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Integrated control of *Tetranychus urticae* with *Phytoseiulus persimilis* and *Stethorus bifidus* in commercial raspberry gardens

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Abstract Two-spotted mite (TSM) (*Tetranychus urticae* Koch) control was studied in commercial raspberry gardens in Nelson and Hastings. In both regions, the predators, *Phytoseiulus persimilis* Athias-Henriot and *Stethorus bifidus* Kapur, were found regularly on foliage samples in association with TSM. In Hastings, both predators showed a clear numerical response to TSM and populations of all three species increased and declined cyclically. The cycles were not always in phase among the different cultivars of raspberry. *S. bifidus* was an important predator when *P. persimilis* populations were low and unevenly distributed through the property especially in spring. *P. persimilis* controlled TSM in 6–8 weeks in a favourable pesticide environment and, on one cultivar in the Hastings property, no miticides were needed during a 2-year period. When chemicals toxic to *P. persimilis* were used (e.g., benomyl and methomyl), TSM increased to potentially damaging levels although no quantitative assessment of damage was made. *S. bifidus* was killed by organophosphate and carbamate insecticides, but TSM was controlled by *P. persimilis* when carbaryl, azinphos-methyl, and *Bacillus thuringiensis* were used against pests and when iprodione and captan were used against fungal diseases.

Keywords two-spotted mite; *Tetranychus urticae; Phytoseiulus persimilis; Stethorus bifidus;* integrated control

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INTRODUCTION

The two-spotted mite (TSM) (*Tetranychus urticae* Koch) in New Zealand is an important pest of raspberries (*Rubus idaeus* L.) on which prolonged feeding by high numbers of TSM can cause premature defoliation. Although quantitative studies of mite damage have not been carried out in New Zealand, TSM injury to raspberries in the United States increased the susceptibility of dormant bud tissues to injury by cold temperatures, and also reduced starch and sugar reserves in overwintered canes (Doughty et al. 1972). For early season (main crop) cultivars, peak populations of TSM in New Zealand usually occur after harvest and, if necessary, can be controlled by miticides. However, in recent years, the production of autumn-ripening cultivars such as 'Heritage' and 'Southland' has increased, especially for the fresh export market. These cultivars have an extended harvest over 6–8 weeks in February and March when TSM populations are likely to peak. Effective miticides cannot be applied during this period because they leave unacceptable chemical residues on the fruit.

Phytoseiulus persimilis Athias-Henriot is a voracious predator of TSM in the laboratory and in glasshouse crops where it has successfully controlled TSM in biological or integrated control programmes in New Zealand (Burgess 1984) and other parts of the world (e.g., Hamlen & Lindquist 1981; Mori & Saitô 1981; Hassan 1982; Vacante & Firullo 1983). The effectiveness of *P. persimilis* on outdoor crops has been less well studied. TSM was controlled on strawberries in California by annual mass releases of *P. persimilis* (Oatman et al. 1968) which, after the release of a different strain, has now established in parts of California (McMurtry et al. 1978). *P. persimilis* also controlled TSM in vegetable crops in New Caledonia (Cochereau 1976). In New Zealand, *P. persimilis* has become widely established (Walker et al. 1981) and, during the past few years, has consistently survived the winter outdoors to attack new TSM populations in spring. We know of no other occasions when *P. persimilis* has survived a whole year on outdoor crops, and when the predator may be regarded as a permanent feature of the crop system.

This paper describes observations and experiments made during a 4-year period in Nelson and

Hastings to determine whether *P. persimilis* could be an effective predator of TSM in commercial raspberry crops in New Zealand. Raspberries in all the observed gardens were grown in hedgerows on a post and wire trellis which is typical of commercial production in New Zealand.

MATERIALS AND METHODS

Nelson

General observations were made on all species of mites and their predators from 1980 to 1984 in up to 6 berryfruit gardens each year in the Nelson area. All raspberries examined were early-season, main crop cultivars, predominantly 'Marcy'. Foliage samples were taken irregularly, but about every three weeks after TSM were first noticed. Fifty whole leaves were collected at random from within each block, and were selected equally from the upper and lower halves of the trellis. The proportion of leaves containing pest mites and predators was recorded. More detailed work was initiated in Hastings, partly as a consequence of apparent biological control of TSM in the first 2 years of study in Nelson.

Hastings

Mite populations were studied intensively in one commercial berryfruit garden in Hastings, Hawke's Bay, throughout the 1982–83 and 1983–84 growing seasons. The 2.5 ha property contained blocks of several cultivars of raspberry, and the bramble 'Olallie' (*Rubus ursinus* cv. Olallie). A grass sward was maintained between the rows and around the headlands and this contained several weed species that are known hosts of TSM, especially field bindweed (*Convolvulus arvensis*), mallow (*Malva* spp.), clover (*Trifolium* spp.), and dock (*Rumex* spp.). In both seasons, observations were made on TSM and its predators from the cultivars 'Haida' (harvested in December–early January) and Heritage (harvested from the beginning of February until the end of March). These cultivars were chosen because of their different management techniques and because it was suspected that Haida was particularly susceptible to TSM. In Haida, dormant primo-canes were retained during winter and fruit developed from lateral buds in spring, whereas Heritage canes were removed at ground level in autumn, and new primo-canes grew in spring and fruited in late summer.

In all properties in both districts, cultural and management activities, with the exception of chemical pesticide applications, were carried out according to normal commercial practice. In Nelson, insecticides were applied according to the Ministry of Agriculture and Fisheries (MAF) recommended schedule, and miticides were applied if TSM was considered a problem after harvest. In Hastings, insecticides and fungicides were initially applied according to the MAF recommended schedule, but this was sometimes modified to be compatible with predator activity. No miticides were applied during the study period. Pesticides were assumed to be directly toxic when reductions in numbers of mites or insects per sample were accompanied by the presence of their corpses on sprayed leaves. Sublethal toxicity (e.g., sterility) was detected by the changing age distribution (e.g., ratio of active stages : eggs) in the samples. Other possible sublethal effects of pesticides, such as changes in behaviour, were not detected.

Sampling in Hastings

Preliminary collections showed that leaf samples collected at random from plots with low TSM populations contained many TSM-free leaves. If predator populations were also low relative to those of the TSM, then, for a reasonably sized sample, the number of leaves with both TSM *and* predators was too small for interpretation of the effects of predation. Consequently, leaves were only collected if they showed the 'spotting' on the upper surface that was characteristic of TSM feeding on the underside. Even single adult female TSM were detected by this sampling method. Because all leaves in the sample were known to contain TSM, the true level of predation was more accurately assessed, and the presence and development of the predator populations could be followed from manageable samples.

Samples of foliage were collected weekly after TSM were first noticed (30 September) in the spring of 1982–83, and from budburst (7 September) in 1983–84. Active stages of TSM, and all stages of TSM predators were counted under a binocular microscope. Raspberry leaves consisted of 3, 5, or 7 leaflets. The total leaf area available for TSM feeding was approximately the same on 3, 5, or 7 leaflet leaves and, hence, numbers of TSM and predators/whole leaf were recorded. About 40 leaves were collected from each cultivar per week, and leaves were sampled from the same rows on each visit. Approximately equal numbers of leaves were taken from the upper, middle, and lower thirds of the trellis.

RESULTS AND DISCUSSION

Seasonality of TSM and predators

Only a few species of insects and mites were consistently present on the raspberry leaves, in both

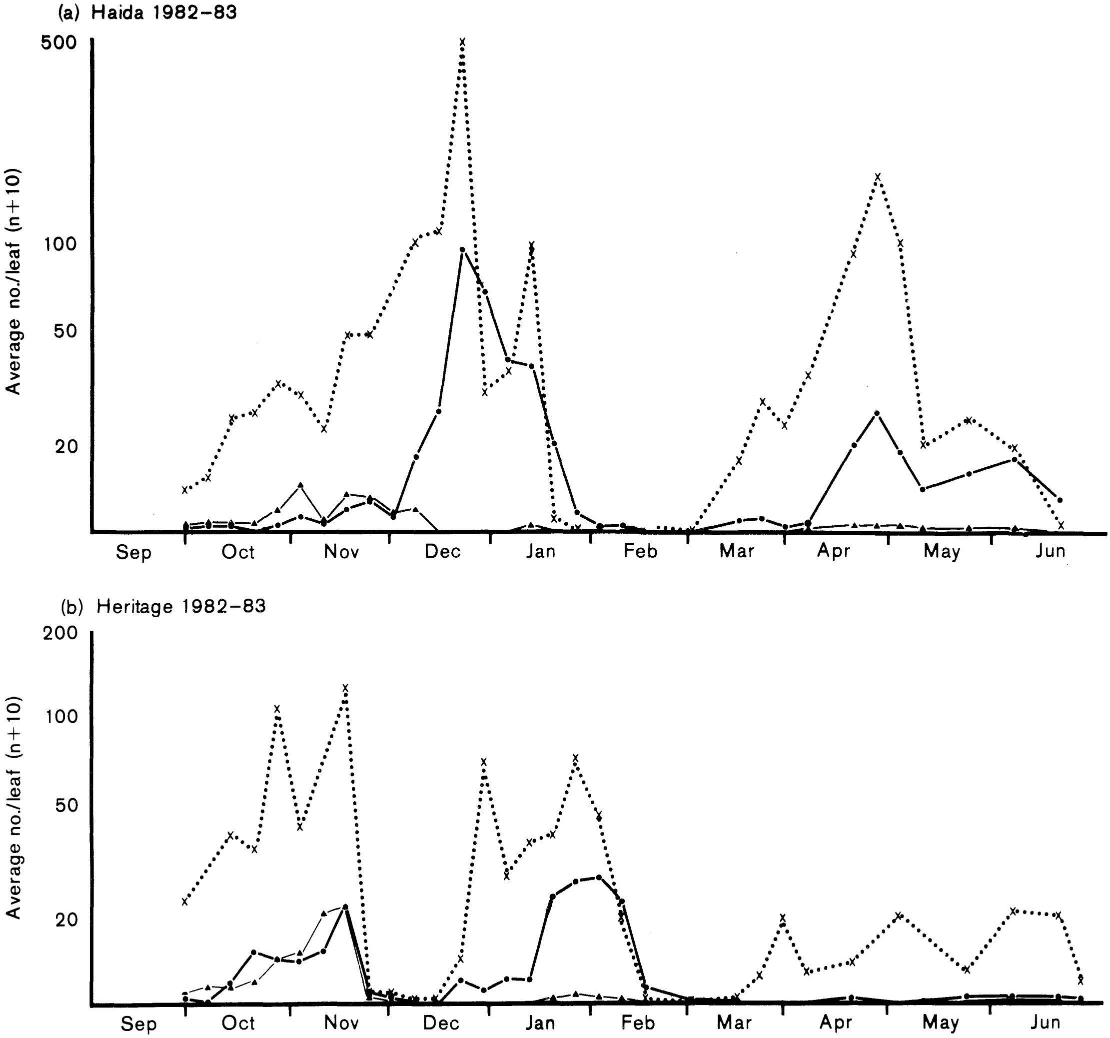

Fig. 1 *1982–83.* Population fluctuations of *Tetranychus urticae* (×······×), *Phytoseiulus persimilis* (●———●), and *Stethorus bifidus* (▲———▲) on TSM-damaged raspberry leaves in Hastings: (a) cv. Haida; (b) cv. Heritage.

Nelson and Hastings. Apart from TSM, the European red mite (ERM) (*Panonychus ulmi* (Koch); Tetranychidae), and the predatory mites, *P. persimilis* and *Typhlodromus pyri* Scheuten (Phytoseiidae), were frequently encountered. All stages of the ladybird, *Stethorus bifidus* Kapur (Coleoptera: Coccinellidae), were also common.

Nelson

TSM was abundant in hot, dry weather, particularly in well sheltered areas of intensively sprayed gardens. ERM was also common, usually in restricted numbers, but occasionally causing leaf spotting. ERM was almost always found with *T. pyri* and, in cooler seasons, was more common than TSM. Both TSM and *P. persimilis* were found on ground cover throughout the year and, in August 1982, during a relatively cold winter and after a series of −7°C frosts, both species were found feeding and reproducing on weeds. During the mild spring of 1980–81, TSM were found on raspberries in November and increased rapidly, reaching a peak before mid February. Early summers were cooler than usual from 1981 to 1983 and TSM and *P. persimilis* numbers were low until late December. Populations of both species then increased and

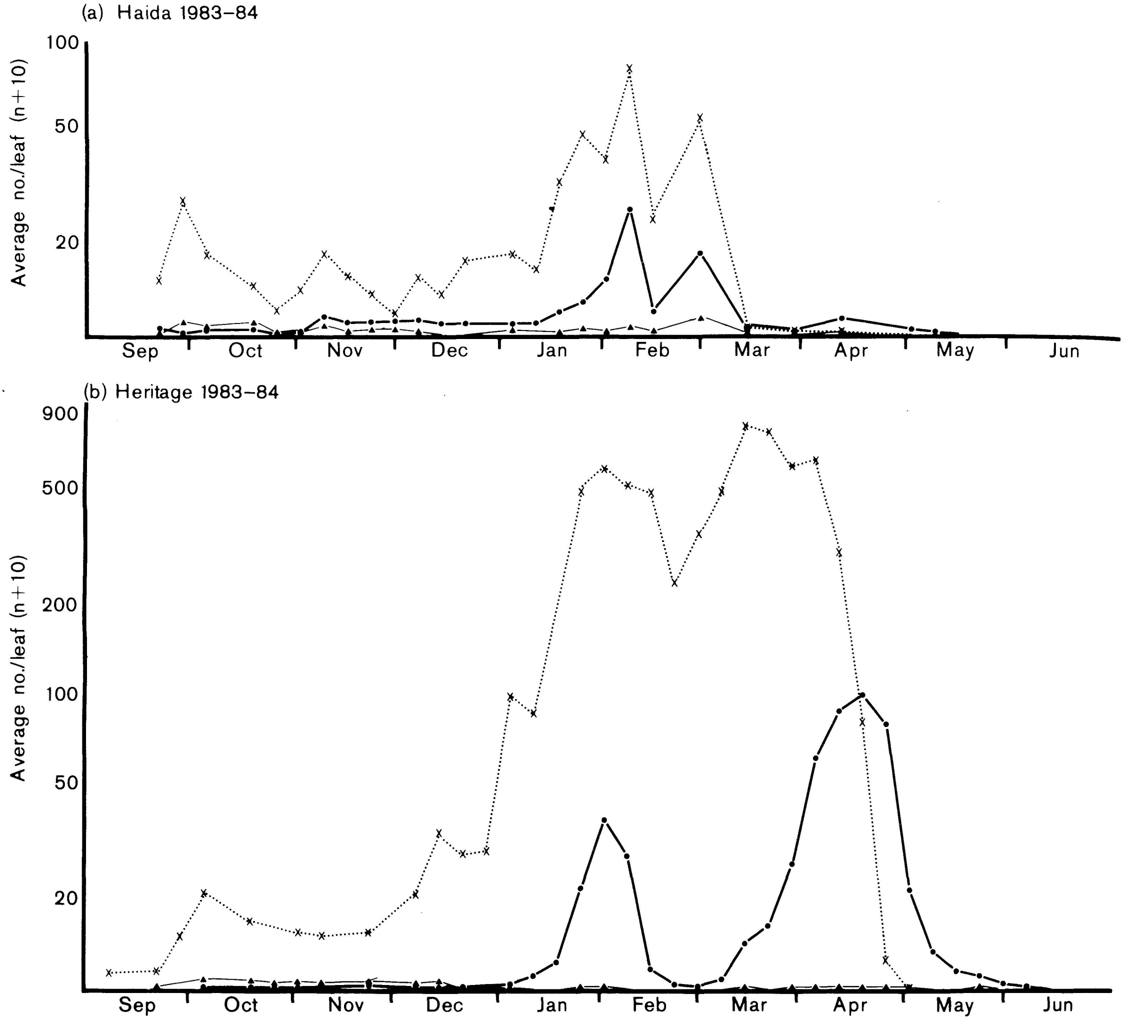

Fig. 2 *1983–84.* Population fluctuations of *Tetranychus urticae* (×······×), *Phytoseiulus persimilis* (●———●), and *Stethorus bifidus* (▲———▲) on TSM-damaged raspberry leaves in Hastings: (a) cv. Haida; (b) cv. Heritage.

declined rapidly over a period of c. 2 months as *P. persimilis* brought TSM under control in late February or early March. *S. bifidus* was very susceptible to pesticides and only became established after harvest, by which time TSM was abundant. *P. persimilis* was more tolerant of most common spray chemicals, and usually appeared with the early TSM infestations.

Hastings

TSM and *P. persimilis* were present in the berryfruit property throughout the study period. *S. bifidus* was common, especially in early spring and post-harvest, when the raspberries were free of pesticide residues. ERM and *T. pyri* were consistently present in low numbers. *T. pyri* fed on TSM when ERM were absent, but was not able to control the TSM population. Fig. 1 and 2 show the numbers of mites (TSM and *P. persimilis*) and *S. bifidus* on TSM-damaged raspberry leaves on both Haida and Heritage cultivars in the 1982–83 and 1983–84 seasons. In 1983–84, overwintered TSM (recognised by their orange–red colour) and fresh eggs were found on the first leaves of new cane growth in early September. The first 'summer' female eggs were found on 28 September, yet overwintered females were recorded until 6 October. Thus, TSM generations overlapped from early spring. Subsequently, TSM populations rose and fell cyclically and were regulated by predation. *P. persimilis* was a most effective predator, and showed a distinct and consistent numerical response to TSM populations in both cultivars in both seasons. *S. bifidus* was also an effective predator when, at times, it also demonstrated a clear numerical response to TSM (e.g., November 1982, Heritage). The interaction, if any, between the 2 predators and how this may have affected their ability to control TSM is not known, but the relationship is currently under investigation. Populations of TSM and predators changed very rapidly and weekly sampling was essential to monitor changes accurately. The time span of the cycles, from the initial rapid rise of the TSM population to its equally or more rapid crash, was similar in both years, and lasted 6–8 weeks (with the exception of Heritage in 1983–84). This time span was similar to that in the Nelson properties. However, in Hastings, the cycles were not synchronised between the 2 cultivars, and mite numbers were sometimes in a trough in one block but at a peak in the other, even though the 2 blocks were only 20 m apart. The asynchrony in cycles was also observed in other cultivars which were not regularly monitored and probably resulted from a combination of environmental and management differences between the cultivars.

Numbers of TSM and *P. persimilis* per damaged leaf varied widely within samples. The influence of very high numbers of mites on a few leaves within a sample was reduced by transforming the TSM numbers on each leaf to a rating, according to Table 1. Also, experience showed that, once *P. persimilis* arrived, they eventually ate all the TSM on a leaf. In mid summer (when maximum daily temperatures frequently exceeded 30°C), *P. persimilis* developed through > 1 generation/week and TSM on some leaves were exterminated between sampling dates. It was therefore decided to display the *distribution* of predators among the TSM population, rather than the number of predators/leaf, to give a more realistic impression of the effects of predation on the TSM population, and possibly also of the potential for biological control at any one date. Fig. 3, 4 display the data of Fig. 1, 2 for TSM, *P. persimilis*, and *S. bifidus* in this modified form, with TSM shown as an average rating per leaf, and predators as percentages of the TSM-damaged leaves which also had predators on them. In addition, the applications of pesticides (fungicides and/or insecticides) are shown. The cyclic progressions of TSM and predator populations are again evident (as in Fig. 1, 2), but it can also be seen that *P. persimilis* continued to occupy a high percentage of leaves for several weeks after the end of a TSM cycle, in spite of the lack of food. The continued presence of predator mites throughout the block was an effective buffer against either a resurgence of TSM within the block or reinfestation from immigrating mites.

Table 1 Rating scheme adopted for two-spotted mite on damaged raspberry leaves 1982–84.

Rating	No. per leaf
0	0
1	1
2	2–4
3	5–8
4	9–16
5	17–32
6	33–64
7	65–128
8	129–256
9	257–512
10	513–1024
11	1025–2048
12	2049–4096
13	4097–8192

The presence of *P. persimilis* early in the cropping cycle is considered important for the successful control of TSM, both in glasshouses (Hamlen & Linquist 1981) and in outdoor strawberries (Oatman et al. 1968). But *P. persimilis* in this study, although present from early spring, did not usually respond numerically to TSM until at least November. *Stethorus* females are characteristically highly mobile, are efficient locators of TSM populations, and lay their eggs near high prey densities (e.g., Huffaker et al. 1970). Their presence in early spring, therefore, was probably important for control of TSM during this period, as indicated by the rapid rise in TSM numbers when *S. bifidus* was eliminated by insecticides (e.g., Fig. 3a, December). *S. bifidus* should be regarded as an important predator in raspberries, especially when *P. persimilis* numbers are low or unevenly distributed (e.g., Fig. 3a, 4a, b).

TSM is well known as a difficult pest to control, even with effective miticides, and many growers have been educated to apply chemicals when TSM are first seen. Yet predators commonly control their prey even though they may be greatly outnumbered for much of a predator–prey cycle. This is often a difficult concept to convey to growers unfamiliar with biological control. Thus, a further advantage of the style of display in Fig. 3, 4 is that it provides a more realistic visual impression of predator supremacy over TSM than shown in Fig. 1, 2, and is more likely to convince a grower of the ongoing success of biological control in his property.

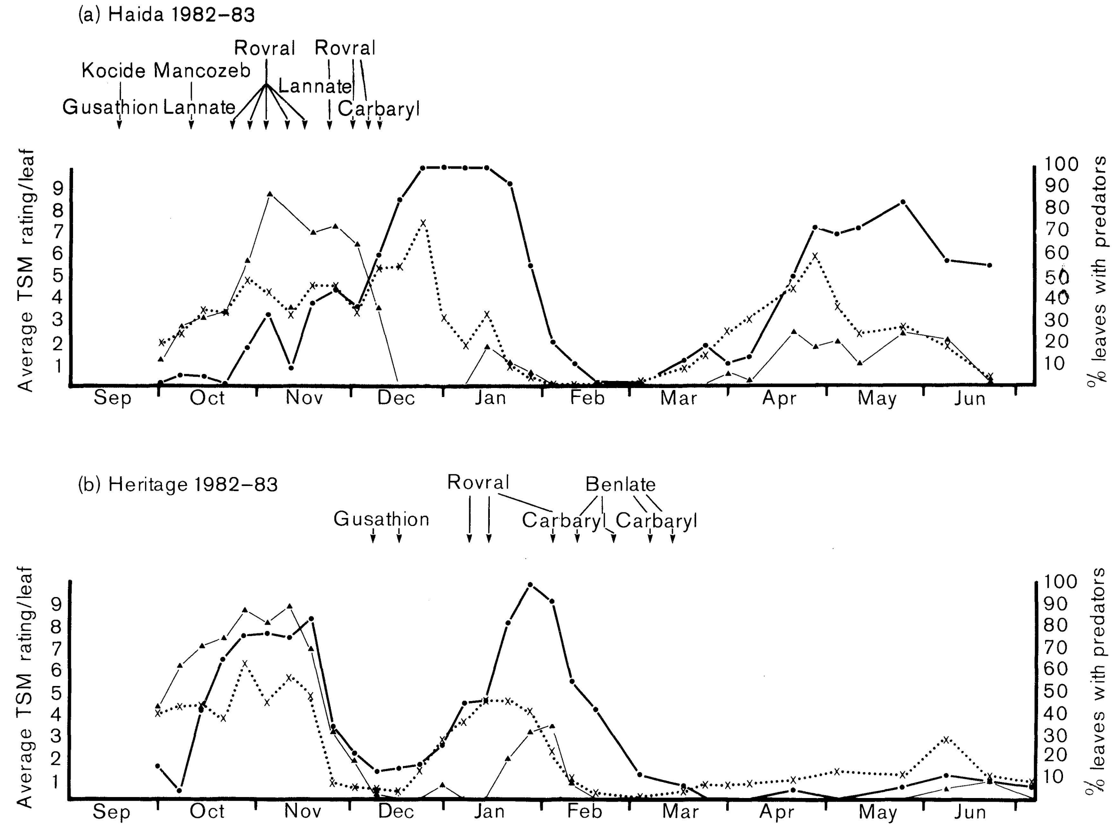

Fig. 3 *1982-83.* Population fluctuations of *Tetranychus urticae* (×······×), *Phytoseiulus persimilis* (●———●), and *Stethorus bifidus* (▲———▲) on damaged raspberry leaves in Hastings, expressed as an average rating per leaf for TSM and as percentage of leaves occupied with predators: (a) cv. Haida; (b) cv. Heritage. Arrows denote pesticide applications.

Damage by TSM

No attempts were made to quantify TSM damage to the raspberry plants in these studies. In Washington State, United States, premature defoliation by TSM in autumn resulted in freeze injury to dormant raspberry canes (Doughty et al. 1972), but this has not been tested in the milder winters of New Zealand. 'Damage' in this discussion is a subjective value, based largely on the perception of experienced growers. Thus, although claims of damage were not quantitatively assessed, they were a useful guide to the levels of TSM at which chemical action may be taken in New Zealand.

Nelson

TSM was rarely noticed by growers until after harvest. Miticides were applied to some properties when there were large numbers of heavily spotted leaves, particularly at the tops of canes. Damage was restricted to hot, dry seasons when plants may have been suffering from stress because of lack of sufficient water. In 1982, one grower allowed *P. persimilis* to successfully control TSM rather than apply a miticide.

Hastings

In 1982–83, the grower did not acknowledge TSM to be a potential problem until an average rating of 5 was reached (Fig. 3). At this level (17–32 active TSM/whole leaf), spotting was quite visible on attacked leaves, but most of the leaves in the row were free of TSM. A miticide would usually have been applied, but the dominance of *P. persimilis* and *S. bifidus* (Heritage, October-November 1982) and of *P. persimilis* (Haida, December 1982) persuaded the grower that chemical action was not

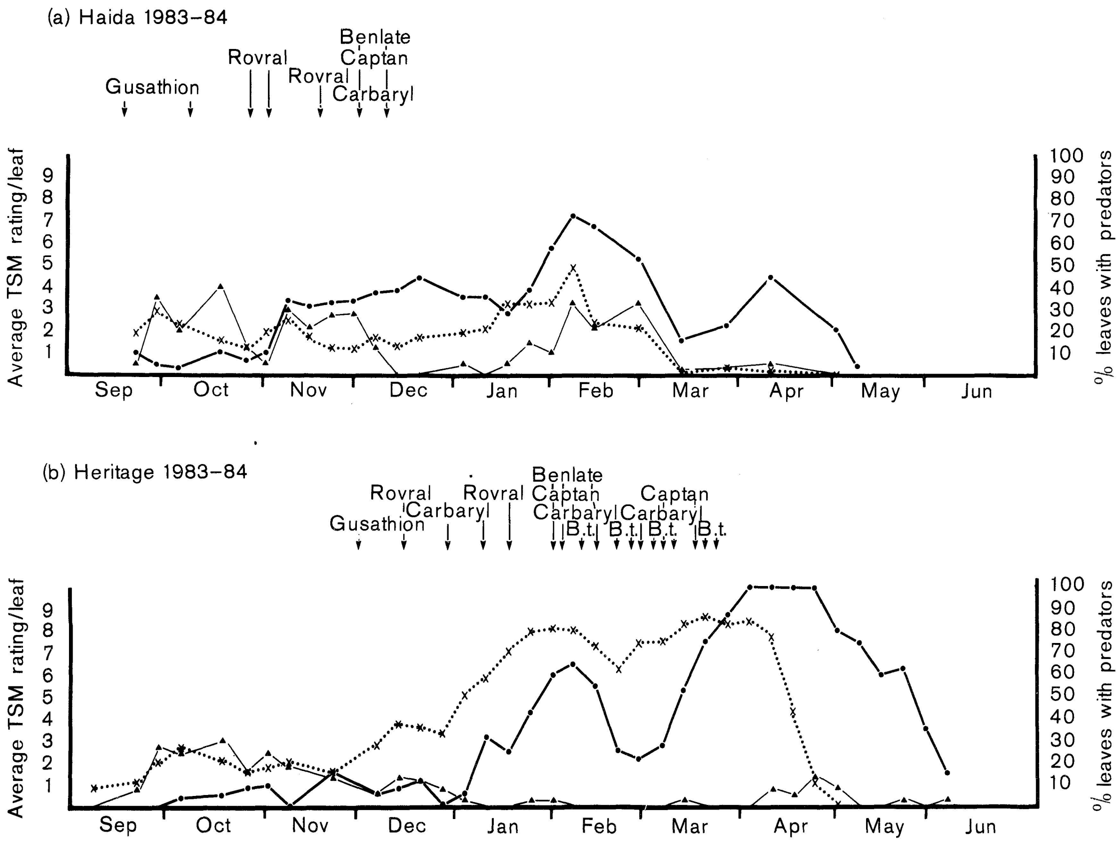

Fig. 4 *1983–84.* Population fluctuations of *Tetranychus urticae* (×······×), *Phytoseiulus persimilis* (●———●), and *Stethorus bifidus* (▲———▲) on damaged raspberry leaves in Hastings, expressed as an average rating per leaf for TSM and as percentage of leaves occupied with predators: (a) cv. Haida; (b) cv. Heritage. Arrows denote application times of pesticides.

needed. TSM was subsequently controlled before damage was perceived.

In 1983–84 (Fig. 4), the TSM population on Haida was too low throughout the year for any miticides to be considered necessary. In Heritage, TSM began to increase at the end of December. *P. persimilis* did not respond quickly and TSM numbers rapidly reached a level that the grower considered to be unacceptable (average rating of 7–8 or 65–256 mites/leaf), and which persisted for nearly 3 months during the harvest period. By the end of March, most of the leaves in the middle and upper canopy were very badly spotted, but premature defoliation did not occur, and the grower did not detect any deterioration in crop weight or quality during the harvest period. No mites were found on harvested fruit.

The influence of pesticides on the control of TSM

Insecticides

Insecticides were applied primarily for the control of Lepidoptera (especially Tortricidae) larvae at budburst, at flowering, and again throughout harvest. *S. bifidus* did not survive repeated applications of insecticides and thus was absent from the canes for much of the season. In contrast, *P. persimilis* survived applications of azinphos-methyl (Gusathion®) and carbaryl (Septan®) during the harvest period, and resistance to these chemicals has been confirmed in laboratory tests (M. Bryham pers. comm.). All active stages of *P. persimilis* were killed by methomyl (Lannate®), although some eggs survived a single application. *Bacillus thuringiensis* (Thuricide®), had no detectable effect on *P. persimilis.*

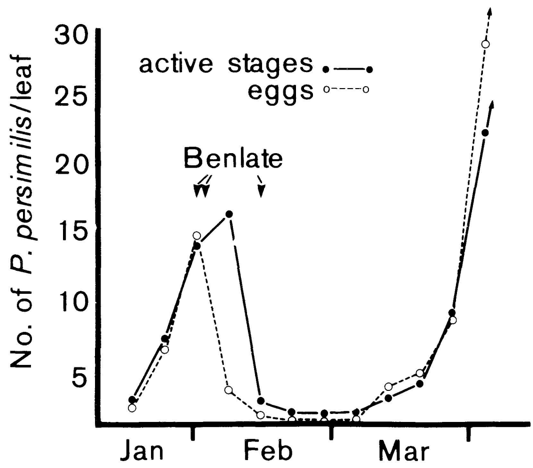

Fig. 5 Suppression and subsequent recovery of *P. persimilis* in *Rubus idaeus* cv. Heritage after applications of benomyl in February 1984.

Fungicides

Iprodione (Rovral®) and captan had no visible effect on TSM or either predator. Benomyl (Benlate®), however, clearly suppressed mite numbers and, when applied to Heritage during February 1984, suppressed both TSM and *P. persimilis*. The TSM population was so high that there was little or no benefit to the canes from the temporary decrease in pest numbers, which was caused by the ovicidal action of benomyl (Spadafora & Lindquist 1972). The ovicidal activity on the *P. persimilis* population was dramatic (Fig. 4b, February). Fig. 5 shows that the numbers of eggs and active stages of *P. persimilis* were increasing equally in January. One week after the first application of Benlate (the second application was made within 2 days of the first after a heavy rain shower), egg numbers/leaf had declined from 14.6 to 2.4; and, with no recruitment, the numbers of active stages remained similar (13.6–16.2/leaf) and subsequently declined. By the end of February, after a third Benlate application, numbers of *P. persimilis* were < 0.4/leaf. The population did not recover to the pre-Benlate level until the end of March. Thus, the applications of Benlate delayed the predator response to TSM by c. 8 weeks and, consequently, increased the TSM infestation period on the crop during harvest by this length of time.

The potential for biological control of TSM in commercial berryfruit gardens

P. persimilis is now widespread in New Zealand from Nelson northwards, and *S. bifidus* and other *Stethorus* spp. are distributed throughout the country. These trials showed that natural enemies alone, especially *P. persimilis*, were able to limit TSM to acceptably low levels in commercial berryfruit gardens under pesticide regimes that provided high quality fresh fruit for the export market. However, the study also showed that some commonly used chemicals were toxic to both predators and were not compatible with biological control of TSM.

The recent registration of Thuricide on berryfruit in New Zealand allows *B. thuringiensis* to be used for the control of lepidopteran pests throughout the harvest period without the worry of unacceptable pesticide residues, and without danger to bees or natural enemies of TSM.

These studies have provided the basis for the development of an integrated control programme for pests of export raspberries in New Zealand. The central feature of this programme would be the control of TSM by predators, which would survive in a favourable spray environment of non-toxic fungicides, carefully chosen insecticides before harvest, and a biological insecticide (such as *B. thuringiensis*) during harvest. During the long harvest of autumn-ripening raspberries, it may be possible to spray a short-lived, broad spectrum insecticide such as carbaryl towards the end of harvest, if necessary to control non-lepidopteran pests, without risking damage by TSM. Further trials will be carried out to investigate the practical applications of this programme.

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