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Predation on Twospotted Mite, *Tetranychus urticae* Koch (Acarina : Tetranychidae) by *Haplothrips victoriensis* Bagnall (Thysanoptera : Phlaeothripidae) and *Stethorus nigripes* Kapur (Coleoptera : Coccinellidae) on Seed Lucerne Crops in South Australia

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Abstract

Three predators were commonly associated with twospotted mites *Tetranychus urticae*: the tubular black thrips *Haplothrips victoriensis*, the black mite-eating ladybird *Stethorus nigripes*, and a predatory mite *Phytoseiulus persimilis* Athias-Henriot (Acarina : Phytoseiidae). Of these, *H. victoriensis* was the most abundant, especially at low mite densities; *S. nigripes* was present when mite numbers were high; *P. persimilis* appeared only in cooler months, when mite activity had waned. A beating method for simultaneously sampling towspotted mites and their predators was developed as a quick method of estimating populations on closely planted lucerne. In laboratory feeding studies, larvae of *H. victoriensis* completed development on either mite eggs or lucerne pollen or both. Development was quickest on lucerne pollen. The mean consumption rate of thrips fed only mite eggs was 40 eggs per day for the 3-day first stadium and 108 per day for the 10·3-day second stadium. Where the ratio of thrips to mobile mites in the field was less than about 1 : 10, as occurred when chemicals were sprayed, the mite population had the potential to increase rapidly. A damage assessment study indicated that lucerne plants could tolerate moderate mite feeding (up to an average of 45 mites per leaf in the middle part of the plant). It is concluded that predators can exert effective control of mites under most field conditions.

Introduction

Twospotted mites first occurred as a pest in seed lucerne crops in South Australia during the summer of 1978–79. Before 1978, a number of organophosphate and organochlorine sprays were applied each season against a number of pests, but apparently not frequently enough to result in noticeable mite activity. In 1978 increased frequency of spraying for spotted alfalfa aphids, *Therioaphis trifolii* (Monell) f. *maculata*, caused an increase in the number of twospotted mites which resulted in severe damage to lucerne crops, many fields being defoliated by mite feeding.

The aims of this study were to identify the main predators of the twospotted mite in lucerne seed crops, to assess their relative contribution to controlling mites in sprayed and unsprayed crops, and to try to estimate whether predators could control mite numbers in seed lucerne below a level at which yield was affected.

Methods and Results

Sampling Twospotted Mites and their Predators

(i) *Leaf counts and beating trays*

A single trifoliate leaf of lucerne was used initially as a sampling unit. Observations on the behaviour of mite populations in crops during the 1979–80 season indicated that mites started at the base of the lucerne plant early in the season, and moved upwards later. For sampling purposes, the plant was divided into three roughly equal parts, extending from ground level to 20 cm ('low'), 21–40 cm ('mid') and 41+ cm ('high'). Equal numbers of leaves were collected from within each of these strata.

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Preliminary sampling early in the season was aimed at finding a sample size, for estimate of density, which would allow detection of a doubling or halving of the population, i.e. a standard error of 25% of the mean (Southwood 1978). Results of preliminary counts showed that this objective was not practicable if mite numbers were low, but if the mean number of mites exceeded about two per leaf a sample of 50 leaves per stratum gave reasonable precision. The time taken to count the number of mobile mites on 50 leaves under a binocular microscope ranged from 0·5 to 3·0 person-hours, depending on mite density.

The leaf count method was not practicable for estimating numbers of predators. Mobile predators usually dropped from the leaf when it was picked, and although coccinellid eggs and larvae, and predatory mite and thrips eggs, remained on the leaves after picking, a large number of leaves would need to be sampled for these stages, because predators were scarce. For this reason a beating method was developed which gave quick estimates of both twospotted mites and their predators, and sampled flowers as well as leaves. It is assumed that roughly similar numbers of leaves and flowers are sampled at different sampling sites. This is not an unreasonable assumption with irrigated seed lucerne, where the leaves form a more or less continuous canopy throughout the crop. However, some differences in leaf cover between crops can be expected.

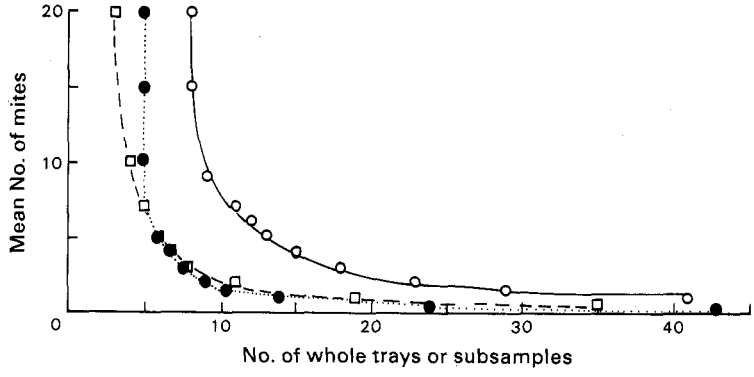

Fig. 1. Sample size required at each site to achieve 25% [i.e. 100 × (SE/mean)] precision for different population densities, by the tray beating method of sampling. □ *S. nigripes*. ● *T. urticae*. ○ *H. victoriensis*. The number of *T. urticae* is given per leaf; that of *H. victoriensis* per square centimetre of tray; whole trays are 126 cm^2; subsamples of 3 by 1 cm^2.

A convenient sampling device was a white plastic tray 14 by 9 cm with a transparent plastic lid, available commercially as a refrigerator meat tray. The floor of the tray was ruled into 126 1-cm^2 squares. The tray was placed at the base of a lucerne plant, and the leaves and flowers beaten over it by 15 beats of the hand. Plant debris was removed by gently inverting the tray; mites and their predators clung to its floor. The upright tray was lightly shaken to distribute the mites evenly over the floor. A preliminary assessment was made of the number of mites sampled; if these were 'high' (more than 100–200 per tray), the mites were counted in three squares haphazardly subsampled. If numbers were 'low', all the mites in the tray were counted. At each sampling site, 20 tray samples were taken on each sampling occasion. In a preliminary test the sampling precision [100 (SE/mean)] of this method ranged from 11% (mite density 52 cm^{-2}, 0·9 h sampling time) to 22% (mite density 3 cm^{-2}, 0·2 h sampling time).

Other insects, such as *Heliothis punctiger* Wallengren larvae, mirids and aphids, living on the lucerne foliage, could also be sampled by this method. The number of species of mite predators in each tray was recorded.

A sample of 20 trays per site was initially chosen arbitrarily, because the mites could be counted in a reasonable time (10–20 min) in the field. These initial sampling data were used to produce an estimate of the number of trays required for a sampling precision (see above) of 25% of the mean, which is sufficiently accurate for detection of a doubling or halving of the population. Fig. 1 shows the number of trays required at various densities of *S. nigripes*, *H. victoriensis* and twospotted mites to achieve this precision.

The data in Fig. 1 were calculated for each species by regressing mean crowding, $\overset{*}{X}$, on the mean of 20 tray counts per sample on different sampling occasions and at different sites. Mean crowding is

defined as $\overset{*}{X} = \bar{X} + (S^2/\bar{X} - 1)$, where S^2 is the sample variance and $\bar{X}$ the sample mean (Iwao and Kuno 1971). Regression coefficients were then calculated for each species:

Twospotted mites: $y = -0{\cdot}38 + 1{\cdot}26x$ (9 observations);
Stethorus nigripes: $y = 0{\cdot}005 + 1{\cdot}17x$ (9 observations);
Haplothrips victoriensis: $y = 1{\cdot}191 + 1{\cdot}38x$ (33 observations);

these were used in Iwao and Kuno's (1971) formula to calculate sample size: $n = (1/D^2)\{[(\alpha+1)/\bar{x}] + (\beta - 1)\}$, where n is the number of sample trays required, $\bar{x}$ is mean density per tray on each sampling occasion, D is the accuracy required (in this case 0·25), and α, β are the regression coefficients of $\overset{*}{X}$ on $\bar{X}$.

The sample sizes calculated in Fig. 1 indicate that for the range of predator and prey densities encountered in the field, 20 trays were an adequate sample for a site, and this number was used throughout the study.

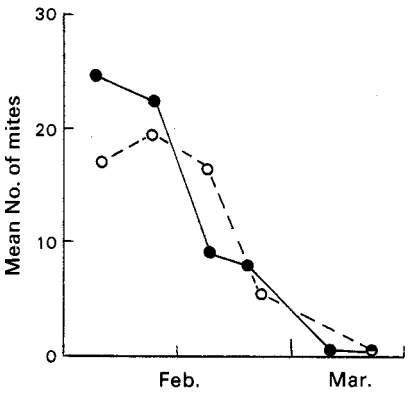

Fig. 2. Comparison of mite numbers estimated by the leaf count method (●——●, as number per leaf), and the foliage beating method (○– – –○, as number per square centimetre of tray). Samples were collected from a fixed area, 10 by 10 m, in a field of cv. Hunter River lucerne.

(ii) *Comparison of mite sampling methods*

Two different methods were used to sample mites, and in February and March 1981 both were used concurrently in the field. Fig. 2 compares the leaf count with the beating method at one sampling site. To allow for the different numbers of mites in each of the three strata of the plant, the mean number of mites per leaf counted in each stratum was weighted by the proportion of leaves in each stratum, as determined by leaf counts of 10 representative plants, and the products added. The methods agreed reasonably well in their estimate of the density of mobile mites.

Interactions of Mites and Predators in the Field

In 1981, mite numbers at a sampling site sprayed with insecticide increased rapidly in mid-January, and remained high until mid-February (Fig. 3). At a nearby unsprayed sampling site, numbers rose to a level similar to those at the sprayed site, but quickly declined to low levels in early February.

The decline in mite numbers was associated with the occurrence of the mite-eating ladybird, *Stethorus nigripes*, in the lucerne (Fig. 3). The beating method of sampling predators was first used in February 1981, and *S. nigripes* were not counted earlier, although eggs and larvae were present in January. The slow increase of *S. nigripes* numbers at the sprayed site compared with that at the unsprayed site (Fig. 3) may be attributable to insecticide residues on the plant foliage.

In March 1981, the predator mite *Phytoseiulus persimilis* was detected in the tray samples, but was not numerous enough to account for the decline in mite numbers. High numbers of this predator mite had been observed in April 1980, during the previous season, in a number of lucerne fields in the district.

In March 1981, larvae of the tubular black thrips, *H. victoriensis*, were observed eating eggs of twospotted mites. The red-coloured larvae had been conspicuous in previous tray samples, but had not been counted. This species of thrips had not previously been recorded

as a predator (Pitkin 1973). The identity of samples of about 50 thrips collected from seed lucerne crops at Keith, S.A., in February 1982 was confirmed as *H. victoriensis* by L. A. Mound and J. M. Palmer of the British Museum (Natural History). No other species of *Haplothrips* was present.

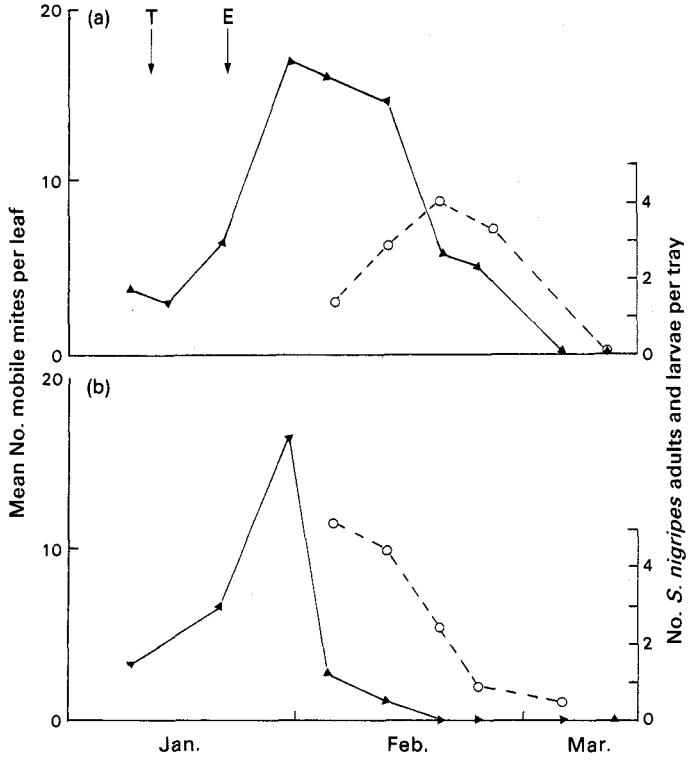

Fig. 3. Interaction of *T. urticae* (▲——▲) and *S. nigripes* (○- - -○) in sprayed (*a*) and unsprayed (*b*) plots. Sampling for *S. nigripes* started in early February. T, trichlorfon. E, endosulfan.

In the 1982 season, the number of sampling sites was increased to four, each with sprayed and unsprayed areas. Also, counts were made of the immature and adult stages of *H. victoriensis*. The results from these sites are shown in Fig. 4. At unsprayed sites H, D and W, the numbers of mites were low and the numbers of thrips were high. However, at site S the thrips population remained low, and the mite population increased. In the sprayed plots the numbers of immature thrips were reduced compared with the unsprayed plots (Fig. 4); and this allowed mite numbers to increase at sites H and D, although they did not do so at sites W and S.

The data in Fig. 4 suggest that if the proportion of predators to prey is reduced below a certain level, prey numbers tend to increase. The data in Fig. 4, together with data from other sites not part of the main study, are presented in Fig. 5 as predator : prey ratios plotted against numbers of mobile mites. A more direct relationship would have been between predators and mite eggs, since *H. victoriensis* feed mainly on mite eggs (see later). However, during summer, when these observations were made, mite eggs hatch 3–5 days after laying, and mite stages overlap completely, so that the supply of eggs is more or less continuous. Under these conditions, the ratio of predators to mobile mites on a particular sampling date could be expected to reflect the ratio of predators to eggs on the preceding days.

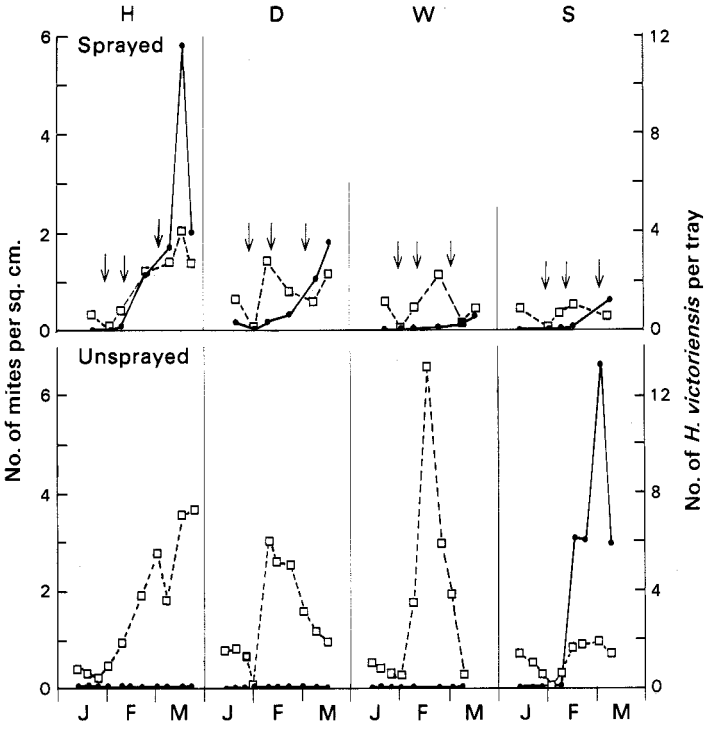

Fig. 4. Numbers of *T. urticae* (●——●) and predator thrips *H. victoriensis* (□- - -□) at four sampling sites, H, D, W and S, each with sprayed and unsprayed plots, in January–March 1982. Arrows indicate times of spraying.

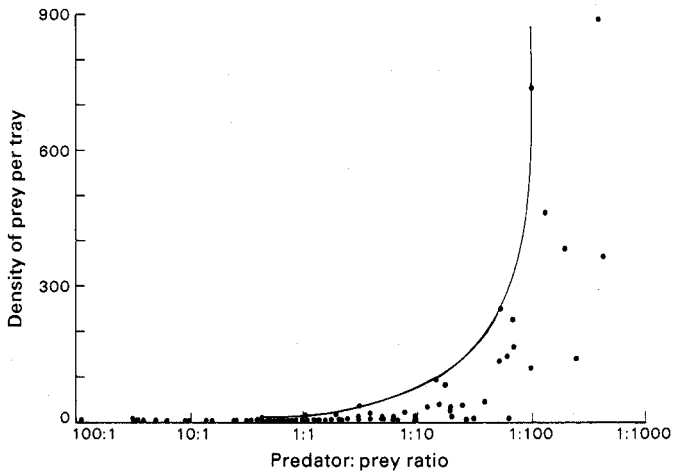

Fig. 5. Relationship between predator : prey ratio and prey density. Each point represents the mean of 20 tray samples of predators and prey.

There was a tendency for mite numbers to increase when the number of predators fell from one per prey to one per 10 prey. Mite numbers tended to increase rapidly when the proportion of *H. victoriensis* fell below one per 10 mites. Sometimes a low predator : prey ratio was associated with low mite numbers (Fig. 5); this may reflect the inability of twospotted mites to increase their numbers in some environments despite the absence of predators.

Voracity of Haplothrips victoriensis *in the Laboratory*

(i) *Laboratory measurements of the voracity of predatory thrips*

Adult thrips were collected from lucerne plants in the field and were allowed to lay eggs on caged lucerne plants in the laboratory. These eggs were collected, and when they hatched the larvae were used in feeding experiments. These experiments were conducted in multi-well plastic plates, each well having a capacity of 3·5 ml and a floor area of 2 cm^2, which was the effective searching arena. One thrips was placed in each well, and a predetermined number of mite eggs presented on a lucerne leaflet. The temperature of rearing and feeding experiments was $25 \pm 2°C$.

(ii) *Life cycle in the laboratory*

Adult female thrips laid eggs on the flowers of lucerne plants, and in the absence of flowers were rarely observed to lay on vegetative parts. The eggs hatched after 5 days at 25°C. Two larval instars were observed, both being light red in colour and quite conspicuous in the field. Both stages were active feeders. Their duration varied with the type and quantity of food available.

Only one pupal moult was observed, but during the pupal stage the wing buds elongated. Since Steele (1935) observed a propupal stage and two prepupal stages of *H. victoriensis*, it seems likely that we did not properly recognise these stages. The pupa is darker red than the larva, and its abdomen mottled with white patches. It was inactive, and did not appear to feed when offered pollen or mite eggs. The pupal stages lasted 5–7 days.

Adults from immature stages reared in the laboratory did not survive more than a few days when kept in a well, although they were offered both lucerne flowers and mite eggs. However, field-collected adults placed on lucerne plants in a cage survived up to 30 days and laid eggs.

(iii) *Feeding habits*

H. victoriensis larvae were observed to feed on mite eggs in the field, but not on the mobile stages of mites. When presented with both eggs and mobile mites in a test well, the thrips invariably ate the eggs. However, when placed in a well containing only mobile mites as food source, second-instar larvae ate an average of 2·3 deuteronymphs or one adult female mite per day.

Larval thrips were presented with eggs of *Etiella behrii* (Zeller) and *Heliothis punctiger*, two major moth pests of seed lucerne crops, but they would not eat these eggs even if deprived of other food. They would, however, eat eggs of their own species if no other food was available. Steele (1935), observed that second-instar larvae would feed on each other and on thrips eggs when confined in feeding chambers.

Larval thrips completed their development in 9·9 days (mean of 12 observations) when provided with a freshly cut lucerne flower every 2 or 3 days, in the absence of mite eggs; this closely corresponds with the combined larval development time of 9·6 days for this species fed on *Plantago lanceolata* flowers at 26°C (Andrewartha 1936). The development time of second-instar larvae was less when they were fed on flowers (6 days, mean of 24 observations) than when they were provided with an excess of mite eggs (8–10 days, mean of six observations). Attempts to feed the thrips on lucerne flower anthers alone were not successful because the anthers quickly became mouldy. When a single second-instar larval thrips was provided with a flower and mite eggs (10 observations), the mite eggs remained virtually uneaten.

However, if two second-instar larvae were placed in a well with a lucerne flower and 20 mite eggs on a lucerne leaflet, all eggs were eaten after 24 h. When one thrips was eating mite eggs, the other remained in the flower. It is possible that one thrips drove out the second from the flower, and the second was then obliged to eat the less preferred food. This would explain the field observation that thrips are associated with mites on leaves throughout the lucerne plant, and not just in the vicinity of flowers.

Adult thrips were observed to eat mite eggs, but they did not survive for long without flowers. In addition, the failure to maintain cultures of adults on mite eggs and lucerne flowers alone suggests that the early stages of adulthood require an additional resource provided by the intact lucerne plant. Such a resource could be plant juices from intact leaves (Putman 1965), or a more favourable humidity.

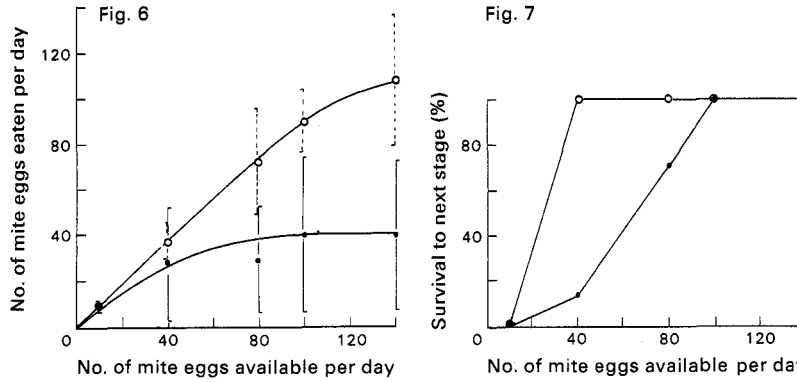

Fig. 6. Functional response of the first two instars of *H. victoriensis* to increasing prey density. ● First instar. ○ Second instar. Vertical lines span 95% confidence intervals.
Fig. 7. Survival of first-instar (○) and second-instar (●) *H. victoriensis* when provided with different quantities of mite eggs. Each point represents the mean of 8–12 observations.

(iv) *Voracity of* H. victoriensis *larvae*

The functional response of the immature stages of *H. victoriensis* when provided with increasing numbers of mite eggs is shown in Fig. 6. First-instar larvae can consume a maximum of about 40 eggs per day, and the second-instar larvae can consume over 100 per day. Within the prey density range of 10–140 eggs per day, the estimated time for the first-instar larvae to complete development was 3–6 days (17 observations). When allowed to feed only on flowers, first-instar larvae moulted in 4 days (24 observations). Developmental time to complete the second-instar ranged from 18 days at 40 eggs per day to about 9 days at 140 eggs per day (eight observations), and 6 days (24 observations) when the larvae were allowed to feed on flowers alone.

Survival was also affected by prey density. First-instar larvae required at least 40 mite eggs per day to ensure that most of the population developed to the next stage, and second-instar larvae required 100 mite eggs per day for all to complete development (Fig. 7).

(v) *Comparison with* S. nigripes

S. nigripes is recorded as an important predator of twospotted mites on a number of field-grown crops in South Australia (Richardson 1977). In field studies on seed lucerne, *S. nigripes* and *H. victoriensis* commonly occurred on the same plants, so their voracity is one aspect of their comparative effectiveness in controlling mites in the field.

Under similar experimental conditions to those described above for *H. victoriensis*, Richardson (1977) found that all stages of *S. nigripes* are voracious feeders on twospotted

mite eggs and show a marked functional response to increases in prey density. The daily egg consumption by larvae of *S. nigripes* and *H. victoriensis* which were given, respectively, 150 and 140 mite eggs per day was:

Stage	*S. nigripes*		*H. victoriensis*	
	Duration (days)	No. of eggs per day	Duration (days)	No. of eggs per day
Larva I	2·6	21	3·0	40
Larva II	1·4	48	10·3	108
Larva III	1·4	67		
Larva IV	3·0	147		

Apparently, the pupal stage of neither predator feeds. Adult males of *S. nigripes* eat an average of 62 mite eggs per day, preoviposition females 87, gravid females 130 and non-reproductive females 51.

Mite Density and Seed Yield

This experiment was designed to test whether lucerne plants could tolerate some level of mite feeding without yield being affected. Results of such an experiment may allow a statement to be made of the relative usefulness of predators in preventing yield loss caused by mites.

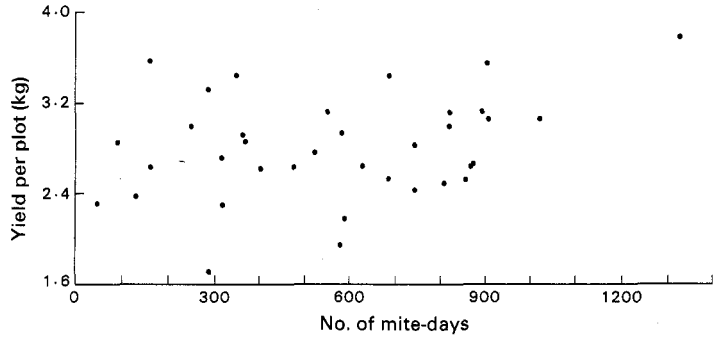

Fig. 8. Yield of lucerne seed related to the intensity of mite feeding measured in mite-days.

(i) *Measuring effects of mites on lucerne seed yield*

In an attempt to measure the effect of mite numbers on seed yield, 36 plots, 7 by 4 m each and surrounded by a 2-m buffer zone, were laid out in a complete randomised block design having 12 blocks each with three treatments, on a large field of Hunter River lucerne. Mite numbers were manipulated by applying three treatments respectively to plots in each block starting, 26 February 1981: (1) five sprays of 0·5% fenvalerate insecticide; (2) two sprays of 0·5% fenvalerate; (3) spraying with a miticide. Fenvalerate killed mite predators and allowed mites to increase in numbers for a time.

It was possible to localise mite populations within each plot, and mites did not appear to migrate across the buffer zones. Mites were counted on mid-stratum leaves. Defoliant was applied to the lucerne on 26 March 1981, and the seed was harvested with a small-plot harvester on 6 April 1981.

(ii) *Effects of mite numbers on seed yield*

The attempt to manipulate mite numbers by use of different insecticides and number of sprayings did not in any plot produce such numbers of mites as were present in 1979, when they were extremely numerous over wide areas of seed lucerne. In the present experiment, mites were most numerous in the plots sprayed with five fenvalerate sprays. In these, the mite population increased at the base of the lucerne plant and by harvest was greatest in

the mid stratum, but did not become so numerous at the top of the plant as to cause chlorotic areas.

The sprays produced a range of mite densities rather than three distinct densities each corresponding to one treatment. Thus, on 10 March 1985, 56 days after spraying commenced, the mean density in the mid stratum of the plots sprayed with miticide was 0·5 mobile mites per leaf (range 0–2·1 per leaf), in the plots given three fenvalerate sprays it was 15·8 (range 3·2–31·5) and in the plots given five fenvalerate sprays it was 11·8 (range 2·5–24·8). No predators were observed in the fenvalerate plots or the miticide plots. The density of mites in each plot fluctuated throughout the experiment, and the relative densities also varied between plots. To simplify the presentation of these data, the mite densities of each plot, measured four times during this experiment, were integrated as 'mite-days' (Hoyt *et al.* 1979) as an expression of the intensity of mite feeding over the period of the experiment.

No effect of mite numbers on seed yield could be demonstrated within the range of 0–1330 mite-days (Fig. 8). Numbers were at their peak towards harvest time, and caused some defoliation. However, seed-growing practice is to defoliate the lucerne crop with a chemical defoliant before harvest, to allow the seed to be harvested. The action of mites may have done no more than hasten this process.

Discussion

H. victoriensis is common on lucerne crops in South Australia, and its predatory activity may explain the rarity of *T. urticae* in these crops under most conditions. The ability of its larvae to survive on pollen means that it may be present in a crop in some numbers before mites are detectable. In unsprayed crops, *H. victoriensis* probably maintains mites at low levels; it occurs in crops when twospotted mites are not detectable, nor any other predators, e.g. *S. nigripes*, present.

H. victoriensis is very sensitive to insecticides. Filter papers sprayed with field-strength concentrations of DDT, chlorpyrifos or parathion, respectively, and exposed to the weather caused 100% mortality of thrips after 8 days (unpublished data). Yet in the field thrips reappear in sprayed plots within a week after spraying. This appears to be due to the ability of adults to reinvade the sprayed area. The growth of floral parts after spraying probably allows sufficient insecticide-free surface for the adults to feed and lay eggs. The recolonization of sprayed lucerne was rapid in small plots, but may take longer when large areas have been sprayed.

The temporary release, by insecticides, of the mite population from predation is countered by the ability of thrips to take advantage of the new food source, and presumably to increase in numbers to more than those possible if only lucerne flowers were available.

The ability to control mites after insecticide sprays is reduced when spraying frequency is increased, because this prevents a buildup of thrips numbers. If large areas of lucerne are sprayed, the ability of thrips to reinvade is presumably reduced, since there are no reservoirs to immigrate from. These may be explanations for the sudden pest status of twospotted mites in lucerne following the introduction of spotted alfalfa aphids. The frequency of spraying almost doubled from that previously and, further, many fields of lucerne tended to be sprayed at one time.

S. nigripes is also an important predator of mites, but its increase in numbers tends to lag behind those of the mites, which is a consequence of its being an obligate mite-eater. It is probably for this reason that *S. nigripes* appeared as a high-density predator in the present studies; this also confirms the field studies of Lamacraft (1972) that *S. nigripes* has high rates of reproduction and survival only when mites are abundant. Although the voracity and functional response to increasing mite density of *S. nigripes* are comparable to those of *H. victoriensis* (Richardson 1977), its numbers in lucerne fields were less. As with *H. victoriensis*, *S. nigripes* is susceptible to insecticides (Walters 1976).

The predatory mite *Phytoseiulus persimilis* gives good control of twospotted mites in European glasshouses, but in seed lucerne at Keith it occurs too late in the growing season to prevent these mites reaching high numbers. Slide dip tests of this mite in solutions of a number of organochlorine, organophosphate and pyrethroid insecticides (unpublished data) indicated that it was at least as resistant to insecticides as its prey. Thus insecticides are unlikely to have prevented twospotted mites increasing in numbers during the hot months of January and February, and it is possible that it cannot increase in numbers during hot weather.

Results of the yield experiment indicate that Hunter River lucerne plants can withstand moderate levels of mite feeding during the main period of seed production (January–February) without the yield being affected. Since lucerne is able to tolerate some mite feeding, there are good prospects for mite control by predators in commercial seed lucerne crops.

The results of this study suggest a management strategy of reducing the frequency of spraying against primary pests such as spotted alfalfa aphids, *Heliothis punctiger*, *Etiella behrii* and *Phaulacridium vittatum* (Sjostedt). Provided that the ratio of *H. victoriensis* to *T. urticae* does not fall much below 1 : 10 at times when mite numbers are starting to increase, predators should be able to control them. By means of this strategy, predators have been almost the exclusive form of mite control on commercial irrigated seed lucerne since 1982.

It is possible that *H. victoriensis* may affect lucerne other than as a mite feeder. Seed lucerne yields in the U.S.S.R. were reduced by flower damage caused by 46 species of phytophagous thrips, including some species of *Haplothrips* (Dyadechko *et al.* 1984). It is also possible that pollen-feeding thrips such as *H. victoriensis* may contribute to pollination of flowers (Kirk 1984). Neither of these possibilities was investigated in the present study.

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