of workers in tobacco and tomato growing than those now in fashion.

4. Vector Control

The many ramifications of inoculum dispersal by insects have been thoroughly covered by Broadbent in Chapter 4, and in a recent review of insecticidal control of the spread of plant viruses (Broadbent, 1957). Additional comment comes from Smith and Brierley (1956) and in a number of texts, summary articles, and research reports. A related topic, the resistance of plants to insects, with obvious implications for vector relationships, is covered by Painter (1958).

Vector control illustrates, as does no other phase of the subject, the diverse nature of cultural control. There seems to be almost no detail of transmission of pathogens by insects which, when scrutinized, cannot be shown to have some relationship to possible control measures. In a sense, one could rest content with an admonition to learn all that can possibly be known of the biology of the host-pathogen-vector relationship—and then to so manage affairs that the effectiveness of transmission is held to a minimum. But this would be to beg the question, and a few selected examples will very likely prove helpful—bearing always in mind that the summary is in no way complete.

Vectors are not always insects. Some few vertebrates, notably birds, are responsible for inoculum spread, and various soil microfauna have been implicated from time to time. By all odds, however, insect- or arthropod-transmission is the most frequent association of pathogen and vector and is satisfactorily illustrative of the basic viewpoints and problems encountered.

Provided the ecology of the insect population and the biology of its vector role are adequately known, worthwhile results can be expected. Depending upon individual circumstances, removal of diseased plants may be useful if diagnostic symptoms are such as to be apparent before
transmission to new hosts has occurred or where the diseased host serves as a site for increase in vector populations (elms, killed by Dutch elm disease, harbor the beetle vector and furnish conditions ideal for its multiplication). Physical barriers and removal of native reservoir hosts (see Section VI, B, 1-2) can, without directly affecting the insect vector, contribute to the desired end of reducing disease incidence in cultivated crops, just as silvicultural methods (Graham, 1951, 1956) directed against insect populations may, in special instances, be invoked against vectors. Occasionally (Galakhov, 1946) readjustments in crop rotation and rescheduling of sowing dates can be instituted to upset the pattern of reproduction, hibernation, and dispersal of the vector. Finally, there is always the possibility of utilizing biological control of arthropod vectors, where appropriate predator species are known.

The greater emphasis in arthropod vector control has always been upon insecticides, a very natural outgrowth of the extensive use of chemicals against insects causing direct damage by feeding and oviposition. Principles are not entirely the same, for the effectiveness of vector insects is not necessarily proportional to the degree or duration of the infestation, and the level of insect kill must be very high as well as quickly accomplished.

In writing of virus transmission, Broadbent (1957) shows that insecticides more often than not are ineffective in stopping the spread of disease even when inspection seems to indicate that the vector has been largely eliminated. This is especially true of those viruses which are quickly inoculated into the plant—the nonpersistent group—and which allow, therefore, very little time for the toxic substance to take effect. It thus proves better strategy either to spray contact insecticides on the source plants with a view to killing the largest possible number of insects before they depart for new hosts or to apply persistent chemicals, i.e., those which remain active for some period, such as DDT or Parathion, to the surface of plants to be protected in the hope of killing viruliferous insects as they arrive. Slower-acting materials can be used against vectors carrying viruses of the persistent group, which require an appreciable incubation period in the insect. Systemic insecticides are much like the long-lasting surface materials, with the added advantage that they better protect new foliage as it appears and act more selectively against only the harmful insect species. There is a genuine need for development of new insecticides especially suited for the problems posed by vector control as distinct from general insect control.

B. Affecting Hosts Other than the Primary Crop

At times cultural measures center about other host plants, their destruction, removal, or manipulation. Naturally, these control practices
are often employed in league with efforts with inoculum or principal host, and depend for their effectiveness upon how closely and importantly the secondary host species is tied in with the survival, reproduction, and spread of the pathogen.

1. Alternate and Reservoir Hosts

As a rule, cultural control measures receive little recognition either publicly or privately. To this generalization, the control of heteroecious rusts by the removal of their alternate host species is a conspicuous exception. The fact is that such success as has been attained has in each case required sympathetic response from an informed public. Removal of the economically less important host species has been widely advocated and vigorously prosecuted in North America in three instances: (1) barberry (stem rust of wheat); (2) currant and gooseberry (white pine blister rust); (3) cedar (apple rust). The story of these campaigns need not be retold here, although each is a fascinating study encompassing the biology of the organisms, the economics of crop production and cost of eradication procedures, the strategy of mobilizing public opinion, and the traditions and technicalities of legal codes. Suffice it only to remind ourselves that the success of any eradication and the strategy of its program depend upon the role played by the alternate host in the life of the pathogen. In the case of apple rust, all of the infection of that host comes from spores produced by the cedar phase of the pathogen; alternation is, then, absolutely critical to the continuation of the pathogen. Because leaves and fruit are shed each fall, the apple host commences each spring season free of the pathogen, and will be invaded only if cedar has been allowed to remain nearby.

New infections of white pine rust, likewise, come only from currant and gooseberry, but, since pine cankers form in tissues which persist from year to year, an individual once diseased will be progressively damaged as time goes on, even if the native alternate host be completely eliminated.

Cereals, the economically more desirable member of the pair of alternate hosts of black stem rust, carry not only spores which infect barberry, but, unfortunately, also spores capable of reinvading wheat. Thus disease incidence is not entirely dependent upon barberry once the pathogen is established on wheat. The once very vigorous and extensive eradication program has been continued, but on a new and somewhat reduced basis—primarily to limit the number of new genetic races evolving out of sexual reproduction on barberry.

By "reservoir" hosts are meant those species, frequently indigenous,
which are not demonstrably involved in any exact or exclusive way with the life cycle of the pathogen, as are alternate hosts, but which provide an additional site of persistence or multiplication of the pathogen. There are a large number of these recognized, and probably many more not yet incriminated. The concept of reservoir hosts includes not only species serving as sources of air-borne inoculum of vector-borne diseases and as sites of vector survival and multiplication (Steinbauer and Steinmetz, 1945). It involves instances wherein weeds: (1) provide means of pathogen survival when cultivated hosts are inaccessible; (2) are the site where new pathogenic races arise; (3) act as accessory hosts of pathogens. Finally, it should be extended to include what might be called "carrier" varieties—varieties of crop plants in which viruses known to be responsible for destructive diseases do not produce visible effects, but from which they can be transmitted to other varieties of the same crop.

There is a considerable literature on weed control by mechanical, biological, or chemical methods—it would be impossible to include even a representative sample at this point. Probably the most striking trend in recent years is the almost explosive development of herbicidal chemicals, many of them highly selective in their action. Adoption of these means has in no wise changed the rationale for cultural control of diseases by this approach but has favorably altered the economic aspects of the situation. Some interesting viewpoints on the over-all biology of weeds are to be found in a paper by Weiss (1949), including speculations on their striking freedom from disease.

Piemeisel (1954) describes a somewhat different form of weed control associated with disease reduction as "replacement control," or "changes in vegetation in relation to control of pests and diseases." By and large this is a special case of applied ecology or of range management whereby pest populations and pathogen load are reduced through changes in the vegetation from weeds and other ephemerals toward grasses and native perennials. As alteration from the original becomes progressively greater, the problem of replacement control is made more difficult, and the length of time required for its realization longer. With special reference to curly top of sugar beet and other crops in the semi-arid west, the usual story has been the loss of natural cover, occupation of the denuded lands by weeds, enormous increases in the beetle leaf hopper populations, and subsequent increase in disease incidence and damage. By returning all lands not continuously farmed to good desert range—not necessarily either climax or even of what was originally there—the threat can be substantially reduced.
2. Trap and Buffer Crops

A final category in the area of cultural control as it pertains to host species other than the primary crop concerns trap crops and buffers.

Plantings used as buffers are in reality a special instance of the general category of physical barriers introduced under Section V, B, 3; strictly speaking, the species utilized are not even hosts to the pathogens or vectors. One might go so far as to consider isolated plots, seed beds, etc., as extreme examples of protection by barriers, wherein the areas occupied by the buffer species far exceed that occupied by the host. A more useful concept would confine the term to situations where the preponderance of area is occupied by the principal crop and the buffer is truly marginal. Forest windbreaks have been employed in part for disease control (Beilin, 1951) and presumably reduce the overland movement of air-borne inoculum. Their effect on microclimate, especially as they increase temperature and retard drying up of surface moisture, is often to increase disease hazard.

Barriers are reported effective in some instances against spread of insects to seedbeds and cropped areas. Stakman and Harrar (1957, p. 442) find some evidence that legumes sown with Hevea brasiliensis form root barriers which retard the growth of subterranean mycelium of fungi causing root rot of the rubber tree, and they suggest that similar relations might pertain to citrus, grapes, and orchard fruits. Sideris (1955) recounts the occurrence of a leaf tip necrosis of pineapple appearing within 1.5 miles of the sea in plantings exposed to wind-blown sea water; partial control can be achieved by establishing multiple rows of Casuarina equisetifolia on the seaward side in order to trap wind-blown sea water. The effects on pineapple can also be partly overcome by ample applications of nitrogen and potassium. Chester (1946) mentions the possibility of a rust barrier zone in the south central plains of the United States.

Use of trap or catch crops is based on the notion of providing a host species other than the primary crop, which is particularly susceptible to the pathogen, and, at an appropriate later time, destroying both host and pathogen in a single operation. By so doing it is hoped that the more valuable host will be left relatively free of the inroads of the pathogen.

In field and greenhouse trials with pineapple root knot nematode in Hawaii, Godfrey and others (Godfrey and Hagan, 1934; Godfrey and Hoshino, 1934) found that the population could be very greatly reduced by one or more plantings of a crop such as tomato if the latter were killed at the most favorable time either by mechanical means or by poisons. Decay or destruction must come before eggs are produced or
the net result will be to worsen rather than to reduce the population problem. These studies seemed to indicate that the best that can be hoped for is a quick reduction of heavy infections, not complete eradication, and that to plant the trap crop beside the pineapple row was ineffective. Weed killers appear to be a satisfactory means of destroying the catch crop.

Berkeley (1944) includes a somewhat different type of catch or trap crop in pointing to the use of indicator plants of three different varieties in areas of Ceylon about to be replanted to Hevea rubber. The chief purpose here is not to destroy the soil pathogen but quickly to establish its presence and extent of infestation in order that diseased material may be identified, removed, and burned.

VII. SUMMARY AND PROGNOSIS

Several points emerge conspicuously from our consideration of cultural control. In the first place, cultural measures are a miscellany. A few are well recognized and widely adopted; many are obscure or so intricately tied in with other steps in the agricultural program that they are not accorded full credit for their contributions to crop production. Curious anachronisms show up as one studies disease control by cultural means. It has, on the one hand, been characteristic of primitive agricultures, poverty of scientific information, and inadequate supplies of agricultural chemicals and equipment; on the other hand, it requires the most exacting, critical, and detailed knowledge of the biology of disease—far beyond that needed for more orthodox operations. In one sense these can be the least expensive and most rewarding of disease control efforts; in another, because the full cost is often immediately apparent and chargeable to the individual producer, cultural control is avoided as being too expensive and troublesome. Reduction of disease damage by cultural means involves more variables, is more difficult to evaluate by controlled experimentation, requires more extensive cooperative action, and impinges on the complex structure of agricultural and forest practice at more points than any alternative pathway open to the pathologist and producer.

No one can possibly say with certainty what the future will bring. It is more than likely that there will be no sudden shift in the popularity of cultural control measures as a whole, although we can expect continuing change and improvement in individual techniques. As time goes on and the knowledge of disease as a pathologic phenomenon accumulates, there is every likelihood that new and provocative cultural control devices will be developed and that more and more producers will take advantage of what this sector of plant pathology has to offer. More
particularly, cultural control will continue to be important in situations where other methods prove inadequate, in cases where the biology of pathogenic disease is particularly well known, in the preservation of harvested materials and produce, in forest pathology, as an adjunct to chemical control, and, of course, in alleviating many nonpathogenic troubles. We can also hope that the economy of cultural practices will in time be more realistically evaluated and this obstacle to their wider adoption removed.

It will be immediately apparent that no complete review of the literature of disease control by cultural methods has been attempted. In selecting the few titles to be cited in the bibliography, at least four points were emphasized: (1) where possible, reference is made to survey and review articles, thus affording access to the often very complete and far-ranging literature compilations included there and materially reducing the number of bibliographic entries in the present paper; (2) recent papers were given priority over older publications, particularly from the works of a single author; (3) emphasis was upon readily obtainable material from established sources; and (4) an effort was made to strike some sort of balance among the multiplicity of subtopics comprising the very diverse subject of cultural control.

We are greatly indebted to recent texts and monographs by Chester (1946, 1947), Stakman and Harrar (1957), and Stevens and Stevens (1952), to which a number of page references are made; and to reviews by N. E. Stevens (1938a) and N. E. Stevens and Nienow (1947).

**REFERENCES**


Boyer, C. A. (undated) Bramble fruit plant inspection in Michigan. 3 pp. mimeo.


Darpoux, H., and A. Vuittenez. 1949. Role des peritheces de Venturia pirina dans la region parisienne. Influence de l’elimination des fulles mortes par le bechange sur l’intensite des premieres contaminations et sur l’évolution ultiere de la...


10. CULTURAL PRACTICES IN DISEASE CONTROL


