DISTRIBUTION OF SIX-SPOTTED MITE, GREENHOUSE THRIPS AND BROWNHEADED LEAFROLLER IN AVOCADO ORCHARDS

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ABSTRACT

During the 2002-2003 season research was carried out to validate and improve the AvoGreen® sampling methodology. Studies of the spatial distribution within blocks of leafrollers, greenhouse thrips (GHT) and six-spotted mite (6SM) were undertaken. Pest distribution within blocks was studied in the Far North, Whangarei and Bay Of Plenty regions. All the trees in a block were sampled from the ground with 10 shoots or five fruit sites/tree inspected. The results showed that leafrollers and GHT were irregularly distributed throughout the blocks, while 6SM populations were also irregular but tended to a more even distribution at higher population densities.

Vertical distribution of leafroller caterpillars and GHT on host trees was investigated by sampling at three height strata for 10 trees in each block. The results indicated that the height of sampling did influence the number of thrips or caterpillars found, in contrast to the previous season.

Degree-day models for predicting armoured scale and GHT infestations were evaluated. For armoured scale, the observed infestation of fruit by the second generation was in good agreement with that predicted from a phenological model based on a generation time of 1,056 degree-days. For thrips, degree-day accumulations, and therefore the timing and number of generations, varied little between regions indicating that this aspect did not account for the variation among regions in pest status of GHT.

The use of pheromone traps to measure leafroller populations was investigated as an alternative to the standard technique of caterpillar monitoring. AvoGreen® monitoring data was compared to trap catches in two Bay of Plenty orchards. The number of male leafroller moths caught in pheromone traps did not reflect the number of caterpillars present in the orchard.

Keywords: Degree-day accumulation, leaf distribution, spatial distribution, asymmetric distribution

INTRODUCTION

AvoGreen® is an IPM system where pest management decisions are based on assessments of the pest populations within an orchard. The sampling methodology used must deliver robust assessments of the pest population, in order for control decisions to be effective. Brookbanks and Steven (2002) evaluated the sampling methodologies currently used within AvoGreen for two of the major pests of avocado in New Zealand, leafrollers and greenhouse thrips (GHT). They found that for these pests the AvoGreen sampling methodologies were generally adequate. However, the results were derived from a single season of data and therefore further research was undertaken. The second season of study focused on evaluating monitoring systems for six-spotted mite (6SM) and armoured scales, and also included continued research on both leafroller and GHT sampling to substantiate previous findings. A major aim was to explore alternative methods for determining the risk a pest presents to the crop, and to investigate possibilities for reducing monitoring costs in order to maximize the financial benefits of the AvoGreen system.

Six-spotted mite *Eotetranychus sexmaculatus* has continued to infest avocado orchards throughout the major growing districts of New Zealand. Its feeding results in varying degrees of damage up to severe leaf fall. Monitoring for 6SM incidence and abundance is difficult at low infestation levels, when the distribution within an orchard block is thought to be most irregular. The consequences of failing to detect a "hot spot" could be that severe damage results in part of a block. The sampling strategy of repeatedly visiting marked trees is likely to be less effective in detecting an irregular pattern than random sampling of trees on each visit. The latter method should better deal with the observed pest ecology and so provide more robust information to determine the risk level to the crop.

The current system for determining armoured scale levels is based on sampling of inner canopy leaves. Armoured scales (latania scale *Hemiberlesia lataniae* and greedy scale *H. rapax*) result in cosmetic damage to fruit surfaces and become a quarantine issue where fruit is destined for some Asian markets. Phenological studies of insect populations generally use a starting date or biofix that relates to a distinct life history event (Blank *et al.*, 1995). For these armoured scale species the biofix is an arbitrary date since egg production and crawler release occurs through much of the year although it is limited by low temperatures over winter. Blank used the 1st August as the starting date in a study of greedy scale phenology on taraire trees. Knowledge of the timing of important life cycle events can help determine when control strategies are required (Blank *et al.*, 1995).

Under the current AvoGreen monitoring programme for leafroller caterpillars (which is actually a number of species, principally brownheaded leafroller *Ctenopseustis obliquana*), terminal shoots are monitored from fruitset until January when scouts switch to fruit bunches. Tomkins *et al.* (1987) found a relationship between pheromone trap catches in apple orchards and the numbers of gravid females caught in port wine traps suggesting that pheromone trap catches could predict the risk of leafroller damage (Bradley *et al.*, 1998). As pheromone traps are simple to operate, their use as an alternative monitoring technique for avocados merited investigation.

The current study evaluated the AvoGreen monitoring protocols through assessments of spatial and vertical distribution. It also included a study of the phenology of armoured scale invasion of avocado fruit, and examined the relationship of scale infestation to degree-day accumulation using Blank's model. Regional degree-day temperature data over the last season and a greenhouse thrips degree-day model were used to determine whether regional effects on development times could explain regional differences in pest status. Leafroller pheromone trap data and AvoGreen monitoring data from two BOP orchards were compared to determine if any pattern of correlation existed between them.

MATERIALS AND METHODS

Pest distributions were investigated in six orchard blocks spread through the Te Puke, Katikati and Far North regions (Table 1). In each block a one off "snap-shot" sample was collected at various dates between September 2002 and April 2003. Table 1 indicates whether spatial or vertical distribution (to determine if there was a pattern of height stratification) was being studied in each case. AvoGreen sampling protocols were used to determine pest levels within an orchard block. Tree selection was random on each occasion.

Table 1. Details of orchard blocks monitored

Region and site	Aspect Studied	Sampling date (s)	Tree Age, Spacing and Height	Pest Sampled
Awanui	Spatial	26.10.02	3 yrs, 7x7m, 2m high	6SM
Whangarei	Time of fruit infestation	Feb – June 03	5 yrs, 7x7m, 4m high	Armoured scales
Katikati A	Spatial	17.9.02, 29.1.03	10 yrs, 8x8m, 5m high	6SM Leafrollers
Katikati B	Spatial	13.3.03	5 yrs, 8x8m, 4m high	GHT
Katikati C	Spatial	08.4.03	3-10 yrs, 8x8m, 4-6m high	Leafrollers GHT
Te Puna	Vertical	20.3.03	15 yrs, mixed spacing, 8m	Leafrollers GHT
Te Puke	Spatial, vertical	18.2.03	20 yrs, 20x20m, 8m high	Leafrollers

Timing of scale infestation of fruit, and scale development

A study was conducted on a Whangarei orchard in which five fruit on each of 22 trees were tagged in January and assessed monthly until June. Temperature data was collected using a Tiny Tag TGU-1500. A development base temperature of 9.3°C was used to calculate degree-day accumulation with overall mean generation time based on 1,056 degree-days (DD) (Blank *et al.*, 1995). Temperature data was collected from 1st August 2002 until July 2003 when the loggers were removed for analysis. A comparison of the infestation of inner and outer canopy leaves was carried out in June, and scale position on the leaves noted. No organophosphate or other scale-killing insecticides were used on this block during the study period.

Spatial sampling
All trees within a block, with a minimum of 30 trees, were sampled from the ground using either one of two methods. These were:

a) 10 terminal shoots/tree monitored for 6SM and leafroller presence (between 17th September and 20th March); or
b) five fruit clusters/tree monitored for leafroller presence and damage, and the presence of larvae or adult GHT, and thrips damage (mid-February to April).

Vertical sampling
Ten trees per block were each sampled at three height strata, although the actual height bands above ground varied slightly. A total of 100 terminal shoots and/or 50 fruit sites were monitored at each level, giving a total of 300 terminal shoots or 150 fruit sites per block.

Pest monitors also recorded the compass quadrant within which leafroller larvae or GHT were found, i.e. N, E, S or W. Excel surface charts were used to depict the distribution of pests in a block.

RESULTS AND DISCUSSION

Armoured scale infestation and development
During the assessment period the total degree-day (DD) accumulation using 9.3°C as base temperature reached 1,056 by late January- early February (Figure 1). The crawler is the only motile stage in the life cycle of armoured scales so that, assuming that the first generation started on the 1st August, and that the only substrate present at that time was leaves (i.e. no fruit), then there should be no scale present on fruit until the second generation crawlers emerged.

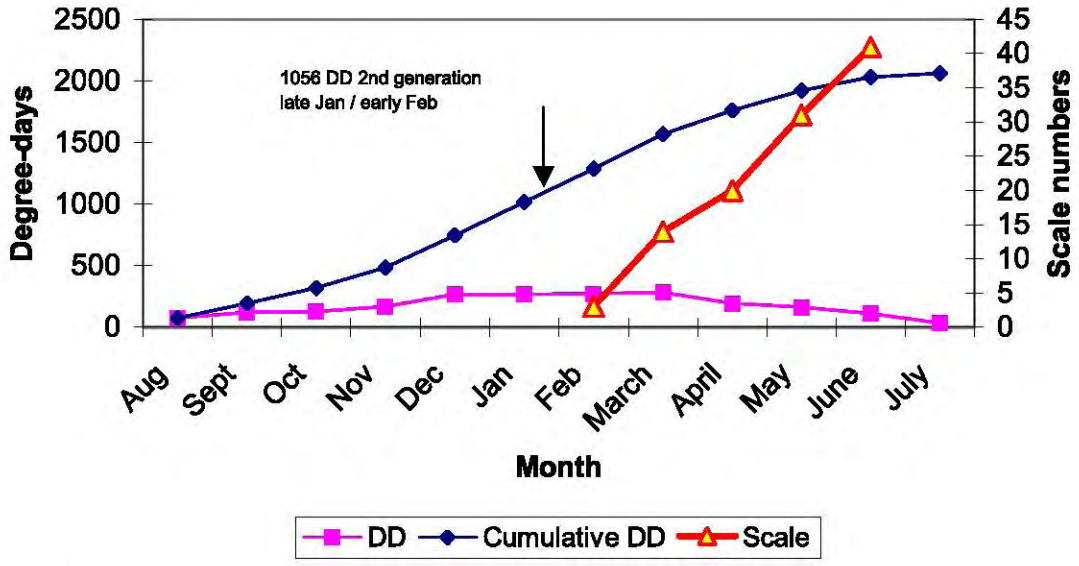

Figure 1. Growing degree-day (DD) accumulation with a base temperature of 9.3°C in relation to observed scale numbers from 1st to 3rd instar for a Mid North orchard.

The appearance of second generation scale (1st instars or whitecaps) was in agreement with the calculated generation time. The model predicted no further generations of scale would be completed that season, which again agreed with the field monitoring data.

Distribution of scales on avocado leaves

Leaf sampling showed a significantly higher ($p<0.005$) level of infestation on leaves taken from within the canopy (28 scale/100 leaves) than on leaves from the outside (12 scale/100 leaves) ($chi^2 = 13.8$, $p_{1df, .005} = 7.88$). This suggests that on this site the infestation originated within the tree rather than coming from external sources e.g. shelter species such as willows and poplars. In other crops external sources can often be very important (Anon. 2003). Similar percentages of scales were dead in samples of inner and outer canopy leaves indicating that either the inner canopy is a preferred site, or that there is differential mortality of the crawler stage before it settles. Gerson and Zor (1973) also found that the inner parts of avocado trees in Israel were consistently more heavily infested than the outer parts.

Of the scale found, 21% were in the middle third of the leaf, generally close to the main vein, and 78% in the basal third of the leaf, also generally by the main vein. Crawler settlement of scales follows a characteristic pattern on a host plant, and *H. lataniae* was found inhabiting mainly the basal part, around the main rib, on both sides of avocado leaves in Israel (Gerson and Zor, 1973). Infestation in New Zealand was predominately (*ca* 95%) on the underside of the leaves. The higher number of scale found on inner canopy leaves supports the current AvoGreen protocol of sampling inner canopy leaves.

Spatial analysis of leafroller, greenhouse thrips and six spotted mite

Results from the whole block monitoring showed an irregular distribution of both leafrollers and GHT throughout the blocks sampled (Figures 2 and 3). The Katikati site was narrow but had more infested trees along the SW side than the opposite side. In the previous year leafrollers were found more abundantly at the southern end of the block sampled. For the Te Puke and Katikati A sites 46% and 58% of trees were infested, respectively. This was a relatively low infestation level for this time of year when infestation is usually high. When the number of samples per tree was doubled to 20 shoots/tree, 80% of trees were found to be infested, an increase of 22% (Figure 4). This demonstrates that there is a linkage between sample size and any reaction threshold set. Note, however, that the distribution retained the same pattern for both sampling regimes.

In the Katikati block 6SM egg and adults infested 86% and 89% of the trees, respectively. Figure 5 shows the distribution of 6SM motile stages, with a very similar pattern recorded for 6SM eggs. There appear to be at least four foci of infestation. The block faced south with pine shelter to the W, N and E. The distribution of 6SM in the Far North block sampled was more uniform with 77 % of trees infested, but there were still hot spots with much higher population densities (Figure 6). The infestation was higher at this site than at Katikati, which may well have contributed to the apparent uniformity. At this site the external shelter was pine trees and there was internal shelter of elephant grass.

GHT motile and immature stages infested 70% of trees in Katikati B orchard (Figure 7), while 79% of trees were infested by this pest in Katikati C orchard (Figure 8). In both cases a few

foci of infestation were apparent. Leafroller levels were too low in the latter block to provide any meaningful data.

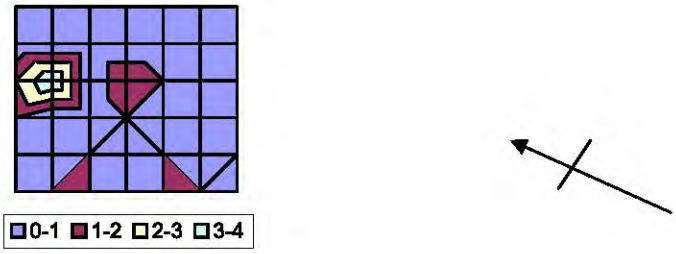

Figure 2. Distribution of leafrollers (number per tree) in an orchard in Te Puke, 18th February 2003.

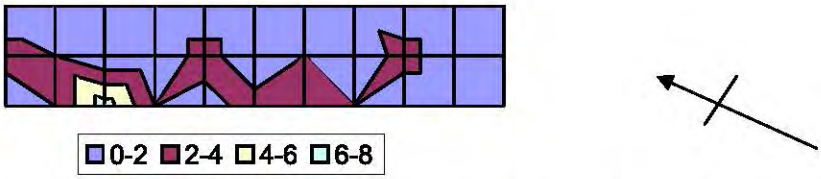

Figure 3. Distribution of leafrollers in Katikati orchard A, 29th January 2003 based on a sample of 10 leaves/tree. Block of 10 trees/row by 3 rows

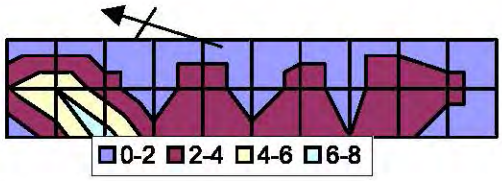

Figure 4. Distribution of leafrollers in Katikati orchard A, 29th January 2003 based on a sample of 20 leaves/tree

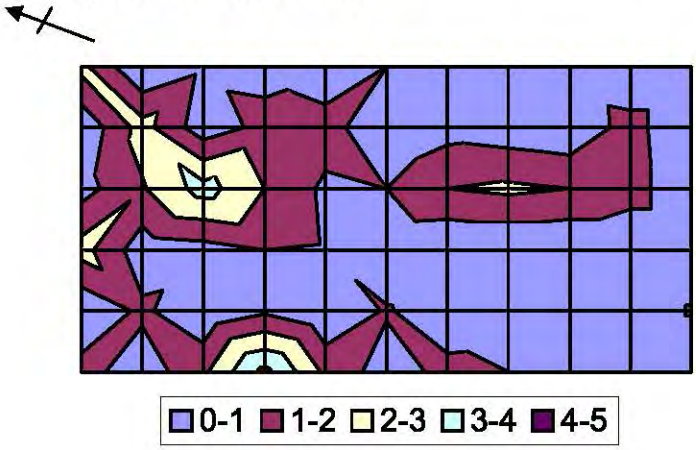

Figure 5. Distribution of 6SM motile stages (mites/leaf) in Katikati orchard A, 17th September 2002.

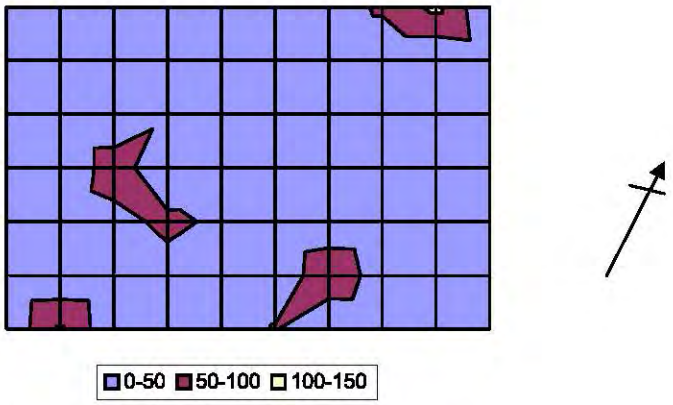

Figure 6. Distribution of 6SM in a Far North orchard

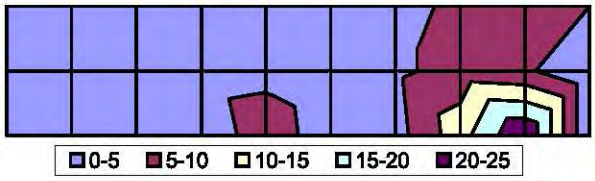

Figure 7. Distribution of GHT in Katikati orchard B, 13th March 2003

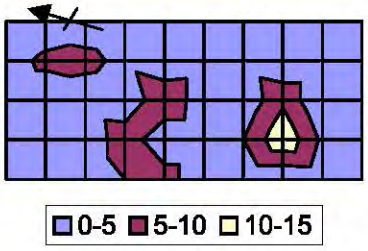

Figure 8. Distribution of GHT in Katikati orchard C, 24th March 2003

Asymmetric distribution through compass quadrants.

The aspect or compass quadrant within which GHT were found on trees is presented in Table 2. In both Katikati B (Organic) and C (Conventional) the highest incidence of immature and adult thrips were found between touching fruit in the NE quadrants, with the adult incidence the same in each block at 87%. One tree contributed the total number of immature stages found on the S aspect of the tree in Katikati B block. A correspondingly high number of adult thrips were found on the northern side of the same tree. Numbers tended to be lowest in the SW quadrant.

Table 2. Asymmetrical distribution of GHT through compass quadrants.

Quadrant	Katikati B, 13 March 2003				Katikati C, 24 March 2003			
	Immature	%	Adult	%	Immature	%	Adult	%
N	31	41	22	53	7	20	17	27
E	15	20	14	34	25	74	39	60
S	21	28	3	8	0	0	5	8
W	8	11	2	5	2	6	3	5
Total	*75*	*100*	*41*	*100*	*34*	*100*	*64*	*100*

Vertical distribution

This year sampling from the ground up to 2m found no leafrollers or greenhouse thrips with these pests only found in samples taken from higher strata (Table 3). Pests were not evenly distributed across strata. At the Te Puke site Lorsban 50WP was applied by helicopter on 23rd December 2002 and Averte on 22nd February 2003. This differs from the previous year's findings when there was a more even distribution among vertical strata (Brookbanks and Steven, 2002). The same block was used in both seasons. However, there was a much lower crop load in 2003, with few fruit in the lowest strata, and this is likely to have affected the result obtained.

Table 3. Vertical sampling results for leafroller caterpillars and GHT on 20th March 2003 and results of chi-squared analysis. LR = Leaf roller, GHT A = Greehouse Thrip adult, GHT L = Greenhouse Thrip larvae, Gd = ground.

Orchard	Date	Pest	Height in each stratum				
			Gd	5m-6m	7-8m	χ^2	Significance
Te Puna	20.3.2003	LR	0	10	2	14.0	p<0.005
		GHT A	0	2	9	12.1	p<0.005
		GHT L	0	5	1	7.0	p<0.005
Te Puke	20.2.2003	LR	0	79	126	118.6	p<0.005

Pheromone trapping versus monitoring

Leafroller pheromone traps at a Kauri Point orchard caught several moths at irregular intervals and caterpillars were frequently found during monitoring (Figure 9). However, there is no clear pattern of results or correlation between pheromone trap and monitoring data. Numbers of moths trapped and caterpillars found were very low, so that any interpretation must be tentative. Brown-headed leafrollers take 44.1 days to develop from egg to adult at 25°C constant temperature (Clare and Singh, 1990). Constant laboratory conditions bear little relation to variable outdoor conditions, but the average temperatures prevailing at that time of year would be considerably less than 25°C, giving a longer time for full development of the caterpillar stage. Thus the caterpillars found could have originated from moths flying up to at least 50 days previously. However to relate flight times to any subsequent find of caterpillars, we would need to know the duration of the egg stage, the age of caterpillars found and the time required to reach that stage at prevailing temperatures. The current case simply serves as an example of the delay between adult flight and larval detection.

At Athenree in the western Bay of Plenty, leafroller flights were recorded in pheromone traps on the 24th February, 16th March and 8thApril, while AvoGreen monitoring only detected leafroller larvae on the 2nd April, 38 days after the first flight recorded (Figure 10). However, as with the Kauri Point site there is no clear pattern of results.

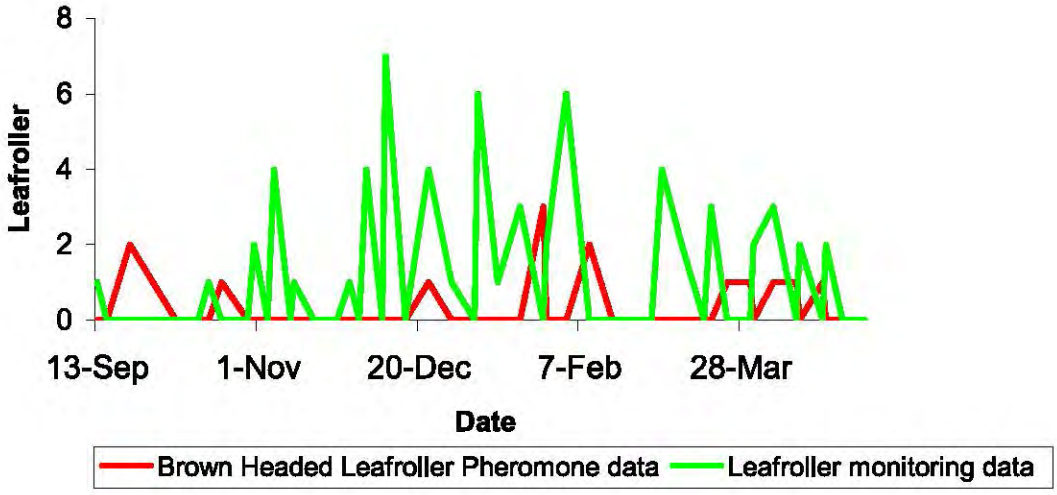

Figure 9. Leafroller flights at Kauri Point September 2002- March 2003.

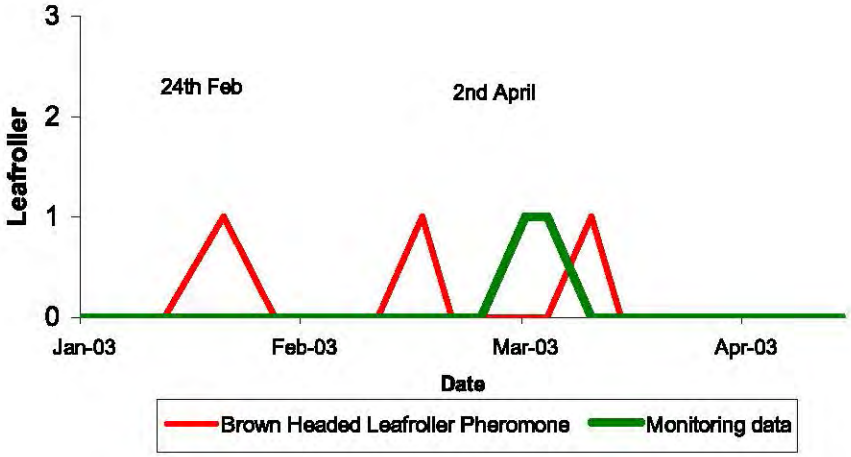

Figure 10. Leafroller flights at Athenree January –May 2003

Greenhouse thrips biology

Rivnay (1935) studied the effect of temperature on the rate of development of GHT in detail. At 23°C the development time from egg to the pre-oviposition period was 42 days, while at temperatures below 10°C there was no insect development. He determined the thermal constant (Th.c) to be 504 degree-days (Rivnay, 1935). Using this, a degree-day model for

greenhouse thrip development was applied to temperature data from three major growing regions, the Mid North, Katikati and Te Puke. The biofix was set as late September 2002. The generational time, 504 DD, was reached in all regions at similar dates (Table 4), all within an 11-day window. This is less than the variability shown in the duration of life cycle when GHT is reared under constant conditions (Bodenheimer, 1951).

Table 4. Regional degree-day (DD) accumulation with number of days taken to accumulate 504-degree days, and the date on which this was attained.

Region	Number of days	504 DD Dates
Mid North	168	15th Jan 2003
Katikati A	159	6th Jan 2003
Katikati B	162	9th Jan 2003
Tauranga	164	11th Jan 2003
Te Puke	157	4th Jan 2003

Practical implications

The scale phenology study identified that only two generations per season occurred. This is similar to the situation in kiwifruit (Steven, 1999). Scale controls are best targeted at the crawler and first instar stages. These occur 1) from mid-September on when the crawlers of the first generation move onto leaves and 2) from mid-February onwards when the second generation crawlers move onto new fruit. Practically, targeting control options at the first stage in September is limited to DC-Tron Plus applications as this has no withholding period (WHP), whereas organophosphate sprays have WHPs varying from 49 –210 days. Control of the second generation in February can use more options, assuming all mature fruit have been harvested. These include Attack, Averte, Diazinon and DC-Tron Plus. However, as crawler production in these armoured scale species is protracted over several months timing sprays to target crawler production is less effective than in soft scales where crawler production occurs over a short period (Steven, 1999).

The validity of the simple degree-day model indicates that growers or AvoGreen operators could use regional weather stations to help time spray applications for scale control. However, the extended period of egg production in these armoured scale species precludes this approach from conferring significant advantages. The studies of scale distribution on leaves indicates that the current AvoGreen monitoring protocol, which recommends sampling leaves from the inner canopy, is appropriate and can be continued as a valid sampling method. The restricted spread of scales across leaves does offer ways to refine the sampling protocols.

The spatial analyses indicate the need for a sampling system to adequately deal with the irregular distribution patterns of both leafrollers and GHT in blocks. There is a need to better understand both the causes of local irregularities or hot spots, and the variability of results from year to year. The AvoGreen protocol does suggest that blocks be stratified to deal with areas that repeatedly have greater infestation levels of any particular pest. The sampling had been

carried out when pest levels were anticipated to be high although the Te Puke and Katikati A blocks had relatively low incidences of leafrollers. Many factors can influence populations including climatic, biological and management variables, and those that are critical should be factored into the sampling protocols. However, accuracy and cost-effectiveness are opposing forces when determining optimal sample size and frequency. Stratification is a way to try to balance these aspects.

Targeting sites within a tree that are most likely to be infested by major pests at particular times of the year is a technique to make sampling more effective and cost-efficient. For example the site provided in March by touching fruit will harbour both GHT and leafroller larvae, which allows targeted sampling for both pests.

The change in the level of leafroller infestation when the sample size was doubled shows how the detection of pests is affected by sample size, and thus the need to link action thresholds to the sampling process employed. In general, conservative action thresholds are used in AvoGreen to provide a safeguard against variability.

Distribution of 6SM in blocks appeared to show hot spots that could not be easily explained by obvious features of the local environment. More extensive studies of a range of situations are required to determine whether random sampling each time or the use of marked trees would have significant advantage, especially in determining incipient infestations. Low infestation levels are generally better determined through random sampling. Local research has not yet determined what level of mite infestation is responsible for leaf drop. Without this, any speculation on a threshold is premature. Indeed many factors may influence the risk of damage, such as the crop stage, occurrence of tree stress, and level of mite infestation.

The asymmetric distribution of GHT within each tree confirms the findings last year that both stages of GHT were more numerous on the warmer aspect of the tree (Brookbanks and Steven, 2002). Note that the apparent reversal in the Katikati B orchard for thrips larvae was due to the results on a single tree. When monitoring specifically for GHT, focussing on fruit sites in the NE quadrant of the tree would save time.

The contrast in the vertical distribution of leafrollers and GHT this year does demonstrate the need to have an extensive data set covering more than one year in order to be confident that that the orchards sampled are representative of the general industry situation. The fact that neither pest was found in the ground level stratum was probably caused by a low crop loading in 2003. When fruit are scarce, fruit clusters are limited and the AvoGreen protocols allow fruit with touching leaves to be used instead. However, the effect of this substitution has not been directly investigated. High infestation levels in the tops of the trees even though helicopter applications of general insecticides had been used earlier do cast doubt on the efficacy of the control measures undertaken. GHT are known to prefer avocado fruit to leaves (P. Stevens, *pers. com.*), especially in shady sites, so that predominance in the tops of trees would appear to be an anomaly.

With leafrollers, the pheromone trap data showed little correlation with the monitoring results. The two different measurements of activity could not be related using available laboratory data

on development. However, the pheromone catches did not exceed 3-moths/trap/week, which indicates a low level of moth activity. Considerably more work would be required to determine if there is any benefit from using traps as an indicator of pest pressure.

The use of air temperature data to model the development times of GHT in various regions showed little difference among regions. The small differences noted were less than the variability among individual thrips noted in the research used to establish the degree-day model (Bodenheimer, 1951). This limits the usefulness of such modelling as a practical control tool. Relative humidity can also have a critical influence on the development of some stages of GHT (Bodenheimer, 1951), and further studies may demonstrate that this aspect can explain the regional differences observed in New Zealand in the importance of GHT as a pest of avocados.

CONCLUSIONS

A variety of investigations were conducted in order to gain basic information needed to test the assumptions incorporated into the monitoring protocols for the AvoGreen IPM system. This is part of on an ongoing process to refine and improve the protocols. IPM systems have to be robust in order to cope with the variability experienced both from season to season and among regions within any season. This is illustrated by the differences in the vertical distribution of greenhouse thrips and leafrollers found this season and last. In a similar vein IPM systems have to balance the need to estimate accurately the risk of pest damage (which drives an increase in sample size and frequency), against pressures to make monitoring more cost effective by minimising sampling. The heterogeneity of pest populations, especially with regard to spatial distribution, is of prime importance in optimising sampling systems.

Two further techniques can be effectively used to optimise sampling. The first ensures that pest pressure in an area being sampled is as homogeneous as possible by stratifying the area in relation to physical or biological features known to affect particular pests. Separately sampling outer rows adjacent to shelter trees known to host scales is an example of this approach. The second uses either pest phenology or the past history of an orchard to target sampling at critical times for specific pests.

The current studies have focussed on improving basic aspects of the sampling systems used in AvoGreen, but have also begun the research needed to determine the pest distribution and hence its heterogeneity and the underlying causes of this. Such information can be used to model the effects of adopting various sampling strategies.

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