The Glasshouse Environment in Relation to Disease and Insects

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This talk was given by Professor Baker at the 1965 Cornell Short Course. Every grower must understand these relationships to have a successful pest control program.

Glasshouses apparently developed from the sunroom or orangery in the eighteenth century, primarily as a means of tempering the extremes of climate. Subsequent modifications in these structures have largely been made to more effectively control the environment. Today's grower is able with reasonable accuracy to control the air and soil temperature, the atmospheric humidity and soil moisture, light intensity and duration, atmospheric content of carbon dioxide, plant nutrients in the soil, soil pH, soil aeration through the type of soil mix used, and other factors as well. The development of the glasshouse industry, resembling both the evolution of living things and man's social institutions, is thus the story of the effort to control the external environment. In that sense, we are today considering one of the most successful advancing frontiers of biology.

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It is a curious fact that plant diseases and insects are still commonly regarded by many who should know better (e.g., plant pathologists in fungicide companies, entomologists in insecticide companies, floriculturists in universities) as something apart from the culture of the crop. Too frequently one is asked to devise for a given disease a control that will not disturb established operations. Diseases and insects are as much a part of a plant's environment as the air itself, and may in fact determine what a grower does, how and when he does it, and why. A disease should never be viewed as an isolated phenomenon controllable by a single treatment; it is really one of a series of interrelated problems requiring simultaneous, rather than piecemeal solution. Not infrequently a tug-of-war develops between a grower's wish to continue present methods of operation, and the economic necessity of changing them in order to control a serious disease, and thus keep the banker from his door. The factor most restrictive to economic production in a given situation is the one that must determine the course of action. An advance in one subject nearly always brings about changes in the others. This basic unity in the many factors in the production of glasshouse crops is forgotten at one's peril.

The Remaining Problems

The historical sequence of the diseases considered most damaging to floricultural crops is of interest in this connection. The rusts of mums and carnations were both conspicuous in the literature around 1900. Better control of glasshouse environment reduced the importance of these troubles, and increasing information revealed the importance of the soil-borne fungus and bacterial vascular diseases. At first these were alleviated by moving to new land for outdoor-grown crops, and by changing the soil in the glasshouse benches. These diseases were brought under control by soil treatment, resistant varieties, and by the use of clean stock. Viruses were largely controlled by healthy planting stock. The leafspots were likewise brought under control by clean stock and by fungicidal sprays. The plant pathogens specific to one host, and usually able to kill it, have thus been fairly well reduced to minor importance. The change in the disease situation of floricultural crops in the last 30 years is indeed impressive, as anyone who recalls the ragged carnation and mum beds of the 1930's, the cankered gardenias, the roses defoliated by blackspot, can testify. Lest we become too complacent, however, it is well to remember that some of the widespread, generalized, low-grade pathogens remain to be coped with, and they are no mean adversaries.

The situation with insects is much the same. In the not-so-good old days growers fumigated with cyanide or nicotine, syringed for red spider (and thus enormously complicated the disease picture), and sprayed a little with refined oils. With the development of the new insecticides, the picture changed. The grower is now concerned about the development of insect strains resistant to the highly specific effects of these potent insecticides, with human hazards from their use, and about the importance of insects in spreading virus diseases. Concern seems to have shifted from gross damage to the plant from the devouring or sucking hordes, to the occasional insect which spreads a virus—a shift from the obvious to the insidious. In fact, the less favorable a block of plants is as a food plant for an aphid, the more likely he is to spread a virus because of his continuing efforts to find a suitable food plant. Control of these insect-virus teams centers as much in getting rid of the sources of the virus, or in keeping the insects out of the mother-block house by screens or positive air pressure, as it does in control of the insect itself.

Control of the generalized pathogen and the host-seeking insect are at the heart of the present problems of disease and insect control. We shall see that in each case a broad multiple-pronged control program is necessary for success; rarely is a single-shot procedure successful. These difficult problems which remain call for more detailed consideration here. The Botrytis Story includes most of the ideas and techniques for this group of organisms and is, therefore, given as a representative sample.

Conditions for Botrytis Infection

Botrytis cinerea is the common gray mold of many floricultural crops. The several factors required for an outbreak of this disease are:

1) *An abundance of Botrytis spores.* The fungus develops copiously on dead plant parts. It is omnivorous, widespread, and prevalent, growing on many kinds of debris. Spores are developed under cool moist conditions, not when the material is dry. The powdery spores are easily carried on air currents and are usually prevalent in the air of a glasshouse range; it is reasonably certain that lack of these spores is not the factor that keeps the disease in check. While it is certainly helpful to prevent accumulation of decaying and sporulating debris on the premises, this procedure alone can never achieve control.

2) *A susceptible host,* both in terms of variety and stage of development. Physiologists state that by the time most flowers open, they must have reached their peak of respiration, and that the petals are already beginning to senesce. Thus, most flower petals are in an increasingly senescent state, and thus increasingly susceptible. Localized killing of epidermal cells by Botrytis spores results on petals without subsequent invasion necessarily occurring. There are marked differences in susceptibility to petal spotting among cymbidium clones; California growers utilize this fact by placing known susceptible clones under a protective cover when the buds begin to show color.

3) *Senescent or dead tissue. Botrytis cinerea* has only limited ability to infect healthy plant tissue. It may invade through injured or dead cells in wounds of various kinds, or in old tissue. The fungus grows in such a food base and produces toxins and enzymes formed which kill the next cells, and so on. Thus, although the fungus lives in dead cells, it is

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able to cause a great deal of damage to crops. Old flowers of tetraploid snapdragons wither in place, become infected, and may advance down into the stem and girdle it at this point. Dead geranium petals may fall on a living leaf or flower, become infected, and the fungus grow into the healthy tissue beneath. Infection may also occur through attached dead leaf scales (geranium), leaf tips killed by accumulated soluble salts (stock), or an exuded drop of latex (lettuce, poinsettia).

4) *Cool conditions of about 45-60°F* are most favorable for outbreaks of Botrytis. The fungus is able to grow freely even at 41°F, and slowly at 32-36°F, thus meriting its reputation as a low-temperature organism. Every degree that the temperature rises above 70°F, the more certain one may be that development of the fungus will be checked. Growth of the fungus is strongly inhibited at 86-95°F, and killed in 15 min. at 131°F under moist conditions. When the crop plant can tolerate temperatures above 70°F, the fungus may be checked by this means; when it cannot, heat must be used in conjunction with ventilation to lower the humidity.

5) *Free moisture on the part to be infected.* Free moisture is necessary for 8-12 hr. or more, depending on temperature and the susceptibility of the tissue, before the fungus is able to produce a spot or to infect. If moisture dries before infection in depth has occurred, the fungus will be killed, producing only a small fleck. Under continuously moist conditions, however, the lesion may continue to spread until all the tissue is decayed.

Relative Humidity and its Control

Relative humidity is very important in determining the severity of Botrytis diseases, because it affects the drying rate of moisture on the surface of plants, and of the dead tissue in active spots. Since the spores of *B. cinerea* are said not to germinate below 93% relative humidity, it is possible to prevent the disease by maintaining the humidity of the air below 80-85%. Because of the importance of atmospheric humidity in the control of disease caused by Botrytis and other pathogens (e.g., *Fusarium roseum* on carnation, downy mildews of rose and snapdragon) it is discussed in some detail.

Condensation of moisture from the air, which we call dew, provides an excellent source of water for infection. Because, however, it condenses in place on the plants and usually does not run over the surface, it is not important in pathogen spread. Common experience provides a basis for understanding the condensation phenomenon. We recognize that air holds varying amounts of moisture when we say "The air is very dry today." The fact that the warmer the air the more water it will hold is the basis of operation of the modern clothes dryer. The condensation of dew with falling temperatures during the night indicates that as air cools it holds less moisture. It follows that dry air evaporates water faster than will moist air, and this is acknowledged in the saying "It ain't the heat, it's the humidity." Moving air dries a wet object faster than still air, as housewives observe when they dry clothes outdoors on a windy day.

Air will absorb moisture up to its capacity at a given temperature; beyond that water will condense. Air at 70° will hold about twice as much moisture as at 50°; there is thus almost twice the margin of safety in 70° as in 50°F air. It is thus understandable why it is more difficult to control condensation in a 50° carnation house than in a 70° lily house. It is mainly for this reason that Botrytis is most destructive on the flowers of the cool crops, mums, carnations, and snapdragons, rather than on warm crops such as lily, cattleya, or foliage plants. If the air in a glasshouse has a relative humidity of 80%, and the temperature drops from 70° to 63°, condensation will occur with only the 70° temperature drop. In a glasshouse filled with plants, neither the temperature nor the humidity is uniform. Air next to the wet soil or bench contains more moisture than that a few feet higher, and is likely to be cooler. Warm moist air circulating in a glasshouse is, therefore, apt to condense on the cool basal leaves and stems of the plants. In times of very cold weather, the temperature next to the roof and walls is cooler than that at plant level, and the air is continually dehumified by the glass. In cold areas blackspot of rose thus tends to be worse in glasshouses during the fall and spring months.

It is of interest that 260 years ago, before the parasitism of fungi was understood, J. P. de Tournefort stated, "The moldiness is, moreover, a very dangerous disease, which attacks the plants in greenhouses which remain humid during the winter. The humidity opens the eggs where the seeds of certain . . . . fungi are found in the fissures of the surface; in the same manner it comes on the surface of morocco leather . . . which has been kept in the cellar. . . In order to avoid this disease it is only necessary to hold the greenhouses very dry." When M. J. Berkeley made the first report of downy mildew of rose over 100 years ago, he suggested for its control ". . . take care first that the house in which the plants are stored shall be well ventilated, that no syringing be used, and that no more water shall be given than is absolutely necessary, while care is taken that this shall go as little on the leaves as possible." The advice of these two ancients is equally valid today—and often still unfollowed!

Some of the most troublesome diseases of glasshouse crops may be prevented by keeping the plant surface dry. By proper balancing of heat and ventilation the humidity may be kept 10-20% below saturation to cushion against a sudden temperature drop. Watering plants in the morning, rather than at night, gives time for a reduction of humidity before the evening temperature drop. Syringing should be avoided. At sundown the change from day to night temperature is made with the top ventilators slightly open and heat in the pipes. The rising column of air carries off the excess humidity so that night temperatures are reached without condensation. The ventilators should not be closed at sunset to "hold in the heat."

Because it is abrupt temperature drops of even a few degrees that cause condensation, the widespread use of

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steam rather than hot water for heat may contribute to the problem. Because of the fast and excessive heat supplied by steam, there is a tendency to delay turning it on until the temperature is quite low, it then overshoots the level desired, and a bumpy heat curve results. J. E. E. Jenkins reports that in English glasshouses with hot-water systems a rather uniform temperature results, and with it relatively little trouble from tomato leaf mold, Botrytis, and other high humidity diseases. England does not have the abrupt cold fronts which, in the northern states here, necessitate steam heat. Interestingly, the new glasshouses at Cornell University use hot-water heat. Is it possible to devise some combination system which will use a hot-water line or a small steam line for humidity control, and retain present steam lines for heavy-duty heating? In areas of more moderate temperatures (e.g., coastal California), perhaps we should reexamine our ideas on heating glasshouses.

If the large volume of air in the house is maintained at a moderate humidity, this will also hold the air at the soil surface below the condensation point. Heat reduces humidity in a glasshouse by (a) raising the temperature, (b) producing air movement and reducing stratification, and (c) by causing an outward flow of humid air through the open top-ventilators. Temperature requirements of crops reduce the utility of the first two methods, but the third is extremely useful. Growers must use heat for humidity as well as temperature control if they wish to combat these generalized pathogens. Humidity indicators throughout the range are necessary for this. A Chicago grower essentially eliminated losses from Botrytis in a snapdragon crop a number of years ago by heating and ventilating whenever the humidity exceeded 75-80%, instead of merely holding a 50° night temperature.

In every glasshouse there is some stratification or localization in the temperature and moisture conditions (e.g., in cold corners, under roof leaks, by side vents). If the air is kept in motion, greater uniformity will result. This is one of the primary virtues of the fan and pad system. The reasons this cooling system does not seem to increase Botrytis may be that (a) the temperatures usually are above the best range for the fungus, (b) the temperatures insure a considerable margin of safety against condensation, and (c) the air is kept in motion, insuring a maximum drying effect. When the weather is so cool that it is unnecessary to use moist pads, some growers have found it desirable to continue to use the fans for air movement. The new Floriculture glasshouses at Cornell University use a unique, automatically controlled system in which the air can be recirculated through the house or fresh air merely be moved through it, depending on glasshouse humidity and temperature.

Many growers have found it desirable to position fans so as to direct air movement into dead-air pockets in the houses. Because moving air picks up moisture faster than still air, this is helpful in disease control, even though the humidity may remain fairly high.

Another recent development, the use of carbon dioxide in the glasshouse air, will complicate the control of Botrytis. The release of CO_2 during the light period is, for economic reasons, usually done with little or no ventilation, and with resulting high humidity. Condensation may occur during the day, but if temperatures are about 70° little Botrytis infection should result. At sunset, however, when the CO_2 generators are turned off and the temperature falls, there is considerable hazard of both condensation and Botrytis infection. The generous use of heat and ventilation may be necessary to avoid trouble. Another associated problem may be anticipated: the accumulation of ethylene in the closed house during the day may cause, for example, flower shedding of snapdragon or calceolaria, and sleepiness of carnations. Since Botrytis-infected plant tissue releases large amounts of ethylene, which predisposes healthy tissue to Botrytis infection, a chain-reaction escalation of damage may result.

Air pollution of the smog type, a problem that growers used to come to Los Angeles to see, is now recognized as a real or potential problem in every urban area. Thus far, it has not proved economical to use the necessary carbon filters to condition commercial glasshouses against smog, but the methods have been developed and used on experimental ranges. It is likely that someday one cannot afford not to install smog filters. This may parallel the change from the old practice of yearly migration to escape losses from root diseases of outdoor crops, to the present continuous growing in a few fields and the adoption of disease-control methods. This change to filters may be expected to alter the glasshouse environment to favor Botrytis, even as the CO_2 enrichment has, and greater care in heating and ventilating will then be required.

Although control of Botrytis in outdoor or cloth-house plantings of mums, cymbidiums, or carnations is more difficult because the environment cannot be as accurately controlled, some relief is possible. Overhead sprinkling should be avoided on any of these crops. The rows should run in the direction of the prevailing wind.

Because the retained heat of a plant in the open is radiated after sunset, the plant may rapidly drop below air temperature and condense dew on its surface. This can be largely prevented by using a radiation barrier of plastic above the plants, insulating them somewhat from rapid radiation and temperature drop. How tight this insulating canopy should be is still a debatable point. A space over the walk between the covers will permit the moist air to escape, but the rain that enters there will increase the moisture under the canopy. A solid canopy may prevent this leakage but will trap moisture, which will condense on the roof and drip onto the flowers. Large fans blowing under the canopy will reduce the trapped moisture. Perhaps the best solution is the saw-tooth roof type of structure used in southern California, with adjustable vents on each vertical face, and with large fans at the end of each house.

In any case, overhead sprinkling and syringing should be avoided on flower crops. California growers have long benefited from the semi-arid climate which has been a natural check to many diseases (e.g., Septoria leafspot of mum, blackspot of rose, azalea flower blight, Ascochyta

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ray blight of mum) difficult and expensive to control in the humid east. Following the usual intermittent rain in California, humidity falls, and plants dry off quickly because the moisture is absorbed from the air by a multitude of partially saturated surfaces. In areas of higher rainfall, all exposed absorptive areas become saturated and may help maintain a high humidity by giving off moisture to the air. The plants then remain moist for extended periods. In California today, the population explosion has taken over much of the flat land irrigable by ditches, and crops are being forced into the foothills, which can be watered only by overhead sprinkling. While this is a move toward eastern conditions, and some "new" diseases have now come into prominence (e.g., angular leafspot of cotton, halo blight of bean), there are still some advantages over the humid east. Because of the localized area and short time of overhead sprinkling, the dry atmosphere will bring about quite rapid evaporation unless the sprinkling is done in the evening or at night.

Fungicidal Sprays for Botrytis Control

Fungicidal sprays have proved helpful in reducing Botrytis flower decay, especially when the environment can be so altered as to reduce the severity of the disease and thus reinforce the control by chemical means. Zineb, Captan, or Thiram (½ lb per 100 gals, with a suitable spreader) misted over the open flowers every day or two during wet periods, less often when drier, has continued to give fair success.

The Soil, and Root Disease

It is a curious fact that in many experimental studies involving rigorous control of temperature, light, CO_2 content of the air, etc., the soil conditions and the amount of root growth are ignored. In addition to the point that "out of sight *is* out of mind," there still seems to be a prevalent notion that, if the roots are suffering any serious derangement, it can be recognized by the appearance of the tops. Unfortunately, the emphasis of earlier growers on the importance of "root action," as evidenced by the presence of abundant white root tips, has gone out of fashion. Loss of root area, or decreasing its efficiency, may have several injurious effects: (a) absorption of water and minerals from the soil may be decreased; (b) an important area for synthesis of amino acids, necessary to plant growth, is diminished; (c) structural anchorage is reduced; (d) perhaps growth-regulating substances essential to top development may be deficient; (e) toxins may be formed in parasitized roots which are injurious to top development. The total effect may be that the plant simply does not grow as rapidly nor produce as well as it might. It is a mistake to concern oneself only with root troubles which kill or obviously cripple a plant. Root nibblers probably cause as much aggregate loss as the more conspicuous killers. Experience has demonstrated that many investigators and growers have never seen a really healthy plant of the type they are growing, and thus lack a valid standard for comparison.

Growers in the past learned to live with a disease by careful cultural manipulation. Thus, Verticillium wilt of mums was checked by using resistant varieties and by careful watering. With the Verticillium-free cuttings and soil treatments used today, wilt has become so rare that many growers wouldn't recognize the disease if they saw it, just as doctors may fail to recognize cases of cholera or typhoid fever. With the essential elimination of this disease, varieties are no longer selected for resistance. Removal of this stricture has facilitated the development of the wide array of chrysanthemum colors, types, and temperature and day-length groupings that have been necessary for the present spectacular year-'round mum production.

Elimination of a disease from practical floriculture inevitably expands the growth potential of the crops concerned. The full range of growth conditions of a crop may then be explored to find those best for commercial production, and this makes for easier, less restricted culture. Finally, with disease eliminated, the benefits from improvements in culture will be increased. Healthy plants are able to make maximal use of each improvement in nutrition, for example. It is not accidental that the greatest benefits from improved culture methods are enjoyed by the growers with the healthiest plants, and that greatest gains from healthy stock are obtained by growers with the best cultural techniques. This is a practical example of the unity of all factors in floricultural production.

It is a point worth making in passing that the continuous or intermittent elongation of roots necessarily serves more purposes than merely to explore new soil areas for nutrients and water. Their continuous development provides, among other things, the essential means of adjustment to a changing environment. Thus, the sudden waterlogging of a soil previously only moist will kill the roots of most plants, with or without parasites. These same plants may be grown in water culture, however, provided the roots are formed under those aquatic conditions. The formation of new roots thus provides a mechanism of adjustment to the constantly changing soil environment. The early floriculturists were definitely on the right track when they laid great emphasis on "root action," and the modern grower would do well to emulate them in devoting more attention and study to the welfare of the roots of his crops.

The aeration of the soil mixes is another factor the importance of which is only recently coming to be recognized. Following the lead of the U C-type mixes, many light porous media have been sponsored by various experiment stations, and these have provided good root aeration. With proper nutrition, excellent growth should result in many of them. Although it is ridiculous to spend vast sums for environment control and then grow the plants in any old clay that happens to be on hand, I have seen this happen.

Among the several factors, other than soil and environment, which affect uniformity of plant growth are the genetic variability between seedlings, even within a horticultural variety, and the vigor of the individual seed and its germination rate. While these differences may be less important in vegetatively propagated plants, the

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studies with chrysanthemums certainly indicate that one must carefully produce a single type of cutting if uniformity is desired. The more favorable the growing medium, nutrition, and environment, the more will these differences be accentuated. A plant from a seed that germinated a few days later than its neighbors will obviously appear relatively small under conditions favoring rapid growth than it will under less favorable conditions. Plants grown under optimum conditions may then be sorted, accurately matched, and practically all poor plants eliminated, with the assurance that the maximum variability is revealed. The uniformity of growth through the full cycle of the plant, obtained by J. G. Bald and the late P. A. Chandler at UCLA in an ordinary greenhouse with this technique, exceeded that seen in some of the expensive phytotrons using clay soils. This is pointed out as a reminder that plants respond to the total environment, and that the maximum utility from controlled-environment conditions comes only when one keeps the plant's response firmly in mind. The plant is never pre-occupied with equipment, only its effects!

It must be clear from these partial outlines of the importance of environmental control in prevention of disease in floricultural crops, why the magnificent new Bioclimatic Laboratories of Cornell University come at so propitious a time.

Number of days to flower The flowering time was generally quicker than normal, but this undoubtedly was due to the very long storage time. We had expected greater differences than indicated, however, the trend did show that the larger size bulbs would flower faster than the smaller sizes.

Number of flowers Again greater differences and larger number of flowers were expected; but, because of the longer storage period, this was undoubtedly reduced. The general trend, however, was clear and the larger size bulbs produced more flowers.

Number of leaves The larger the bulb, the larger the number of leaves. This is perhaps a good indication of quality.

Height The larger bulbs produced taller plants than the smaller bulbs. The difference being 4 inches between the smallest and largest.

Stem diameter This measure was made at the same distance above the rim of the pot in every case. The measurement is in millimeters. The figure indicates the stem diameter increased as the bulb size increased. This again would be a fairly good indicator of plant quality.

SUMMARY

The results were not unexpected, and the following would be true as the bulb size was increased:

1. A decrease in forcing time
2. An increase in flower number
3. An increase in leaf number
4. An increase in height
5. An increase in stem diameter

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