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Temperature in the Management of Insect and Mite Pests in Greenhouses

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Worldwide, the total area for greenhouse crop production was estimated by Lenteren & Woets (1988) at 150,000 ha. Only about 18% of this area is covered by traditional glass greenhouse coverings; the remaining area consists of polyethylene or acrylic-covered structures. Some greenhouses have sophisticated environmental control computers that regulate many facets of greenhouse operations, including environmental factors such as temperature, light, and humidification. Others have only minimal environmental controls *e.g.* heaters. The remaining greenhouse area consists largely of polyethylene-covered structures which do not have environmental controls.

Shipp et al. (1991) stated that manipulating the greenhouse environment, including temperature, is perhaps the most underutilized tactic in greenhouse crop pest management. On a practical level, however, there seem to be relatively few options for using temperatures alone to control insects and mites in a greenhouse crop integrated pest management (IPM) program. Most modern greenhouses produce crops more or less continuously. Temperatures are controlled as much as possible to be favorable for plant growth. In most cases these temperatures are also favorable for insect and mite development.

In greenhouses, temperature manipulation, usually in combination with relative humidity/vapor pressure deficits, is used more commonly to manage plant pathogens and weeds than insects and mites. This is mostly because the opportunities are greater; plant pathogens often have quite specific environmental conditions governing their survival. Most insects and mites can survive over quite a wide range of environmental conditions. However, there are some direct and indirect ways that temperatures are or could be used in insect and mite management in greenhouse crops.

Using Temperatures to Control Pests Directly

Steam Treatment of Soils or other Root Media.

Many greenhouse flower and vegetable crops are produced in soil ground beds. Crops such as carnation, chrysanthemum, rose, tomato, cucumber, and lettuce, are commonly grown in this way. Prior to the now widespread use of "soilless" potting mixes, nearly all potted crop plants were also produced in soil. The application of steam heat prior to planting to treat these soil beds, or soil for potted plants, has been done for decades. In addition to killing weed seeds, fungi, bacteria, and most plant viruses, steam treatment can also kill soil insects in areas where temperatures are sufficiently high. The soil temperature must reach 71/C for 30 min following the time that the coolest spot reaches this temperature, to be lethal to insects (Nelson 1991). The soil should be moist for best results. The steam is applied either by using an existing network of perforated pipes buried beneath the soil or is applied over the tops of areas of soil that are covered to retain the steam and heat. Buried steam pipes should be just below the depth of cultivation.

Although quite effective, there are several problems with using steam. Some pests, *e.g.* nematodes, symphylids, and root-feeding insects, can escape to areas deeper within the soil, where the steam does not penetrate. Other, probably more serious problems are cost and time to treat large areas and shortage of equipment. Many greenhouses in which steam pasteurization would be very useful are too large to be treated in a cost-effective way. Unlike North America or northern Europe, greenhouses in Central and South America are not equipped with large boilers for heating. Portable steam generating equipment must be purchased or rented, and this equipment cannot treat large areas at one time.

However, even in areas without built-in equipment, treating plant propagation beds with steam heat using portable steam-generating equipment is a practical pest and disease control method. Propagation areas tend to be on defined benches containing soil or other material that can be easily raised to the proper temperatures throughout.

Soil Solarization and Lethal Warm Air Temperatures

Soil solarization utilizes solar radiation to heat soils. The area to be treated in this way is normally covered with a plastic mulching material with the objective that the sun's rays will generate temperatures high enough to be lethal to pathogens, pests or weeds (Stapelton & DeVay 1995). Nearly all published research deals with results against soil pathogens and weeds (De Vay et al. 1990). Although solarization is successful against some of these organisms, the time involved to complete the process and inconsistent results have prevented widespread use of this technique. However, Stapleton & DeVay (1995) reported that the greatest use of solarization as a pest management tool is in greenhouses, organic farms, and backyard gardens.

The main limiting factors to the use of solarization in greenhouse crop production are the long time that areas must remain out of production (1-2 months), the location of many major greenhouse production areas in cooler climatic areas, and the fact that soil temperatures may not be high enough for good control of many pests. However, it may be possible to combine solarization with reduced dosages of chemical fumigants to obtain good insect control.

In parts of Japan, hundreds of hectares of greenhouses that produce cucumber or sweet pepper are treated by solarization for 7 days following crop removal (Horiuchi 1991). The main target pest for this treatment is the melon thrips, *Thrips palmi*. Heating the soil is not the objective in this case, but rather raising the air temperature to heat the crop residue and the thrips that remain on the plants. All plants are pulled from the soil and left in the greenhouse. This treatment results in significant insect reduction within the greenhouse. However, the long-term effects may be minimal because the thrips are found outdoors on numerous hosts and can easily move into the greenhouses when the next crop is planted, unless insect-screening or some other barriers are used.

Some crop advisors suggest leaving the greenhouse vacant for 1 to 4 wk between crops and maintaining normal plant production temperatures rather than cooling the greenhouse. The theory behind this is that insect and mite pests from the previous crop will continue to develop, emerge from soil or other root media, and starve. This has been documented in commercial greenhouses; for example, Costello & Gillespie (1993) found that maintaining greenhouse temperatures at 25/C for 10 days after removing all plant residues killed adults of the pepper weevil, *Anthonomus eugeni*. However, maintaining this temperature in British Columbia winters was too expensive for profitable crop production, so a combination of maintaining 20/C and deploying large numbers of yellow sticky traps to capture adults was used successfully. Keeping the greenhouse cool (2-10/C) between crops allowed pepper weevils to survive much longer (Table 11.1).

Pepper weevils would likely survive for longer periods without food at higher temperatures than smaller insects such as whiteflies and thrips. For these pest groups the greenhouse might not need to remain vacant for more than a few days if temperatures were warm.

Solarization is only practical in a few situations, even if keeping the greenhouse warm between crops would not be too expensive.

Leaving the greenhouse vacant between crops is done more easily with vegetables than ornamentals. Vegetable crops tend to be finished at one time, with greenhouse areas then cleaned and prepared for the subsequent crop. Many greenhouses that produce ornamental crops are never totally empty, either because of the diversity of crops produced or the sequential harvesting and replanting of individual beds or benches of the same crop within a greenhouse. Some specialty crop greenhouses, such as those that produce only bedding plants, or bedding plants in the spring followed by poinsettias in late summer, use this technique by default simply by having large blocks of time between crops.

TABLE 11.1 LT_{50} and LT_{100} in days for adult pepper weevils held without food at different temperatures (modified from Costello & Gillespie 1993).

Temperature (/C)	LT_{50}	LT_{100}
2	11	24
5	13	27
10	12	28
27	4	7

Post-harvest Treatments

One of the most promising areas for the use of temperatures as part of an IPM program for greenhouse ornamentals is in the area of post-harvest disinfestation. Hara (1994) reviewed current practices for post-harvest treatment of ornamental plants. Many greenhouse products, especially cut flowers and foliage plants, are exported from quarantined areas. The presence of insects or mites, whether harmful or beneficial, in flowers or on plants may cause a delay or a rejection of the entire shipment at border quarantine inspection facilities. If flowers must be fumigated as a quarantine treatment, the current fumigants are methyl bromide and hydrogen cyanide. Methyl bromide may not be available in the future due to environmental regulations. Both fumigants can injure flowers, reducing shelf life and/or directly damaging flower parts. Combining warm temperatures with controlled atmospheres and/or methyl bromide fumigation are possibilities to obtain insect and mite control and reduce phytotoxicity (see Chapter 8).

Most of the research on controlled atmospheres in pest management has been with high carbon dioxide or nitrogen concentrations, combined with low oxygen and low temperatures (Hara 1994). For example, one potentially useful method of treating cut flowers is to keep them in an atmosphere containing 30 to 45% CO_2 for one wk at 0-1/C (Seaton & Joyce 1989). Because of the treatment time involved the types of flowers that could be treated are limited to those sent by sea freight. Also, certain tropical flowers are injured at temperatures <10/C.

Temperature also affects the success of fumigation with methyl bromide. Effects are evident on both plants and insects. As a general rule, plant injury increases as temperatures increase. Wit & van de Vrie (1985) found that as treatment temperature increased from 17 to 23/C at 30 gm$^{!3}$ methyl bromide for 1.5 h, phytotoxicity increased in several cut flower crops, including chrysanthemum, carnation, and alstroemeria.

Mortimer & Powell (1984) compared the toxicity of methyl bromide to medium and large leafminer larvae, *Liriomyza trifolii*, on chrysanthemum at 8 and 15/C. As shown in Table 11.2, the percentage mortality of large larvae was affected by fumigation temperature over a range of concen-tration time products (concentration x exposure time), or CTP's, with less mortality at 8/C.

Vapor heat (hot, water-saturated air) and/or hot water treatments may be useful in certain situations (Hara 1994). Vapor heat (43.3/C for 3h)

TABLE 11.2 Mortality of *L. trifolii* large larvae with methyl bromide fumigation of chrysanthemums at two temperatures and 7 CTP's (Mortimer & Powell 1984); British Crown Copyright, MAFF Central Science Laboratory.

CTP (g h/m^3)	*15/C* *% Corrected kill*	*8/C* *% Corrected kill*
61.6	--	100
54.0	100	96
40.5	100	67
34.0	100	55
27.0	91	26
20.2	69	--
13.5	22	--

offered effective control of bulb flies *Eumerus* sp. on narcissus bulbs. The same temperature for 20-30 min controlled gladiolus thrips, *Thrips simplex* , on gladiolus corms.

Hansen et al. (1992) used vapor heat of 46.6/C and 90-98% RH for 1 h and controlled >90% of several insect pests on a range of tropical flowers. Flowers that were not injured included heliconias, red ginger, and bird of paradise; others, including anthurium and dendrobium orchids, were injured by this treatment.

Dips in hot water at temperatures of 44-49/C for 5-20 min are sometimes used to treat plants that do not tolerate fumigation well. As with fumigation, the effects vary and seem to be similar to the reactions to vapor heat. There are several successful examples of this treatment. Complete control of cockerell scale, *Pseudaulacaspis cockerelli*, was obtained on bird of paradise using hot water dips at 49/C for 5 or 6 min (Hara et al. 1993). Dipping cape jasmine cuttings in 49/C water for 10 min killed more than 99% of green scale, *Coccus viridis*, nymphs and adults (Hara et al. 1994). The same water treatment temperature for 12-15 min killed >95% of the ant *Technomyrmex albipes,* the banana aphid, *Pentalonia nigronervosa*, and the mealybugs *Planococcus citri*, *Pseudococcus affinis*, and *P. longispinus* in red ginger flowers (Hara et al. 1996). There was no phytotoxicity when flowers were conditioned in 39/C air for 2 h prior to water treatment, with shelf life more than twice that of flowers not conditioned.

One of the most important insect problems on greenhouse ornamental crops at the present time is the western flower thrips, *Frankliniella occidentalis*, and another thrips of quarantine significance is the melon thrips, *T. palmi*. Hara et al. (1995) evaluated several postharvest treatments on dendrobium orchids for control of these pests, including insecticide dips and hot water immersion. Dipping flowers in 49.5/C water for 15-20 sec reduced thrips infestations but shortened the vase life of several cultivars.

Hot water treatment is also suggested for certain pests on potted ornamental plants, but this use is very limited and probably applicable only for home hobbyists. Baker (1990) listed immersion for 15 min in 43.5°C water as a control for cyclamen mites, *Phytonemus pallidus*, on African violets and cyclamen.

Indirect Uses of Temperatures

Pest and Biological Control Agent Interactions

It is well-documented that temperatures have significant effects on biological control agent (BCA)-host interactions in greenhouses. Usually temperature and relative humidity/vapor pressure deficit (VPD) combine to affect pest and beneficial insect and mite development. Two well-known examples from past research that illustrate the effects of temperature and moisture are biological control of greenhouse whiteflies, *Trialeurodes vaporariorum*, and two-spotted spider mites, *Tetranychus urticae* .

In one of many studies of whitefly-parasite interactions, Helgesen & Tauber (1974) studied how the relationship between the greenhouse whitefly by the parasitoid *Encarsia formosa* was affected by temperature. The relationship between the two insects was evaluated on a greenhouse poinsettia crop and results showed that the most important factors affecting the success of biological control included maintaining greenhouse temperatures at an average of 23.3/C. Other important factors included the number of parasites introduced and the timing of the introductions. The warmer temperatures favored the parasitoid over the whitefly. Lenteren & Hulspas-Jordaan (1983) stated that the intrinsic rate of increase favored the greenhouse whitefly below 20/C. Above 20/C the intrinsic rate of increase was greater for *Encarsia*.

Temperatures in temperate latitude greenhouses where vegetables or ornamentals are produced may not be in these favorable ranges often enough at critical times to ensure successful parasite establishment, if temperature were the only factor. Using the heating system to ensure that these tempertures are maintained will probably not be economical in winter. Also, temperatures that favor the beneficial organism may not be optimal for crop production. Increasing the number of parasites introduced will help overcome some of the problems with lower temperatures, but here again economic factors are important. More parasites and more frequent releases increase costs.

Another well-researched example illustrating the relationships between temperature and BCA-host interaction is the ability of the phytoseiid predatory mite *Phytoseiulus persimilis* to successfully control two-spotted spider mites (Stenseth 1979). This relationship also is affected by temperature, but in a different manner than the whitefly-*Encarsia* situation described above. Relative humidity/VPD also play significant roles. Basically, the predators do best in high humidity/low VPD situations over a wider range of temperatures between 10 and 30/C, than at low humidity/high VPD. Some commercial insectaries offer a “tank mix” of different phytoseiid predators that will thrive under different environmental conditions.

Current research is directed at further elucidating temperature and moisture interactions for many greenhouse pest-BCA combinations, such as the western flower thrips, *F. occidentalis* and predatory mites such as *Amblyseius cucumeris*. Mathematical models are being developed to help predict the effects of these environmental factors on both pests and beneficials (Shipp & Gillespie 1993, Houten & Lier 1995).

Although these recent and past studies have demonstrated that there are some opportunities to manipulate temperature and moisture in greenhouses to favor BCA’S over the pests, the difficulty for biological control implementation in greenhouses is that temperature will not affect all BCA-pest relationships in a consistent manner. However, knowing what the effects are will help predict and/or explain pest management success or failure in a given crop-pest-biological control system.

Temperature and Diapause Regulation

Some beneficial insects and mites enter diapause during short days in temperate latitudes. Temperature manipulation can be used to help prevent this in some cases, although possibly at too high a cost. Morewood & Gilkeson (1991) found that a predatory mite, *Neoseiulus* (=*Amblyseius*) *cucumeris* did not enter reproductive diapause if greenhouse temperatures remained above 21/C. Maintaining these temperatures in temperate latitude greenhouses during winter is extremely costly.

Temperature and Microbial Pesticides

A number of entomopathogenic fungi have been studied for their effects on insect and mite pests in greenhouses. Fransen (1990) reviewed the literature on fungi affecting whiteflies. Although not yet a commercial product, the fungus *Aschersonia aleyrodis* has been thoroughly researched for its effect on the greenhouse whitefly *T. vaporariorum*. Relative humidity is a very important environmental factor affecting the success or failure of this and other fungi, but temperature can affect results as well. *A. aleyrodis* is able to infect *T. vaporariorum* nymphs at a range of temperatures from 15 to 30/C. Infection takes much longer at 15/C than at 25 or 30/C. The best temperature for development of the fungus is approximately 25/C. Greenhouse whiteflies develop well at 21/C, so it is possible for the whiteflies to develop faster than the fungus and escape infection.

Day-Night Temperature Differences

Differences in day and night temperatures may have implications for biological or chemical control. The relationship between day and night temperature is called DIF, and is the average night temperature subtracted from the average day temperature (Nelson 1991). A positive DIF (warmer day temperatures relative to night temperatures) is the norm. A technique used to control the growth and flowering of some plants without using chemical plant growth retardants is to modify the normal day-night temperature relationship to a negative DIF, *i.e.* cooler temperatures during a portion of the day than night temperatures. The temperature reductions are usually done early in the morning for approximately 2 h before and just after sunrise. Apparently, plants react as if these cooler early morning temperatures are the all day temperatures (Ball 1991). Negative DIF will reduce the height of several plant species and reduce the need for chemical sprays to retard height.

Ascerno & Erwin (1991) conducted experiments to determine effects of 16 positive and negative DIF treatments on greenhouse whitefly development. Results showed no overall differences in whitefly survival, with the number of days to first adult whitefly emergence being equal. However, there were significant differences in whitefly developmental stage distribution. There were fewer adults and more immature stages in treatments with the higher night temperatures. If DIF could be manipulated at practical levels to affect whitefly growth stage development, this could affect the success of biological and/or chemical control. Chemical controls could be timed to affect certain whitefly growth stages and/or biological control introductions could be timed to ensure that susceptible hosts were present.

Future Directions

What is the outlook for using temperatures as insect and mite pest management tactics in greenhouses? It is unlikely that the present primary direct uses of temperatures in greenhouse crop pest management (steam pasteurization, solarization) will increase significantly in the future. In a recent review of integrated pest management in greenhouses, Ramakers & Rabasse (1995) did not mention temperature as a primary or significant pest management tool. However, from the information reviewed for this chapter and the examples presented, combining temperature modification with other biotic and abiotic factors (controlled atmospheres, water immersion, and water vapor) for postharvest treatment seems to offer excellent potential for expanded future use. Developing effective postharvest treatments is important, as methyl bromide, the current primary method, appears to have a limited life in pest management because of impending environmental regulations.

It is also likely that the indirect uses of temperature will increase. As greenhouses install more sophisticated environmental controls and monitoring equipment, knowing how temperatures affect pest development, and pest-BCA interactions will be very useful for predicting outcomes of chemical and biological management programs.

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