Integrated Pest Management
of
Thrips tabaci Lindeman [Thysanoptera: Thripidae]
in
Greenhouse Cucumber Production

By

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DEDICATION

To my parents, Helen and Terry, for always emphasizing the importance of education and

encouraging my pursuit of knowledge in a multitude of directions in science and in life;

without whose wisdom and support I could never have made it this far.

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ABSTRACT

Various aspects of integrated pest management (IPM) for onion thrips, *Thrips tabaci* Lindeman [Thysanoptera: Thripidae], in greenhouse cucumber (*Cucumis sativus*) were studied. An experiment was conducted to determine and compare the predation rate of the gravid females of two predatory mites, *Amblyseius cucumeris* (Oudemans) and *Iphiseius degenerans* (Berlese) [Acarina: Phytoseiidae], on first and second instar onion thrips larvae on cucumber cv 'Jessica' leaf disc arenas. Significantly more first instar thrips (3.6 ± 1.13) than second instar thrips (3.4 ± 0.81) were preyed upon by the gravid female mites. There was no significant difference between the predation rate of *A. cucumeris* or *I. degenerans* for either first or second thrips larval instars suggesting that these mites have an equal potential to control onion thrips in greenhouse cucumbers.

The effect of the addition of the volatile chemical attractants, p-anisaldehyde (4-methoxybenzaldehyde) and ethyl nicotinate (3-pyridinecarboxylic acid), to commercially available blue and yellow sticky traps was examined for adult onion thrips in greenhouse cucumber production. Two studies were conducted at separate locations: a commercial cucumber greenhouse and two research greenhouses. There was no interaction between scent and colour at the commercial site. Anisaldehyde significantly increased captures by a factor of 1.7 over ethyl nicotinate and 1.2 times more than the control. Ethyl nicotinate did not increase captures over the control. Blue sticky traps caught twice as many thrips as yellow traps, and yellow caught 5.0 times more than clear. This indicates that blue is the colour of choice for capturing adult onion thrips in greenhouse cucumber production. In the research greenhouses, there was a significant interaction between ethyl nicotinate and yellow traps. This combination caught 1.6 times as many thrips as the next most attractive combination, non-baited blue traps. The factors and thrips behavioural mechanisms for host-finding cues affecting these differential results between locations are discussed. Captures on the non-baited traps of the commercial site data were correlated with leaf samples taken within one metre of the trap to determine if sticky trap captures were indicative of infestation levels on the leaves. There was no correlation between either blue or yellow sticky traps, and a moderate correlation between clear traps and adult thrips captures. Captures of *Orius* predators on scented sticky traps were also examined. Scent did not increase captures of these predators on sticky traps. As reflected in the thrips results, blue sticky traps were 1.4 times more attractive than yellow and 15.0 times more than clear, indicating captures were not incidental and biological control agents may also be susceptible to cues similar to those of their prey.

The spatial distributions of *Thrips tabaci* larvae and adults and the predatory mite, *Amblyseius cucumeris*, on greenhouse cucumbers were calculated using two variance-mean models: Iwao's patchiness regression (IPR) and Taylor's power law (TPL). Both models determined thrips larvae and adults to be contagiously distributed in greenhouse cucumbers with a density contagious coefficient, b_r, (IPR) and index of aggregation, b, (TPL) significantly greater than one. The predatory mites population studies yielded ambiguous results for b_r, according to IPR they were not contagiously distributed while TPL revealed they were. The index of basic contagion, a_r, (IPR) reflected that aggregates were the basic component of thrips larvae populations only. Based on these parameters, Iwao and binomial sequential sampling plans were developed for thrips larvae and adults on greenhouse cucumbers. The economic threshold was estimated at 75 percent of a working economic injury level of 9.5 larvae and 1.7 adults and calculated to be 7.1 and 1.3, respectively. The ensuing maximum sample number to be taken was 66 for larvae and 46 for adults for Iwao's plan. The maximum sample number for the binomial sequential sampling plan was 39 for larvae and 67 for adults. These plans need to be validated before they can be applied to commercial production.

List of Abbreviations and Symbols

a	scaling factor related to sample size (Taylor's power law)
a_r	index of basic contagion (y-intercept of Iwao's patchiness regression)
a.i.	active ingredient
b	index of aggregation (Taylor's power law)
b_r	density contagious coefficient (slope of Iwao's patchiness regression)
cv	cultivar
d	confidence interval of estimated mean density of Iwao's sequential sampling
EIL	economic injury level
ET	economic threshold
h	precision level of maximum sample number of binomial sequential sampling
IPM	integrated pest management
IPR	Iwao's patchiness regression
m	population mean
R^2	coefficient of determination
σ^2	population variance
s^2	sample variance
SD_{50}	saturation deficit
TSWV	tomato spotted wilt virus
TPL	Taylor's power law
VPD	vapour pressure deficit
$\overset{*}{x}$	Lloyd's mean crowding index

ACKNOWLEDGEMENTS

1. LITERATURE REVIEW

1.1 Introduction

Greenhouses cover approximately 150,000 hectares worldwide. They offer an excellent opportunity to grow high quality products in large quantities within a small surface area (van Lenteren 1990). In Canada, there is an increasing trend in total greenhouse area, product volume, and subsequently, revenue. Greenhouse cucumber production alone increased from 735 tonnes of cucumbers in 1995 to 1059 tonnes in 1996 resulting in a $10.20 million increase in revenue in that time period. This trend is reflected in Nova Scotia greenhouse cucumber production where total revenue increased from $1.40 million in 1995 to $1.98 million in 1996 (Statistics Canada 1998).

Unfortunately, greenhouses also provide optimal conditions for development of pest insect and mite infestations due to maintenance of warm temperatures, high humidity, confined growing area, and monoculture. Foliage and fruit feeding arthropods are among the most diverse and destructive pests occurring in vegetables (Trumble 1994). Abundant international trade has resulted in the unintentional import of numerous pests (van Lenteren 1990). One of these pests imported from Europe was the onion thrips, *Thrips tabaci* Lindeman [Thysanoptera: Thripidae]. In North America, the onion thrips has a host range of over 300 plant species and is a recognized economic pest of many crops. Thrips initially invaded greenhouses from nearby fields, however they have successfully adapted to greenhouse conditions (van Rijn *et al.* 1995). Damage due to thrips is caused by feeding on the leaves and fruits or through transmission of virus particles. Due to its high capacity for population growth, broad host range, and potential for pesticide resistance, the pest status of

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the onion thrips remains a concern. The importance of onion thrips in greenhouses is enhanced where insecticidal pressure applied against other pests is relaxed because of biological control programmes (Binns *et al.* 1982). Research and development have successfully identified biological control agents for multiple classes of greenhouse pests such as whiteflies, spider mites, fungus gnats, and aphids. Natural enemies developed for thrips have been inconsistent, and onion thrips are frequently reported to escape these natural enemies and reach epidemic levels. This ultimately requires the use of pesticides which are seldom effective or compatible with biological control agents, thereby disrupting the natural enemy complex established in the greenhouse.

The overall objective of this study was to develop various aspects of an integrated pest management (IPM) programme for onion thrips in greenhouse cucumber production.

1.2 *Thrips tabaci* Lindeman

1.2.1 Taxonomy and synonymy

The onion thrips, *Thrips tabaci* Lindeman [Thysanoptera: Thripidae], has had a stable taxonomic position since it was described by Lindeman (Daniel 1904). The onion thrips features two subspecies, *T. tabaci tabaci* and *T. tabaci communis* (Schliephake and Klimt 1979).

1.2.2 Origin and geographic distribution

The onion thrips originate from Central Asia (O'Neil 1960) and are now known world wide. These thrips were introduced to North America from Europe in the early 1900's (Anon.

1968) and have since become established as serious pests (Edwards and Heath 1964).

1.2.3 Host plants

Thrips tabaci has a number of ecotypes each of which is polyphagous and can be hosted by a wide range of plants (Tommasini and Maini 1995). They infest several species of various families such as the following reported by Sakimura (1932):

Amaranthaceae	Compositae	Gramineae	Malvaceae	Rubiaceae
Araliaceae	Convulvulaceae	Labiatae	Nyctaginaceae	Solanaceae
Boraginaceae	Cruciferae	Leguminosae	Oxalidaceae	Sterculiaceae
Bromeliceae	Cucurbitaceae	Liliaceae	Phytolaccaceae	Umbelliferae
Caryophyllaceae	Euphorbiaceae	Lythraceae	Portulacaceae	Verbenaceae

Practically all plants in the greenhouse are attacked by the onion thrips. Amongst those that suffer most severely are cucumbers, roses, carnations, and chrysanthemums (Metcalf and Metcalf 1993).

1.2.4 Life cycle and behaviour

The onion thrips undergo a six stage life cycle: the egg, two larval instars, prepupa, pupa, and adult (Palmer *et al.* 1989). The delicate, translucent white, reniform (Bailey 1933) egg is laid just under the surface of the leaf and is large (about 0.11 mm wide and 0.22 mm in length) in comparison to the female body (Salas 1994). As the embryo develops the outline of the larva, in particular the eye spots, is visible through the thin chorion and leaf surface. Upon hatching, the shell splits lengthwise and the larva pulls itself out of the shell. Feeding commences immediately (Bailey 1933).

The newly emerged larva is translucent white in colour with comparatively large head, antennae, and legs. It measures 0.29 mm (Bailey 1933) to 0.34 mm (Salas 1994) in length. The body of the second instar is yellowish with variable crimson blotches. This instar averages 0.96 mm in length (Bailey 1993). Both larval instars have two compound eyes, no ocelli, short eight segmented antennae, three pairs of legs, and no wing pads (Salas 1994). The onion thrips larvae are thigmotactic, resting in veins or other distinct grooves close to their emergence sites forming a colony (Salas 1994). The larvae drop from the leaf to pupate on the soil surface or in natural crevices in the soil (Binns *et al.* 1982).

The prepupal stage is considered an intermediate stage between the larva and the true pupa where feeding ceases, respiration is retarded, but no cocoon is formed. Its shape resembles that of the mature larva with a general body colour that is yellowish to orange with translucent white legs and antennae and an average size of 1.01 mm. The eyes are dark orange with a few visible facets. The wing pads are very short, translucent white, with a few scattered setae.

The pupal stage can be divided into two periods: early and late. The pupae are sensitive to light and are also thigmotactic, remaining in enclosed surfaces such as cracks or crevices, during pupation (Salas 1994). In the early stage the colour is orange and the prior red markings are reduced. The body appears shorter and stouter than the prepupa averaging 0.86 mm in length. The antennae are folded back over the head. The eyes are much larger and darker red and the three orange coloured ocelli are visible between the eyes, their location forming a triangle. The wing pads are translucent white, have scattered setae and are extended to the sixth and seventh abdominal segment. The ovipositor is clearly demarked in

the female so the sexes can be readily distinguished (Bailey 1933). In the late stage the antennae come forward, straighten out, and darken. The abdomen begins to exhibit considerable pigmentation, the wings within their cases darken, followed by the legs, then the head, and lastly, the thorax. This reticulation can be seen on the surface of the body. Moulting and emergence of the adult occur at this point (Bailey 1933).

Newly emerged adults are inactive for about twenty-four hours. Feeding begins on the second day and mating occurs after feeding. Of the adults, the male is smaller than the female and has a tapering abdomen (Bailey 1933). Copulation begins on the second day after emergence (males) while oviposition begins on the third day (females) (Bailey 1933). Peak oviposition is within the first ten days (Salas 1994) and may occur anytime throughout the day. Mean fecundity is 37 eggs per female, or 1.9 eggs $\cdot$day$^{-1}\cdot$female^{-1}.

Reproduction may be sexual or parthenogenic. In the wild mating is required to maintain some percentage of males. A large number of males is not required because they are very promiscuous and fertilize a large number of females (Bailey 1933). Although T. tabaci originated in the outdoors, van Rijn et al. (1995) suggests a specific greenhouse population has evolved. In European and British greenhouses, males are virtually unknown (Morison 1957). Parthenogenesis is the most common reproductive strategy employed by imported species as it is the easiest and most direct method of reproduction (Bournier 1983). Onion thrips exhibit thelytokous parthenogenesis in which unmated females produce only female offspring (Lewis 1973). The advantage to this is two fold: first, the population growth is promoted by all female offspring; secondly, at low densities the population growth is not limited by the availability of males (van Rijn et al. 1995). The onion thrips hibernate as adults

in several types of vegetation and residues outside the greenhouse. In late October to early November egg laying ceases, followed by copulation, and finally feeding. There is significant mortality during the five month duration of hibernation (North and Shelton 1986). When females emerge in the spring they are capable of oviposition and can reenter the greenhouse.

Duration of the life cycle is influenced by several factors including temperature, humidity, sometimes expressed as vapour pressure deficit, and suitability of the plant cultivars grown (Allen 1995). In a life history study of onion thrips on cucumber leaf discs at 25°C, *T. tabaci* had an intrinsic growth rate of 0.17 thrips daily (van Rijn *et al.* 1995). The life stadia (in days) were as follows: egg (3.9), first instar (2.1), second instar (3.2), prepupa (1.3), and pupa (2.4). From egg to adult, a total of 12.9 days is required. Including a preoviposition period of 1.9 days, the period from egg to egg was 14.8 days. Atmospheric humidity is of great importance to the survival of the larva. At high temperatures, a relatively high atmospheric humidity (RH > 70%) is necessary if the insects are to reach maturity.

The median adult life stadium of the onion thrips is reported to be approximately 12 days. Total mortality from egg to adult in these trials was nineteen percent with more than half occurring during the second larval instar (van Rijn *et al.* 1995). Temperature was the primary factor affecting mortality - at either end of the temperature range mortality increased. Below 12°C mortality increased due to the extended developmental time. Maximum survival occurred at 23°C (van Rijn *et al.* 1995). During hot months with air temperatures approximately 30°C, populations in the greenhouse may increase steadily for six weeks (Allen 1995). Consequently, *T. tabaci* can have up to ten generations a year (Lewis 1973); however, five to eight are generally encountered (Metcalf and Metcalf 1993).

The flight ability in the thrips is not well developed (Bailey 1933). It is assisted by the curling of the abdomen upwards to separate the wings and hopping (Allen 1995). Thrips' rhythm of flight tends to be random in the greenhouse and is affected by air currents and structures, thus resulting in the development of areas of high densities commonly referred to as hot spots (Allen 1995). Thrips undergo two major dispersal periods a day, one in early morning and the other in late afternoon. These activity periods are natural daily ones (circadian rhythms) and are not influenced by the presence or location of the crop nor cropping practices. Flight activity of thrips may also be influenced by environmental factors. Shipp and Zhang (1997) studied the effect of temperature and vapour pressure deficit on flight activity of western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae]. Humidity expressed as vapour pressure deficit (VPD) is defined as a measure of the difference in air moisture between the saturated and actual water vapour pressure at a specific temperature (Clarke *et al.* 1994). After three hours, thrips exposed to 23°C and VPD of 1.42 kPa showed the greatest flight activity.

Thrips populations are not independent from each other (Suman *et al.* 1980). This behaviour, called contagion, is a departure from a random to a clumping distribution where the presence of one insect in a unit increases the probability of the occurrence of other insects in that unit. These factors may explain the rapid reinfestation observed when thrips are removed or new plants are introduced at any time (Allen 1995).

1.2.5 Economic importance

Feeding by thrips can cause direct and indirect damage. Indirect damage arises from feeding on parenchyma of leaves and subsequent reduction in photosynthetic ability of the plant. In cucumbers, direct damage results from feeding on the fruit causing the fruit to curl and rendering it unmarketable. Damage from oviposition and hatching is minimal (Bailey 1933).

The economic importance of thrips is dependent on their unique, asymmetrical, piercing-sucking mouthparts (Lewis 1973). Both feeding damage and virus transmission are facilitated by the feeding apparatus. Two types of feeding are identified in the thrips: shallow feeding which involves applying the mouth cone directly to the leaf, flower, or fruit surface; and, deep feeding, which involves sucking sap through the stylets (Mound 1971). When feeding is initiated, the mouth cone is applied to the leaf surface. The single left mandibular stylet pierces the membrane, then it is withdrawn rapidly and replaced by the paired maxillary stylets which form a tube, *i.e.* 'tongue and groove' system, which penetrates the deeper cell layers. This tube is supported and protected inside the mouth cone through which fluid passes into the food canal. Liquid is drawn up the food canal by the pumping action of the cibarium which has a valve at both ends to regulate food intake. To aid in feeding, saliva is produced by the labial glands to partially digest food prior to cibarial pumping (Chisholm and Lewis 1984). Saliva could also serve to lubricate the mandible and stylets by flooding the area around the point of insertion, preventing leakage of plant cell contents, and providing adhesion of the mouthcone to the surface and between the protracted stylets (Heming 1978). Probing and feeding removes surface wax from the leaves, exposing the cuticle; thus,

mouthparts were formerly referred to as rasping-sucking (Lewis 1973). With cibarial pumping at a rate of two to six pulsations·second^{-1}, thrips can consume sap at a rate of 8.5x10^{-5} µL·minute^{-1} or 12.5 percent of their body weight per hour (Chisholm and Lewis 1984).

Feeding of thrips is not confined to leaves alone, but to all vegetative parts of the plant. In cucumbers, they concentrate on rapidly growing tissues of the leaves, flowers and fruits (Ananthakrisknan 1979). Feeding in the growing tips and flowers causes deformed leaves and fruits, while feeding on the leaves and fruits causes tissue scarring. Superficial appearance of feeding damage is silvering or streaking and distortion. The cells beneath the pierced epidermal cells are usually completely emptied of their contents. Under intensive feeding many mesophyll cells are totally destroyed with whole chloroplasts, measuring approximately 6 µm in diameter, ingested through the 1 µm diameter mouth cone. Other cells suffer extreme plasmolysis due to contorted grana sacs and the formation of starch grains caused by desiccation (Chisholm and Lewis 1984). The epidermal cells above this internal damage are collapsed, the outer cuticle is wrinkled and appears silvery before turning yellow and brown. This superficial scarring, distortion, and silvering is attributed to shrinkage of the epidermal and mesophyll cells and the penetration of air following the removal of sap. Necrosis and discolouration spread as punctured areas coalesce (Chisholm and Lewis 1984). Cucumbers can tolerate a leaf area loss up to thirty percent before yield is affected (Hussey and Parr 1989). If left untreated, thrips can cause a leaf area loss of twenty percent within nine weeks due to thrips feeding (Jacobson 1995). Although it is necessary to gain control of thrips quickly, thrips populations need only to be maintained at levels sufficient to avoid

economic losses. Damage is accentuated by stress which retards growth (Rossiter 1980).

Disease transmission is another form of indirect damage. Feeding wounds caused by thrips enhance entry and development of diseases by providing alternative penetration sites (McKenzie *et al.* 1993). Fungi can either invade the damaged tissue or grow on the outer surface nourished by thrips faecal deposits (Chisholm and Lewis 1984). Onion thrips are known vectors of viral and bacterial diseases (Lewis 1973). This is particularly dangerous because they have an extensive host range from which diseases can be retrieved. Viral diseases, such as tomato spotted wilt virus (TSWV), are transmitted internally, *i.e.* feeding larvae acquire the virus and transmit it through the saliva of the ensuing adult. Of onion thrips, only the subspecies *T. tabaci tabaci* is reported to transmit TSWV (Zawirska *et al.* 1979) and there have been no reported incidence of transmission of TSWV by onion thrips in Canada (Paliwal 1974). Transmission of virus particles is also achieved externally via infected pollen, where the thrips carry the pollen to susceptible plants and transmit the disease through pollination. Continuous redistribution of thrips in the greenhouse accounts for rapid dissemination of the virus they transmit (Allen 1995).

1.3 Integrated Pest Management (IPM)

There is a need for a more holistic approach to pest management policy which will effectively and safely respond to the need for a wholesome and adequate food supply (Wilde 1981). One control strategy used singly is not likely to disadvantage thrips sufficiently to adequately manage their number and virus spread in greenhouses throughout the year (Allen 1995). Thus, an integrated approach with less dependence on toxic pesticides is necessary

and becoming accepted practice. Integrated pest management (IPM) is a complex approach to pest control which incorporates all available tactics to reduce pest populations to an acceptable level in a cost effective and environmentally rational manner (Murphy *et al.* 1995). Biological control techniques play a crucial part in IPM programmes, but, these strategies also draw on physical and cultural measures. If these tactics fail, pest control can still be accomplished through effective and selective use of target-specific insecticides to maintain fluctuating pest populations below economic injury levels. A 1994 survey indicated that IPM is often used in greenhouse edible crops in Canada and north-west Europe, but is much less common elsewhere (Jacobson 1997). Limiting factors preventing the adoption IPM practices in other areas, particularly hotter climates in the northern hemisphere, include difficulties in combatting sudden and huge pest invasions, speed of development of crops, and the fear of virus infections spread by insects. In Australia and Japan, the limiting factor is the unavailability of biological control agents (Jacobson 1997).

1.3.1 Monitoring

Due to their cryptic behaviour, thrips are difficult to detect in the initial stages of an infestation, thus timing of control measures is difficult. This is further complicated in biological control situations by the slow response time of beneficials to become established and achieve control (Frey *et al.* 1994). Systematic monitoring of the pest and determination of its damaging densities is one of the most important factors determining the long term success of plant protection in greenhouses (Frey *et al.* 1994). Monitoring provides an early means of detecting the pest, enabling prompt intervention with appropriate control measures

before crop yield and quality are affected. It is therefore important to develop and optimize monitoring tools suited for plant producers. The effectiveness of these monitoring tools relies on protocols for deciding on the need for some management intervention based on an assessment of the state of the pest population, and ideally its natural enemies (Binns and Nyrop 1992). These protocols, or control decision rules, consist of at least two components, and possibly a third.

The first component is a procedure for assessing the density of a population. In greenhouse cucumber, the recommended sampling methods for monitoring the population densities of thrips are blue sticky traps (Gillespie and Vernon 1990) and leaf samples (Steiner 1990). Coloured sticky traps are mainly used to detect potentially harmful populations early enough to allow preventive action. Yellow sticky traps are often used in greenhouses because a wide range of pests is attracted to this colour (Shipp 1995). Blue sticky traps are specific to thrips species in greenhouse cucumbers and are well suited for long term monitoring (Frey *et al.* 1994). The number of thrips on such traps is not a reliable indicator of other thrips populations on nearby plants or the amount of damage that has occurred (Allen 1995). It mainly indicates relative population level and overall trends in the population, whether it is increasing, decreasing, or stable. This information helps growers determine action thresholds, which varies not only within crops but within varieties grown. At this point the grower can establish the base upon which to build an efficient control. Management benefits include compatibility with biological control techniques and the ability to assess the effectiveness of control treatments. Yearly trap sampling records provide an indication of when to expect pest invasions in subsequent seasons and likely peaks in activity (Jackson and Scopes 1993).

Because management tactics are directed towards the injurious insect, assessment of pest infestation usually requires obtaining actual counts of the pest. Density (a mean number of insects inhabiting a plant) or intensity (a proportion of plants infested with insects) are typically used as the injury unit (Brewer *et al.* 1994). Plant age does not affect thrips reproduction, whereas leaf age is strongly correlated with resistance of mature plants in the greenhouse (de Kogel *et al.* 1997b). In dual choice assays, thrips preferred younger leaves over older leaves for oviposition, indicating that differences in leaf suitability are an important factor in determining thrips distribution on cucumber plants (de Kogel *et al.* 1997a). Steiner (1990) studied distribution characteristics and established sampling procedures for western flower thrips and its predatory mites on greenhouse cucumbers. Mature, middle leaves were determined to be the most consistent reliable sampling unit for determining thrips densities.

The second component is an economic threshold which is derived from an understanding of the economic injury level (EIL), which is a function of yield and market value of the commodity per production unit, cost of managing the insect per production unit, the injury potential per insect infestation unit, management tactic effectiveness, and the environmental cost-benefit associated with the management tactic (Pedigo and Higley 1992). Steiner (1990) determined a working EIL for cumulative numbers of western flower thrips in greenhouse cucumber of 1.7 adults or 9.5 larvae per leaf sample. Finally, a phenological forecast is often necessary to determine the appropriate time to assess population densities (Logan *et al.* 1979).

1.3.2 Control Measures

1.3.2.1 Cultural and physical control

Management strategies and conditions within the greenhouse must be such that they enhance crop productivity, foster the activity of biological control agents, and hinder the development of pests and diseases (Clarke *et al.* 1994). These methods are considered preventive rather than curative. Vigorous crops are able to tolerate much higher populations of thrips (Rossiter 1980). Sanitation measures begin in and around the perimeter of the greenhouse. Crop residues should be removed well away and downwind from the greenhouse. Weed control inside and outside the greenhouse is essential to eliminate alternate hosts and overwintering sites of onion thrips (Anon. 1993). To reduce the chance of pest carryover, thoroughly clean and disinfect empty structures, allow sufficient time between crop removal and replanting, inspect new stock before introduction in the greenhouse, and avoid overwintering garden or house plants in the greenhouse. Sowing or replanting when another crop is in proximity should also be avoided. Optimum nutrition produces sturdier plants that are better able to withstand attack. Monitor potassium, nitrogen ratios, and calcium levels because they are associated with plant resistance.

Environmental factors can alter host susceptibility to attack, pest population levels, host or pest phenologies, or pest occurrence in a host (Higley and Peterson 1994). Manipulation of the greenhouse environment is one of the most underutilised methods of discouraging thrips establishment in the greenhouse. Microenvironments exert a significant influence upon the behaviour and population dynamics of arthropods (Willmer 1982) and the greenhouse represents a plant production system where critical control of environmental

parameters is feasible (Shipp and Gillespie 1993). Temperature and humidity or vapour pressure deficit have been shown to affect thrips development and flight activities (Shipp and Zhang 1997) and influence effectiveness of biological control agents in the greenhouse (Shipp *et al.* 1996). Growth, reproduction, and survival of insect pests can be positively correlated with nutrients in their food. Some plant nutrients are components of antifeedants and toxins or are present in forms that are not readily utilizable by the insects (Hunt *et al.* 1998). In modern hydroponic systems, control of plant nutrition and crop growth is a promising method for controlling greenhouse pests.

Many consider plant resistance a separate category in control measures, but the choice of crop variety grown is a management decision. Host-plant resistance offers the most potential for future advancements in pest management (Anon. 1993). Varietal resistance to thrips has been found in peppers, lettuce, and tomatoes (Mollema and Cole 1996), cabbage (Shelton *et al.* 1983), chrysanthemums (De Jager *et al.* 1993), and roses (Gaum *et al.* 1994). In greenhouse cucumber cultivars, resistance linked to amino acid content has been recognized. In greenhouse trials, these cultivars lived five weeks longer than registered cultivars before succumbing to attack. Unfortunately, these cultivars are unable to compete with market leaders in yield or quality (Long 1995). These cultivars provide genetic material for future breeding programmes.

Screening the vents is a physical control that may be employed. However, the mesh size required to exclude thrips would be so fine, it would become expensive and decrease air flow (Anon. 1993). Another solution is to suspend polyfilm several inches above the crop in strategic locations (Allen 1995). When placed between benches and along walkways it can