Final Report

Pest Status and Management of SSM *(Eotetranychus sexmaculatus)* in WA Avocado Orchards

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Western Australian Agricultural Authority (Department of Primary Industries and Regional Development) and Biological Services

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Pest Status and Management of SSM (Eotetranychus sexmaculatus) in WA Avocado Orchards – AV15012

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Summary

Avocado orchards in south western Australia are vulnerable to attack by the exotic mite, six-spotted mite (SSM), *Eotetranychus sexmaculatus*. If left untreated, trees in infested orchards will be defoliated resulting in sunburnt, unmarketable fruit and reduced tree vigour.

Miticides are available to control SSM but currently products containing only three different active ingredients are available, two of which have a reputation as being toxic to predatory mites. Also, the risk of miticide resistance occurring is ever present and alternative or complementary management practices are required.

This project sought to assist growers in undertaking their own monitoring and implement appropriate management techniques to protect trees from damage by SSM and to assess the role of predatory mites in suppressing SSM.

Identification kits were prepared and distributed to growers at talks about SSM. Growers developed knowledge on identifying leaf symptoms of SSM presence and how to identify SSM and associated fauna. One grower developed their own monitoring protocol and discussed this at grower talks.

The role of at least four species of predatory mites was assessed. This included at least one identified species already present in orchards, *Euseius elinae,* and releases of the commercially available mass reared species *Metaseiulus* (*Typhlodromus*) *occidentalis*, *Neoseiulus californicus* and *Typhlodromus doreenae*.

Assessments of the effect of the releases of commercially available predatory mites on SSM involved leaf monitoring in commercial orchards and one glasshouse study of artificially infested young avocado trees. During the field studies, specimens of predatory mites were collected for identification to be determined by a mite taxonomist.

Results of the glasshouse study showed that *M. occidentalis* was a predator capable of reducing SSM numbers, but that *E. elinae* and *N californicus* were poor predators. These conclusions were not supported by results of field monitoring, where, of these three species, only *E. elinae* was identified from predatory mites collected from orchards.

Field monitoring showed predatory mites can play a role in the suppression of SSM, and that this occurred despite releasing the mass reared species. This conclusion was confirmed by the identification of the species of predatory mites from release and no release areas being primarily the endemic species *E. elinae*. From these identifications, a hitherto unidentified predatory mite was recorded. This mite, *Amblydromalus lailae*, was found in a nursery and two avocado orchards. In one of the orchards, significant numbers occurred. These two species are assumed to be naturally occurring and probably involved with suppression of SSM. More work is required to quantify the role of *A. lailae*, either alone or in combination with *E. elinae*.

A recent scientific paper casts doubt on the identity of the pest mite in WA avocado orchards being *E. sexmaculatus*. The suggestion is that the pest mite is in fact a native species *E. queenslandicus*. Submitting specimens from WA has not resolved this taxonomic issue and further investigations are required before the issue is resolved. The same is the case to clarify the identity of an as yet unidentified species of a 'brown mite' recently recorded damaging leaves in WA avocado orchards.

Results of SSM monitoring which clarified its seasonality, indicated that prevention of spring outbreaks of SSM is best achieved by reducing their abundance in late summer/early autumn. If present in reasonable numbers at this time in association with low or no predatory mites, falling temperatures reduce the impact of predatory mites and miticides are likely to be less effective in cooler weather. In all cases, some monitoring for SSM through winter is recommended.

Monitoring by growers has proven a challenge and some are relying on a consultant to undertake this. Aspects of monitoring that requires more attention are the interpretation of SSM and predatory mite numbers for basing decisions on the need to intervene, and the reliability of monitoring based on leaves collected at ground level compared to higher points in orchards where tree height can be 8m or more.

Miticides were relied upon where predatory mites were unable to contain SSM. Growers are aware of the potential for resistance to develop and are rightly cautious of relying on this means alone for crop protection. The Minor Use Permit Program of Hort Innovation is an important part of chemical options

to be integrated in the management of SSM with an emphasis on selecting miticides with a reputation of having little direct toxic effect on predatory mites.

Over the duration of this project, the area where SSM has required action expanded and so more orchardists are now potentially affected by this mite. Meetings with avocado growers to discuss results of this project and on-going interchange on developments will be encouraged.

As well as clarifying an action threshhold involving SSM and predatory mite abundance levels, more work is required on the susceptibility of avocados trees to SSM attack in relation to tree stage and health, and time of year. Such investigations would contribute to the development of a sustainable SSM management strategy.

Keywords

Avocado; six-spotted mite; *Eotetranychus sexmaculatus*; Integrated Pest Management; predatory mites; *Euseius elinae*; *Amblydromalus lailae*.

Introduction

Six-spotted mite (SSM) is an exotic species to Australia and is present in all production areas. It has been reported from China, India, Iraq, Japan, Korea, New Zealand, Taiwan, Hawaii and mainland USA. This mite was a major pest of avocado orchards in New Zealand late last century during which occasion miticides were registered (Froud et al, 2002). The importance of the mite in New Zealand declined but more recently has recurred (David Logan, pers. comm.). SSM is present in avocado orchards in eastern Australia and it is assumed this is the basis for the registration of the miticide fenbutatin oxide for its control possibly as long ago as 1988 (Maddox, pers. comm. 2019). Currently reports from eastern Australia indicate the mite is no longer regarded as a pest there (Maddox, Newett, Newton, Seeman, pers. comm. 2019). The reasons for this may be related to the more frequent application of insecticides for control of pests which are not known to occur in WA but which may have activity against mites (Maddox, pers. comm. 2019).

This mite was first recorded in the Pemberton region of Western Australia (WA) in 1986 on avocado nursery stock from eastern Australia (Anon. 2018). The success of actions taken to eradicate this incursion was not verified. In 2006 the mite was detected again in vineyards in the Karridale region of WA which is about 90km north west of Pemberton. At that time, surveys undertaken showed the mite was present in most avocado orchards as well as some vineyards in the Pemberton region.

Up to 2014, in WA SSM had been a pest in vineyards primarily, causing premature defoliation affecting fruit maturation. In avocado orchards, there was only one case where an inadvertent application of insecticide resulted in a mite outbreak with subsequent complete defoliation. At that time, observations in a number of avocado orchards in the Pemberton district showed most were infested with SSM, but it appeared they were in balance with natural enemies, especially predatory mites with the main species detected being *Euseius elinae* (det. Knihinicki, NSW DPI (New South Wales Department of Primary Industries)). The density of SSM mite was very low.

In the spring of 2014, SSM was detected at very high numbers in one avocado orchard and in moderate numbers in at least four others in the Pemberton and south Manjimup areas. In one of these avocado orchards, the defoliation was so severe, fruit harvesting was expedited to prevent exposed fruit being sunburnt. Such fruit would otherwise be downgraded reducing returns. This situation affected the harvest program for other orchards to avoid flooding the market.

The reasons for the outbreak of SSM are unclear. There was no difference in the foliar spray program regarding pesticides, for example control of dieback disease *Phytophthora*, or application of nutrients. Few predators were found associated with the pest mite, indicating that natural suppression was not occurring.

Most avocado orchardists in the SSM affected areas of WA relied on miticides to protect crops. Apart from the cost of chemical and application, using miticides comes with the risk of chemical resistance developing.

After harvest, the more severely affected avocado orchards were sprayed with miticide. This was reasonably successful but growers expressed interest in whether releases of the commercially available predatory mites *Metaseiulus occidentalis* and *Neoseiulus californicus* could control SSM and thereby reduce the reliance on chemicals. If the predatory mites were effective against SSM, this would be a more sustainable means of achieving orderly production of quality avocados.

Some research has been undertaken to identify species of predatory mite to help control SSM. In New Zealand, Stevens and Jamieson (2002) showed that the commercially available predatory mites *Phytoseiulus persimilis* and *Neoseiulus* (=*Amblyseius*) *cucumeris* were ineffective. Predatory mites have been studied in avocado orchards in California, USA where mixed pest mite populations occur and include SSM, persea mite (*Oligonychus perseae*) and avocado brown mite (*Oligonychus punicae*) (Anon, 2016). For SSM, the predatory mites (Family Phytoseiidae) that are reported to help control it include Amblyseius (=*Typhlodromalus; Amblydromalus) limonicus (=lailae)*, *Galendromus helveolus* and *Typhlodromus rickeri*. Another predatory mite species involved, *Euseius hibisci,* a shiny pear-shaped predator, is important in part because it can maintain and increase its numbers on avocado pollen. This species is also reported to prey on SSM around Santa Barbara County. The spider mite destroyer lady beetle *(Stethorus picipes)* and six-spotted thrips *(Scolothrips sexmaculatus)* are other important natural enemies in California. In WA, the only known naturally occurring predators of SSM are considered to be *E. elinae*, a species of *Stethorus* and a predatory thrips, *Scolothrips rhagebianus* (Mound, 2011). Identifications of phytoseiid predatory mites collected from horticultural crops during a survey in WA by Whitney & James (1996) and reviewed and added to by Steiner et al (2003), include the predatory mite species *E. elinae* and *A. limonicus* (*T. lailae*) collected from vineyards. Their presence is relevant for suppressing SSM in that crop. A*mblyseius* (=*Typhlodromalus; Amblydromalus) limonicus (=lailae)* was collected from avocados but at that time *E. elinae* was not recorded. The prey for *T. lailae* in avocados was not mentioned.

This project sought to clarify the role of the endemic and selected commercially available predatory mites in managing SSM in WA avocado orchards. In association with this objective, the project developed information packages on mite management to assist growers and other personnel involved with the industry to protect crops from SSM. The project was conducted through a collaboration of Department of Primary Industries and Regional Development (DPIRD) and Biological Services.

Methodology

Predatory mite identifications

Specimens of predatory mites were collected during monitoring when they were abundant and therefore assumed to be important in reducing the abundance of SSM. These were sent to mite taxonomist Dr Jenny Beard of Queensland Museum to identify.

Field releases of predatory mites – two series of field releases

To assess the effectiveness of new species of predatory mite to control SSM, releases were made in portions of commercial avocado orchards in which SSM had been a problem. The details of how the releases were undertaken, leaf damage assessment scored and monitoring methods of pest and predatory mite abundance, are given in Appendix 1 and the laboratory scoresheet used in Appendix 2.

Two series of predatory mite releases were undertaken. In the first series, the predatory mites *Metaseiulus occidentalis* and *Neoseiulus californicus*, available from a commercial mass rearing facility, were released both separately and in combination in four avocado orchards. *M. occidentalis* was mass produced using two-spotted mite as the prey reared on bean plants. Releases involved placing infested bean leaves in branches of avocado trees. *N. californicus* was mass produced using inert media containing non phytophagous prey mites. This predatory mite was released in measured volumes of the media on main branches near the crotch of trees. The release areas were four adjacent rows with the inner rows being the trees from which leaves were collected to assess the effects of the releases. Including a non-release area, four portions of an avocado block were monitored (see Appendix 3).

Following the results from the greenhouse study described below, in the second series of releases, the predatory mite *Metaseiulus occidentalis* was released again together with another mass reared commercially available species *Typhlodromus doreenae*. This other species of predatory mite is mass reared in the same way as *N. californicus* and released in avocado orchards in the same manner. For this second series of releases, only areas where mites were released individually were included for assessment. Therefore for this series, only three areas within an avocado block were monitored (see Appendix 3). Three avocado orchards received these predatory mites.

To gain an understanding of SSM seasonal variation in abundance, other commercial orchards were included in the monitoring.

Because all monitoring was conducted in commercial orchards, results of monitoring were communicated to growers no longer than 3 days after sampling. This information was sent via email; see Appendix 4 for an example of the type of monitoring information sent to orchardists. Should intervention be required, growers were contacted by phone to discuss what action might be required.

Glasshouse study of predatory mites

Three separate rooms with automatic irrigation and temperature control to a constant 25^{o} C in an insect proof glasshouse were used. In each room, fourteen avocado plants about two meters high growing in plant pots were obtained. In September 2016 they were infested with SSM, collected from avocado orchards in Pemberton. The predatory mites *E. elinae,* obtained from an avocado orchard in the Perth Hills and *M. occidentalis* and *N. californicus*, from commercial insectaries, were released on plants in each room. Their efficiency as predators of SSM was assessed by examination of leaves for the presence of both pest and predatory mites.

Fig. 1. Inoculation of the predatory mite *N.* californicus on SSM infested avocado leaves in a glasshouse study to assess their efficiency on SSM. The flaky material on leaves consists of predatory mites that were mass produced using inert media containing non phytophagous prey mites.

Grower liaison

Avocado growers in the south west of Western Australia who agreed to allow a portion of their orchard be used to assess the effect of predatory mites were kept informed of the monitoring. Results of the releases in terms of the abundance of pest and predatory mites and leaf damage were dispatched fortnightly to growers via email. If imminent intervention was considered necessary, growers were contacted by phone to discuss whether and what action would be implemented.

As required, visits were made to other avocado orchards at the request of growers who considered SSM could be a problem.

To provide information to avocado orchardists in the region where SSM was potentially a pest, grower field days were planned. These meetings with growers had the objectives of introducing the project and assisting growers to be able to identify SSM and associated agents both beneficial and benign to encourage self-monitoring. A diagnostic information sheet with photos of these agents and mite damage were to be produced and distributed. Later meetings would be held to provide updates of progress of the project and include discussions with growers to answer queries and receive comment on their experiences with the mite.

Content on the DPIRD web site with background information on SSM in the main host crops of avocados and grapevines was advertised to growers and kept up to date.

Articles on the project and progress were to be written for the national avocado magazine and the local DPIRD Ag Memo.

Outputs

Predatory mite identifications

The identification of predatory mite specimens from blocks where predatory mites were released and blocks where no releases were made, are given in Table 1 (J. Beard, pers. comm. 2019).

Table 1. The identification of predatory mites from avocado orchards and blocks where commercially available predatory mites were released and from other areas where no releases were made.

		*Predatory mite species & **stage of mite															
		Ee				Td				Al				Ad			
Orchard/Bl	Predatory mites released	F	M	N	L	F	M	N	L	F	M	N	L	F	M	N	L
1/1	T. doreenae release area	4	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
1/1	No release area	4	2	1	2	0	0	0	0	0	0	0	0	0	0	0	0
1/2	M. occidentalis release	6	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
1/2	M. occidentalis + N californicus release	1	1	8	0	0	0	0	0	0	0	0	0	0	0	0	0
1/2	N. californicus release	23	3	4	1	0	0	0	0	0	0	0	0	0	0	0	0
1/2	No release	3	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2/1	No release	6	3	2	0	0	0	0	0	0	0	0	0	0	0	0	0
2/1	M. occidentalis + N californicus release	6	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2/2	T. doreenae release area	4	1	0	2	0	0	0	0	0	1	1	0	0	0	0	0
2/2	No release	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
3/1	T. doreenae release area	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3/1	M. occidentalis release	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0
3/1	No release	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3/2	M. occidentalis release	4	0	1	2	0	0	0	0	0	0	0	0	0	0	0	0
3/3	No release	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4/1	M. occidentalis + N californicus release	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4/1	M. occidentalis + N californicus release	27	4	5	2	0	0	0	0	0	0	0	0	0	0	0	0
5/1	M. occidentalis release	5	0	1	1	0	0	0	0	0	0	0	0	1	0	0	0
5/1	No release	0	0	0	0	0	0	0	0	0	0	0	0	2	0	1	0
5/1	M. occidentalis release	5	1	2	0	0	0	0	0	2	3	0	0	0	0	0	0
5/2	T. doreenae release area	0	0	0	0	0	0	0	0	1	0	2	2	1	0	0	0
5/2	M. occidentalis release	0	0	0	0	0	0	0	0	5	1	3	2	1	0	0	0
5/2	No release	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0

*Ee = *Euseius elinae*
*Td = *Typhlodromus doreenae*
*Al = *Amblydromalus lailae*
*Ad = *Amblyseius deleoni*

**F = female; M = male; N = nymph; L = larva

These results indicated that, apart from a record of one individual adult of *T. doreenae*, which could have been from the actual released individuals, none of the species of mass reared predatory mites released established. The dominant species was the "naturally" occurring species *E. elinae*.

Two species of mite identified had not been recorded in earlier surveys by DPIRD personnel. These "new" species of predatory mites identified were *Amblydromalus lailae* and *Amblyseius deleoni*. Records of immature mites of both species confirmed they were breeding in the orchards and so are assumed to be established in WA. In another series of predatory mites from avocado plants in WA also recently sent for identification, both new species were identified (J. Beard, pers. comm. 2019). In the latter series, *A. lailae* was from a nursery and two orchards, one of which was different to the single orchard indicated in Table 1. In the case of *A. deleoni*, it was collected from a single but different orchard to that for Table 1. Also in the latter series, *A. lailae* was collected from strawberries, raspberries and blackberries in the Pemberton, WA area (L. Chilman & J. Beard, pers. comm. 2019).

The occurrence of the predatory mites *A. lailae* and *A. deleoni*, while modest in terms of their distribution and to some extent their abundance, the fact that breeding populations were found on plants infested with six-spotted mites indicates more investigations are required to clarify their role in suppressing this pest mite.

Field releases of predatory mites – two series of field releases

The detailed results of the two series of releases of commercially available species of predatory mites in seven orchards as well as other orchards monitored at the same level of detail, are given in Appendix 6. Those results are summarized here by discussing three scenarios which are representative of the overall results. These scenarios are presented in the knowledge of which predatory mite species were identified from field collections made during the project (Table 1.). None of the released predatory mite species were found to breed within the avocado orchards. Therefore any reduction of SSM abundance is assumed to be primarily related to the abundance of the endemic predatory mite *E. elinae*. While a second species of predatory mite, *A. lailae* was identified, its distribution was limited and therefore it is not considered in the following discussion.

The first scenario presented demonstrates the common result with respect to the first series of releases of mass reared predatory mites against six-spotted mite (Fig. 2.). This series involved setting up three adjacent release areas and they were compared with an adjacent none release area. The three release areas were two of separate species of a predatory mite alone, and the third was where both species were released in combination.

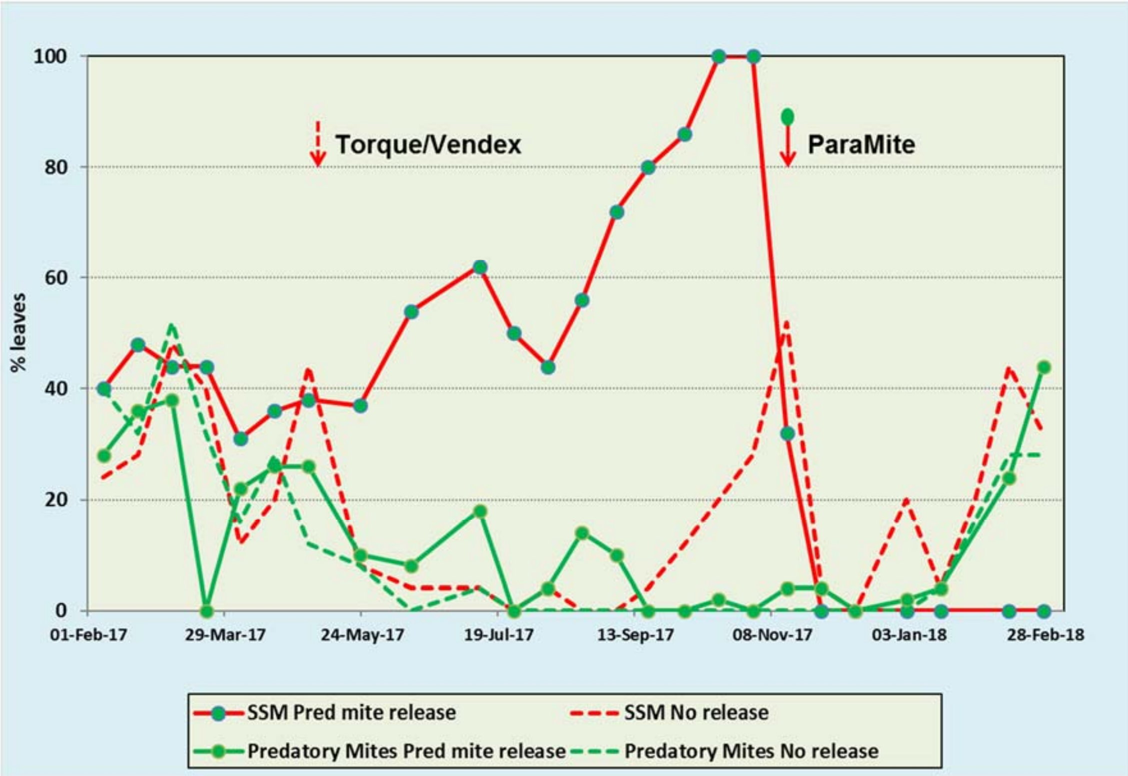

Fig. 2. The percentage of avocado leaves infested with six-spotted mite (red lines) and with predatory mites present (green lines) in areas of an orchard that either received mass reared predatory mites (green dots on the lines) or not. Trees in the latter area were sprayed once with miticide (dashed lines) and trees in the release area were sprayed later and once only also. The timing of miticide applications is indicated by the arrows.

The abundance of SSM and predatory mites in one of the three release areas only is presented in Fig. 2. The result here was similar to that for the other two areas (Fig. A.6.2).

In the release area, SSM abundance remained reasonably steady through the first summer but predatory mite numbers declined. The non-release area was sprayed with miticide in May and numbers of SSM remained low through winter and did not increase until the following spring. In the unsprayed predatory mite release areas, SSM numbers increased as temperatures rose in spring, with predatory mite numbers remaining low. This area was sprayed with miticide in late spring, but not before significant leaf fall had occurred. This was dramatically different to the adjacent non-release area that had been sprayed the previous autumn where leaf fall did not occur.

SSM damage as leaf fall in the twelve rows where predatory mites were released was depicted dramatically in aerial observation by a drone (see Figs. 3 and 4a and b). Because of the defoliation by SSM in the release areas, the flowers of the avocado trees were more exposed resulting in those trees having a yellow appearance compared to the greener appearance of trees in the adjacent area sprayed earlier.

Fig. 3. Drone photo of avocado trees where predatory mites were released to assess their effect on SSM. Release trees are the twelve rows to the left of the shed in the foreground with trees to the right treated with miticide in autumn and predatory mite release trees not sprayed until the following spring. The more yellow trees in the release area are because of greater defoliation by SSM (see Figs. 4a and b.).

Fig. 5a. Drone photo of avocado trees where predatory mites were released to assess their effect on SSM. Release trees are to the left of the shed in the foreground with trees to the right treated with miticide in autumn; predatory mite release trees were sprayed the following spring. The more yellow appearance of trees in the release area is due to exposure of flowers after defoliation by SSM with leaves evident on the orchard floor.

Fig. 5b. Avocado trees where predatory mites were released to assess their effect on SSM are to the left with trees to the right treated with miticide in autumn and predatory mite release trees not sprayed until the following spring. Trees in the release area suffered a significant level of defoliation by SSM so appear more yellow at this time of year when trees in both areas were flowering.

The second scenario presented is where one miticide had been applied in an orchard towards the end of the second season of monitoring (Fig. 6). This orchard was a site for releases of mass reared predatory mites but for ease of presentation and discussion, the data presented in this section of the report shows the monitoring data for a portion of the release site. More detailed information on monitoring results for this, see Appendix 6 (Fig. A.6.15).

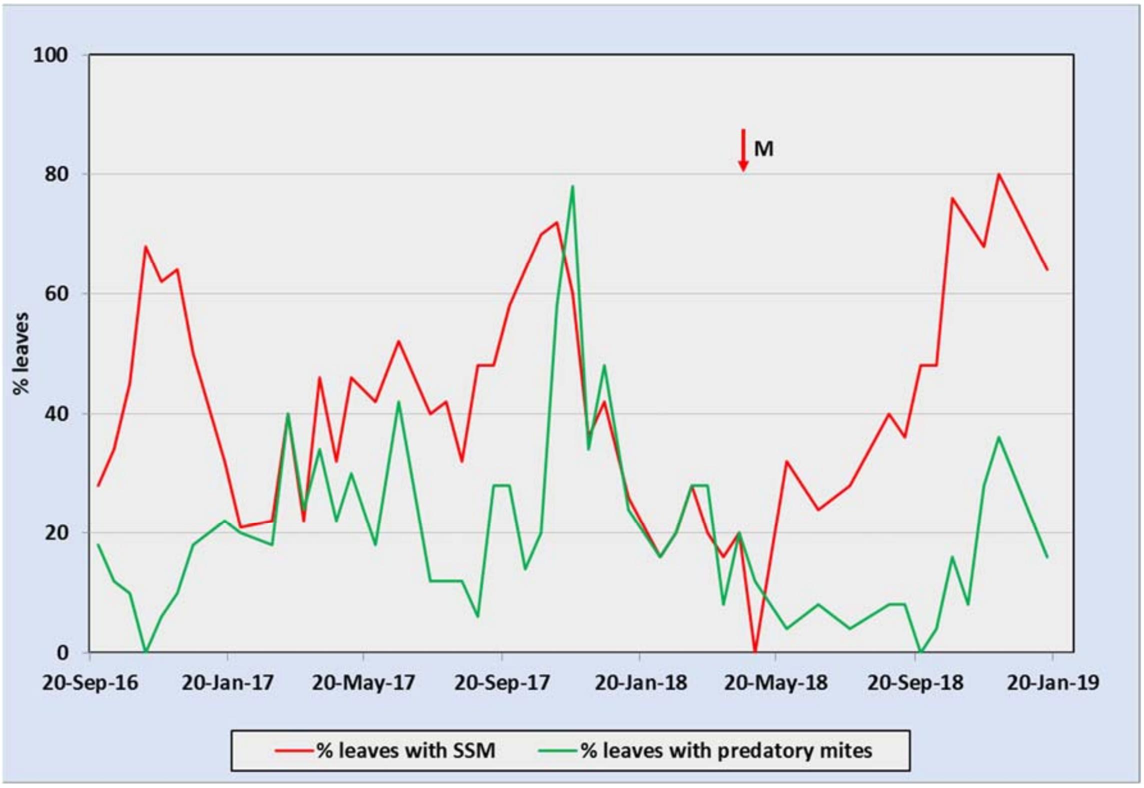

Fig. 6. The percentage of leaves infested with six-spotted mite and presence of predatory mites in an avocado orchard from September 2016 to January 2019 where one miticide was applied.

The infestation of six-spotted mite was high initially with a low level of predatory mites present. This situation lead to leaf fall but not to the extent that sunburn damage to fruit was an issue. Predatory mite numbers increased during summer and SSM numbers fell. During winter predatory mite numbers declined while SSM numbers remained steady and increased in late winter to early spring to result again in some defoliation. SSM numbers were subsequently reduced as predatory mite numbers increased during early summer. A miticide was applied in autumn 2018 which appeared to cause a short duration drop in SSM numbers before they increased again during winter and more rapidly as temperature increased in spring. Predatory mite numbers remained low until the onset of warmer weather. At this time, while SSM reached the highest infestation of the monitoring period, the increase in predatory mite numbers appeared to hold SSM from reaching complete infestation.

In this scenario, the application of miticide may have been disruptive to a situation where predatory mites reached reasonable levels and appeared to be able to hold SSM in check at least to the extent that leaf fall was at a level where little sunburn damage to fruit was observed.

The third scenario presented is where the predatory mite *N. californicus* was released across two adjacent blocks of avocados followed by later releases of *N. californicus* and *M. occidentalis* on the edges of the bocks only (Fig. 7 and for more detail, Figs. A.6.16 & 17).

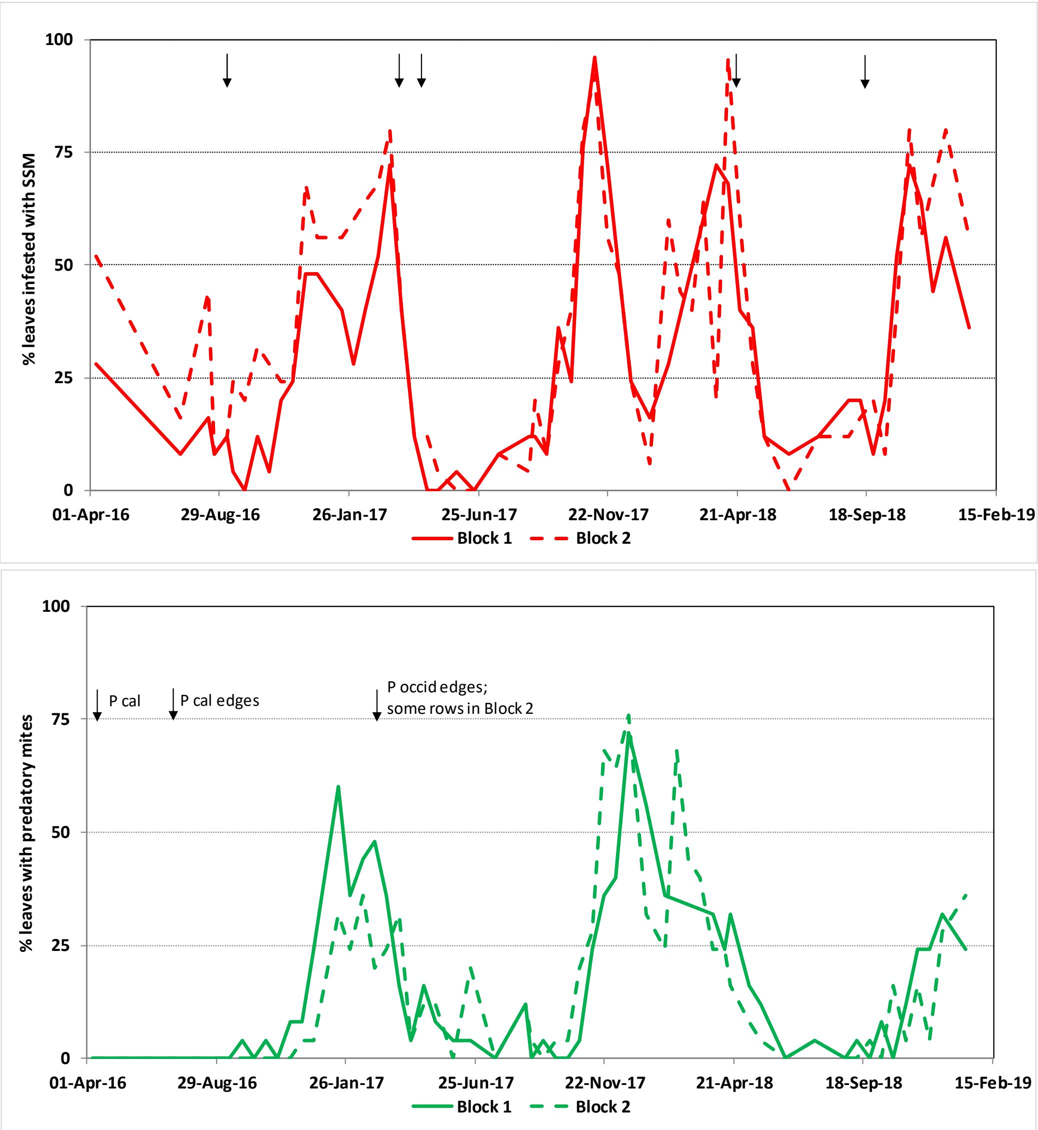

Fig.7. The percentage of leaves infested with six-spotted mite and presence of predatory mites in two adjacent blocks of an avocado orchard from 2016 to early 2019; arrows in the top graph indicate timing of applications of miticide and arrows in the lower graph indicate the species of predatory mite released (see text for details).

Results of this monitoring demonstrate the rigor of the sampling strategy where results for two adjacent blocks of avocados with the same mite management strategy showed very similar trends for SSM and predatory mite abundance as well as similar levels of leaf damage (Fig. A.6.17).

There was an indication that the buildup in abundance of predatory mites had the effect of reducing SSM numbers, especially evident in the summer of 2017. Miticide was applied to give confidence that SSM numbers would be low enough going into winter so that trees in spring would have a strong canopy to ensure fruit was not exposed and trees were able to support spring vegetative flush, flowers, new fruit production as well as supporting mature fruit near harvest on the trees.

Some defoliation of trees from SSM feeding was evident but the fruit was able to be harvested with almost no issue of sunburnt fruit.

One issue arising from this particular orchard was the reliability of the monitoring. This orchard is quite old and the trees near 10m high. The canopy at ground level from which leaves were collected for monitoring was quite sparse. Fruit is this orchard along with any others in the district is harvested with the aid of motorized extendable frames. It was not possible to collect a random sample of leaves in the manner they were collected form the ground by using these mortised ladders, but obtaining leaves form the upper, more dense canopy would have been more reflective of the SSM/predatory mite association there. The orchardist commented that the leaf damage levels from the ground based leaf monitoring underestimated that for the upper canopy.

More investigation is required to determine whether the height from which leaves are collected to monitor SSM is compromised when ground based sampling only is relied upon in mature tall orchards.

Glasshouse study of predatory mites

The results of monitoring SSM and predatory mites on avocado plants where *E. elinae* was released are given in Fig. 8.

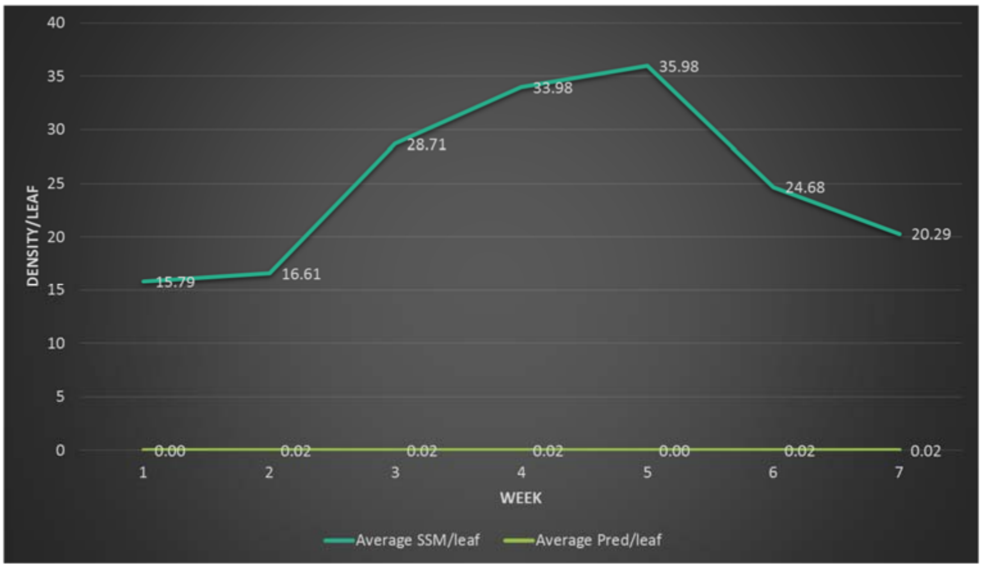

Fig. 8. The abundance of SSM and the predatory mite *E. elinae* on avocado plants in a glasshouse trial.

The predatory mite *E. elinae* did not establish and the population of SSM increased over the seven weeks' duration of the study. This result may be related to the feeding habits of this predatory mite which are not well known. *E elinae* may be a generalist predator with a requirement for alternative sources of food such as pollen and may even feed on the tydeid fungus/detritus feeding mites commonly present in avocados orchards. In the greenhouse trial these extra food sources were not provided.

The results of monitoring SSM and predatory mites on avocado plants where *M. occidentalis* was released are given in Fig. 9.

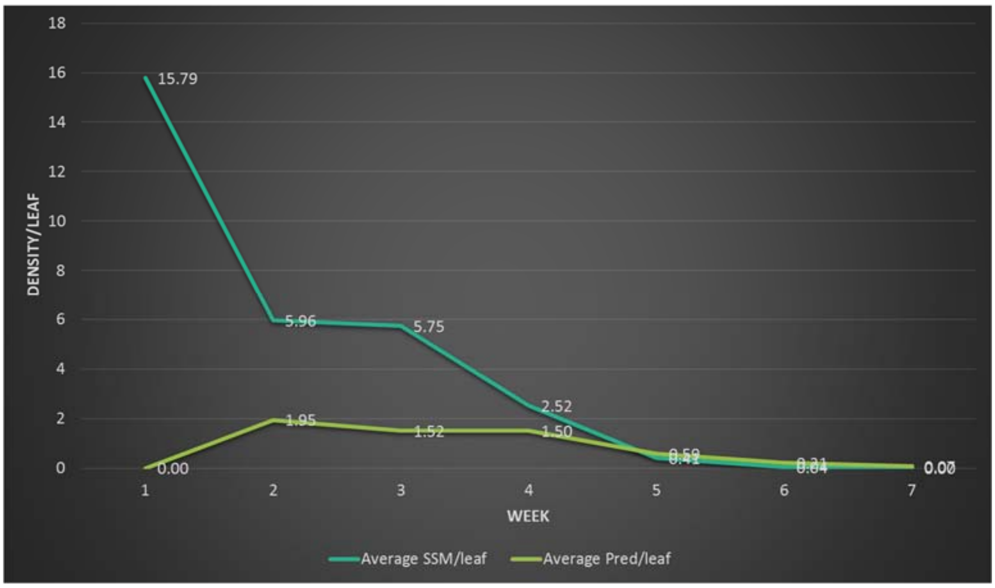

Fig. 9. The abundance of SSM and the predatory mite *M. occidentalis* on avocado plants in a glasshouse trial.

The predatory *M. occidentalis* established well and eliminated SSM over the seven weeks' duration of the study.

The results of monitoring SSM and predatory mites on avocado plants where *N. californicus* was released are given in Fig. 10.

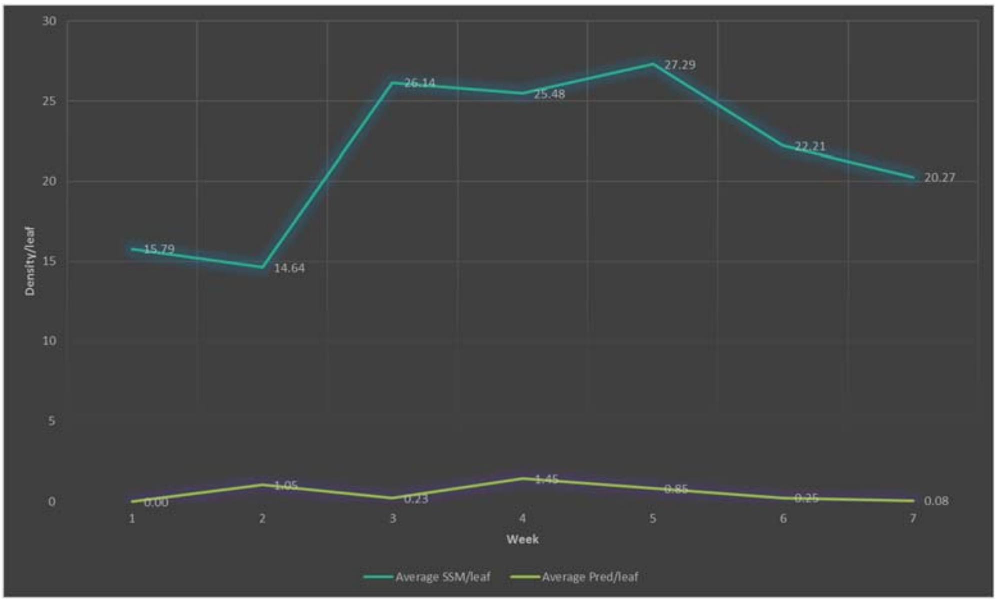

Fig. 10. The abundance of SSM and the predatory mite *N. californicus* on avocado plants in a glasshouse trial.

The predatory *N. californicus* remained at very low levels during the trial and did not control SSM.

Grower liaison

Regular communication of monitoring results

For the avocado orchards used for the predatory mite releases, results of the near fortnightly monitoring were emailed to owners and managers within the week of collection. This included any suggestions regarding management. This information provided useful regular two-way interchange with seven avocado orchardists on matters relating directly to the project.

Grower seminars/training days:

DPIRD - Avocado Growers' Workshop Manjimup Office and Research Facility WA 16 March 2017:

Chilman, L. Control of SSM on avocado trees with three different species of predators.

Learmonth, S.E. Pest status & management of SSM (*Eotetranychus sexmaculatus*) in WA avocado orchards.

Avocados Australia - Grower's Shed, Manjimup WA National Avocado Growers' Workshop 16 March 2017:
Chilman, L., Control of Six Spotted Mites in Avocados, a summary.

Learmonth, S.E. Pest status & management of SSM (*Eotetranychus sexmaculatus*) in WA avocado orchards.

DPIRD - Avocado Growers' Workshop Grower's Shed, Pemberton WA 4 September 2017

Delroy, S. A grower's view on: How to Monitor for SSM.

Learmonth, S.E., Chilman, L. Pest status and management of SSM (*Eotetranychus sexmaculatus*) in WA avocado orchards – An update.

Avocados Australia R&D Planning Forum - Brisbane QLD 8 & 9 November 2017

Learmonth, S.E., Chilman, L. Pest status & management of SSM (*Eotetranychus sexmaculatus*) in WA avocado orchards.

DPIRD - Avocado Growers' Discussion Manjimup Office and Research Facility WA 7 March 2018:

Delroy, S. A grower's view on: How to Monitor for SSM – an update.

Learmonth, S.E., Chilman, L. Pest status and management of SSM (*Eotetranychus sexmaculatus*) in WA avocado orchards – an update.

DPIRD - Avocado Growers' Discussion/Training Manjimup Office and Research Facility WA 3 April 2019:

Learmonth, S.E. Monitoring for six-spotted mite in avocado orchards.

Articles produced:

Learmonth, S.E., Chilman, L., 2018. Quest to find predator for SSM in WA avocado orchards. Good Fruit and Vegetables, April 2018. **https://www.goodfruitandvegetables.com.au/story/5314328/quest-to-find-predator-for-six-spotted-mite-in-wa/**

Learmonth, S.E., Chilman, L., 2018. Eating up SSM – a pest in the west in avocado orchards. Talking Avocados **29** (1):33-35.

Learmonth, S.E., 2018. Check for SSM now to protect next season's crops. DPIRD AgMemo - Horticulture news. 3pp.

Outcomes

The key objective of this project was to clarify the role of releases of certain species of commercially available predatory mites to protect avocado trees from SSM. None of these species had been identified to occur in avocado orchards in the SSM affected region. Results from monitoring small plots in seven orchards in two series of predatory mite releases, as well as orchards where more widespread releases were made, showed that predatory mites species either released or present naturally cannot be relied upon as a stand-alone method of protecting avocado trees from SSM.

The identification of the species of predatory mites most commonly present in WA avocado orchards collected during this study, *E. elinae*, confirmed by association, its importance of having some suppressing effect on SSM populations.

The role of two other species of predatory mites, *A. lailae* and *A. deleoni*, with both showing evidence of breeding on SSM infested avocado plants, indicates more work should be undertaken to clarify their role in SSM management. Little is known of either species as potential effective natural enemy of SSM, but of the two species, there is likely to be more interest in *A. lailae*. This species has been present in WA for some time (Steiner et al, 2003) and seemingly is tolerant of lower temperatures in New Zealand (Min et al, 2018). A perceived shortcoming of *E. elinae* is that it is outstripped by SSM over winter.

The results of this project indicated that predatory mites cannot be relied upon as the sole means of protecting avocados from SSM. They were sometimes present in high numbers that appeared to lead to a fall in populations of SSM. Such a decline in SSM was not sustained and miticides were often required to protect avocado trees. This classic prey/predator lag/ prey decline/predator decline/ prey resurgence is not understood. Until this association is clarified, miticides will be required to redress the balance of prey and predator.

If predatory mite compatible miticides are selected when applications are required, and if predatory mites can be mass-produced for strategic times of release, SSM management can be considered to be more truly integrated.

Specimens of SSM sent for examination indicated that what is considered to be the exotic SSM, *E. sexmaculatus*, may in fact be a native species of mite that occurs in eastern Australia. This native species, *E queenslandicus*, has been described and reported by Seeman et al (2017). Some detail on this native species as well as SSM can be found on the Queensland Museum web site (Beard, 2019).

The other important objective of the project was to give growers confidence in recognising the fauna on avocado leaves so they may undertake their own monitoring. This was considered to be achieved through the production of a handout colour photograph guide, running grower seminars where this fauna was on display with dissecting microscopes on hand as a training exercise and one on one visits to orchards where SSM was suspected as causing defoliation. In addition, publications in magazines and the DPIRD web site were produced. Recently some growers have advised the project team that they have engaged a consultant to undertake monitoring. Orchardists noted that time constraints was the main reason for this.

Monitoring is critical to avoid SSM build up to prevent defoliation of avocado trees. As well as giving growers the confidence to recognize the relevant agents, the project sought to use results of monitoring to assess the role of predatory mites, to indicate the key elements of such a guide. While a detailed management plan was not developed in this project, guidelines were outlined (see Appendix 5).

During this study, an unidentified species of 'brown mite' (see Fig. 11 and Anon 2018) not previously recorded in WA avocados was observed in at least three WA avocado orchards, two of which required application of miticide. The miticides used were fenbutatin oxide (Torque, Vendex) and etoxazole (ParaMite) which were successful in controlling the mite. Its identity requires clarification.

Fig 11. Species of mite observed in WA avocado orchards which is yet to be identified. From top left and clockwise – mite adult, leaf symptoms, stethorus larva predator, 'brown mite' egg.

Monitoring and evaluation

Help stakeholders stay focused on M&E information of primary importance

> Liaison with avocado growers was maintained to advise them of research results including other developments in relation to managing SSM. This was achieved through regular contact with individual growers whose orchards were monitored fortnightly as well as via with grower meetings and producing articles on the project.

Provide a framework to ensure the necessary data (both qualitative and quantitative) is collected and synthesized and provide structure for reporting:

> Through the detailed monitoring of SSM in seven avocado orchards for the duration of the project, specific and general information on pest mite abundance and the success or otherwise of predatory mite releases and miticide application recommendations were quantified. Both DPIRD and Biological Services personnel relayed this information to growers. No significant SSM related defoliation events occurred in avocado orchards during the project that had been previously observed.

Is there a sustainable management package available and accessible in the longer term on the DAFWA web site for managing leaf loss resulting from mite infestations in susceptible areas?

> Results of monitoring SSM, predatory mites and SSM leaf damage has given the project team a basis for drafting management guidelines. This can be built upon with further experience of different scenarios and refinements to monitoring, to make further improvements to support long term sustainable management of SSM.

Can avocado orchardists in the south west region accurately identify six-spotted mite, its damage, predatory mites and other beneficial and benign agents?

And

To what extent are orchardists in the south west region aware of the impact of six-spotted mite and the need to monitor its presence and manage infestations?

> Avocado growers in both the SSM affected areas and those in nearby areas on south western Australia are aware of the signs and symptoms of SSM and its effects on avocado trees through direct experience or through communication with project staff and fellow avocado growers. They have a good level of confidence in recognising SSM and related fauna on avocado leaves.

Can orchardists in the south west region accurately interpret monitoring results and confidently determine management options to address infestations?

> One orchardist has adapted information supplied by members of the project team to develop their own monitoring program. For other orchardists who are time poor but aware of the potential for this mite to cause adverse effects, they have opted to utilize the services of a consultant to monitor their orchard.

Recommendations

For new areas planted to avocados, ensure plants are SSM free before planting out. This would help new plantings to establish without the added stress of a SSM infestation.

The efficiency of SSM monitoring should be reviewed in relation to the details of leaf sampling – how many and how often; how representative is ground based leaf sampling in orchards where trees are very high.

Avocado growers in those areas of south western Australia where SSM occurs but have yet to observe defoliation, should keep up to date with information on SSM and to implement regular checking of mite levels or confirm whether the cause of any leaf loss is related to SSM. If confirmed, implementation of a monitoring and management program will be required.

Avocado growers in those areas of south western Australia where SSM has caused defoliation should have a year round plan to monitor for the mite and associated fauna, especially during autumn to take pre-emptive action to avoid SSM outbreaks in spring.

The monitoring and management preliminary guidelines suggested from this project require further refinement, for example develop a miticide action threshhold based on time of year, the abundance of SSM and predatory mites, and tree health/tree stress especially in spring.

Further assessments should be conducted on the effect of new species of predatory mites in avocado orchards where SSM has been identified as suitable prey in glasshouse studies.

Where miticides are used, growers should select those least toxic to predatory mites.

Reliance on miticides alone to manage SSM should be discouraged to help slow or avoid the development of miticide resistance. Avocado growers should consider whether predatory mites may help keep SSM in check in some situations and so avoid unnecessary applications of miticide.

Baseline susceptibility levels of SSM for each miticide likely to be used to control it should be determined. Regular checks of SSM susceptibility to miticides should be maintained as a warning of whether miticide resistance is developing. This would influence selection of appropriate miticides as part of resistance management strategy.

The Hort Innovation project to develop minor use permits for horticultural crops includes an examination of active ingredients for use against six-spotted mite. Any new products should be incorporated into a resistance management plan for avocado growers to adopt. Their toxicity to relevant predatory mite species in managing SSM should be assessed

Taxonomy studies are critical to confirm the species of what is considered currently to be the exotic mite SSM as well as related predatory mites and the species of brown mite recently recorded to be a pest of avocados in WA.

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Intellectual property, commercialisation and confidentiality

No project IP, project outputs, commercialisation or confidentiality issues to report.

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The following DPIRD and Biological Services staff are thanked for their efforts in monitoring, discussing the project and administrating the project: Lisa Starkie, Helen Collie, Judy Rose, Alison Mathews, Denise Walsh, Diana Fisher, Benita Rooney, Nel Rooney, Cezar Moraes and Bhavesh Kunadiya.

We thank Dr Jenny Beard of the Queensland Museum for identifying mites and discussing issues relating to both their taxonomy and their occurrence.

Appendices

Appendix 1. Details of monitoring to assess the abundance of SSM, related fauna and leaf damage levels in avocados.

Monitoring was based on leaf sampling from the same rows on each occasion because predatory mite releases were made in designated rows in avocado orchards.

The sampling unit was based on 25 leaves. Leaves were collected on either side of the adjacent rows of a four-row release area. The position on branches where leaves were collected was between four and six below the growing tip to avoid new growth and old leaves both of which would be less likely to reflect the abundance and associated fauna and damage of SSM.

Leaves were held flat and placed in paper bags then within a plastic bag to avid drying out. Leaves were examined in the laboratory using a stereo dissecting microscope. Leaves were assessed for signs of SSM feeding and categorized in these leaf damage categories (see also Fig. A.1.1):

Dam0 = no sign of browning next to the veins;

Dam1 = minor browning next to the main vein and usually adjacent to the petiole;

Dam2 = more widespread browning adjacent to leaf veins along the leaf and obvious when the leaf is first examined;

Dam3 = severe leaf browning next to the leaf veins with more than half the area bronzed by mite feeding. Leaves with category 3 damage would be expected to fall prematurely as a result of feeding by SSM.

Fig. A.1.1. SSM leaf damage categories from top left and then clockwise:Dam0, Dam1, Dam2 and Dam3. See text for details.

The abundance of SSM eggs and motiles were scored rather than counted. The categories were:

0 = no mites present;

1 = 1 to 5 eggs or mites present per leaf;

2 = 6 to 25 eggs or mites present per leaf;

3 = >26 eggs or mites present per leaf.

The natural enemies: predatory mites, Stethorus beetles as larvae, pupae and/or adults, and what were assumed to be predatory thrips were counted. When predatory mite abundance was high, specimens were retained for subsequent identification by a mite taxonomist.

An example of the score sheet used is given in Appendix. 2.

Monitoring was usually undertaken fortnightly throughout the project. This interval was extended to three to four weekly during winter months, depending on mite abundance.

Appendix 2. Score sheet used to record SSM leaf damage level and abundance of pest and related fauna in avocado orchards.

SIX-SPOTTED MITE MONITORING SCORE SHEET - AVOCADOS

Property:..........................

Date leaves collected:.................... Date leaves scored:..........................

Block/Variety/Rows:...Scorer:.........

Leaf No.	* SSM Rating		#Leaf Dam	Steth'us No. & stage	Pred mites No.	Thrips No.	COMMENTS % mites dead; other predators; other insects/mites
	Eggs	Mites					
1							
2							
3							
4							
5							
6							
7							
8							
9							
10							
11							
12							
13							
14							
15							
16							
17							
18							
19							
20							
21							
22							
23							
24							
25							

Property:..........................

Date leaves collected:.................... Date leaves scored:..........................

Block/Variety/Rows:...Scorer:.........

Leaf No.	* SSM Rating		#Leaf Dam	Steth'us No. & stage	Pred mites No.	Thrips No.	COMMENTS % mites dead; other predators; other insects/mites
	Eggs	Mites					
1							
2							
3							
4							
5							
6							
7							
8							
9							
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23							
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25							

* Levels for pest mite eggs and motile mites abundance:

0 = no mites; L (low) = 1 to 5 mites / field; M (medium) = 6 to 25 mites / field; H (high) = > 25 mites / field

#Leaf damage. Rating of purpling on avocado: 0 = none; 1 = minor; 2 = moderate; 3 = severe.

Appendix 3. Details for releasing predatory mites in avocado orchards.

Two series of releases were made to assess the effective ness of three different species of predatory mites.

In the first series, four commercial avocado orchards were selected based on the presence of at least moderate infestation level of SSM. Two species of predatory mites were released on two occasions on the four selected orchards. Releases of the two species of predatory mites were made separately and in combination in four adjacent rows for each of these releases. The area where predatory mites were released in combination was made in the central four rows of the twelve rows used for predatory mite releases. These three release treatments were compared with a nearby area where predatory mites were not released. Monitoring was conducted in the central two rows of each of the four rows in which releases were made. The same rows were used for collecting leaf samples from release and non-release trees for the duration of the assessment period. Monitoring was undertaken fortnightly.

In the second series, three commercial avocado orchards were selected as described above. Two species of predatory mites were released but the treatment involving a combination of the predatory mites was not included.

The target release rates for the predatory mites were:

5 litres/ha *N. californicus* delivered as a volume rate per tree from inert media with prey mites;

50,000 *M. occidentalis*/ha delivered as stems of bean plants infested with two-spotted mites;

1 to 2L of *T. doreenae* mites per 10 trees.

Appendix 4. Example of monitoring information on SSM leaf damage, pest levels and predatory mite abundance sent to collaborating avocado orchardists.

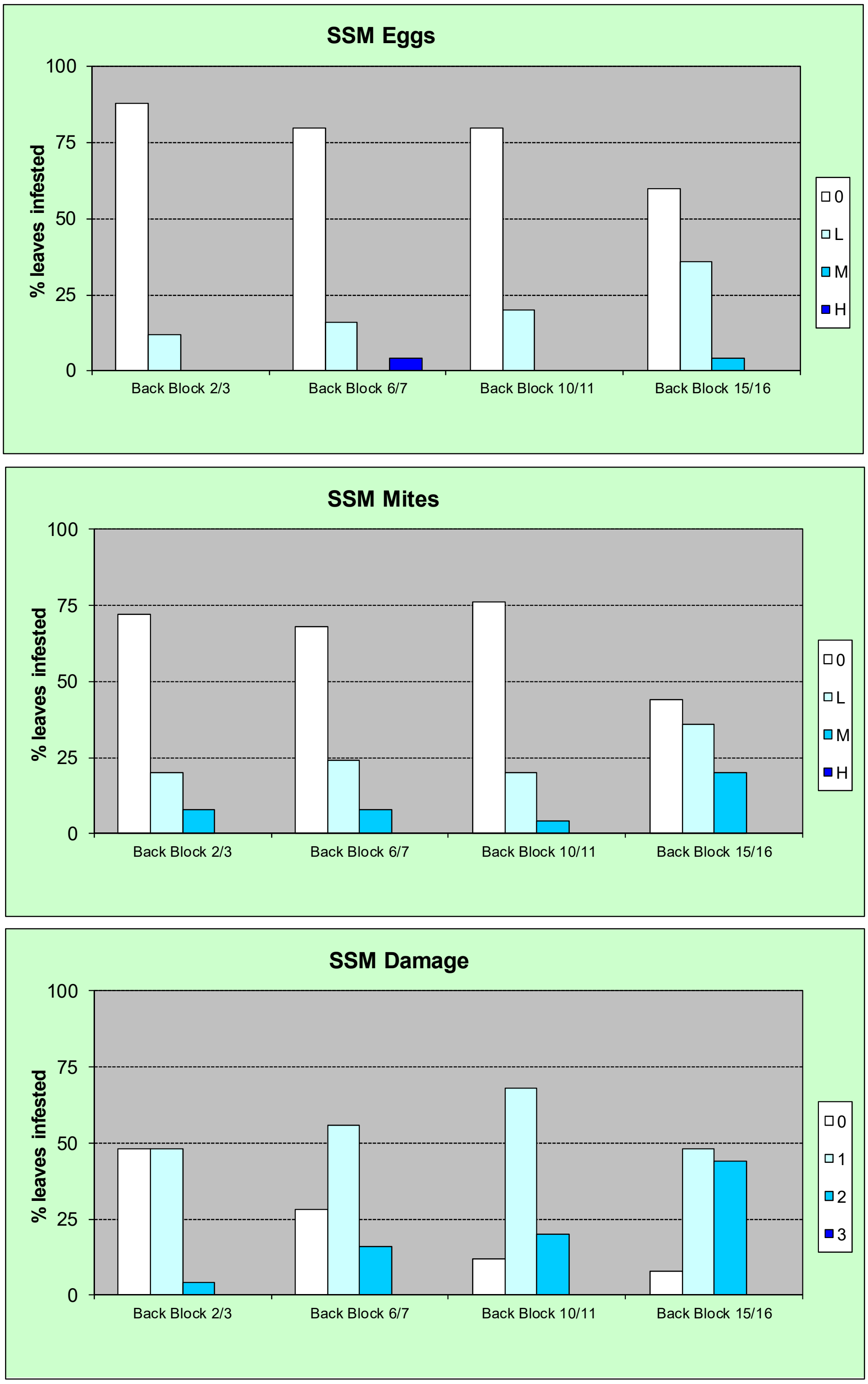

Fig. A.4.1. The top and centre graphs show the average level of abundance of SSM eggs and motiles respectively (0 = no eggs/mites; L (low) = 1 to 5 eggs/mites per leaf; M (medium) = 6 to 25 eggs/mites per leaf; H (high) = > 25 eggs/mites per leaf) and leaf damage over 25 leaves per sampling time in WA avocado orchards. SSM Damage: 0 = no sign of SSM browning adjacent to leaf veins; 1 = minor browning, usually near the petiole; 2 = more widespread browning along the leaf; 3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely

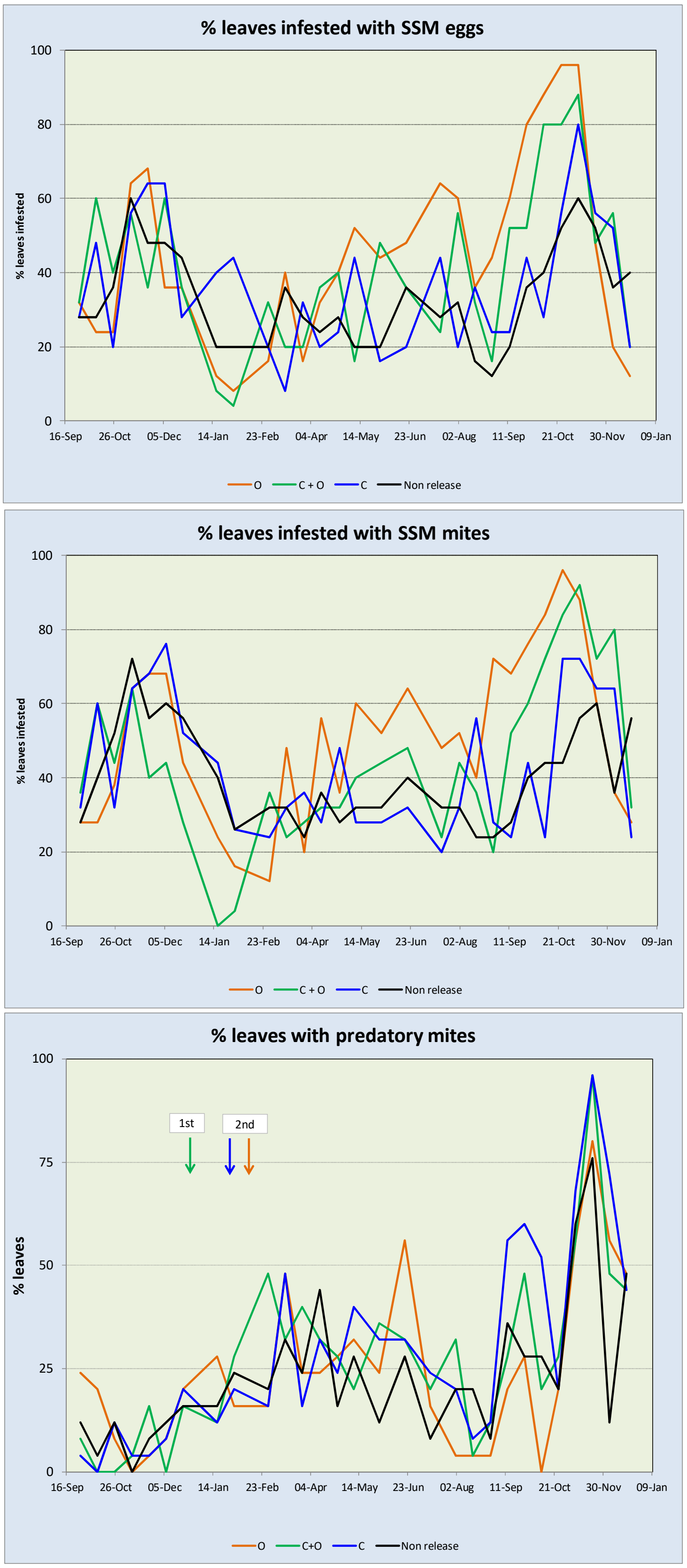

Fig A.4.2. The average percentage of leaves infested with SSM eggs or motiles and the percentage of leaves with predatory mites over 25 leaves per sampling time on avocado trees where predatory mites were released or not, the arrows indicating the time of two releases (O = *Metaseiulus* (= *Typhlodromus*) *occidentalis*; C + O = *M. occidentalis* + *Neoseiulus californicus*; C = *N. californicus*).

Appendix 5. Six-spotted mite management guide - Note to avocado growers on recommendations for monitoring and applying miticide to protect avocado trees from defoliation by six-spotted mite.

SIX-SPOTTED MITE MANAGEMENT GUIDE

- Avocado growers in Manjimup/Pemberton should check trees for six-spotted mite (SSM), especially if leaf fall is heavy.
- In spring, trees with mature fruit, flowering and new leaf growth are under stress and the level of stress is increased if SSM is present in reasonable numbers.
- To avoid a spring surge in SSM, autumn is an important time to check for SSM in the lead up to cooler weather in winter when predatory mites are less active.

Identification

For colour pictures of SSM and associated leaf damage, another red/brown pest mite, predatory mites and "look alike" neutral fungus feeding mites, see attached and for more detail refer DPIRD website: https://www.agric.wa.gov.au/avocados/six-spotted-mite-pest-avocados-and-grapevines.

Monitoring

SSM occurs on the underside of leaves next to the main vein. Feeding leads to bronzed discolouration of the leaf next to the vein. A 10X hand lens will confirm whether the mite is present. When monitoring for mites:

- Check at least two sets of two adjacent rows in every block of avocados.
- Check at least 10 leaves randomly but evenly along each monitoring row.
- Select leaves about four down from the growing tip.
- Record whether SSM and predatory mites are present.
- Monitor fortnightly until confident that this period may be increased.

As a guideline, an infestation level of around 40% of leaves with mites indicates the potential for leaf fall. Because of varying situations regarding tree health, stress in spring and presence of predatory mites, grower experience with SSM must be taken into account before making a management decision.

How can I manage six-spotted mite?

If predatory mites are present on more than 1/4 to 1/2 of leaves with SSM and leaf fall is minor continue regular monitoring. Predatory mites may provide adequate control.

If spraying is required, there are three registered/permitted chemicals all with a 14 day withholding period. The table below provides more information on them. Read all label and permit information prior to use.

Chemical	**Product example**	**Temperature / efficacy**	**Bee toxicity**	**Predatory mite toxicity**	**Withholding period days**	**Note**
fenbutatin oxide	Torque, Vendex	Works more rapidly in higher temperature	Low	Low	14	Two sprays a fortnight apart are required unless predatory mites are abundant
etoxazole	ParaMite	No mention of temperature requirement on label	High	High	14	One spray per season only
abamectin	Sorcerer, Vertimec	No mention of temperature requirement on label	High	High	14	Add a summer oil to the spray for improved control

More information:

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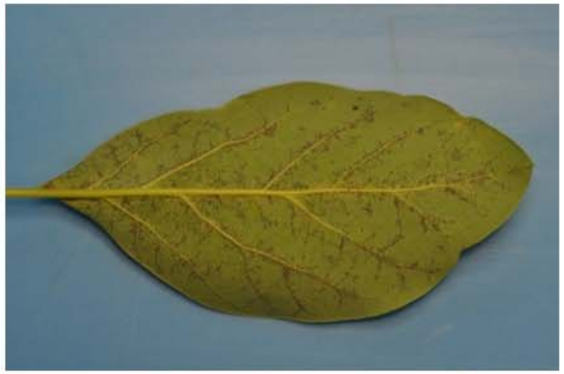
Department of Primary Industries and Regional Development, Manjimup, WA
9777 0000, alison.mathews@dpird.wa.gov.au 3 April 2019

Monitoring for six-spotted mite in avocado orchards

Sign of six-spotted mite (SSM) presence on avocado leaves and similar symptoms:

Six-spotted mite leaf damage levels: categories from top left and then clockwise: No damage; early signs of bronzing next to the main vein; more advanced level of bronzing; high level of bronzing next to all veins

Upper leaf uninfested and lower leaf infested with SSM and associated yellowing adjacent to the main vein



"Physiological purpling" adjacent to leaf veins is **not SSM related**

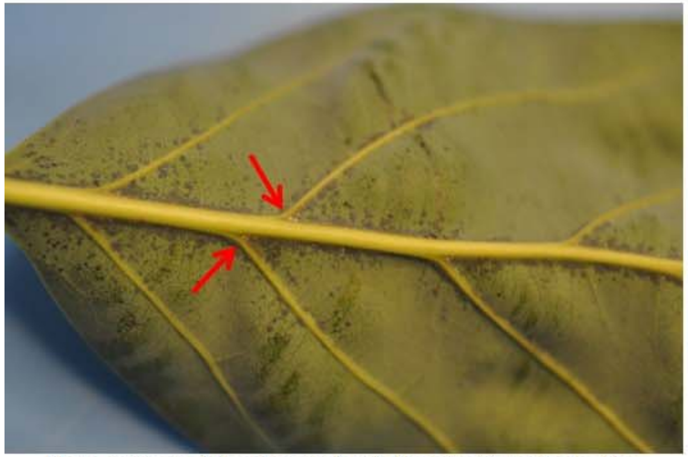
Monitoring for six-spotted mite in avocado orchards

Mite species likely to be seen – six-spotted mite, predatory mites and tydeid mites (detritus feeder) :

Six-spotted mite damage and mites next to the main vein of an avocado leaf

Six-spotted mite adult and circular eggs

Predatory mites feed on SSM. Inset – their eggs are oval shaped



Non-mite related purple "pimples" next to the main vein of an avocado leaf and arrows point to tydeid mites in axils of veins

Tydeid mite – white legs, pale brown, white line along back, "coffin" shaped - in axil of veins on an avocado leaf.

Red predatory mite on an avocado leaf. There is an equivalent shaped predatory mite species but bright yellow.

Species of mite observed in WA avocado orchards which is yet to be identified. From top left and clockwise – mite adult, leaf symptoms, stethorus larva predator, 'brown mite' egg.

Appendix 6. Detailed results of mite monitoring: abundance of eggs and motiles of six-spotted mite and predatory mites and leaf damage levels.

Field releases of predatory mites - Series 1: two species alone and combined

This series involved releases of the predatory mites *M. occidentalis* and *N. californicus* in avocado orchards in the Pemberton district of Western Australia (WA). The percent leaves infested with eggs and mites of six-spotted mite (SSM), percent leaves with predatory mites and SSM damage levels to leaves in each of four orchards are given below in Figs. A.6.1, 2, 3, 4, 5, 6, 7, 8.

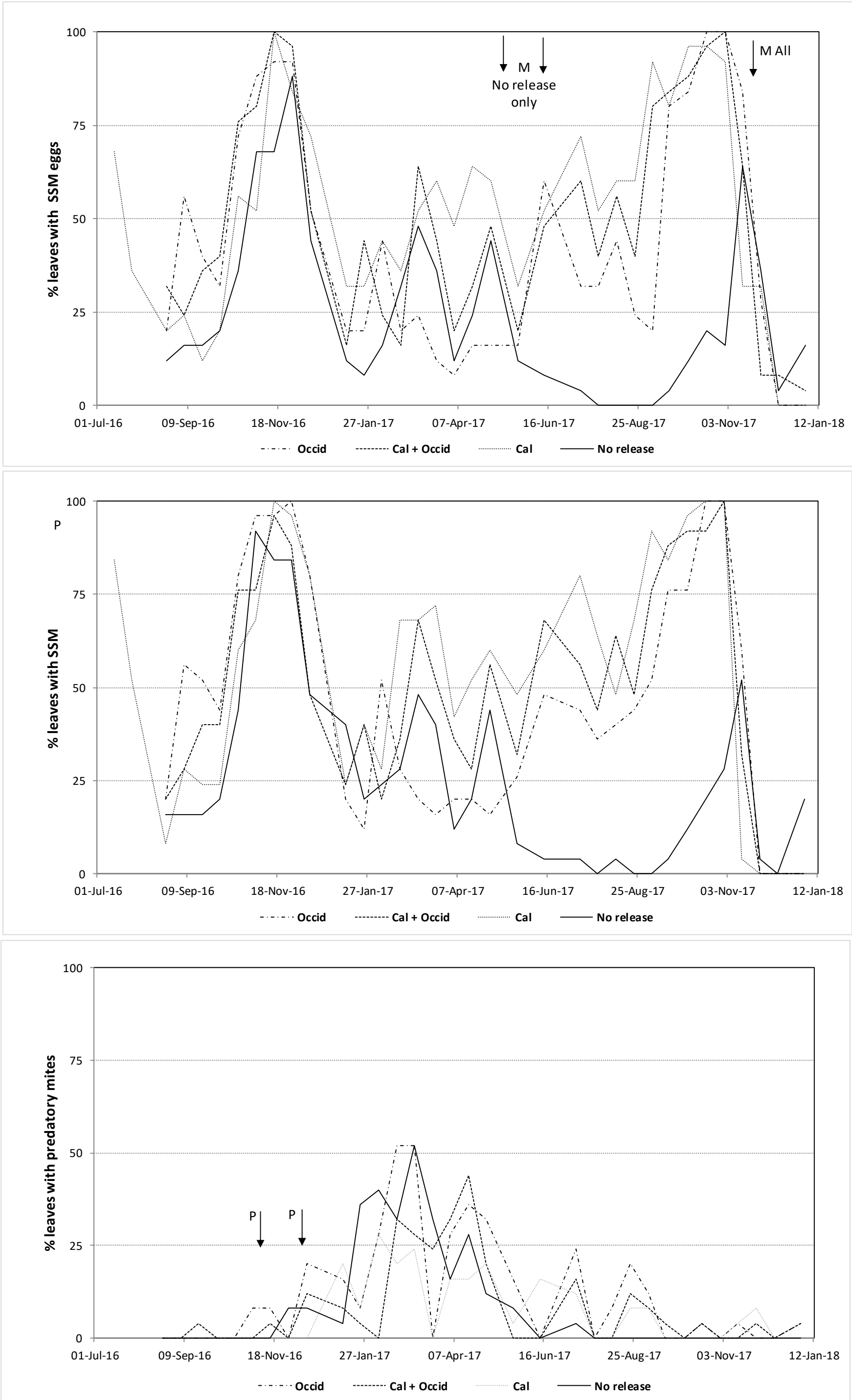


Fig. A.6.1. The percentage of leaves infested with SSM eggs and mites and predatory mites where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and 'Cal') or combined ('Cal+Occid'). Arrows with P indicate times of predatory mite releases and M as times of miticide application.

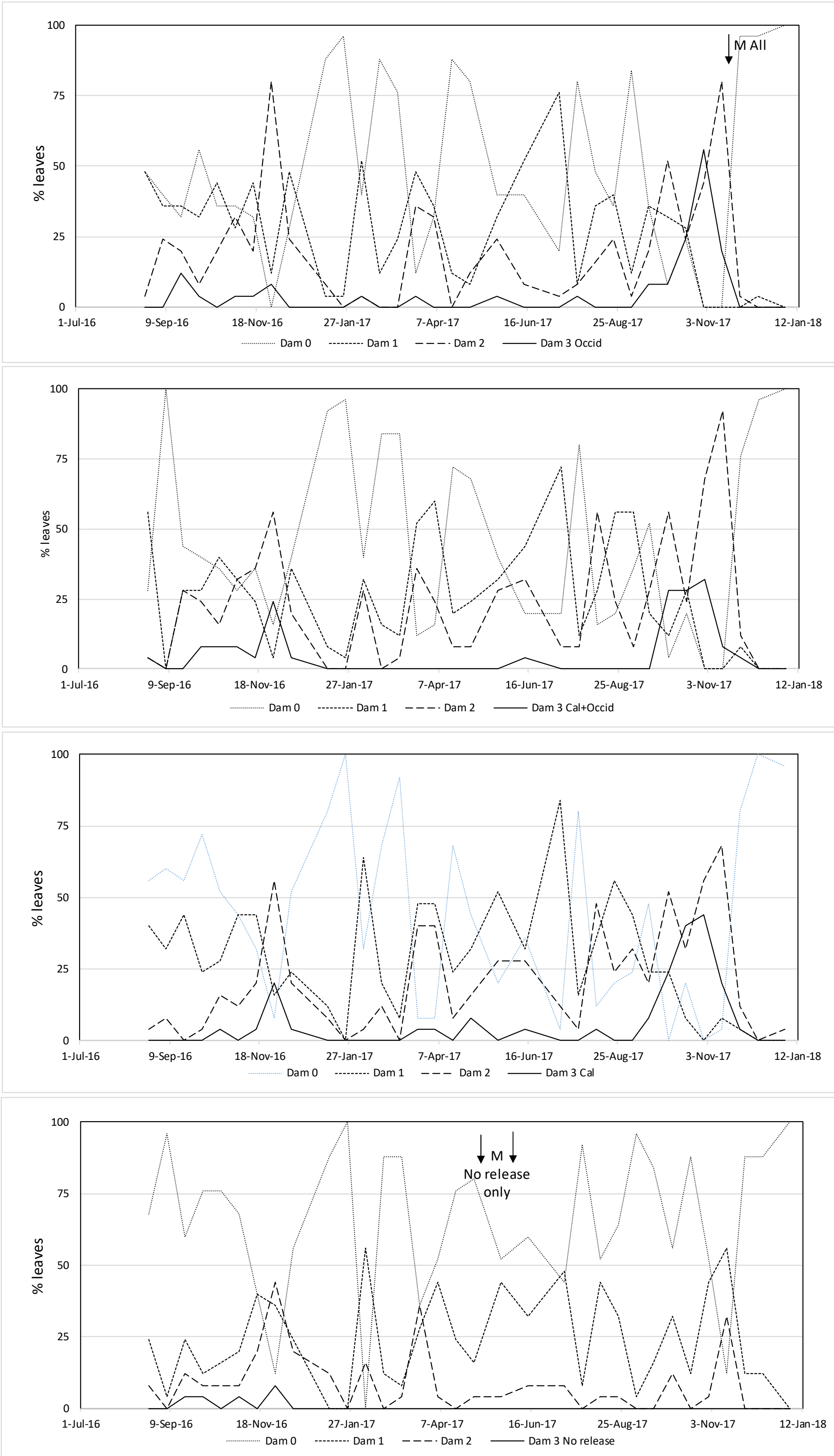


Fig. A.6.2. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and 'Cal') or combined ('Cal+Occid'). The predatory mite release treatment is indicated after "Dam 3" category in the legend on each graph. Arrows with M indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

There was no apparent increase in the abundance of predatory mites in the three release areas compared to the rows in which no predatory mite releases were made. (Fig. A.6.1). There was a rapid increase in SSM abundance in spring after predatory mites were released and an equally rapid decline in abundance in early summer. Predatory mite abundance increased and then inexplicably fell allowing SSM numbers to increase. Miticide was applied to the no release area only in autumn with consequent fall in SSM abundance. SSM continued to increase in abundance in the three predatory mite release areas which is reflected in the proportion of leaves in the highest damage category (see Fig. A.6.2). For more discussion on leaf loss and aerial photographs of this site, see Outcomes section of this report.

Results of monitoring in the second orchard with respect to SSM egg and mite abundance, proportion of leaves with predatory mites present and proportion of leaves in four damage categories are given in Figs. A.6.3 and 4.

SSM abundance increased from the time of release of predatory mites in all areas including the rows where no releases were made. Number fell dramatically in summer before increasing again in late summer into autumn. With only a small increase in predatory mite numbers which did not appear capable of controlling SSM, a miticide was applied in late autumn. There did not appear to be any effect of the predatory mite release to increase their abundance compared with no release trees.

The level of leaf damage increased as mite numbers increased, especially in late autumn. To reduce mite abundance in trees through winter, miticide was applied in late autumn in order to prevent defoliation from occurring in trees in the following spring.

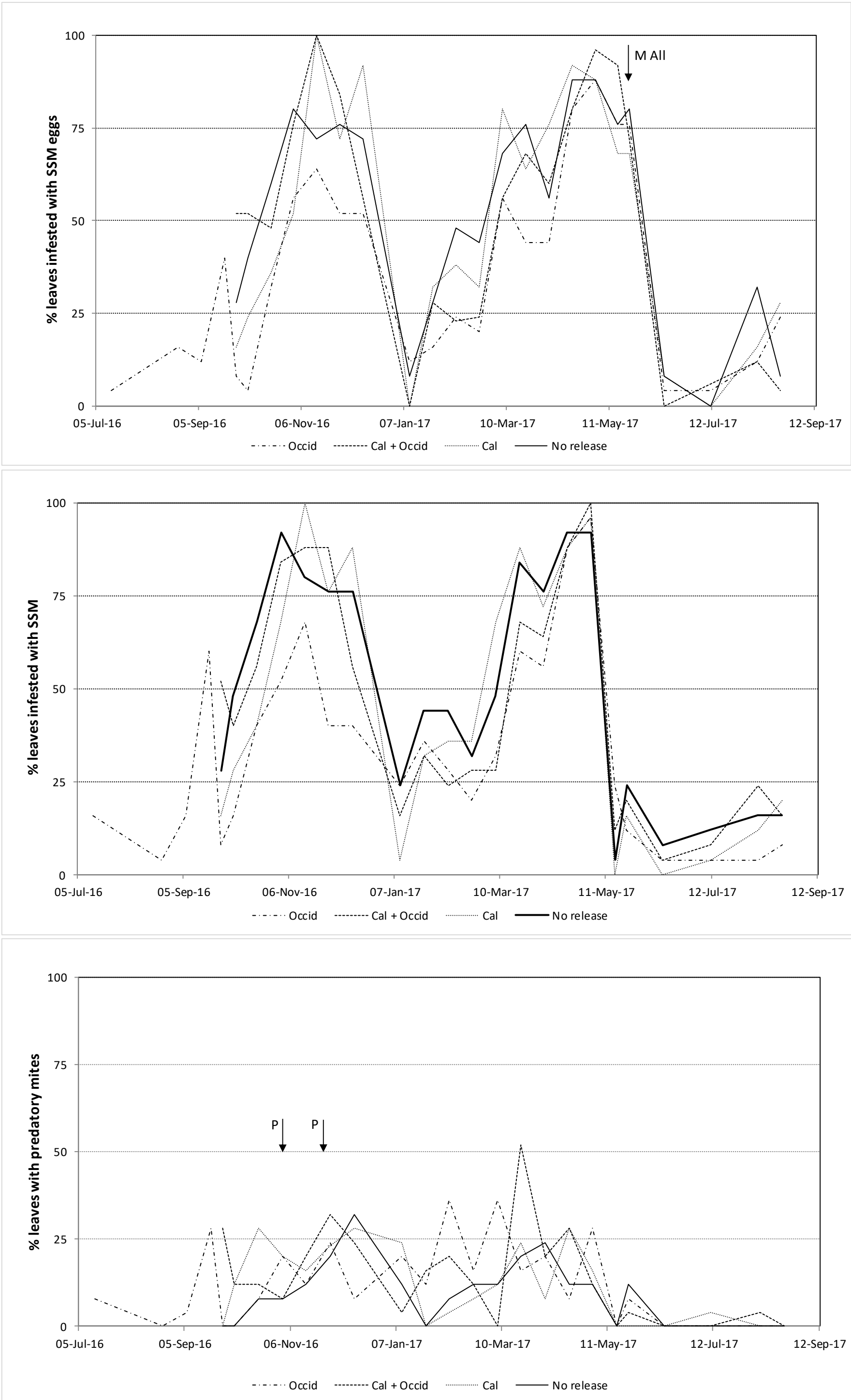


Fig. A.6.3. The percentage of leaves infested with SSM eggs and mites and predatory mites where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and' Cal') or combined ('Cal+Occid'). Arrows with P indicate times of predatory mite releases and M as times of miticide application.

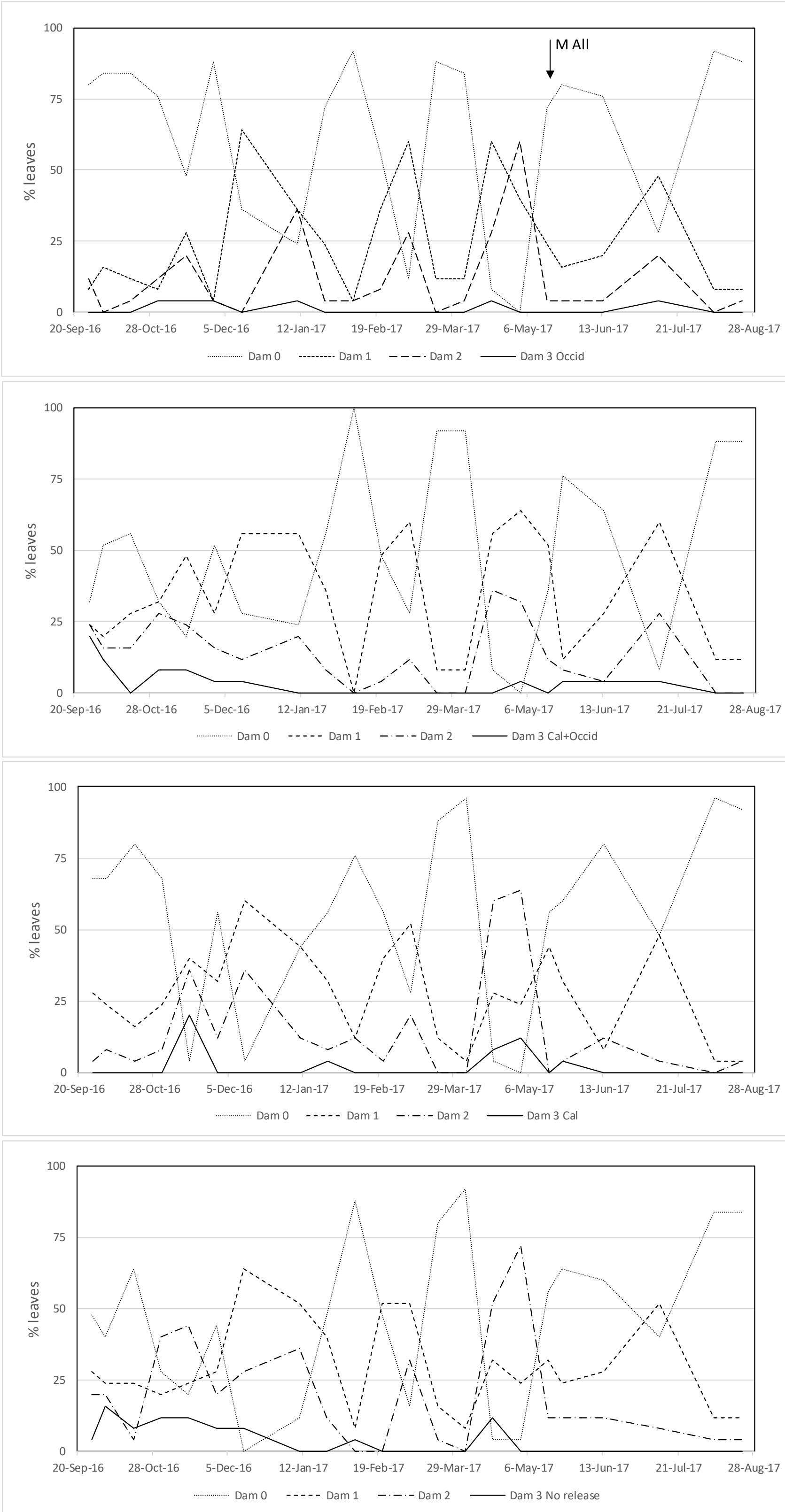
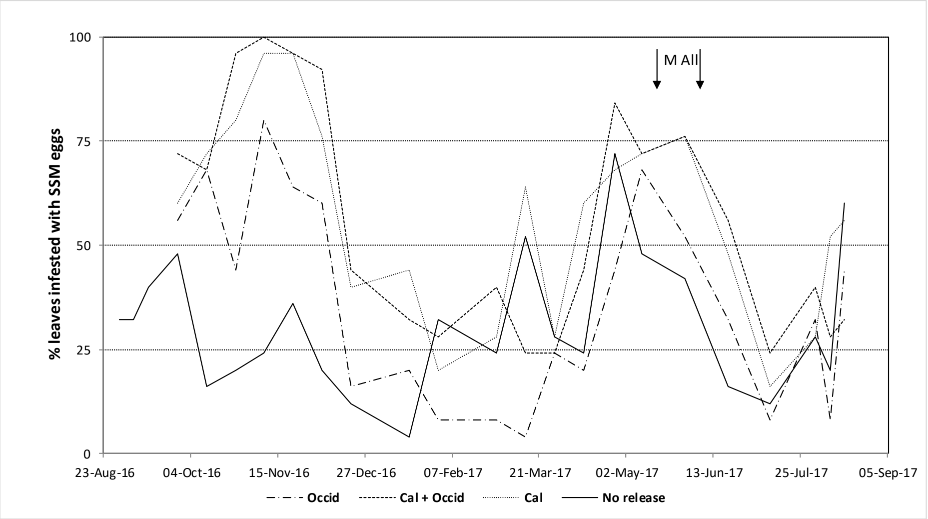
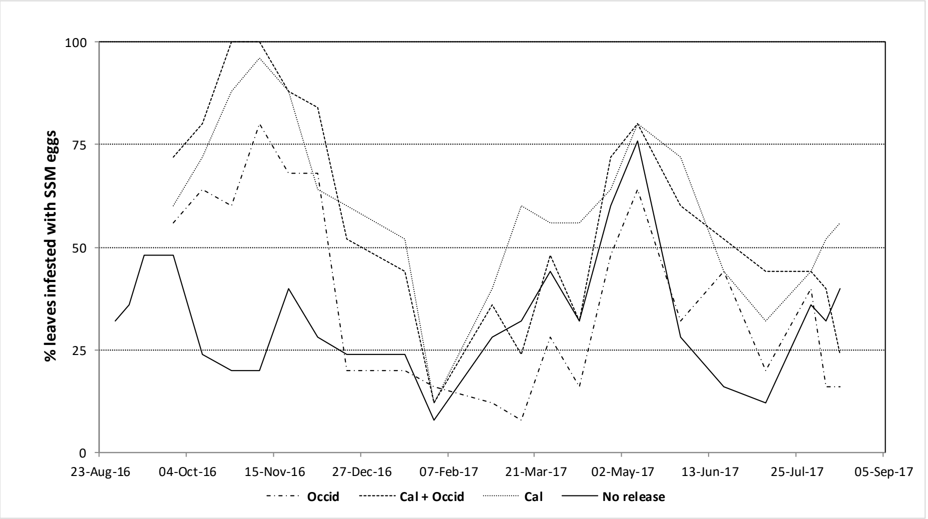


Fig. A.6.4. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species (‘Occid’ and ‘Cal’) or combined (‘Cal+Occid’). Predatory mite release treatment indicated after “Dam 3” category in the legend on each graph. Arrows with M indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

Results of monitoring in the third orchard with respect to SSM egg and mite abundance, proportion of leaves with predatory mites present and proportion of leaves in four damage categories are given in Figs. A.6.5 and 6.





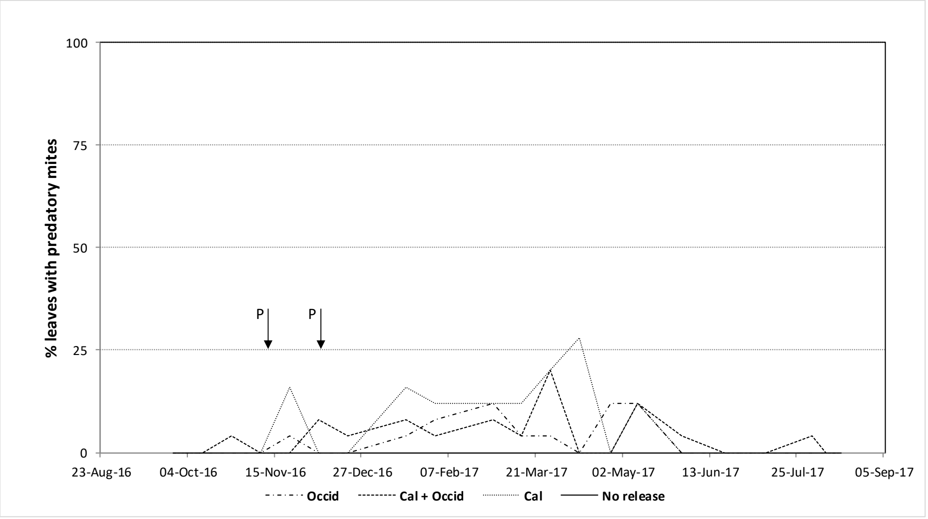


Fig. A.6.5. The percentage of leaves infested with SSM eggs and mites and predatory mites where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and 'Cal') or combined ('Cal+Occid'). Arrows with P indicate times of predatory mite releases and M as times of miticide application.

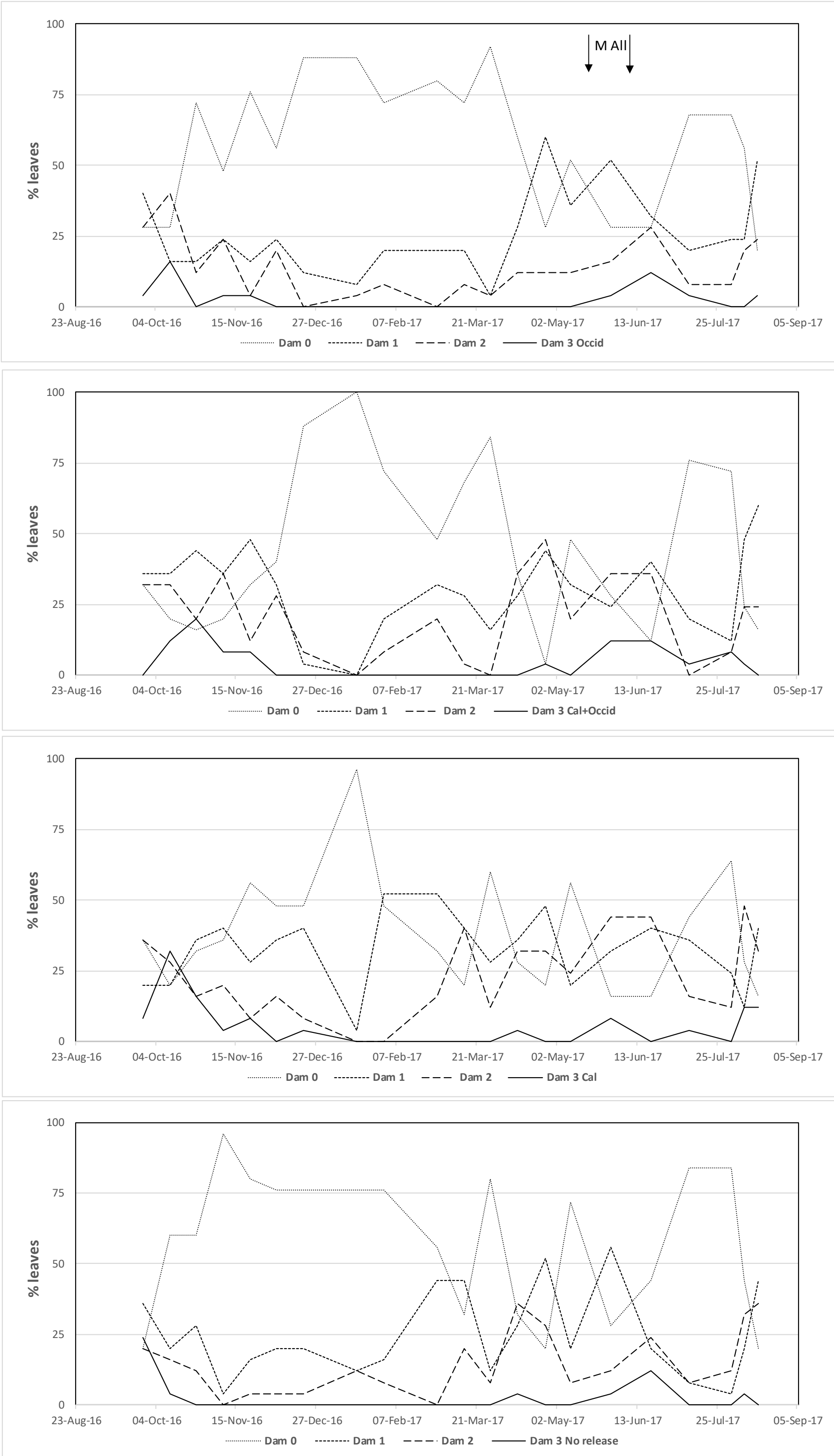
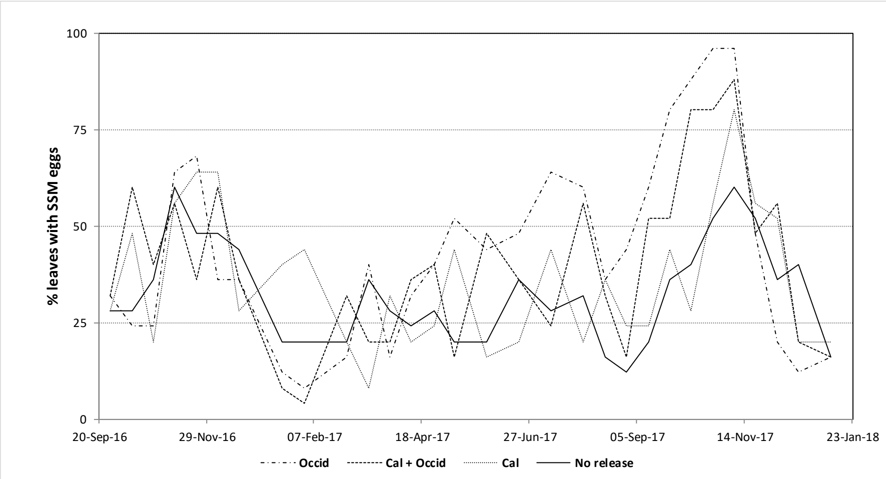
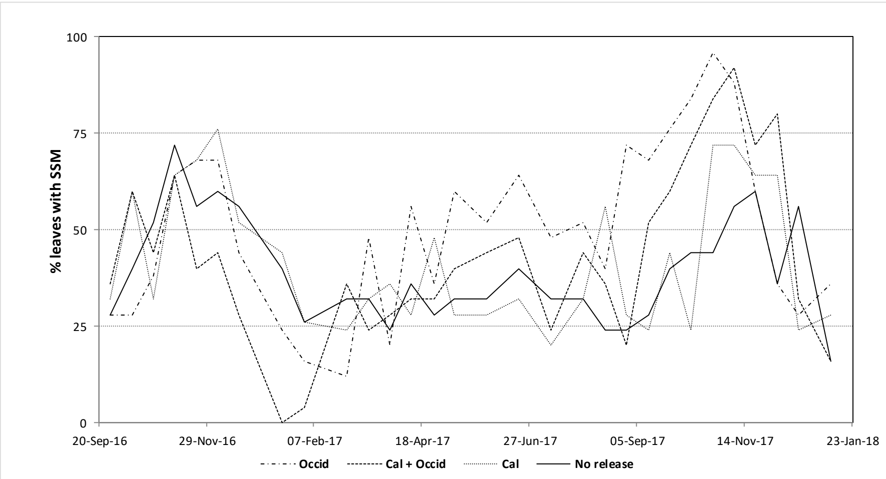


Fig. A.6.6. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and 'Cal') or combined ('Cal+Occid'). Predatory mite release treatment indicated after "Dam 3" category in the legend on each graph. Arrows with M indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

Despite SSM abundance being very high when predatory mites were released, the abundance of the predatory mites was never very high. After a short period over which pest mite numbers declined, their rapid rise in autumn without consequent increase in predatory mite presence necessitated an application of miticide.

Results of monitoring in the fourth orchard with respect to SSM egg and mite abundance, proportion of leaves with predatory mites present and proportion of leaves in four damage categories are given in Figs. A.6.7 and 8.





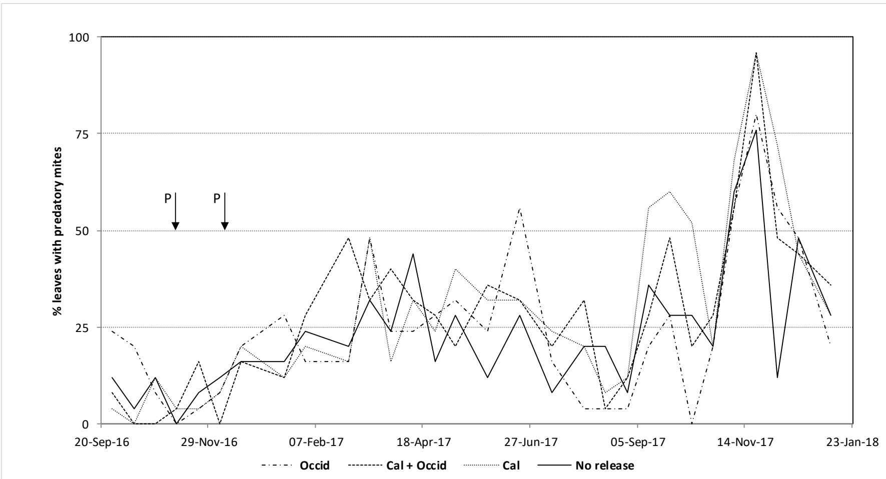
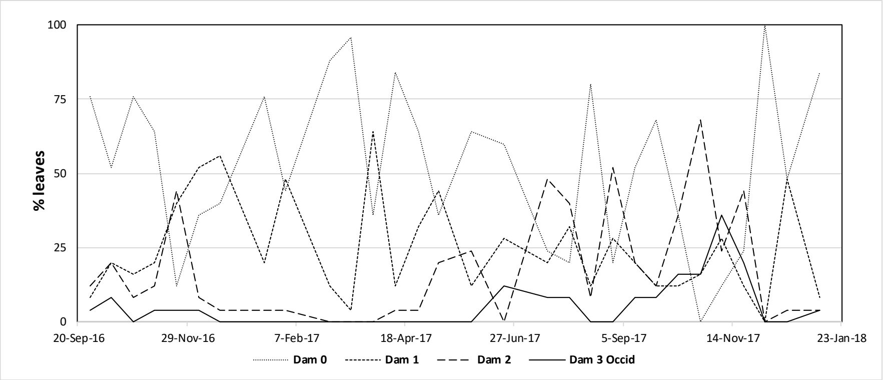
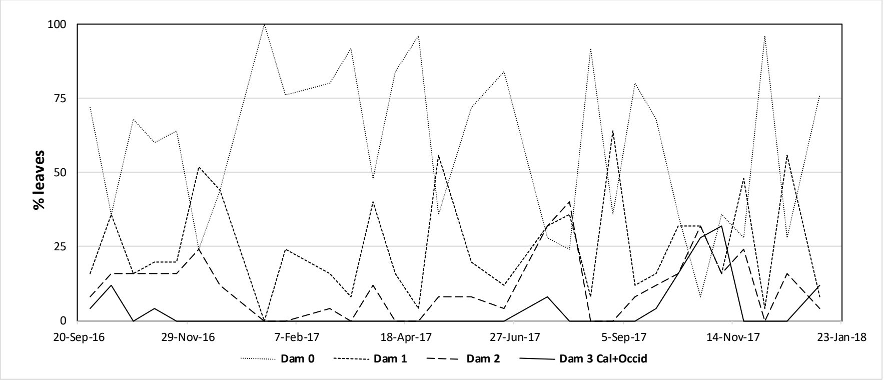
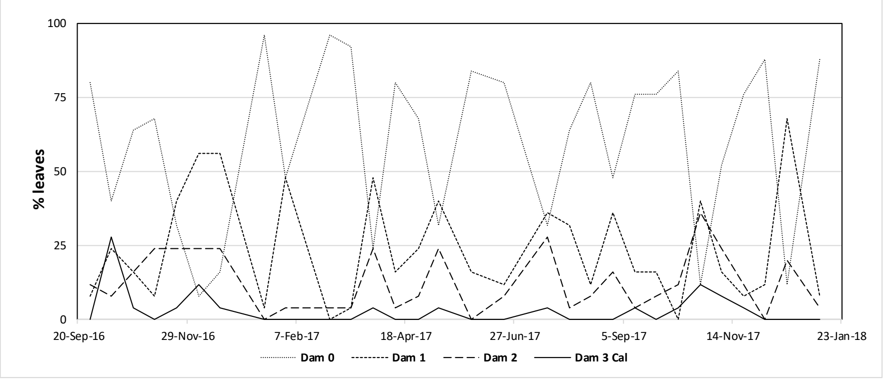


Fig. A.6.7. The percentage of leaves infested with SSM eggs and mites and predatory mites where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and 'Cal') or combined

('Cal+Occid'). Arrows with P indicate times of predatory mite releases. No miticide was applied during this monitoring period.







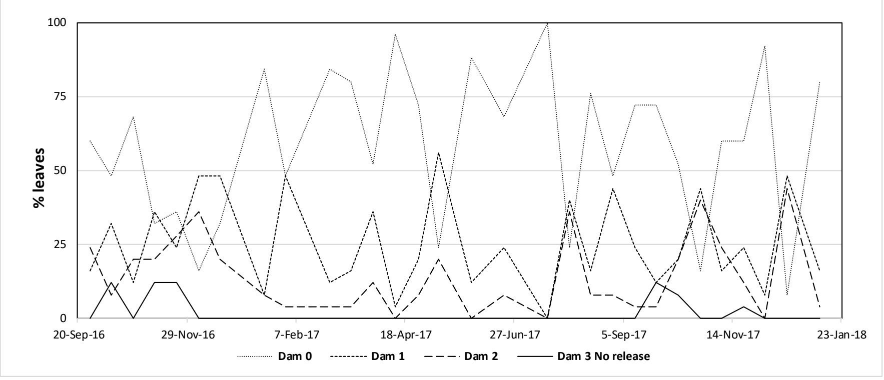


Fig. A.6.8. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites *M. occidentalis* and *N. californicus* were released as individual species ('Occid' and 'Cal') or combined ('Cal+Occid'). Predatory mite release treatment indicated after "Dam 3" category in the legend on each graph. No miticide was applied during this monitoring period. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

SSM abundance was moderate at the time predatory mites were released. The abundance of predatory mites increased after the releases were made. Mite numbers stabilised at moderate levels through winter but increased reasonably rapidly as temperatures increased after spring. Predatory mite numbers increased at this time as well and appeared to suppress SSM as their abundance fell in late spring. At this time, probably as a result in the fall in the abundance of pest mites, predatory mite abundance also declined.

There was no apparent consistently higher level of predatory mite presence in any of the release areas compared to the no release area.

While there was a reasonably high proportion of avocado leaves assessed as having the highest lead damage category and there was some defoliation, the level of defoliation was not high enough to warrant the application of miticide.

Field releases of predatory mites - Series 2: two species alone

This series involved releases of the predatory mites *T. doreenae* and *M. occidentalis* in avocado orchards in the Pemberton district of Western Australia (WA). The percent leaves infested with eggs and mites of six-spotted mite (SSM), percent leaves with predatory mites and SSM damage levels to leaves in each of four orchards are given below in Figs. A.6.9, 10, 11, 12, 13, 14.

The percent leaves infested with eggs and mites of SSM, percent leaves with predatory mites and SSM damage levels to leaves in the first of three orchards are given in Figs. A.6.9 and 10.

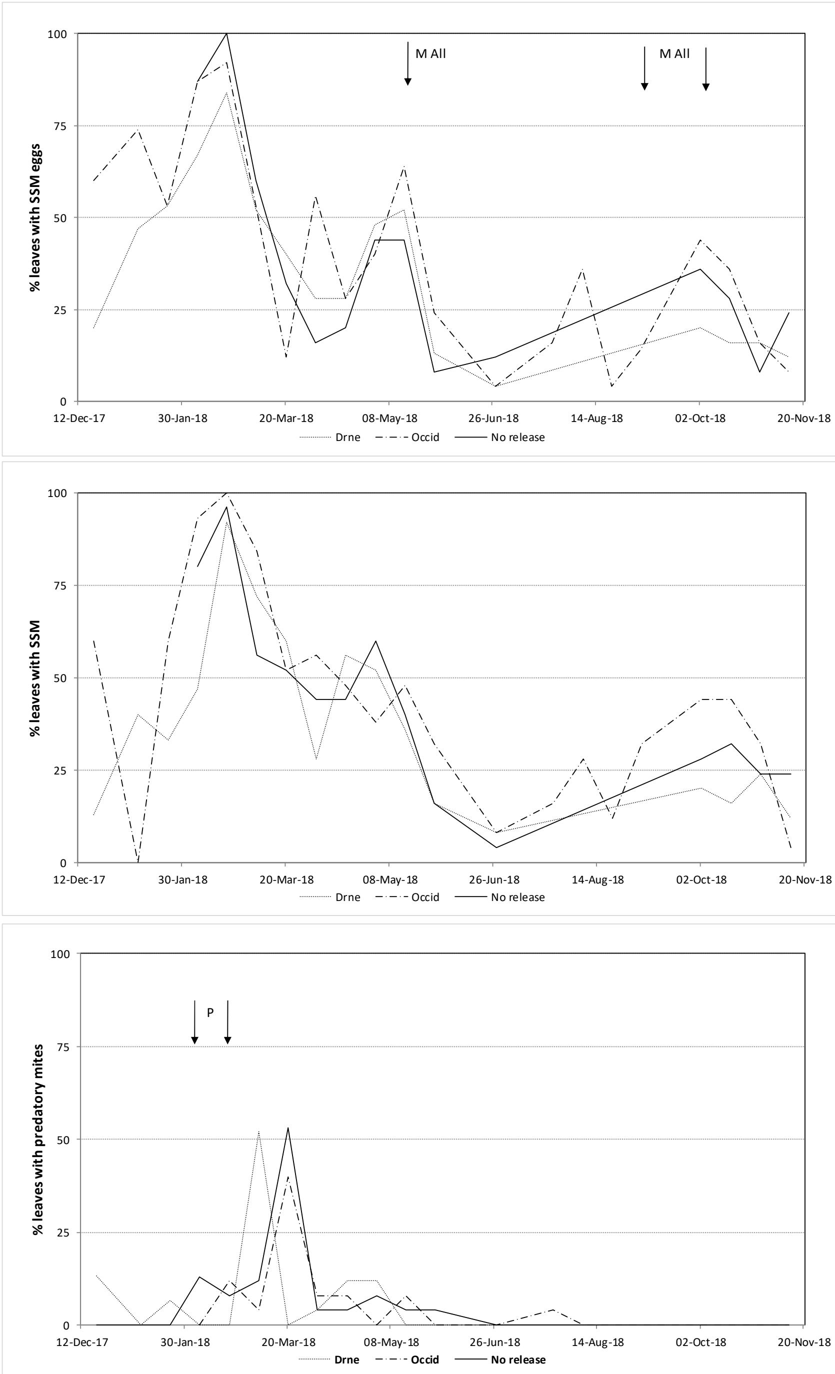


Fig. A.6.9. The percentage of leaves infested with SSM eggs and mites, and predatory mites where the predatory mites *T. doreenae* ('Drne') and *M. occidentalis* ('Occid') were released. Arrows with P indicate times of predatory mite releases and M as times of miticide application.

The predatory mites were released into a situation of reasonably high mite abundance, but although predatory mite abundance increased after release, it was not sustained despite the continuing presence of prey. Miticide was applied before winter and predatory mite numbers did not recover. Two applications of miticide were made again in spring to prevent any further increase in SSM abundance.

Leaf damage levels increased during autumn as SSM abundance increased (see Fig. A.6.10) and decreased after the autumn application of miticide. The follow-up applications of miticide in spring suppressed any further major increase in leaf damage.

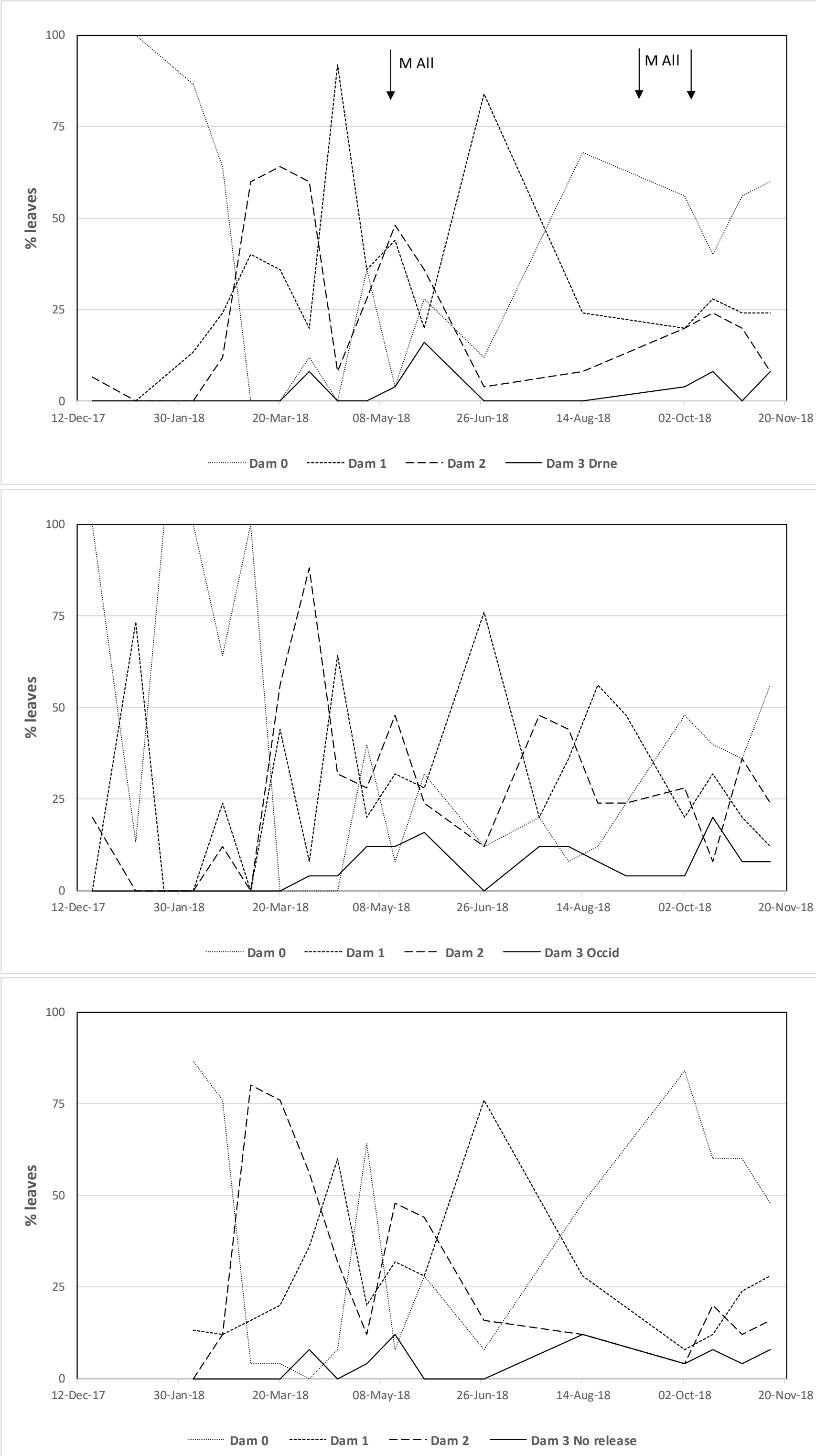


Fig. A.6.10. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites T. doreenae ('Drne') and M. occidentalis ('Occid') were released. Predatory mite release treatment indicated after "Dam 3" category in the legend on each graph. Arrows with M indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

The percent leaves infested with eggs and mites of SSM, percent leaves with predatory mites and SSM damage levels to leaves in the second of three orchards are given in Figs. A.6.11 and 12.

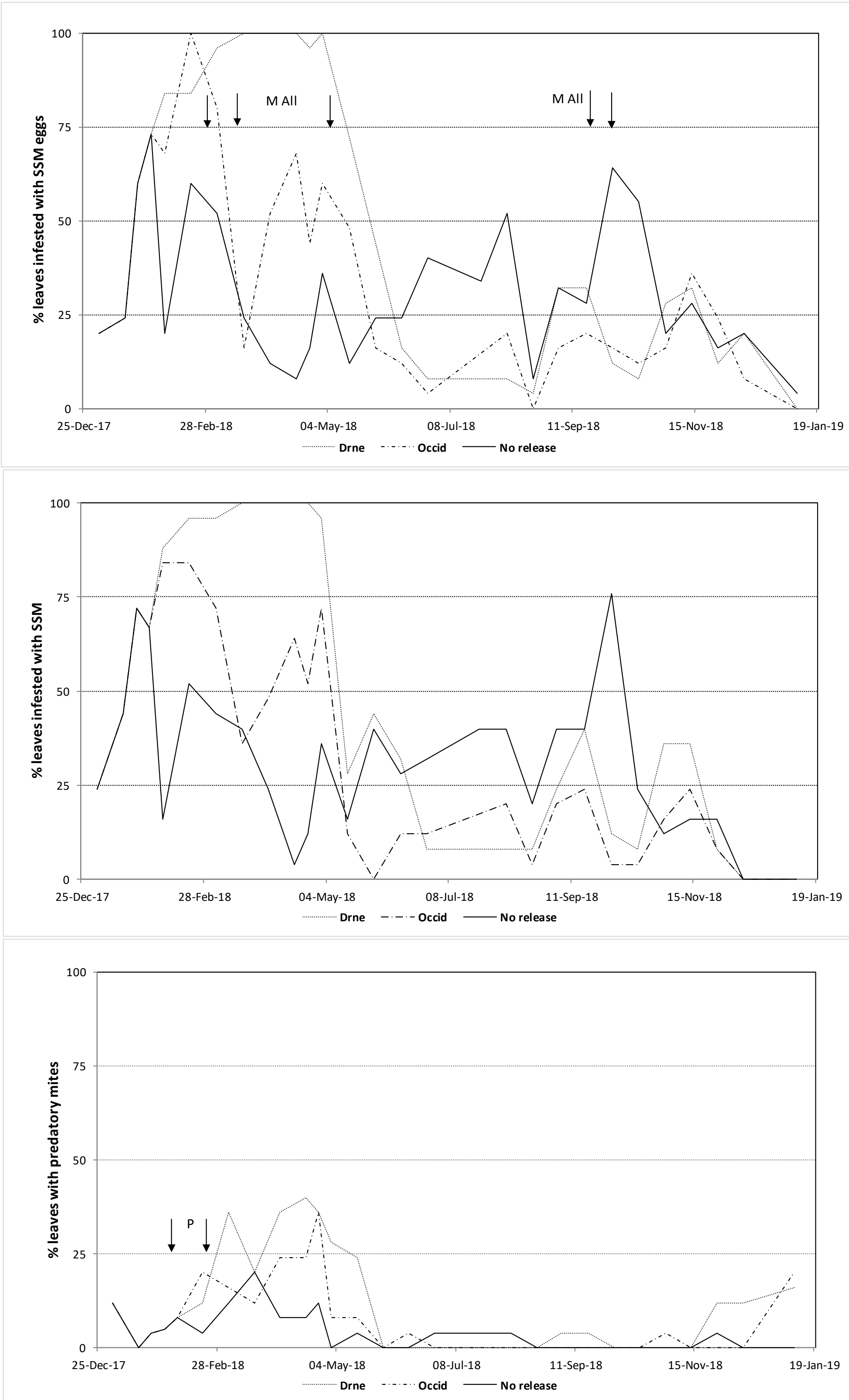


Fig. A.6.11. The percentage of leaves infested with SSM eggs and mites and predatory mites where the predatory mites *T. doreenae* ('Drne') and *M. occidentalis* ('Occid') were released. Arrows with P indicate times of predatory mite releases and M as times of miticide application.

Predatory mites were released into trees with the abundance of SSM being high. This necessitated the application of miticide. Probably as a result of a reduction in SSM abundance, predatory mite numbers did not increase to any significant levels. Subsequent miticide applications were required to protect trees from SSM (Fig. A.6.11, 12).

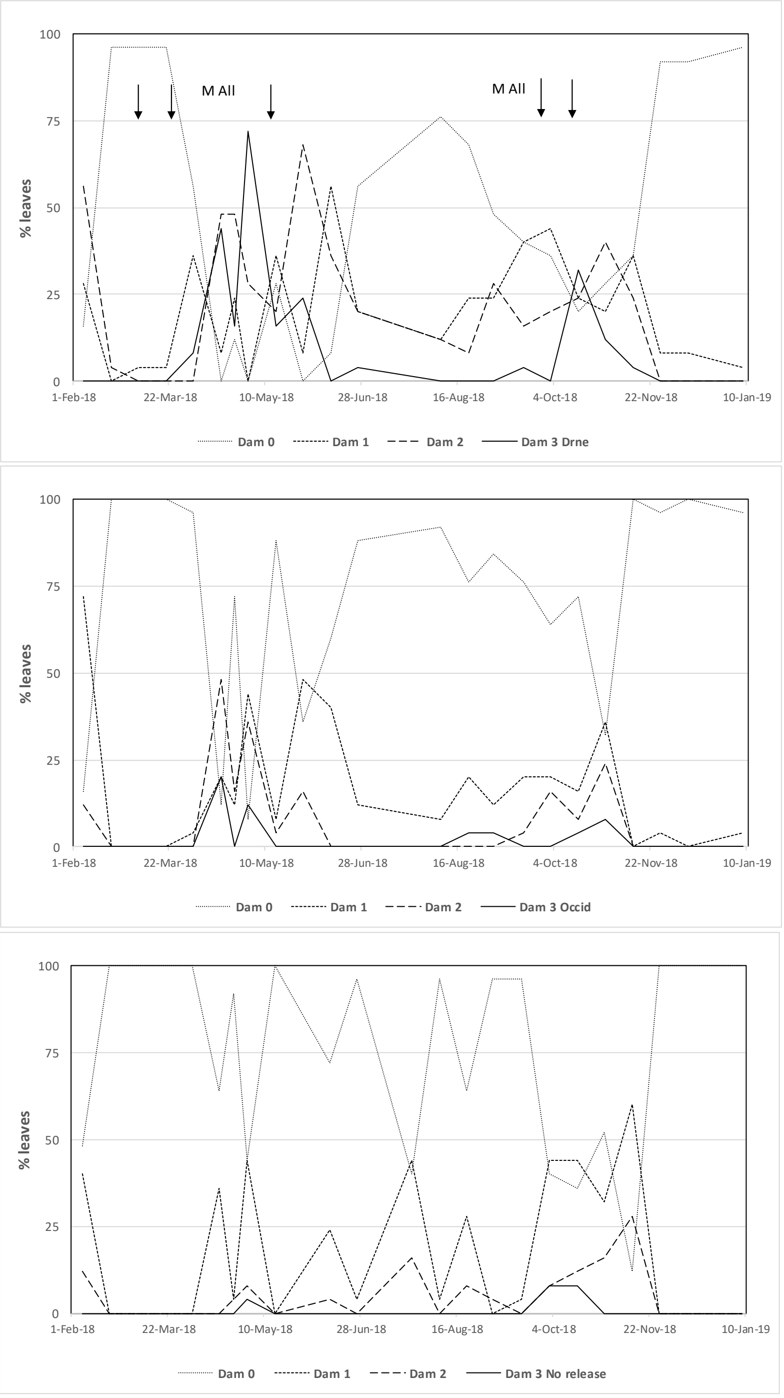


Fig. A.6.12. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites *T. doreenae* ('Drne') and *M. occidentalis* ('Occid') were released. Predatory mite release treatment indicated after "Dam 3" category in the legend on each graph. Arrows with M indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

The percent leaves infested with eggs and mites of SSM, percent leaves with predatory mites and SSM damage levels to leaves in the third of the three orchards where *T. doreenae* and *M. occidentalis* were released are given in Figs. A.6.13 and 14.

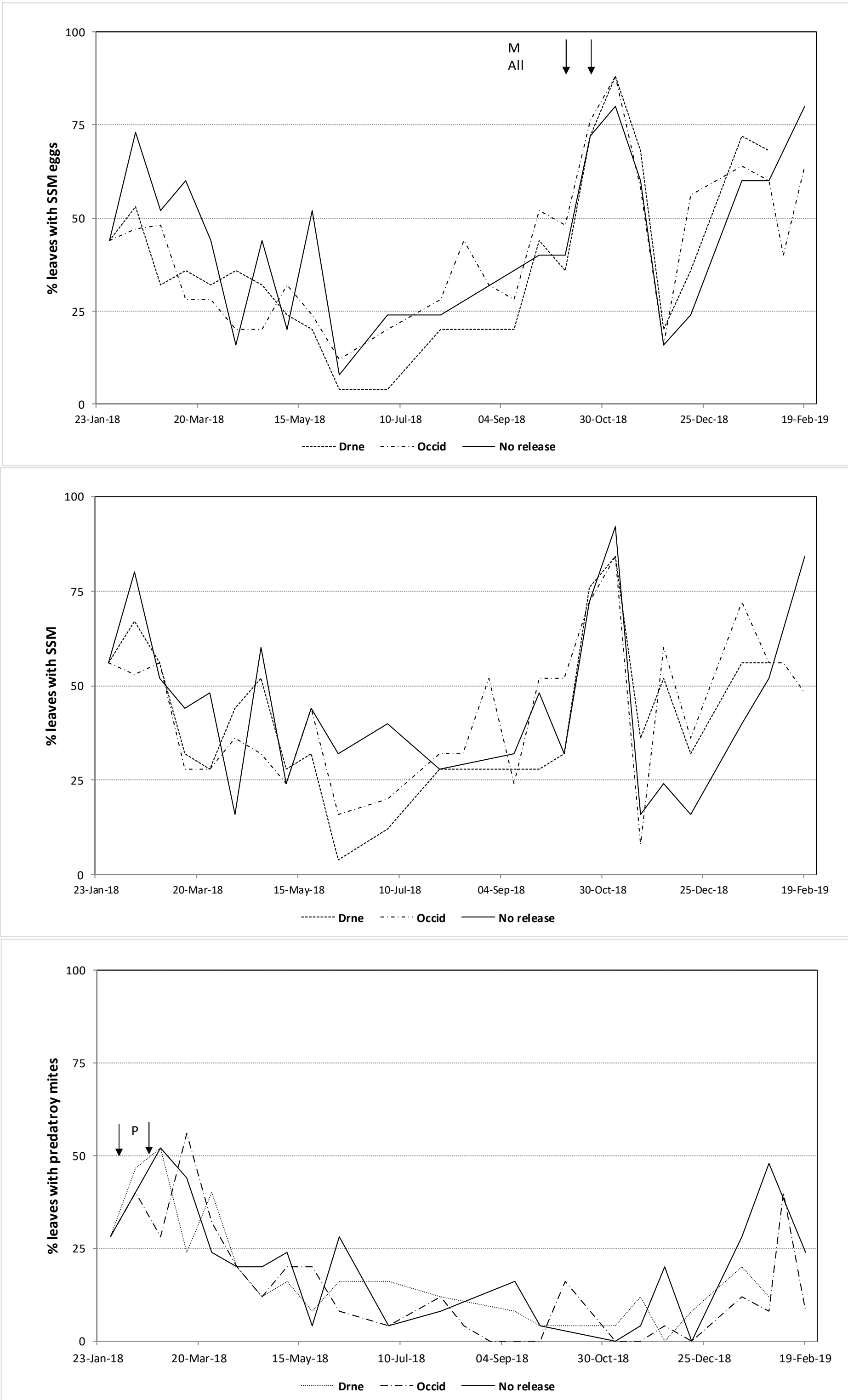


Fig. A.6.13. The percentage of leaves infested with SSM eggs and mites and predatory mites where the predatory mites *T. doreenae* (Drne) and *M. occidentalis* (Occid) were released. Arrows with P indicate times of predatory mite releases and M as times of miticide application.

Predatory mites were released into trees where the abundance of SSM was moderately high (Fig. A.6.13). SSM abundance fell after the releases as did damage levels of leaves (Fig. A.6.13). Subsequently predatory mite abundance decreased as well. SSM abundance increased rapidly the following spring and predatory mites were not at a level likely to be able to increase sufficiently rapidly to contain them. Miticide applications were made at that time to protect trees from SSM (Fig. A.6.13, 14).

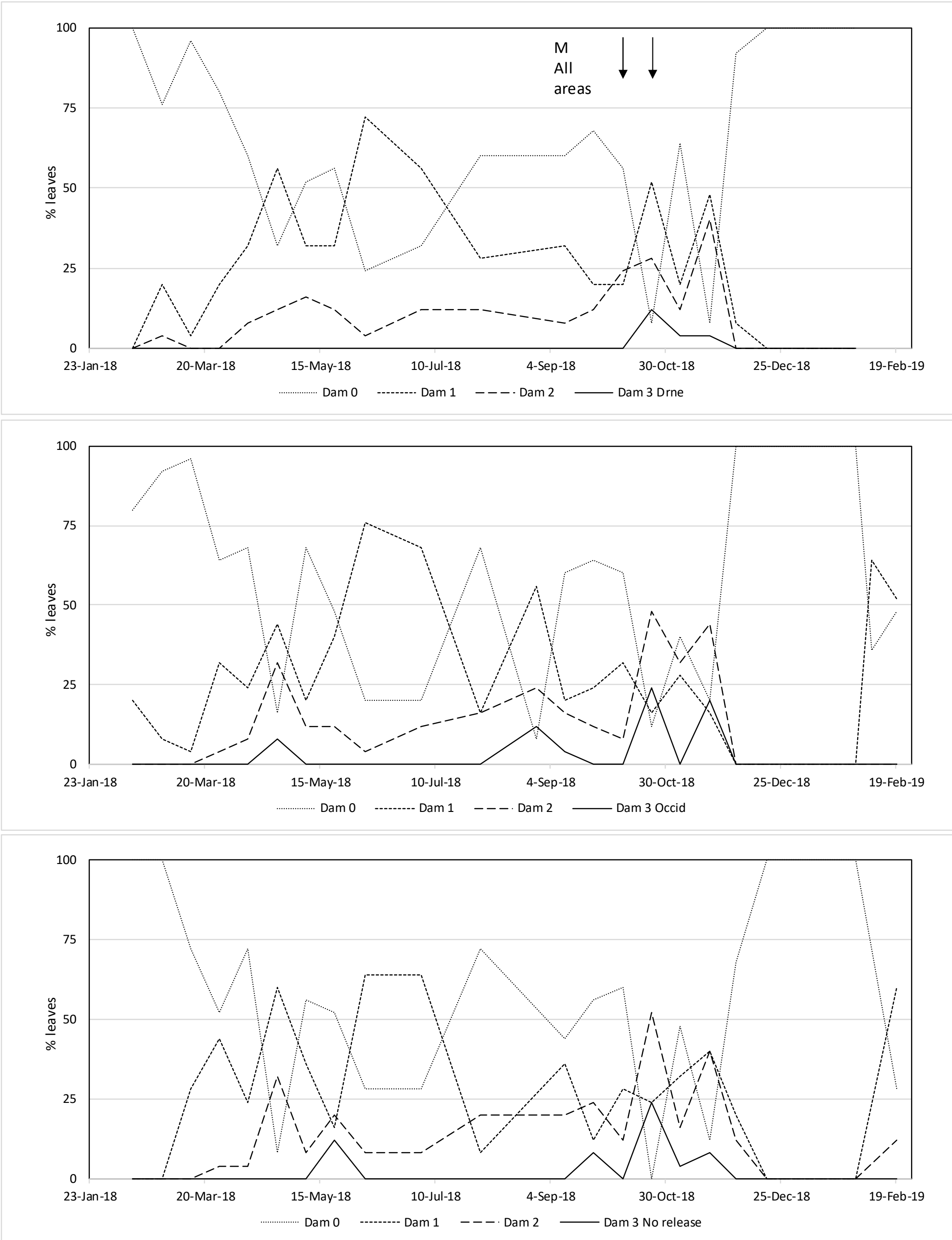


Fig. A.6.14. The percentage of leaves in each of four leaf damage level categories in areas where the predatory mites *T. doreenae* (Drne) and *M. occidentalis* (Occid) were released. Predatory mite release treatment indicated after “Dam 3” category in the legend on each graph. Arrows with M indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

Detailed monitoring for SSM in other avocado orchards

To indicate the range of trends associated with SSM in avocado orchards during the project, the seasonal changes in abundance of SSM, predatory mites and leaf damage levels, is presented for four scenarios in avocado orchards that either did not involve releases of predatory mites as described in the two series above or predatory mites were released as single species only for demonstration purposes.

In the first scenario, where predatory mites were released and one miticide application was made in the second season of monitoring, results from monitoring are given in Fig. A.6.15.

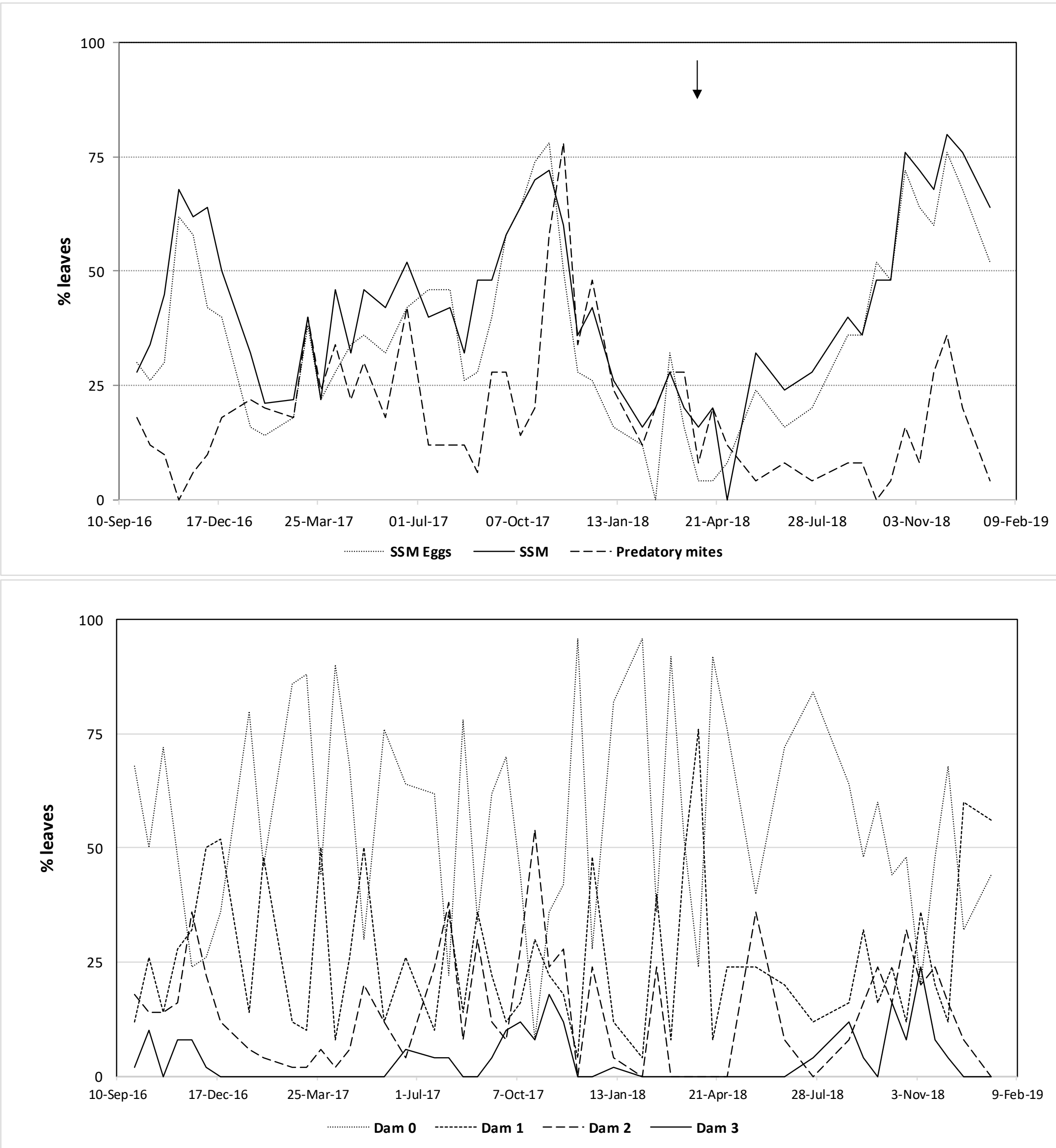


Fig. A.6.15. In the top graph, the abundance of SSM and its eggs and predatory mites on avocado leaves are given, and in the bottom graph, are the proportions of leaves in each of four mite leaf damage categories. The time of application of miticide is indicated by the arrow in the top graph. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

From spring 2016, SSM abundance increased as temperatures rose, declined during summer then increased again during winter peaking in spring 2017. After this time numbers declined through summer to autumn before increasing again during winter then peaking in late spring/early summer. Predatory mite abundance lagged behind the rises and falls in SSM abundance for most of the time and generally appeared to have an influence on SSM abundance. The only exceptions to this pattern were the initial decline in predatory mite numbers in the spring of 2016 despite the presence of a high SSM population and then again from winter to summer 2018. The grower was contemplating miticide application after the end of this monitoring as SSM numbers rose and predatory mite numbers did not increase.

The highest proportion of leaves in the highest damage category (Dam3) occurred at the same time that SSM abundance peaked. There was never more than 25% leaves in this highest damage category and while there was some resultant leaf fall, it was not considered sufficiently severe by the grower to warrant applying a miticide.

Overall, it appeared that the predatory mites species already present in the orchard possibly along with the growth habit of avocados and any reduced mite reproduction rate in relation to lower temperatures, were able to keep SSM in check.

In the second scenario, initially the predatory mite *N. californicus* was released across the entire orchard and later on edges only. Later, the predatory mite species *M. occidentalis* was released also, but limited to around the edge of the orchard and along some rows. Results of the monitoring in two adjacent blocks in this orchard are given in Figs. A.6.16 and 17.

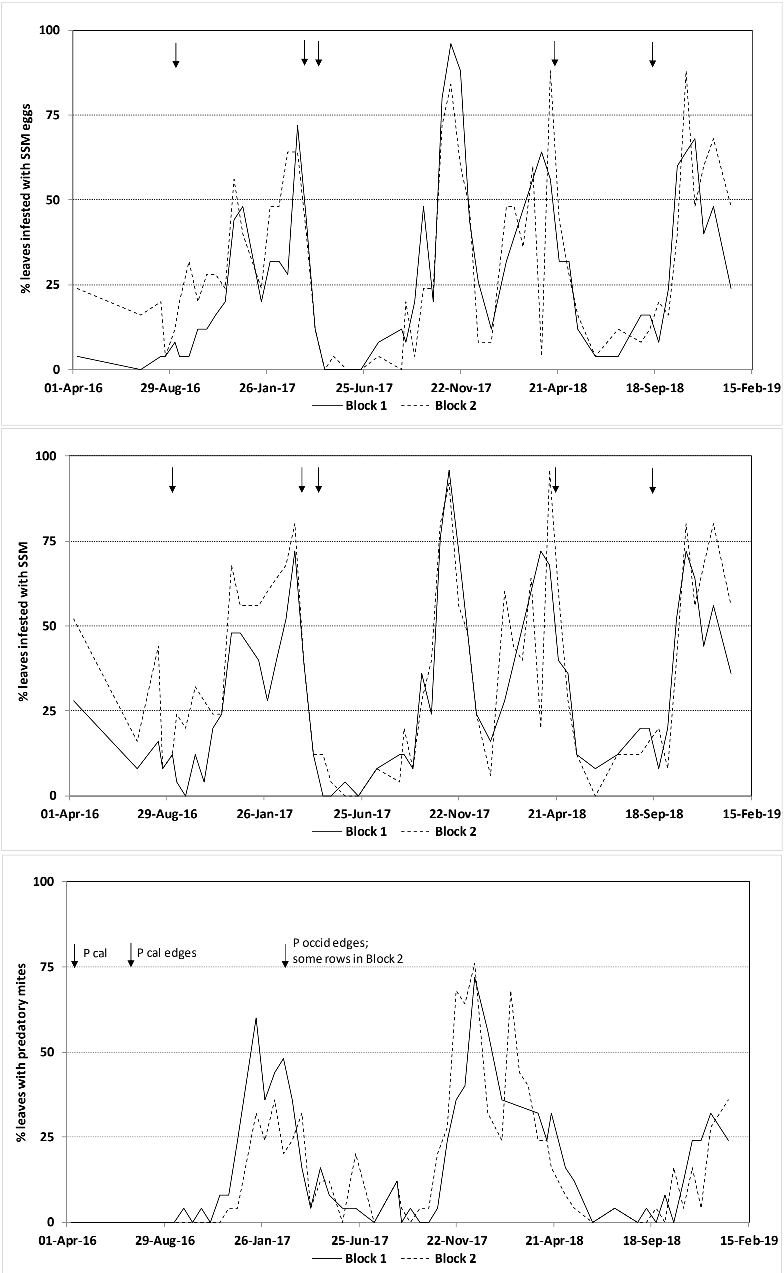


Fig. A.6.16. The percentage of leaves infested with SSM eggs and mites and predatory mites in two adjacent avocado blocks. Arrows in the top graph indicate times of miticide application. Arrows in the bottom graph with 'P cal' and 'P cal edges' indicate times of releases of the predatory mite *N. californicus* across the blocks and on the edges of the blocks. 'P occid edges; some rows in Block 2' indicates time of releases of *M. occidentalis* on edges and along some rows in Block 2.

Results of this monitoring demonstrate the rigor of the sampling strategy where results for two adjacent blocks of avocados with the same mite management strategy showed very similar results for SSM and predatory mite abundance (Fig. A.6.16) as well as similar levels of leaf damage (Fig. A.6.17).

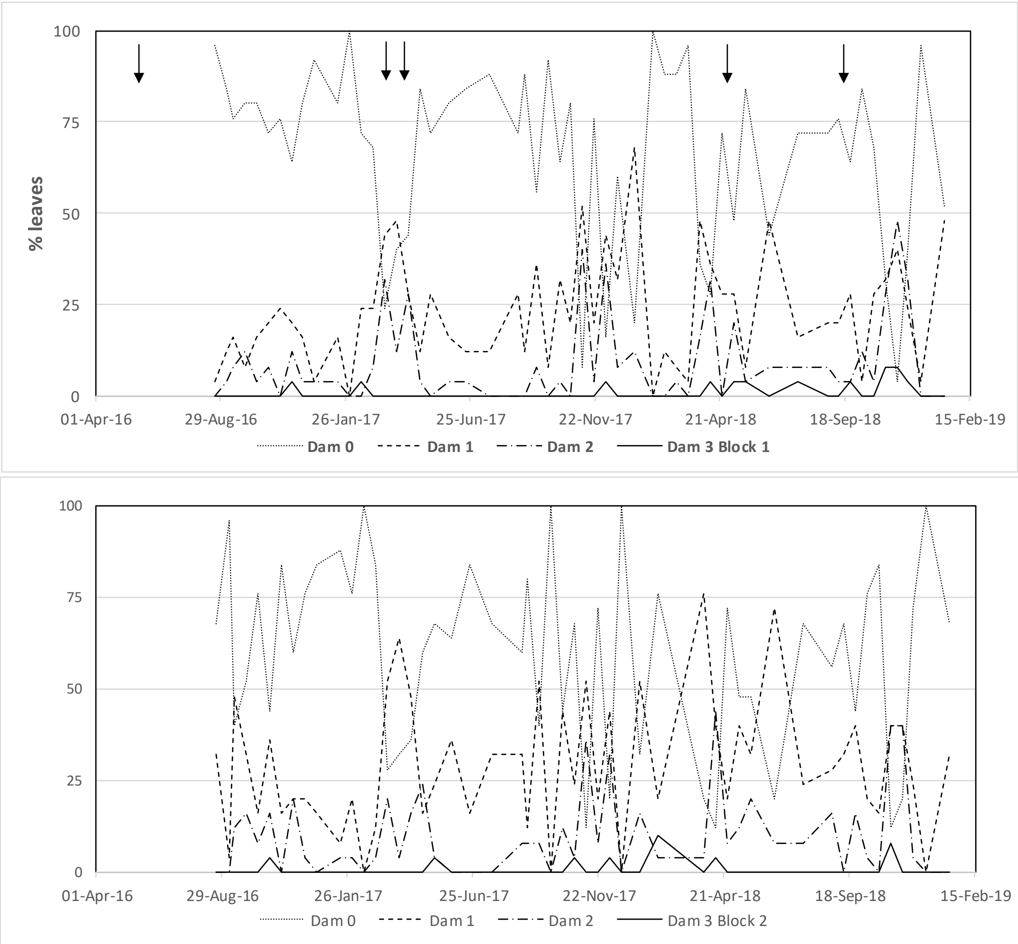


Fig. A.6.17. The percentage of leaves in each of four leaf damage level categories in two adjacent avocado blocks. Arrows in the top graph indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

There was an indication that the buildup in abundance of predatory mites had the effect of reducing SSM numbers, especially evident in the summer of 2017. Miticide was applied to give confidence that SSM numbers would be low enough going into winter so that trees in spring would have a strong canopy to ensure fruit was not exposed and trees were able to support spring vegetative flush, flowers, new fruit production as well as supporting mature fruit near harvest on the trees.

Leaf damage levels on trees in both blocks was similar as were the SSM populations. Some defoliation of trees from SSM feeding was evident but the fruit was able to be harvested with almost no issue of sunburnt fruit.

The abundance of SSM eggs and mites and predatory mites as well as leaf damage levels in two other avocado blocks on one property are given as further scenarios of pest and predatory mite interaction in the SSM prone area of south western Australia.

In the first block (Fig. A.6.18), no predatory mite releases had been made up to the summer of 2018. At this time, releases of *T. doreenae* and *M. occidentalis* were made but an inadvertent application of miticide soon after the release of predatory mites is thought to have prevented their establishment because of the reduction in SSM, the target prey for the predatory mites. These areas were averaged from that time to the end of the monitoring period for the project (Fig. 24).

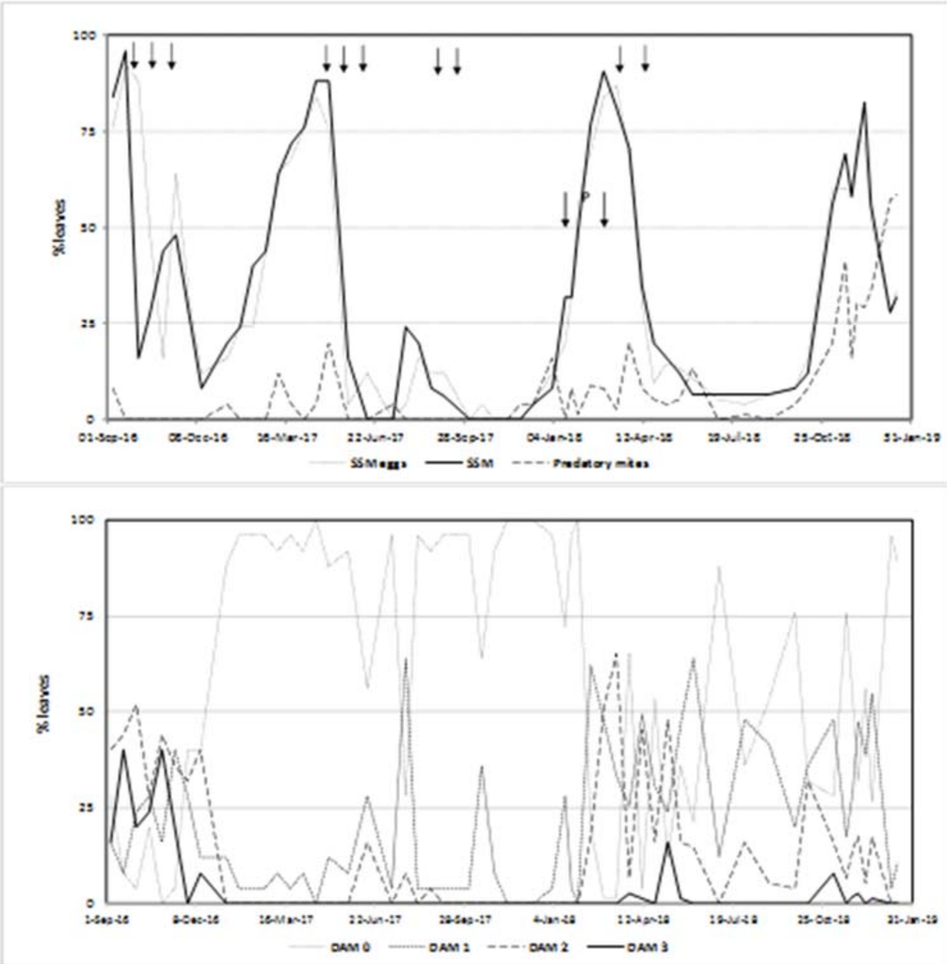


Fig. A.6.18. The percentage of leaves infested with SSM eggs and mites and predatory mites in the top graph, where 'P' and adjacent arrows indicates the timing of releases of predatory mites (see text for details); the lower graph shows the percentage of leaves in each of four leaf damage level categories for an avocado block in the SSM prone area of south western Australia during the current project. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.

On the first monitoring occasion in this block in spring 2016, the infestation by SSM was obvious and heavy. Three miticide applications were made and despite this, some defoliation occurred. This was to be expected as the trees were carrying mature fruit and would have been under considerable stress at this time of year. Miticides were applied in autumn in the following two seasons and leaf loss was minimal. Towards the end of the monitoring period for this project, predatory mite numbers had built up to such a level that they appeared to be giving good suppression of SSM.

In the second block on the same farm, *M. occidentalis* was released in a small part of this block which was monitored separately (Figs. A.6.19 and 20).

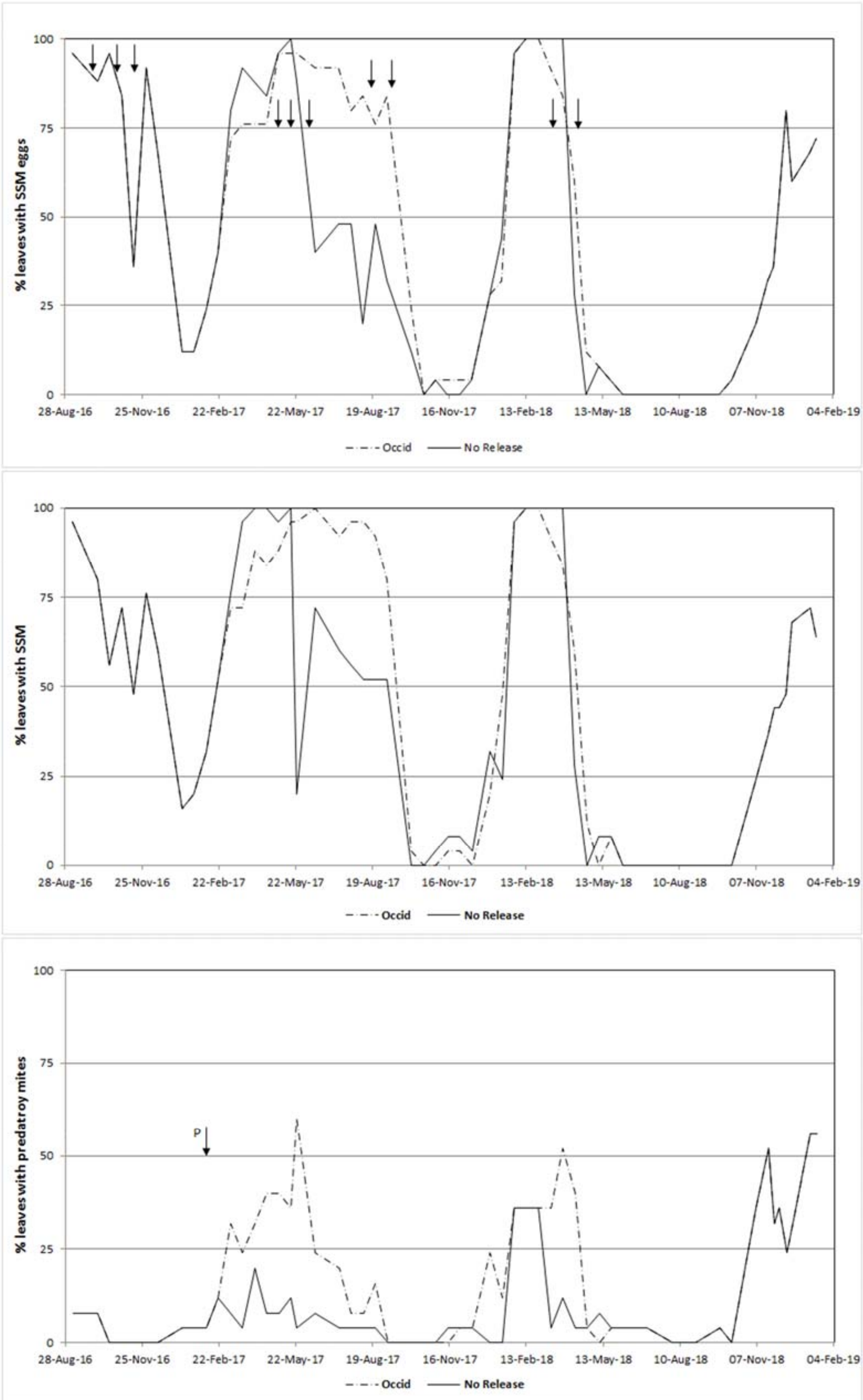


Fig. A.6.19. The percentage of leaves infested with SSM eggs and mites and predatory mites in two areas of an avocado blocks. Arrows in the top graph indicate times of miticide application. Arrows in the bottom graph with 'P' indicate the time of release of the predatory mite *M. occidentalis*. In May 2017, only the no release area received three miticide applications.

The level of damage to leaves in this block was high when monitoring began (Fig. A.6.20). This damage was reduced after miticide was applied. After the release of *M. occidentalis*, there was an increase in predatory mite activity in that area over the no release part of the block and an associated slightly lower abundance of SSM. The no release area was sprayed with miticide in May 2017 but the release area was not sprayed. As SSM increased in the release area, this part of the orchard was sprayed along with the release area in August 2017.

Further miticide applications were required over the monitoring period as SSM numbers increased as did leaf damage.

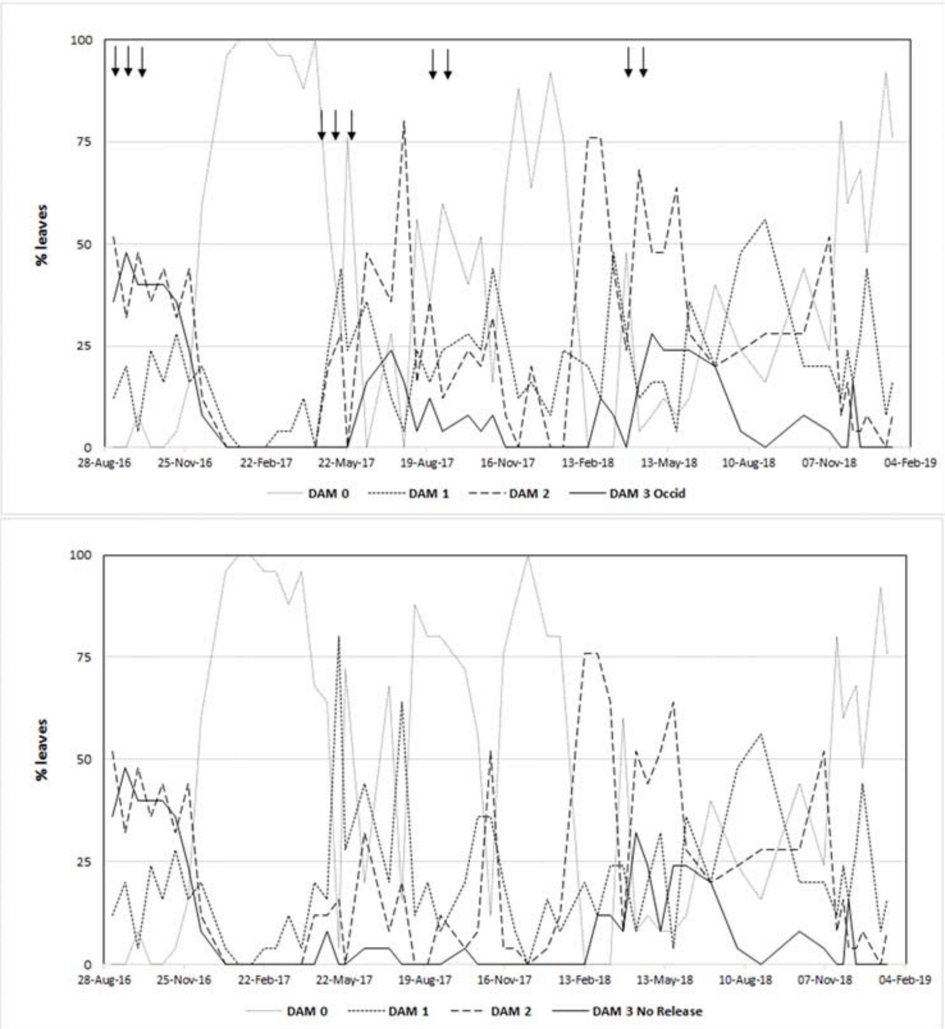


Fig. A.6.20. The percentage of leaves in each of four leaf damage level categories in two adjacent avocado blocks. Arrows in the top graph indicate times of miticide application. Dam0 = no sign of SSM browning adjacent to leaf veins; Dam1 = minor browning, usually near the petiole; Dam2 = more widespread browning along the leaf; Dam3 = severe leaf browning with more than half the area bronzed; such leaves would fall prematurely.