Final Report

Management of six-spotted mite in WA avocado orchards – Phase 2

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Management of six-spotted mite in WA avocado orchards – Phase 2 (AV19002)

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Public summary

Six-spotted mite are the most commonly occurring pest of mature avocado orchards in southwest WA. Unmanaged populations can rapidly increase in number leading to severe defoliation, this in turn can lead to sunburnt, reduced quality fruit and large disruptions to harvest schedules. Sustainable integrated pest management (IPM) practices are desired by industry to ensure reliable long-term management of this pest.

To achieve an integrated approach to management several different areas of monitoring and management were investigated, these being; the taxonomy of the pest mite; development of a reliable and user friendly monitoring program; the potential role of predatory mites, both naturally occurring and mass-reared; the relationship between tree nutrition, SSM and defoliation; on-farm biosecurity and the spread of SSM; sustainable miticide use, including case studies of effective and ineffective management; and alternative pesticide products. The project also collaborated with a researcher in New Zealand, the only other place in the world where SSM is considered a pest of concern in avocados, to ensure the most up-to-date research and management practices for this pest in the world informed the management recommendations devised for Australian growers.

Long-term and intensive monitoring was conducted in over 24 orchard blocks over two years to determine seasonal trends and mite distribution patterns that were then used to develop a monitoring protocol. Case studies of miticide and spray oil products for SSM control and management thresholds were also developed. The results showed that monitoring is essential to determine if management is necessary. Monitoring should be done fortnightly in both autumn and spring, which are also the two times of year when management with miticides is recommended if monitoring indicates SSM numbers above the 'threshold'. A threshold of 40% leaves infested in spring and 10% leaves infested in autumn was devised.

The cases studies developed demonstrated the importance of monitoring and managing blocks separately, given the variability of SSM numbers between blocks. They also highlighted the importance of following label instructions and ensuring adequate spray coverage as not doing so can lead to lower than expected levels of control. Two spray workshops for avocado growers in Manjimup and Pemberton were attended by the project team, however, further extension work is recommended in this area to further improve spray practices to achieve good spray coverage and mite control results.

The previous project, AV 15012, trialed the release of three different species of mass-reared predatory mites without success but made the recommendation to look into the role of *Euseius elinae* and *Amblydromalus lailae*, two species that have been found living in WA avocado orchards. The mass release of *A. lailae* and the application of a pollen/prey mix to increase *E. elinae* numbers were not successful in either increasing predatory mite numbers or decreasing SSM numbers.

Two different studies investigated the relationship between leaf nitrogen, SSM and defoliation. Neither study provided clear indications of relationships that could lead to management recommendations.

The nitrogen trials, case studies and anecdotal evidence from both WA and New Zealand all indicate that there are other factors that influence spring defoliation in avocado trees and that stressed trees are more likely to defoliate when SSM are present. These other factors likely include, water stress, fruit load, level of flowering, pressure from other pests and disease and general tree health, and they need to be taken into account when deciding if and how to manage SSM.

The on-farm biosecurity survey and review of SSM spread concluded that SSM can spread naturally via aerial dispersal, however, human aided spread is more targeted and has the potential to more quickly bring SSM into orchards and should be managed. To reduce the risk of SSM being spread between properties the project made recommendations that machinery and equipment coming into orchards be clean and free of plant debris and that new planting stock be inspected for pests and controlled if need be.

Multiple workshops were conducted and articles published over the life of the project to inform growers of project progress and to extend the recommended monitoring and management practices. An IPM guide for SSM in avocados was developed at the end of the project and is available to growers online, along with a series of videos to assist with accurate mite monitoring. The IPM guide contains information on when and how to monitor, identification of pest mites and beneficial arthropods, on-farm biosecurity as well as SSM management practices.

To build grower knowledge of SSM IPM the project took part in six workshops and published six articles. Avocado SSM management guidelines have been developed and further resources to assist growers with monitoring and identifying mites. These are being made available online via the DPIRD website and Avocado Australia's Best Practice Resource. Approximately 36% of the 144 growing entities in the Manjimup, Nannup and Bridgetown-Greenbushes shires, the area impacted by SSM, attended a project workshop and/or had direct one-on-0ne contact with the project team. Many more growers were directly presented with projects outdates and outputs at the Avocados Australia Avoskills workshop and WA regional forum. 100% of respondents to final project feedback survey said the project had increased their knowledge

of sustainable SSM monitoring and/or management practices. 89% of respondents said the project had increased their confidence to make changes to your SSM monitoring and/or management practices. 78% of respondents said they have or intend to make changes to the way they monitor and/or manage SSM based on information from this project. 56% of respondents think changes they have made due to information from the project have, or will, lead to less leaf loss due to SSM in their avocado orchard.

Further research into the areas of the role of stethorus beetles in SSM control, the use of pollen producing orchard floor plants to increase numbers of beneficial arthropods, the impact of pesticides on the predatory mites species present in WA orchards, how tree stress can relates to defoliation and can be used to inform thresholds and cultural management of SSM as well as the potential use of sulfur and oil as SMM spray options, would all help to expand management options and refine the IPM strategy.

Keywords

Avocado; six-spotted mite; Eotetranychus sexmaculatus; Eotetranychus queenslandicus; Integrated Pest Management; predatory mites; Euseius elinae; Amblydromalus lailae; pest monitoring; case studies; systematics; taxonomy

Introduction

A species of mite in the Family Tetranychidae has been associated with defoliation of avocado trees in Australia. It had been identified as six-spotted mite (*Eotetranychus sexmaculatus*), which is an exotic species to Australia. *E. sexmaculatus* was first described in the USA from citrus, but there are issues with its true identity with several potential synonyms across the world. It was first recorded in Australia by Froggatt in 1921, however this is a vague reference apparently without vouchers. Other Australian specimens previously identified as *E. sexmaculatus* were later identified as the native species *E. queenslandicus*, based on the examination of type material of the latter species. The actual identity of the mite referred to as SSM in Western Australian avocado orchards needs to be determined as there are implications for management as different species may be more or less susceptible to different biological control agents and pesticides. This project seeks to clarify this taxonomic issue. Until this occurs, the pest mite will be referred to as six-spotted mite (SSM).

SSM is present in all production areas in Australia. It was a major pest of avocado orchards in New Zealand late last century and a number of miticides were registered there in response. Although the importance of the mite in New Zealand had declined in the past, more recently it has recurred as a pest of importance and dedicated research has recommenced.

SSM was first recorded in WA on avocado nursery stock imported from eastern Australia in 1986. Up to 2014 SSM was almost solely a pest of WA vineyards. In avocado orchards there was only one reported case of SSM induced defoliation where an application of insecticide resulted in an explosion of the SSM population and subsequent complete defoliation. At that time, examination in several avocado orchards in the Pemberton district showed most were infested with SSM at low levels, and that the pest was being kept in balance with naturally occurring enemies, especially predatory mites, with the main species detected being *Euseius elinae* (Fam. Phytoseiidae).

In the spring of 2014, more widespread defoliation occurred in orchards in the Pemberton area. The reasons for this outbreak were unclear. There were no pesticides applied known to negatively impact on beneficials, and no difference in the foliar spray program involving pesticides, for example control of dieback disease Phytophthora spp., or nutrients from previous seasons. However, in this instance there were only low numbers of predators found associated with SSM which suggests that natural suppression of the pest was not occurring.

In subsequent years more orchards have reported SSM induced defoliation. While the SSM do not cause direct damage to the fruit, defoliation exposes fruit leading to sunburn. Exposed fruit must be harvested quickly to avoid sunburn and the resultant downgrading in quality and price received. When large areas are defoliated, as occurred in one orchard in 2014 as well as in subsequent years, the change in harvest schedule for that orchard has flow on effects to other orchards and potentially the market. Large numbers of fruit must be picked in a short period of time which can lead to an oversupply and subsequent drop in market price, other orchards must alter their harvest schedule accordingly. With the effective management of SSM the decline in fruit quality and disruption to consistent supply over the season can be avoided.

In 2018 there were reports of mite outbreaks and associated defoliation in orchards further north than had been previously recorded. The expansion in planting areas and geographical spread of the pest will lead to a greater impact on the industry in the future. According to a recent survey as part of project AV19001 (Page 2022), SSM were the second highest occurring pest in Western Australia avocado orchards, after garden weevil which generally only warrants control in young trees.

The recently completed Hort Innovation project AV 15012 (Learmonth 2019) found that releases of the mass reared predatory mites *Galendromus occidentalis*, *Neoseiulus californicus* and *Typhlodromus doreenae* (all Phytoseiidae) were not able to establish in commercial avocado orchards trees or provide adequate control of SSM. That project identified the presence of another species of naturalised predatory mite, *Amblydromalus lailae*. Whether this species and the most commonly found predatory mite, *E. elinae*, can provide control of SSM as a result of mass releases or through building numbers with altered cultural practices is yet to be determined.

SSM is a Tetranychid mite, a group with a long history of resistance development, the most notorious being two-spotted mite, *Tetranychus urticae*, which has 552 resistance cases noted in the Arthropod Pesticide Resistance Database (Michigan State University 2022). It is likely that SSM can also develop resistance just as readily. Insecticide resistance can lead to further problems such as environmental and commodity contamination as well as destruction of beneficial agents and secondary pest outbreaks resulting from the need for higher rates and/or more frequent applications, possible cross resistance selection, and the ever increasing escalation of community concerns around pesticide use. Developing and extending appropriate IPM strategies for SSM management in avocados will help reduce the risk of resistance developing.

The role of tree health on the level of defoliation is unknown. There is a high level of variability in the magnitude of leaf defoliation in orchards of avocado affected by SSM. It has been suggested that the leaf nitrogen level in the tree, and its relationship to carbohydrate levels, is responsible for some of this variability. Research on this aspect could lead to nutrition being used as a preventative cultural management practice.

Growers require a successfully demonstrated integrated pest management (IPM) plan for the monitoring and management of SSM that is based on solid research to give them the confidence to employ it themselves. IPM combines biological, cultural and chemical practices to managed pests. IPM programs look at preventing pests reaching economically damaging levels as a first line of control, regular monitoring is also done to determine if threshold levels have been reached and if so, targeted management is carried out that has the least impact on beneficials and the broader environment as possible. This project used a multipronged approach to produce an overall picture of SSM in avocados that could be used to devise an integrated management approach, potentially incorporating biological, cultural and chemical practices. Work on taxonomy, mass-reared and naturally occurring predatory mites, biosecurity, spray applications and tree health, as well as a focus on the optimisation of monitoring techniques would all contribute to this goal. All of this information is then extended to industry in workshops, field walks and on-line extension materials for growers.

Methodology

Taxonomy

Morphological descriptions were completed for *Eotetranychus sexmaculatus* specimens borrowed from various scientific mite collections from around the world and fresh specimens of SSM collected from Florida USA, Western Australia and New Zealand. Morphological descriptions were completed for type specimens of *E. queenslandicus*, *E. asiaticus* and *E. spanius*. Fresh collections of *E. asiaticus* were sent from Japan for comparison. Collection of fresh specimens of *E. queenslandicus* was attempted in north Queensland without success. Over 1000 specimens were examined and 100 specimens were measured, drawn and photographed for the new description and manuscript.

Samples from Florida USA, Western Australia, New Zealand and Japan sent to Canada for molecular analysis.

Further detail on the taxonomy methodology can be found in appendix 1

Biosecurity

A literature review of possible modes of transmission of mites between properties was conducted and current on-farm biosecurity practices of growers, nurseries and packing sheds determined via a short survey. The results from these were assessed to determine if they posed a biosecurity risk and finally recommendations made for growers to minimise the likelihood of SSM entering their orchards. Thirty-one growers, seven nurseries and four pack sheds were approached to complete the survey. This included all the known nurseries to supply trees to this region and all packing sheds known to pack fruit from orchards other than their own.

Survey questions for the three different groups, growers, nurseries and pack sheds, and further details on the methodology can be found in appendix 2.

Monitoring and sampling

To develop robust and user-friendly monitoring and sampling protocol four areas of SSM distribution were examined

1. Temporal distribution: Results from the 26 regularly monitored orchard blocks were used to determine seasonal trends and the key monitoring times and intervals.
2. Canopy distribution: Twenty-four leaf types, varying in leaf age, height in canopy, side of tree and inner and outer canopy were sampled, SSM counted and results analysed to determine optimum leaf types for sampling. Leaves were sampled from multiple trees in multiple orchard blocks in both spring and summer
3. Spatial distribution: In three orchard blocks every tree in set sub-sections were sampled one-off and SSM counted. Results were used to determine if there was a relationship between hotspots and local landscape features, and consistency in hotspots between years. Consistency in hotspots between years was also examined from results from unsprayed blocks amongst the 26 regularly monitored orchard blocks.
4. Optimum sampling. Sampling results from the spatial distribution monitoring were used. Multiple scenarios of trees and total leaves sampled were established; scenario 1: 5 leaves from 3 trees (15 leaves total), scenario 2: 5 leaves from 6 trees (30 leaves total), scenario 3: 5 leaves from 9 trees (45 leaves total), scenario 4: 5 leaves from 12 trees (60 leaves total). These scenarios were then simulated many thousands of times to determine the average error. Taking into account the average error from different sample sizes, the time taken to sample x number of leaves and the need to maintain user friendly monitoring recommendations a recommended sample size was chosen.

Predatory mites

Several aspects of predatory mites were considered as part of this project as either trials or monitoring and case studies.

1. Replicated trials of two treatments applied in commercial orchards:
    a. Release of mass reared *A. lailae* as a means to reduce SSM populations.
    b. Application of a pollen, prey mite mix as a method to increase naturally occurring predatory mites numbers and reduce SSM populations.
2. Monitoring to determine the naturally occurring predatory mites present and seasonal distribution of naturally occurring predators and their relationships with SSM populations.
3. Impact of pesticides on beneficial arthropods that may play a role in SSM management through case studies of pesticide use in monitored orchards and a review of pesticide impact databases.

Further details on the predatory mite methodology can be found in appendix 4.

Nitrogen

Two field trials were conducted to determine if there was a relationship between leaf nitrogen, defoliation and SSM population levels.

Trial one: In an orchard in which defoliation due to SSM occurred the following variables were measured for twenty trees in two different blocks.

- Defoliation rating (1-6)
- Average no. of SSM motiles per leaf
- Average no. of SSM eggs per leaf
- Flowering rating (1-6)
- Leaf nutrients; total nitrogen, boron, calcium, chloride, copper, iron, magnesium, manganese, phosphorous, potassium, sodium, sulfur and zinc

Results were analysed to determine if the correlations between variables were statistically significant or not.

Trial two: Ten trees were selected in each of three orchard blocks known to have moderate SSM levels. Leaf drop over the course of spring and early summer, SSM numbers in early and mid-spring, leaf nitrogen levels and flowering were assessed for each of the thirty trees. Measurements were taken prior, during and after the defoliation risk period in spring. Results were analysed to determine if the correlations between variables were statistically significant or not.

Further details on the nitrogen trial methodologies can be found in appendix 5.

Thresholds

In an effort to determine a threshold for SSM in avocados this project hoped to compare the level of leaf drop with mite densities in a broad number of orchard blocks. Unfortunately, despite monitoring in 26 different orchard locations over two seasons none of the monitored areas experienced SSM induced defoliation and so no relationship could be analysed.

Instead, a spring threshold was devised based on experience and observations by the research team. The following factors were also examined to inform the recommended threshold:

- Maximum levels of SSM that occurred in orchards that did not experience defoliation.
- 'Thresholds' set in NZ and California.
- Experience and observations from growers in WA and NZ in regards to tree health/stress and the incidence of defoliation.
- The relationship between the percentage of leaves with SSM and the average number of SSM per leaf.
- The relationship between SSM levels in autumn and levels the following spring.

Further details on the threshold methodologies can be found in appendix 6.

Management case studies

A record of SSM levels and miticide use was kept for each of the 26 regularly monitored orchard blocks. From these case studies were developed to provide examples of when no miticides were required, effective miticide applications and sub-optimal applications. When there was a sub-optimal application, all known factors for that application were taken into account to determine where the weak points and areas for improvement may lie. It must be understood that the reasons for sub-optimal applications proposed here are not definitive. There may be other unknown factors at play, or compounding factors that un-replicated single application examples could not identify. However, the reasons proposed are those considered the most likely reason for the sub-optimal results and are valid and useful examples to understand and learn from to improve future miticides applications for all growers.

A literature review of alternative products was conducted and a case study of spray oil application for SSM management also developed.

From the case studies it was concluded that miticide application practices are an area in which improvements could be made, leading to less miticide being applied. The project engaged with another avocado pest management project, AV19001, that was running concurrently and took part in two spray workshops being run as part of that project in the lower southwest. At the spray workshops information on SSM pest management was presented, including case studies from this project. The case studies were used to highlight the importance of good application practices and linked to the information given by other presenters.

Further details on the management case studies methodologies can be found in appendix 7.

Extension

Project updates and recommended monitoring and management practices were extended to industry through regular articles published in industry magazines and workshops and seminars. An IPM guide for SSM in avocados was developed at the end of the project and is available to growers online, along with a series of videos to assist with accurate mite monitoring. The IPM guide contains information on when and how to monitor, identification of pest mites and beneficial arthropods, on-farm biosecurity as well as SSM management practices. Further information on project extension activities can be found in the outputs section of this report and appendix 8.

Results and discussion

Taxonomy

Despite the presence of slight morphological differences, the molecular approach strongly indicated that all of the specimens analysed from Western Australia, New Zealand and the USA were the same species, *E. sexmaculatus*. The observed morphological differences were consequently further scrutinised and are thought to be the result of different specimen preparation techniques and differences in the interpretation of morphological structures by various researchers.

A taxonomic manuscript covering the history and a new full description of the true SSM will be submitted in early September 2022, authored by Jenny Beard and her two colleagues Dr Fred Beaulieu and Dr Wayne Knee who undertook the molecular analyses (based at the Canadian National Collection of Insects, Arachnids and Nematodes, in Agriculture and Agrifood Canada). Further details of the results can be found in appendix 1.

Confirmation of the species identity of this emerging pest mite of avocado is a significant step in developing a specific pest management program. The literature associated with this species is diverse, but an accurate identification can allow more targeted searches for appropriate literature to be made. In addition, the examination and confirmed identification of 100's of specimens from many hosts and countries of origin builds a stronger knowledge platform on which to more confidently develop a specific control program and ignore irrelevant data from the literature searches.

Biosecurity

Survey responses were received from 21 growers, 0 nurseries and 3 pack sheds. Overall current on-farm biosecurity practices regarding the potential spread of SSM are positive but there is room for improvement. Very little machinery is shared between properties, however, when machinery is shared it should always be cleaned which is not the case now.

Overall bins moving between properties are clean. Eight out of 18 growers that receive bins from a packing shed said that the bins were always clean and 7 responded that they often were. If leaf litter is in bins, it is removed and disposed of out of the orchard. The majority of packing sheds that responded, and a large proportion of the bins used in the region given the size of those packing sheds, always clean bins between properties, which is good practice.

It is unfortunate that only one nursery responded to the survey, although they followed good pest management protocol. Given that SSM first entered WA on nursery stock from interstate and there are anecdotal reports of SSM being found on nursery stock it is a potential channel for the spread of SSM. Also, if a grower receives an order with SSM present on most trees, this will lead to a more widespread population of SSM in the new orchard. Other dispersal methods, such as on equipment or aerial would lead to more random/isolated pockets of SSM. Only four of the 21 grower respondents said that they always check new planting stock for pests. This should be standard practice. Given the cryptic nature of SSM on leaves the inspection of new plants should be thorough and the person checking have confidence in their ability to identify SSM.

SSM disperse aerially on silk threads and are carried passively through the air. The mites are not able to control where or how far they travel by air. It is likely that most aerially dispersing mites do not travel far before falling out of the air (Kennedy 1985) and only an estimated 10% reaching a suitable host (Jeppson referenced in Wosula 2015). There is no way of preventing SSM from entering orchards via natural dispersal. Growers should be aware of it non-the-less as it is a possible means of SSM entering their orchard and becoming established. Natural dispersal means that SSM can enter a property even if the strictest of biosecurity protocols are followed so it is always worthwhile to monitor all orchards at least periodically even if SSM haven't been observed before.

When an incursion does occur in an orchard it would take time for the population to build up to damaging levels. For this reason, even if damage is not observed in an orchard it should not be assumed that SSM are not present. Regular monitoring of all orchards is recommended.

Further details on the biosecurity results can be found in appendix 2.

Monitoring and sampling

Temporal distribution: SSM and predatory mite numbers fluctuate over the year. SSM generally start increasing in late winter to early spring and peak in late spring to early summer. SSM numbers are generally low through summer and winter and there can a smaller peak in autumn. Predatory mites generally increase in number through spring, reaching a peak in late summer/early autumn and falling to low numbers in winter. These patterns are general because there is a lot of variability in SSM and predatory mite numbers and the timing of peaks between different orchard blocks.

Canopy distribution: There is variation in SSM densities within an individual tree canopy. Slightly more SSM were found on leaves 1.5m compared to leaves sampled from 3m and 4.5m. Mature leaves had more SSM than the soft new growth, except in one orchard with very high SSM levels. There was no difference in SSM levels between the inner and outer canopy. SSM were frequently more prevalent on the shadier, southern side of trees compared to the northern side, however this was not always the case

Spatial distribution: There was no pattern in distribution across orchard blocks that could be explained by local landscape features. Very large degree of variability in the number of SSM found on different trees within the same block were found, the most extreme example being a tree that had an average of 154 SSM on the six leaves sampled, compared to the neighbouring tree that had an average of just 2.7 SSM per leaf. Hot spots were not consistently found in the same trees or area of a block between seasons.

Optimum sampling: As expected, the average error of a monitoring sample was reduced as the samples became larger (Table 1). If 15 leaves were sampled from 3 trees there was an average error of 15%. If 60 leaves were sampled the average error is reduced to 5%. This means that if the true percentage of leaves with SSM in a block was 40%, if 5 leaves were monitored from any three trees within that block results from just those 15 leaves would be within a range of 25%-55% leaves infested. However, if 5 leaves are taken from 12 trees the results would be only 5% above or below the true result, that is in the range of 35%-45%.

When more leaves are monitored the average error decreases, but it is a case of diminishing returns, with each additional 15 leaves added to the simulation the reduction in the average error became smaller and smaller. More time could be spent monitoring more leaves, but the benefit in accuracy would not necessarily warrant that extra time. It was decided to recommend to growers to monitor 5 leaves from 10 trees, giving 50 leaves in total. This is a compromise between having a reasonable level of error, only 5-6%, without being overly time consuming. The ten trees across a whole block give a reasonable amount of spread. Also having a 50 leaf monitoring sample makes calculating the percentage of leaves infested very quick and easy.

Table 1. The number of trees and leaves for each simulated scenario and the calculated average error

Scenario	No. of trees sampled	No of leaves sampled per tree	Total no. of leaves sampled	Average error
1	3	5	15	12%
2	6	5	30	8%
3	9	5	45	6%
4	12	5	60	5%

Further details on the monitoring and sampling results can be found in appendix 3.

Predatory mites

Replicated trials of *A. lailae* mass reared predatory mites and a pollen & prey mite mix showed that neither treatment increased predatory mite numbers in the treated trees or reduced SSM numbers.

Orchard monitoring confirmed that the vast majority of naturally occurring predatory mites are *Euseius elinae*, making up close to 85% of those collected. Followed by *Amblyseius deleoni*, which made up 9%.

There was no statistically significant relationship between predatory mites and SSM, stethorus beetle and SSM, tydied mites and SSM or tydied mites and predatory mites, either as percentage of leaves infested of the average number per leaf. From these results no management recommendations can be made regarding manipulating predatory mite, stethorus or tydeid mite numbers to alter SSM numbers in orchards. However, relatively few stethorus were observed and given that they can be voracious feeder of six-spotted mite (E. Barraclough pers. Comm. In Logan et al 2022) and that the above results are based on relatively few observations the potential for Stethorus beetles to be used for SSM management should not be ruled out. This is a potential topic of focus for future research.

Another area of potential future research is to determine how to increase *E. elinae* populations and take most advantage of its presence in orchards. Given the lack of success is establishing other predatory mite species in this and the previous project and that this species consistently makes up a large majority of predatory mites found in orchards makes it a prime subject of research. The pollen prey releases in this project were not successful. However, there are other methods that are worth pursuing, such as the planting of pollen producing plant species in the orchard. These would provide a more consistent supply of pollen for predatory mites such as *E. elinae* but may also have benefits for other beneficial and pollinating species.

According to the databases, of the five actives available to Australian avocados growers for SSM management abamectin is the most toxic to predatory mites. Etoxazole was the next most toxic to predatory mites, followed by mineral oil, then bifenazate and fenbutatin-oxide. Abamectin was also the most toxic to *Cryptolaemus montrouzieri*. There was no rating for etoxazole for this species in either database. The three other products were all in class 1 for their impact on *Cryptolaemus montrouzieri*.

The observations from the pesticide use case studies did not always align with the expected results based on information from the databases, with predatory mite numbers remaining at moderate to high levels after spring etoxazole applications. The pesticide toxicity databases did not have information on the predatory mite species present in avocado orchards and therefore their toxicity ratings are not directly applicable to the crop ecosystem. Bioassays would need to be conducted with the actives and specific predatory mite species of interest to determine their impact.

Further details on the predatory mite results can be found in appendix 4.

Nitrogen

Trial One: There was a significant positive correlation between nitrogen levels and defoliation and a significant negative correlation between nitrogen and average no of SSM per leaves. Higher nitrogen levels were correlated to less defoliation but also with more SSM per leaf. There were also some significant correlations between other nutrients and defoliation. All other correlations analysed were not statistically significant.

Trial two: The following correlations between variables were assessed. None were found to be statistically significant.

- Percentage leaf drop, over all three time periods and leaf nitrogen.
- Average mites/leaf, at both dates measured and leaf nitrogen.
- Percentage leaves infested, at both dates measured and leaf nitrogen.
- Percentage leaf drop, over all three time periods and average mites/leaf, at both dates measured.
- Percentage leaf drop, over all three time periods and percentage leaves infested, at both dates measured
- Percentage leaf drop, over all three time periods and flower rating

The results from both trials did not provide clear indications of relationships that could lead to nitrogen management recommendations regarding mitigating SSM and defoliation. There are other factors that alone, or in conjunction with nitrogen levels, influence SSM populations and spring defoliation. Further research is needed in this area to determine what these factors are and if they can be included in an IPM program for SSM. Potential areas of research are included in the recommendations of this report.

Further details on the nitrogen trial results can be found in appendix 5.

Thresholds

After discussion among the project team, based on observations and experience it has been decided that the level of 40% leaves infested be used as a ‘threshold’ in spring. Based on the pattern of SSM infested between autumn and the following spring an autumn ‘threshold’ of 10% leaves infested was decided on. This is not an economic threshold, but rather a threshold after which action may be considered, such as applying a miticide, while also taking multiple other factors into account.

Neither NZ or California have established thresholds for SSM in avocados. In California observations based on the number of SSM per leaf are used in extension material. 2-3 mites per leaf are a level not to be concerned about (University of California 2017) while 5-10 SSM per leaf will lead to defoliation (Bailey 1990). Based on the data from our monitoring orchards giving the relationship the relationship between the average number of SSM per leaf and the percentage of leaves with SSM this is roughly equivalent to 36-45% of leaves with SSM being a level not to be concerned with, while 57-74% leaves infested is the point at which defoliation will occur. This puts the proposed WA 'threshold' lower than some advice from California. However, earlier extension messages from California that suggested "only a few" (Bailey 1985) SSM were needed to cause defoliation. In NZ the AvoGreen manual 'threshold' is 25% of leaves with less than 5 SSM, or 15% of leaves with 5-10 SSM, or 10% of leaves with greater than 10 SSM. The proposed spring threshold for WA sits between the California and NZ thresholds.

Trees with more than 80% of leaves with SSM in spring that did not suffer any defoliation beyond what is expected at that time of year were observed in the project monitoring orchards. This highlights that that 40% level is not a point at which defoliation is guaranteed to occur but rather a level at which the factors need to be examined closer and management decisions made.

It has been broadly observed by growers in both Australia and New Zealand that defoliation is more severe and occurs more often in trees that are stressed. The stressors and level of stress that make trees more prone to defoliation in the presence of SSM have not been quantified but the following factors have been proposed:

- Water stress, both over and under watering
- High fruit loads
- High level of flowering
- Phytophthora
- Inadequate nutrition
- General tree health

Other factors that growers must take into account before applying a miticide relate to timing and crop and personal factors. They include:

- When has the SSM reached the threshold? Populations naturally decline in summer so if peaking later in the season they may soon decline of their own accord.
- Has the area already been harvested or do the trees have a small crop making a defoliation event less impactful?
- What are the market conditions in terms of price of fruit received and acceptance of lower grade sunburnt fruit?
- Have you experienced defoliation in that area of your orchard under similar conditions and SSM levels? Or, have you experienced higher SSM levels in that that area of your orchard under similar conditions without defoliation?
- What is your personal level of risk acceptance? Do you prefer to hold off spraying if possible?

Further details on the threshold results can be found in appendix 6.

Management case studies

There are seven cases demonstrating what can occur when no miticides are applied. Five of these blocks exceeded the 40% leaves with SSM 'threshold' in both spring 2020 and 2021. Another block exceeded 40% of leaves with SSM in one spring only. In some cases, these blocks exceeded the 'threshold' by a considerable amount. One block had more than 90% of leaves with SSM in spring 2020. Three other blocks had in excess of 70% of leaves with SSM in spring 2020. None of these blocks had any SSM induced defoliation over the project monitoring period. The remaining two blocks had smaller spring peaks of SSM, with less than 25% of leaves with SSM. Despite having low peaks SSM were almost always present over the monitoring period.

Three important learnings can be taken from these case studies.

1. High SSM levels in spring do not necessarily lead to defoliation.
2. The presence of SSM does not necessarily lead to the population increasing to potentially damaging levels.
3. SSM populations can fall steeply over summer without intervention.

There are examples of effective miticide sprays applied in both spring and autumn. There are four actives with label registration or minor use permits for use against SSM, fenbutatin oxide, etoxazole, abamectin and bifenazate. Fenbutatin oxide and etoxazole are the most regularly used actives and hence there are no case studies using abamectin or bifenazate. Four blocks from three orchards were effectively sprayed with etoxazole in autumn 2021. SSM numbers remained low in these blocks through the following spring, so no miticides had to be applied then. These case studies demonstrate exactly what is being aimed for with an autumn application. SSM numbers generally naturally decline coming into winter, but by applying a miticide in autumn when they are still present in reasonable numbers the population can be reduced substantially so that when the population does start to increase again the following spring it is starting from a lower base leading to a later and lower spring peak. If the population increase is pushed further enough back in late spring and/or summer, then only low numbers will be present during the spring defoliation risk period negating the need to spray at that time of year.

Six blocks from three different orchards all received spring applications of etoxazole, that effectively reduced the percentage of leaves with SSM.

Learnings

1. Both spring and autumn sprays can be effective.
2. Be aware of how each active works, i.e. is it a knock-down or not, and use the product best suited to your situation
3. With effective sprays a single application round per year, or less, can maintain the population below the 'threshold' in the spring risk period.
4. Monitor across a whole block, not just a small area. Keep monitoring records and alter monitoring and management areas if need be.
5. Monitor and manage all blocks separately.

Seven case studies of sub-optimal results from miticides sprays were developed. The range of scenarios that likely led to the sub-optimal results including; lack of follow-up spray, temperature at time of application and poor spray coverage due to low water volumes, large tree size and/or poor canopy penetration.

Learnings

1. Continue regular monitoring after each miticide spray to ensure the expected result was achieved and to determine when numbers increase again.
2. Read, understand, and follow label comments and instructions in term of rates, follow-up sprays and any temperature requirements.
3. Use water volumes and a sprayer set-up that optimises spray coverage. Alter for blocks with different tree size, canopy structure and density.
4. Assess spray coverage to ensure it is optimal. Make changes if it is not.

The literature review of alternative spray products determined that spray oil and sulfur were the most likely to effectively control SSM. A case study for spray oil was developed with promising results. The grower was able to quickly reduce the population from very high levels to near zero and the low levels remained for the following months. This saw them through the defoliation risk period without the need for any other miticide applications. Whether or not spray oils are a viable option for autumn spraying has not been assessed. For autumn applications to be effective the SSM population needs to be reduced by a large enough degree to maintain low levels for a longer period, i.e. not just through several weeks of the defoliation risk period, but through all of winter and the following spring. Further case studies and replicated trials of spray oil applications would greatly add to the foundation of knowledge gained through this single case study, allowing for more tailored scenarios involving, for example, different levels of pest pressure, weather, seasonal timing, budget and spray application.

Further details on the management case study results can be found in appendix 7.

Outputs

A detailed list of extension activities conducted over the project life is included in the table below and copies of extension material produced can be found in appendix 8 and the final project outputs of the Avocado SSM management guidelines and Identification guide for mites found on avocado leaves in appendix 9.

Table 2. Output summary in chronological order

Output	Description	Detail
Grower monitoring updates	Fortnightly emails to growers hosting monitoring sites.	The managers/owners of the 13 orchards being monitored every fortnight were sent regular emails updating them of the latest monitoring results. Highlighting any areas of interest, change or concern.
Talking Avocados article, spring 2019 Vol 30 no 3	Article introducing the project.	In the project M&E plan one article per year in an industry magazine and one article per year in DPIRD's Agmemo newsletter were scheduled. The focus moved to industry magazines and other media as Agmemo was wound back in this time. This is the first of six planned articles over the project lifetime.
WA Growers article, spring edition 2020	Article on update of project activities so far and field work planned for the coming spring.	This is the second of six planned articles over the project lifetime.
Grower presentation, 2nd December 2020	Update on the project activities, findings and recommendations to date. Focus on variability in SSM across and between orchards and the need for good monitoring practices, when and how to monitor for SSM.	In the project M&E plan two workshops/field walks per year were scheduled. This is the first of six planned workshops/field walks over the project lifetime.
Talking Avocados article, summer 2021, Vol 31 no. 4	Article on the importance of basing management decisions on monitoring and how to monitor given the variability within and between orchard blocks	This is the third of six planned articles over the project lifetime.
Grower workshop, 18th March 2021	Update on the project activities, findings and recommendations to date. Focus on case studies and sustainable use of miticides. David Logan presented remotely from NZ.	17 growers attended This is the second of six planned workshops/field walks over the project lifetime.
Grower workshop, 23rd August 2021	Workshop targeted at growers that have not previously monitored for SSM. Focus on how and why to monitor and how to identify SSM. Included field and hands-on component	11 growers attended This is the third of six planned workshops/field walks over the project lifetime. A survey of attendees at the start of summer following the workshop was conducted. Eight out of the 9 respondents rated the workshop as at least 4 and mostly 5 out of 5 for relevance to their avocado growing enterprise. Eight out of 9 also said they had implemented new monitoring or management practices based on the workshop content. All growers rated highly that the information was presented in a way that was easy to understand.
Media release, 26th August 2021	Article on the recent monitoring workshop, highlighting the importance of this project and	The media release was taken up by Good Fruit and Vegetable national magazine online and print and

	good management.	the Manjimup Bridgetown Times newspaper. This is the fourth of six planned articles over the project lifetime.
Talking Avocados article, autumn 2022	Article on autumn management of six-spotted mite	This is the fifth of six planned articles over the project lifetime.
Spray workshop presentation, May 2022	Presentations on effective spray use for SSM management. Focus on, basing management decisions on monitoring results, effective spray use, spray coverage and resistance management.	Presentations were done at the Manjimup and Pemberton spray workshops being conducted as part of AV19001. This is the fourth and fifth of six planned workshops/field walks over the project lifetime.
Manjimup Avocado Seminar, June 2022		This is the sixth of six planned workshops/field walks over the project lifetime.
Talking Avocados article, spring 2022	Article on the importance of good spray practices to achieve effective mite management. With reference to the spray workshops run by EE Muir as part of project AV19001.	This is the sixth of six planned articles over the project lifetime.
Avocado SSM management guidelines	Presentation on the major findings from the project, focusing on results of the nitrogen trials, predatory mite releases and miticide use case studies.	Made available on the DPIRD website and Avocados Australia BPR.
Identification guide for mites found on avocado leaves	Printable two-page document with descriptions and high quality colour photos of the most commonly found mite types found in WA avocado orchards. For use during monitoring to identify mites observed.	Made available on the DPIRD website and Avocados Australia BPR.

There were some delays and alterations to the planned output scheduled, largely due to covid restrictions. Most notable there was no autumn workshop in 2020 or 2021 due to travel restrictions, social distancing requirements and uncertainty around changing restrictions. Despite not being equally spaced over the project lifetime there were still six articles and six workshops/field walks produced as planned.

Outcomes

Table 3. Outcome summary

Outcome	Alignment to fund outcome, strategy and KPI	Description	Evidence
Intermediate outcomes			

Increased grower knowledge and confidence in integrated SSM management	Outcome 2: The Australian avocado industry has improved profitability, efficiency and sustainability through globally competitive production systems, orchard management, varieties, innovative research and development (R&D) and sustainable best management practices (BMPs). Strategy 4: Develop and optimise fit for purpose pest and disease management strategies KPI: Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	By increasing grower knowledge of and confidence in using IPM practices for SSM management they will be more likely to implement them.	At workshop 8 out of 9 attendees at workshop Eight out of the 9 respondents rated the workshop as at least 4 and mostly 5 out of 5 for relevance to their avocado growing enterprise. Eight out of 9 also said they had implemented new monitoring or management practices based on the workshop content. In the final project feedback survey 100% of respondents said the project had increased their knowledge of sustainable SSM monitoring and/or management practices. 89% of respondents said the project had increased their confidence to make changes to your SSM monitoring and/or management practices.
Increased researcher knowledge of mite characteristics relevant to management including; taxonomy, within orchard distribution and seasonal population variations Increased researcher knowledge of effectiveness of mite management strategies; preventative, biological and chemical	Outcome 3: Improved capability and innovative culture in the Australian avocado industry maximises adoption of best practices and innovation in productivity and demand. Strategy 1: Deliver tailored extension and communication services to support positive change in the areas of export development and capability, domestic demand creation and BMPs in quality throughout the supply chain, biosecurity, sustainable orchard systems and integrated pest and disease management (IPDM) Strategy 2: Provide the opportunity for engagement between industry, across tree crop producers and other	Improving capability of research staff will lead to more diverse and relevant areas of interest being included in the project. Giving a greater probability of relevant outputs and successful outcomes.	Connections developed between Australian researchers and those in NZ and California, USA that also study mites in avocados. Also connections developed with extension specialist in the field of spray application and Australian IPM specialist through collaboration with project AV19001. Extensive literature reviews in the area of monitoring and sampling, predatory mites, nutrition impacts on mites, miticide application and alternative products and mites distribution and threshold conducted. International presenter (David Logan NZ) at project workshop. Project team made themselves available growers for assistance with SSM queries.
Improved connectivity between growers, advisors, local and international researchers facilitates efficient and targeted research and extension		Improving connectivity between growers, advisors, local and international researchers will lead to more relevant outputs being delivered and ensure the Australian industry is exposed to the most up-to-date international knowledge and experience.	

	stakeholders to innovate		
End of project outcomes			
Increased uptake of integrated SSM management practices by orchardists in affected areas of southwest WA.	Outcome 2: The Australian avocado industry has improved profitability, efficiency and sustainability through globally competitive production systems, orchard management, varieties, innovative research and development (R&D) and sustainable best management practices (BMPs). Strategy 4: Develop and optimise fit for purpose pest and disease management strategies KPI: Development of pest and disease management strategies that mitigate crop loss in collaboration with growers	Increased uptake of IPM practices for SSM management is desirable to reduce unnecessary pesticides application and reduce economic impact of SSM on production	In the final project feedback survey 78% of respondents said they have or intend to make changes to the way they monitor and/or manage SSM based on information from this project.
Less leaf loss from SSM, which leads to higher-grade fruit being produced, and more coordinated management of harvest timing.		The ultimate aim of SSM management is to reduce defoliation to ensure higher quality fruit is produced.	In the final feedback survey for the project 56% of respondents think changes they have made due to information from the project have, or will, lead to less leaf loss due to SSM

Monitoring and evaluation

The key evaluation questions, from the project M&E plan are in table 4 below along with project performance indicators for each KEQ and continuous improvement opportunities when relevant.

Table 4. Key Evaluation Questions

Key Evaluation Question	Project performance	Continuous improvement opportunities
Effectiveness 1. To what extent has the project achieved its expected outcomes?		
a. Is there a SSM management package available and accessible for orchardists to manage leaf loss resulting from mite infestations?	Yes, the package is complete and will be made available on the DPIRD website and Avocado Australia's BPR.	
b. To what extent has the project improved knowledge and confidence of growers to adopt sustainable SSM management practices?	In the final feedback survey for the project: • 100% of respondents said the project had increased their knowledge of sustainable SSM monitoring and/or management practices. • 89% of respondents said the project had increased their confidence to make changes to your SSM monitoring and/or management practices. • 78% of respondents said they have or	

<table>
<tr><td></td><td>intend to make changes to the way they monitor and/or manage SSM based on information from this project.</td><td></td></tr>
<tr><td colspan="3">Relevance
2. How relevant was the project to the needs of intended beneficiaries?</td></tr>
<tr><td>a. To what extent has the project met the needs of industry levy payers?</td><td>Through feedback from growers and the PRG over the life of the project additional activities and outputs were completed. Namely, a mite identification guide, case study into using spray oils for SSM control, a literature review of alternative spray options.

Growers were also given the opportunity to comment on areas of further research beyond this project as part of the final feedback survey. These are listed in the recommendations section of this report.

In the final feedback survey for the project 56% of respondents think changes they have made due to information from the project have, or will, lead to less leaf loss due to SSM.</td><td></td></tr>
<tr><td colspan="3">Process appropriateness
3. How well have intended beneficiaries been engaged in the project?
4. To what extent were engagement processes appropriate to the target audience/s of the project?</td></tr>
<tr><td>a. How many participants attended workshops?</td><td>There were a total of 43 different grower entity participants at the six project workshops. A further nine grower entities made direct contact with the project team to discuss SSM. There was also an opportunity to present at the Avocadoes Australia Avoskills workshop on 10-11th May 2020 and the WA regional forum on 22nd June 2021, where there were 60 and 100+ attendees respectively. These presentations were focused on pest management in avocados more broadly, however, information the project, SSM, it’s monitoring and management was included on both occasions. These events further extended the reach of the project, it’s activities and outcomes, to the WA avocado industry.</td><td>Over the course of the project it was noted that the DPIRD grower database was not up-to-date, if only this was relied upon to promote project events then not all growers would be included. Two improvements made:
• Promote events through the DPIRD avenues and Avocados Australia to ensure broadest coverage.
• Update grower database, this is ongoing.</td></tr>
<tr><td>b. Have regular project updates been provided through linkage with the industry communication project and other extension channels?</td><td>The industry was kept regularly updated of project activities and given relevant seasonal information through 6 workshops over the life of the project, 6 articles in the industry magazine Talking Avocados. Presentations coordinated by the industry communication project at the Avocadoes Australia Avoskills and WA regional forum 2021. Growers that hosted project trial and monitoring sites received fortnightly email</td><td>The project team worked with the avocado industry communication project to update the SSM information contained in the regional seasonal updates. This was not initially planned for but as the project team became aware of these updates changes were made to ensure growers were receiving the most up to date</td></tr>
</table>

	updates.	and consistent information through all communication channels. If future an audit of all communication channels should be conducted to ensure that none are overlooked in the project communication plan.
c. How accessible (including timing and location) were workshops and extension material to southwest WA avocado growers?	All workshops were help in the Manjimup/Pemberton area, the focus region for SSM. All except one workshop was held in autumn or winter, avoiding the busier spring and summer months for avocado crops. The March 2021 workshop was held as a hybrid online/in person event to increase accessibility given COVID restrictions at the time.	
Efficiency 5. What efforts did the project make to improve efficiency?		
a. Were project plans (incl. M&E, activities methodology) done at the start of the project adhered to?	To a large degree yes. More detailed feedback could have been obtained from workshop attendees.	Standardised sign-in sheets and feedback forms should be used for each project activity to more easily measure outcomes and answer KEQ's.
b. Were regular meetings held with project team members and the PRG to discuss project changes?	Regular PRG meetings were held. Meetings dates were 24/2/21, 22/9/21 and 7/4/22. Meetings were supposed to be held every 6 months, given then length of the project two more meetings should have been held. Minutes were taken at all meetings and attendees given the opportunity to provide feedback on project activities and plans.	

In the M&E plan the aim was for 50% of south-west WA avocado growers to attend a workshop, host a project trial/demonstrating and/or making direct contact with the project team. There are 144 avocado properties in the south-west of WA, the project made direct contact with 52 of these through either workshop participation and/or one-on-one communication, this is 36%. Although many more growers were directly presented with projects outdates and outputs at the Avocados Australia Avoskills workshop and WA regional forum.

Recommendations

The recommendations made by the project fall into three categories, those relating to grower practices, further extension activities to increase uptake of recommended grower practices and areas of research to further improve the sustainable management of SSM.

Grower Practice

Biosecurity

Based on the literature review and responses to the survey the following on-farm management practices are recommended to all avocado growers.

- Always thoroughly check new planting stock for pests, including mites, and control if necessary.

- If sharing machinery and equipment always ensure it is cleaned between properties, this includes bins. With particular focus on plant material.
- If machinery or equipment, including bins, entering your property is dirty or has leaf litter in it, clean it away from your production area.
- All orchards should be regularly monitored for SSM, even if strict biosecurity protocols are followed and no damage has been observed.

Monitoring and sampling

It is recommended that all growers follow the monitoring protocols as set out in the SSM management guide produced as part of this project. The guide is available online as attached as appendix 9

Predatory mites

The application of mass reared predatory mite species is not recommended for SSM control.

Be aware of the different impact ratings of the available actives on various beneficial species and make decisions accordingly.

Nitrogen

Stressed trees are more prone to defoliation. However, the exact causes and threshold of this stress are unknown. There are currently no specific management recommendations in relation to tree nutrition and general health to reduce the risk of SSM induced defoliation other than to maintain healthy unstressed trees.

Thresholds

It is recommended that growers use the levels of 40% of leaves with SSM in spring and 10% of leaves with SSM in autumn to consider reducing SSM numbers through management. These levels are not strict thresholds as some trees withstood much higher levels without defoliation. When making a decision to manage SSM with miticides growers should take into account not only the SSM levels but also:

- Are the trees stressed? Include factors related to water stress, high fruit loads in the current and previous season, high level of flowering, disease pressure such as from Phytophthora, Inadequate nutrition and general poor tree health
- When has the SSM reached the threshold? Populations naturally decline in summer so if peaking later in the season they may soon decline of their own accord.
- Has the area already been harvested or do the trees have a small crop making a defoliation event less impactful?
- What are the market conditions in terms of price of fruit received and acceptance of lower grade sunburnt fruit?
- Have you experienced defoliation in that area of your orchard under similar conditions and SSM levels? Or have you experienced higher SSM levels in that that area of your orchard under similar conditions without defoliation?
- What is your personal level of risk acceptance?
- Do you prefer to hold off spraying if possible?

Management case studies

Learnings from all of the case studies are as follows and provide guidance to management practices:

1. High SSM levels in spring do not necessarily lead to defoliation. Other factors around tree stress also play a part.
2. The presence of SSM does not necessarily lead to the population increasing to potentially damaging levels. Not every block will experience are large increase in SSM number in spring.
3. SSM populations can fall steeply over summer without intervention.
4. Both spring and autumn sprays can be effective at reducing spring SSM levels below the 40% leaves with SSM ‘threshold’.
5. Be aware of how each active works, i.e. is it a knock-down or not, and use the product best suited to your situation.

6. With effective sprays a single application round per year, or less, can maintain the population below the 'threshold' in the spring risk period.
7. Monitor across a whole block, not just a small area, as the SSM levels will vary over an area. Keep monitoring records and alter monitoring and management areas if need be.
8. Monitor and manage all blocks separately as mite numbers can vary greatly between blocks.
9. Continue regular monitoring after each miticide spray to ensure the expected result was achieved and to determine when numbers increase again.
10. Read, understand, and follow label comments and instructions in term of rates, follow-up sprays and any temperature requirements.
11. Use water volumes and a sprayer set-up that optimises spray coverage. Alter for blocks with different tree size, canopy structure and density.
12. Assess spray coverage to ensure it is optimal. Make changes if it is not

Extension

There is one major extension recommendations from this project. It is recommended that resources be put towards improving spray application efficacy through extension activities such as spray workshops, one-on-one spray assessments and adjustments and general media on the benefits and how-to of improving spray application efficacy. This recommendation comes largely from the miticides application case studies in the project and the high occurrence of sub-optimal spray applications. This would not only be beneficial for improving mite management practices but also management of all pest, disease and nutritional issues that utilise spray application of products.

Research

There are several areas of future research that the project recommends to increase understanding of the SSM/avocado pest/crop complex and improve sustainable management of this pest. These research areas could be addressed individually or as part a larger project.

In the area of biological control there are three specific research topics that the project recommends pursuing in order the improve the use of biological control agents for SSM management.

- Determine if Stethorus sp. play as role in SSM control and if numbers can be increased to improve SSM management.
- Assess the use of pollen producing ground cover and/or inter-row species to increase numbers of predatory mites and other beneficial invertebrates.
- Assess the impact of the registered miticides and other non-miticide products, including copper, applied to avocados on the most commonly found predatory mites and other beneficials in south-west avocado orchards. This will give miticide impact data specific to this crop ecosystem.

In the area of tree health and cultural management further research that increases the understanding of the relationship between various tree factors and SSM populations and defoliation risk is recommended. With greater understanding of these relationships the threshold recommendations could be tailored to taken specific factors into account and cultural pest management recommendations could be made, further reducing the reliance on miticides. The factors that the project recommends be included in further research are amino acids, starch and sugars, water stress, fruit load, level of flowering, phytophthora and general tree health. It is also recommended that replicated trials play a part in any further projects as the variables can be more accurately controlled and a broader range of treatments applied, making it more likely that causal relationships can be found. Demonstrations in commercial orchards are recommended to increase relevance and uptake to growers.

To further progress the management threshold the project also recommends more intensive and extensive studies such as widespread studies of orchards to increase the chances of encountering blocks with SSM induced defoliation and pot studies of trees inoculated with set levels of SSM and blocks of mature trees with various SSM levels that are not controlled with miticides. This are of research would also benefit from replicated trials with controls in which no miticides are applied, a scenario that is difficult to achieve when working in commercial orchards.

In the area of alternative spray products the project recommends three topics of future research.

- Assess the efficacy of sulfur for SSM control
- Assess the efficacy of oil in different orchard situations and times of year, particularly as an autumn spray.
- If erythritol becomes available commercially in Australia, assess efficacy against SSM.

Grower recommendations

In the final feedback survey growers were asked if there were any areas of further research into SSM management that they would like to see addressed in the future. The following responses were received.

- Further investigation into biological agents which could individually or even as a suite of agents suppress SSM activity.
- Link to nutrition and other stressors
- No this is very adequate
- Resistance to mite sprays

Refereed scientific publications

Journal article

Jennifer J. Beard[1], Fred Beaulieu[2], Wayne Knee[2] & Tetsuo Gotoh[3]. The six-spotted spider mite, *Eotetranychus sexmaculatus* (Riley) (Trombidiformes: Tetranychoidea: Tetranychidae) in Australia, New Zealand, Japan and USA: morphological and molecular comparisons, synonyms, and related species. In progress

[1] Queensland Museum, P.O. Box 3300, South Brisbane, Queensland, 4101, Australia.

[2] Canadian National Collection of Insects, Arachnids and Nematodes, Ottawa Research and Development Centre, Agriculture and Agri-Food Canada, K.W. Neatby bldg., 960 Carling Avenue, Ottawa, ON, K1A 0C6, Canada.

[3] Faculty of Economics, Ryutsu Keizai University, Hirahata 120, Ryugasaki, Ibaraki 301-8555, Japan.

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Intellectual property

No project IP or commercialisation to report

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Appendix 1:Taxonomic status of six-spotted mite

Summary

The spider mite pest causing significant economic damage to avocado orchards in the Pemberton region was initially identified as SSM or *Eotetranychus sexmaculatus*. Jenny Beard from Queensland Museum began research on the species SSM, looking into its whole history, from the first description and host plants to its movement across the world. Jenny revealed that the true identity of this plant feeding mite was not clear-cut and began to research the taxonomy of SSM and its close relatives in an effort to develop better diagnostics for this species, and ultimately assist in the development of more specific management programs. The main objective was to identify what species was feeding in avocado orchards in Western Australia and in New Zealand, and how it compared with the true SSM that feeds in Citrus orchards in Florida, USA. Jenny examined the morphology of over 1000 specimens from many different host plants collected in several different countries and undertook the molecular analysis of fresh specimens from Australia and New Zealand avocado orchards, and fresh specimens from Citrus orchards in Florida. The putative synonym species *E. asiaticus* from Japan was also included in the morphological and molecular analyses. Despite the presence of slight morphological differences, the molecular approach strongly indicated that all of the specimens analysed were the same species, SSM / *E. sexmaculatus*. The observed morphological differences were consequently further scrutinised and are thought to be the result of different specimen preparation techniques and differences in interpretation by various researchers. A taxonomic manuscript covering the history and description of the true SSM will be submitted in early September 2022, authored by Jenny Beard and her two colleagues Dr Fred Beaulieu and Dr Wayne Knee who undertook the molecular analyses (based at the Canadian National Collection of Insects, Arachnids and Nematodes, in Agriculture and Agrifood Canada).

Introduction

Taxonomic status of six-spotted mite (SSM)

In 2014, a spider mite (Acari: Tetranychidae) was recorded defoliating avocado trees in the Pemberton region of southeastern Western Australia. This mite was initially identified as the exotic six-spotted mite (SSM - *Eotetranychus sexmaculatus*); however, as there was uncertainty over the true identity of this mite species, further taxonomic research was initiated by Jenny Beard at the Queensland Museum to resolve this taxonomic issue. SSM was first described in the USA from citrus orchards in Florida over a century ago in 1890, and the first record of *E. sexmaculatus* in Western Australia was made from avocado nursery stock imported from Woombye, Queensland in 1986 (Learmonth, 2020).

Jenny found that one of the characters most critical for distinguishing spider mite species varied significantly in the descriptions of this species, and consequently this variation cast doubt over the taxonomic status of the species SSM. Because of this discrepancy and the existence of several other possible synonyms, the types of each of these species had to be examined to be sure of their true morphologies.

The actual identity of the mite referred to as SSM in Western Australia needed to be determined as the implications for management programs can vary significantly for different species. For example, different pest species vary in their levels of susceptibility to different biological control agents and miticides, and the level of host specificity of biological control agents to be employed can vary significantly, and all these factors contribute to the overall effectiveness of cultural and chemical control methods to be employed.

Methodology

Original Methodology

In the initial project outline, Jenny Beard was to travel to the United States National Collection of Mites, held at the Smithsonian Institution/National Museum of Natural History, to attempt to locate the holotype (or any other type material) of *Eotetranychus sexmaculatus*. In the likely event that the holotype could not be found, historic specimens (the oldest specimen collected closest to the original type location) or freshly collected material from Florida (close to the original type location) was to be used to designate a neotype for *E. sexmaculatus* (sequenced and vouchered). The holotype of the Australian native species *E. queenslandicus* is also located in the Smithsonian Institution and was to be examined as well. Jenny was also due to travel to the Biosecurity Collection in Orange, NSW, to study the earliest Australian specimens identified as *E. sexmaculatus* to confirm and establish the historic presence of this species in

Australia. However, due to multitude of restrictions put in place due to COVID, Jenny was not allowed to travel to the USA or to NSW, and these collection visits did not take place.

Revised Methodology (with COVID restrictions in place)

Jenny began contacting agricultural institutions with significant mite collections across the world within the recorded distribution of SSM, in an effort to borrow material for examination. Many collections were already in lock-down and international mailing of museum loans had been banned, due to delays of significantly increased risks of loss or damage. Despite this, Jenny managed to borrow specimens, or was sent images, from the following collections: University of Hawai'i Insect Museum, USA; the National Bureau of Agricultural Insect Resources, Bengaluru, India; Pusa Collection, New Delhi, India; Institute Entomology, Guizhou University, China; Yuma Experiment Station, University of Arizona, USA; Plant Health & Environment Laboratory, Auckland, New Zealand (including *E. queenslandicus* types); United States National Museum of Natural History, Mite Collection Beltsville, Maryland, USA (specimens from Florida and California); Ryutsu Keizai University, Ibaraki, Japan; Hokkaido University Museum, Japan (*E. asiaticus* types).

Collection of specimens

Jenny contacted the mite curator at the Florida State Collection of Arthropods in Gainesville, Florida, USA for assistance in collecting fresh material of *Eotetranychus sexmaculatus* from near the type location and from the type host, *Citrus* spp. (Rutaceae). Dr Sam Bolton was able to collect fresh material and had it couriered to Jenny's molecular collaborators in Ottawa, Canada, for analysis.

Jenny arranged for fresh specimens of SSM to be collected in Western Australia and in New Zealand, and she had them couriered to Ottawa, Canada, for molecular analysis.

Jenny contacted mite expert Dr Tetsuo Gotoh in Japan for assistance in collecting fresh material of suspected synonym *Eotetranychus asiaticus* for morphological and molecular analysis, and to borrow type specimens of *E. asiaticus* for direct morphological comparison with specimens of SSM from Australia, NZ and USA. Dr Gotoh was able to provide specimens to Jenny and had specimens couriered to Ottawa, Canada for molecular analysis.

Jenny travelled to the Cairns region of north Queensland in an attempt to collect fresh material of *E. queenslandicus* from its host plant, croton *Codaeiuim variegatum* (Euphorbiaceae), in the type location. Despite collecting dozens of samples of wild and ornamental crotons from all over the Cairns region and inland to avocado and Citrus growing regions in Atherton and Mareeba, *E. queenslandicus* was not found or collected. Therefore, only the type material could be used in this research.

Morphological description

Jenny has examined over 1000 specimens identified as *Eotetranychus sexmaculatus* from many hosts (predominantly from the type host Citrus) and many locations (predominantly from USA, Australia and NZ), and has measured, drawn and photographed well over 100 specimens for the new description and manuscript.

Jenny has examined, measured, drawn and photographed the type specimens of *E. queenslandicus*, *E. asiaticus* and *E. spanius*.

The morphological descriptions are based on traditional characters states of both the male and the female, including body size, lengths of dorsal body setae, numbers of leg setae, lengths of key leg setae, patterns on the skin of the female, and most critically the shape and size of the aedeagus of the male. Morphometrics measurements were made of over 70 morphological character states for over 80 individual mites identified as three four different species.

Molecular description

Dr Beaulieu and Knee undertook analysis of the COI region and provided the phylogenetic tree indicating the relationships between the various specimens.

Results and discussion

Despite the presence of slight morphological differences, the molecular approach strongly indicated that all of the specimens analysed were the same species, SSM / *E. sexmaculatus*. The observed morphological differences were consequently further scrutinised and are thought to be the result of different specimen preparation techniques and differences in the interpretation of morphological structures by various researchers.

A taxonomic manuscript covering the history and a new full description of the true SSM will be submitted in early September 2022, authored by Jenny Beard and her two colleagues Dr Fred Beaulieu and Dr Wayne Knee who undertook the molecular analyses (based at the Canadian National Collection of Insects, Arachnids and Nematodes, in Agriculture and Agrifood Canada).

Confirmation of the species identity of this emerging pest mite of avocado is a significant step in developing a specific pest management program. The literature associated with this species is diverse, but an accurate identification can allow more targeted searches for appropriate literature to be made. In addition, the examination and confirmed identification of 100's of specimens from many hosts and countries of origin builds a stronger knowledge platform on which to more confidently develop a specific control program and ignore irrelevant data from the literature searches.

Appendix 2: On-farm biosecurity and inter-orchard movement of SSM

Introduction

Anecdotal evidence suggests that six-spotted mite (SSM) has become more widespread throughout the Manjimup-Pemberton avocado growing area in recent years. Some growers are concerned that SSM has come or will become a pest of concern in orchards that have not previously experienced it. While the spread of SSM into 'new' orchards may or may not be a recent occurrence there are certainly differences in SSM populations between orchards, as shown by the monitoring conducted as part of this project and ad hoc sampling in other orchards. Some orchards have very low SSM populations and others have not recorded any SSM, although more intensive and regularly monitoring may change that. It is worthwhile for all growers to be aware of how SSM can enter their properties and to implement appropriate biosecurity practices to reduce the likelihood of it becoming established in unaffected blocks.

To address growers' concerns, the possible modes of spread of mites between properties were reviewed, current on-farm practices of growers, nurseries and packing sheds assessed to determine if they enabled spread of SSM and finally recommendations made for growers to minimise the likelihood of SSM entering their orchards.

SSM dispersal and spread

SSM can spread between properties through multiple avenues such as by natural dispersal, on avocado seedlings from nursery stock and human traffic between orchards.

Natural dispersal

SSM have been observed along with several other spider mite species to disperse aerially from trees. The mites lower themselves from leaves on a silk thread that detaches from the leaf, and they are then blown to new locations by gentle to moderate breezes. It has been observed that SSM generally spin their thread and lowered themselves in the early evening when there are light breezes and therefore, they didn't necessarily travel in the direction of the stronger prevailing wind (Fleschner et all 1956).

Most spider mites will initiate this form of dispersal when populations reach high levels. Once airborne it is a passive process (Kennedy and Smitley 1986). The mites are not able to control where or how far they travel by air. It is the luck of the draw where they land with only an estimated 10% of spider mites reaching a suitable host (Jeppson et al 1975).

There is potential for mites to travel long distances by aerial dispersal. Undetermined mite species have been collected at 10,000 feet in traps attached to aircraft (Coad 1931 in Fleschner 1956). But it is likely that most aerially dispersing mites do not travel far before falling out of the air (Kennedy and Smitley 1986).

This form of dispersal has likely contributed to the spread of SSM throughout the Manjimup/Pemberton district over time and will continue to do so. However, other forms of dispersal may be more rapid and targeted. Also, reducing aerial dispersal into an orchard is not manageable, but reducing risk of spread via others means can be managed.

Human-aided dispersal

SSM can also be spread via nursery stock and movement of people and equipment between properties. All of which can be managed. The degree to which SSM are spread via people and equipment is not known. However, it has been suggested that spider mites may, and in some cases have been, transported on equipment and clothing (Bender 1993, Stevens 2000, Kennedy and Smitley 1986).

Direct movement of people and equipment, such as bins, between orchards and dispatch of infested trees from nurseries may provide a quicker means of spread rather than the more random aerial dispersal. For these reasons these should be managed as part of standard on-farm hygiene practices.

Survey

Aim

To determine current orchard practices that impact on the likelihood of SSM being inadvertently spread between orchards a short survey of growers, packing sheds and nurseries was undertaken.

Method

The questions for growers, nurseries and packing sheds, are below.

Grower survey questions

1. Do you share machinery between properties? E.g. contractors (spraying, mulching) Yes / No
2. If yes, is it cleaned between properties? Always / Often / Occasionally / Rarely / Never
3. Do you receive bins from the packing shed? Yes / No
4. Are they free of dirt and leaf litter when they arrive? Always / Often / Occasionally / Rarely / Never
5. If they do have leaf litter in them, what do you do with it?
6. Do you check new tree stock for pests? Always / Often / Occasionally / Rarely / Never
7. Do you spray new tree stock before or soon after planting? Yes / No / Only if pests are present

Packing shed survey questions

1. Are bins cleaned between properties? Always / Often / Occasionally / Rarely / Never
2. If yes, how are the bins cleaned?

Nursery survey questions

1. Do you monitor for six-spotted mite in your nursery? Regularly / Occasionally / Never
2. Are miticides applied for six spotted mite control? Regularly / Occasionally / Never / When warranted after mites detected
3. Do you check trees for the presence of six spotted mite prior to dispatch? Always / Often / Occasionally / Rarely / Never
4. Do you apply miticides to control mites prior to dispatch? Always / Often / Occasionally / Rarely / Never / When warranted after mites detected

Thirty-one growers, seven nurseries and four pack sheds were approached to complete the survey. This included all the known nurseries to supply trees to this region and all pack sheds known to pack fruit from orchards other than their own in the region. Responses were received from 21 growers, one nursery and three packing sheds.

Survey results

Only four of the 21 grower respondents shared machinery between properties. There were mixed responses as to whether or not this machinery was cleaned between properties with one response each for always, occasionally, rarely and never.

Eighteen of the growers received bins from a packing shed. Generally, they were clean when received (Table 1).

Table 1: Responses received from growers to the question, are they (bins received from the packing shed) free of dirt and leaf litter when they arrive?

Always	Often	Occasionally	Rarely	Never
8	7	2		1

Of the growers that have received bins with leaves in them, all responded that they cleaned out the bins and disposed of the leaves prior to use. Dirt was sweep out by most, but not all growers.

Just over half of the grower respondents said that they occasionally checked new tree stock for pests (Table 2) and only four of the 21 growers always checked new trees. Most growers sprayed newly received trees (Table 3).

Table 2: Responses received from growers to the question, do you check new trees for pests?

Always	Often	Occasionally	Rarely	Never	N/A
4	11	3	2		1

Table 3: Responses received from growers to the question, do you spray new tree stock before or soon after planting?

Yes	No	Only if pests are present
4	8	8

Of the three packing sheds that responded two always clean bins between properties, one with a bin washer using food grade detergent and the other using just water. The third packing shed occasionally cleans their bins between properties using a high-pressure washer.

The single nursery that responded to the survey regularly monitors for SSM and regularly applies miticides based on their monitoring. They always check trees for SSM prior to dispatch and will apply miticides then if they are detected.

Discussion

Whether or not there has been an increase in the mite's geographic distribution cannot be determined as an area wide survey was not done historically that could be compared to the current situation.

The anecdotal evidence for this increase in distribution comes from an increase in growers experiencing and reporting visible signs of mite feeding and/or mite induced defoliation. This alone cannot be used to conclude that SSM have recently moved into new locations. The increase in incidence may be a result of increases in SSM populations while their distribution remained the same, more damage noticed due to more monitoring taking place and a higher level of awareness and/or other factors increasing the incidence of defoliation.

Experiencing a defoliation event when high numbers of SSM are present does not necessarily mean there has been a recent influx of mites. SSM could be present in an orchard for years, breeding up over time, before their impact is seen. There is also more involved than simply a higher mite population leading to more damage. It is not known what the associated factors are that lead to defoliation, but they may include various stressors such as unfavourable seasonal conditions, tree nutrient and water status, and pressure from other pests and diseases, and general reduced tree health. Therefore, SSM may be present in moderate to high numbers for some time without having an obvious impact on the trees, then one or more of these other factors might come intoplay and in combination with the high SSM numbers lead to defoliation.

The recent projects looking at SSM management have also raised awareness of SSM, the damage they can do and how to monitor for them amongst growers. Growers may now be monitoring for SSM more actively and be better able to identify the damage that they cause than previously, leading to more damage being seen and attributed to SSM.

Lack of on-farm biosecurity measures increases the risk of pests and diseases being spread between farms. This was the case in California when persea mite first entered commercial orchards. Hoddle & Morse (2012) proposed that it was likely that picking bins with infested avocado leaves or unclean equipment moving between groves helped to spread persea mite quickly throughout the states major avocado production areas. Good on-farm biosecurity practices should always be encouraged to reduce this risk.

Overall current on-farm biosecurity practices regarding the potential spread of SSM are positive but there is room for improvement. Very little machinery is shared between properties, however, when machinery is shared it should always be cleaned which is not the case now.

Bins are generally clean when received and if leaf litter is in bins, it is removed and disposed of out of the orchard. The majority of packing sheds that responded, which represents a large proportion of the bins used in the region given the size of those packing sheds, always clean bins between properties, which is good practice. Some grower responses that they occasionally received dirty bins may be from historical experience prior to packing sheds implementing more thorough and regular bins washing practices.

It is unfortunate only one nursery responded to the survey. That nursery has very good mite management strategies in place. However, it is not known if these practices are standard across the industry. Given that SSM first entered WA on nursery stock from interstate and there are anecdotal reports of SSM being found on nursery stock, also in New Zealand nursery stock has also been received with SSM; this is a is a channel with high potential for the spread of SSM. Also, if a grower receives an order with SSM present on most trees, this will lead to a more widespread population of SSM in the new orchard. Other dispersal methods, such as on equipment or aerial, would lead to more random/isolated pockets of SSM. Only four of the 21 grower respondents said that they always check new planting stock for pests. This should be standard practice. Given the cryptic nature of SSM on leaves the inspection of new plants should be thorough and the person checking have confidence in their ability to identify SSM.

There is no way of preventing SSM from entering orchards via natural aerial dispersal. Growers should be aware of it none-the-less as it is a possible means of SSM entering their orchard and becoming established. Proximity to other orchards and the levels of SSM in nearby orchards will likely influence the likelihood of SSM being blown into a property and that varying level of risk may alter the level of monitoring that a grower chooses to do. Also, natural dispersal means that SSM can enter a property even if the strictest of biosecurity protocols are followed so it is always worthwhile to monitor all orchards at least periodically even if SSM have not been observed before.

When an incursion does occur in an orchard it would take time for the population to build up to damaging levels. For this reason, even if damage is not observed in an orchard, it should not be assumed that SSM are not present. Regular monitoring of all orchards is recommended.

Recommendations for growers

Based on the literature review and responses to the survey the following on-farm management practices are recommended to all avocado growers.

- Always thoroughly check new planting stock for pests, including mites, and control if necessary.
- If sharing machinery and equipment always ensure it is cleaned between properties, this includes bins. With particular focus on plant material.
- If machinery or equipment, including bins, entering your property is dirty or has leaf litter in it, clean it away from your production area.
- All orchards should be regularly monitored for SSM, even if strict biosecurity protocols are followed and no damage has been observed.

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Appendix 3: Monitoring and sampling

Seasonal trends

Background

Knowing when seasonal fluctuations occur and what influences the timing and amplitude of the peaks can help growers to more accurately monitor at times of potential population increases and peaks and plan for management activities should those increases eventuate.

Increases and declines in mite numbers can be due to a range of reasons. Such as changes in weather (van de Vrie et al 1972), for example high maximums leading to a population drop (Aponte and McMurty 1997), or cold temperature signally mites to enter diapause. Over-exploitation of host plant material, shortening day length, increases in mite density and high predator population levels can all lead to declining population levels. Differences in host chemistry and/or nutritional value can also impact of mite numbers (Dean 1959 in van de Vrie et al 1972, McMurtry et al 1970).

SSM has shown similar but varying seasonal patterns in different crop hosts and climates around the world, with different conclusions as to why the variation occurs. In citrus in Florida most damage occurs between March and May (spring), with populations declining rapidly in June (early summer) and remaining in very low numbers for the remainder of the year (Qureshi and Stansly 1999). Their abundance in spring is linked to the weather the previous winter, with more SSM following colder winters. It is thought that numbers are suppressed between June and September due to higher humidity at that time of year (Qureshi and Stansly 1999).

In rubber plants in China numbers generally increase from mid-April (mid spring) and reach their peak in late April and May (late spring) followed by a sharp decline in May and June (late spring, early summer). The timing of the peak is influenced by rainfall and the amount of natural enemies present. (Lin and Wang, 2022)

In New Zealand SSM are present throughout the with a peak occurring in spring but not as large a decline in numbers over summer and winter as seen in WA (David Logan personal communication). The New Zealand Avogreen manual (Avocado Industry Council Ltd 2018) recommends monitoring in early spring prior to flowering as well as post flowering, with late summer and winter monitoring optional, but it also states that observation, past experience and records will inform individuals own monitoring periods. From discussion with growers and professional pest monitors in New Zealand in the past monitoring may not have been done for SSM from May to September but currently many orchards are monitored year-round. There is generally more intensive monitoring, every two weeks, in spring, and out to every three or four weeks in late summer and autumn. However, each orchardist can decide their own monitoring schedule.

In avocado in the south-west of Western Australia low numbers of SSM are observed through winter, they increase from early spring, peak in early summer before declining again in mid-summer, and a smaller peak can occur in early to mid-autumn (Learmonth 2019). It is not known what causes these fluctuations or how much they vary from season to season.

In all of these situations the populations peak in spring and are generally low in summer and winter. Given these similarities temperature likely plays a key role in timing and amplitude of population peaks.

SSM development time increases with temperature. Jamieson & Stevens (2007) bred SSM at a series of temperatures from 10°C to 30°C and found mites grew the fastest at 30°C, and the slowest at 13°C. 10°C was too cold for the eggs to hatch Total developmental time from egg to adult ranged from 29.6 days at 18°C to 11 days at 30°C. However, in Florida and California the milder environments with relatively lower temperatures are thought to favor SSM (Pratt and Thompson 1953 and Jeppson 1952 in van de Vrie et al 1972) and low humidity at high temperatures can also lead to desiccation of SSM eggs (Huffaker 1958 in van de Vrie et al 1972).

It was not within the scope of this project to examine all of the factors that could influence seasonal distribution. Instead it was decided to focus on overall seasonal patterns across the region, variations in population levels across time between orchards and the relationship between SSM numbers and weather.

Method

28 orchard blocks were regularly monitored during this project. Trees were monitored fortnightly from January 2020 to June 2022. Five leaves were taken from each of ten trees in each block. Leaves were placed in paper bags inside plastic bags and kept cool until SSM motiles and eggs, predatory mite motiles and eggs, tydeid mite motiles and other arthropods of interest, such as stethorus were counted using a stereomicroscope within 48 hours. A record of all miticides applications made to monitoring areas was kept.

Only data from orchards that had not received a miticide application in the last 6 to twelve months was used as miticide applications would alter the levels of arthropods being counted. Once SSM levels after a miticide application were comparable with non-sprayed orchards and/or levels recorded in that orchard prior to the miticide application, the data from that orchard was once again included with the seasonal trend data.

Weather data was gathered from DPIRD weather station.

Results and discussion

The average of monitoring data from all locations that had not received a miticide application in the last 6 to twelve months across the 2 ½ years confirms the pattern of SSM numbers peaking in spring, with a sharp decline in early to mid-summer, a smaller peak occurring in autumn and low numbers in winter (Figures 1 and 2).

Predatory mite numbers increase from mid-spring, peaking in late summer/early autumn before steadily declining to their lowest point in winter (Figures 1 and 2).

Across the entire monitoring period there were large differences between properties for both percentage of leaves with SSM and the average number of SSM per leaf (figures 3 and 4). At almost all times there was at least one property with no SSM present, or very low SSM. This was not always the same property. The maximum SSM levels recorded show that even though the average pattern consists of peaks and troughs throughout the year the population can remain at high levels year-round. One property in particular, property B, had consistently higher numbers from May to July 2020, March to May 2021 and July to October 2021. This orchard was in close proximity to other monitored orchards and so district level weather conditions are not likely playing a role in the high SSM levels. There may be a local micro-climate that could results in less of a decline in SSM in winter as seen in other orchards.

There were differences in results between the seasons. The SSM spring peak was higher in 2020 compared to 2021 and the summer dip lower in early 2021 compared to 2022 (figures 3 and 4). The differences in spring peaks between 2020 and 2021 may be due to more of the monitoring orchards applying miticides to keep SSM numbers low in spring 2021, therefore reducing the number of orchards that data was taken from for that season and reducing the number of orchards with high SSM, bringing the average down.

To remove the seasonal changes that may be due to different blocks being included in each year figures 5 and 6 use only data from eight of the 28 orchard blocks that were not sprayed with any miticide up until May 2022 and had never previously had miticides applied. The average of these eight blocks also gives a lower spring SSM peak in these blocks in 2021 compared to 2020, but not as low as the average of all blocks. The spring SSM peak was also later in 2021 compared to 2020 in these eight blocks, this is more obvious when looking at the average number of SSM per leaf (figure 6) compared to the percentage of leaves with SSM (figure 5). The spring 2021 increase was more gradual and although the decline was equally as sharp as after spring 2020, numbers did not drop as low. The average SSM numbers for these eight blocks was considerably higher in autumn 2022 compared to the previous two autumns.

The timing of populations peaks and troughs was even more variable between seasons for predatory mites in these eight blocks. In 2021 numbers peaked in April after slowly increasing from early summer. In 2022 the predatory mites peak was higher and much earlier, in January, after more rapidly increasing through summer. The lower SSM peak in spring 2021 was possibly related to the predatory mites peaking earlier.

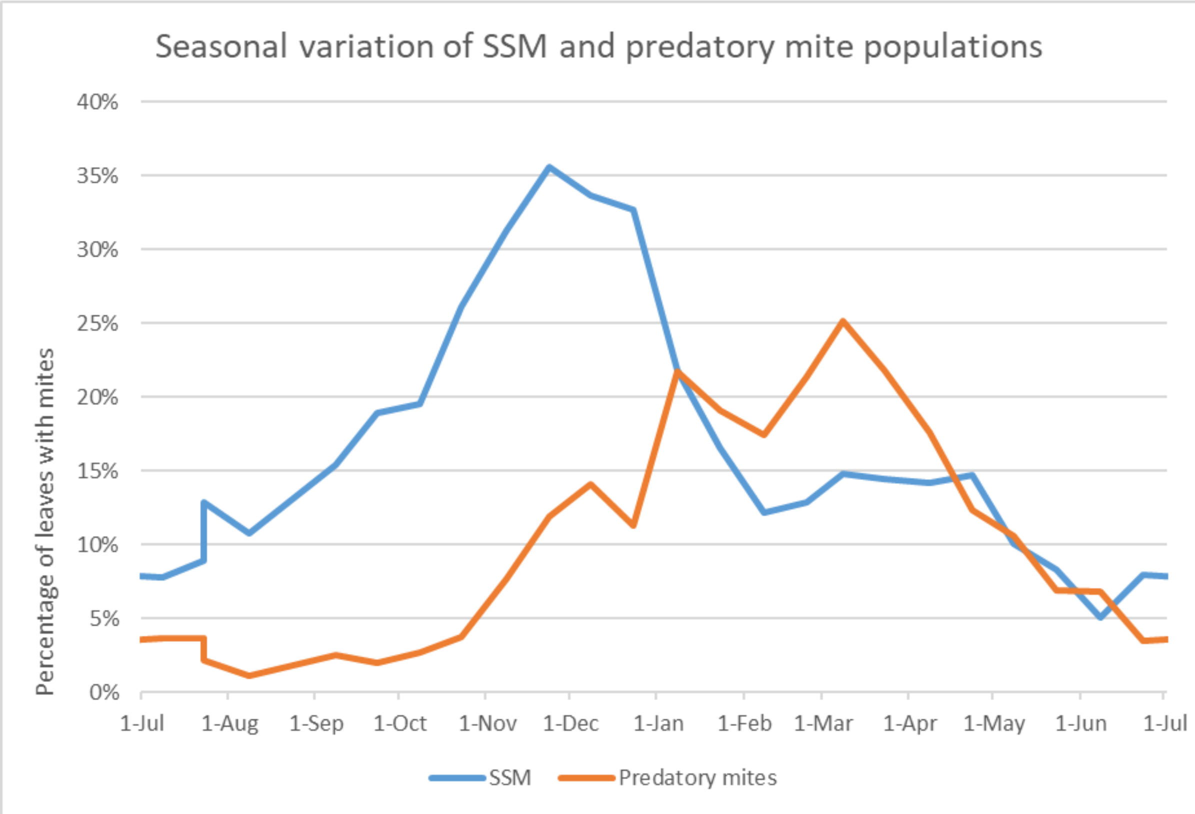

Figure 1: Seasonal patterns of SSM and predatory mite populations measured at the percentage of leaves with mites.

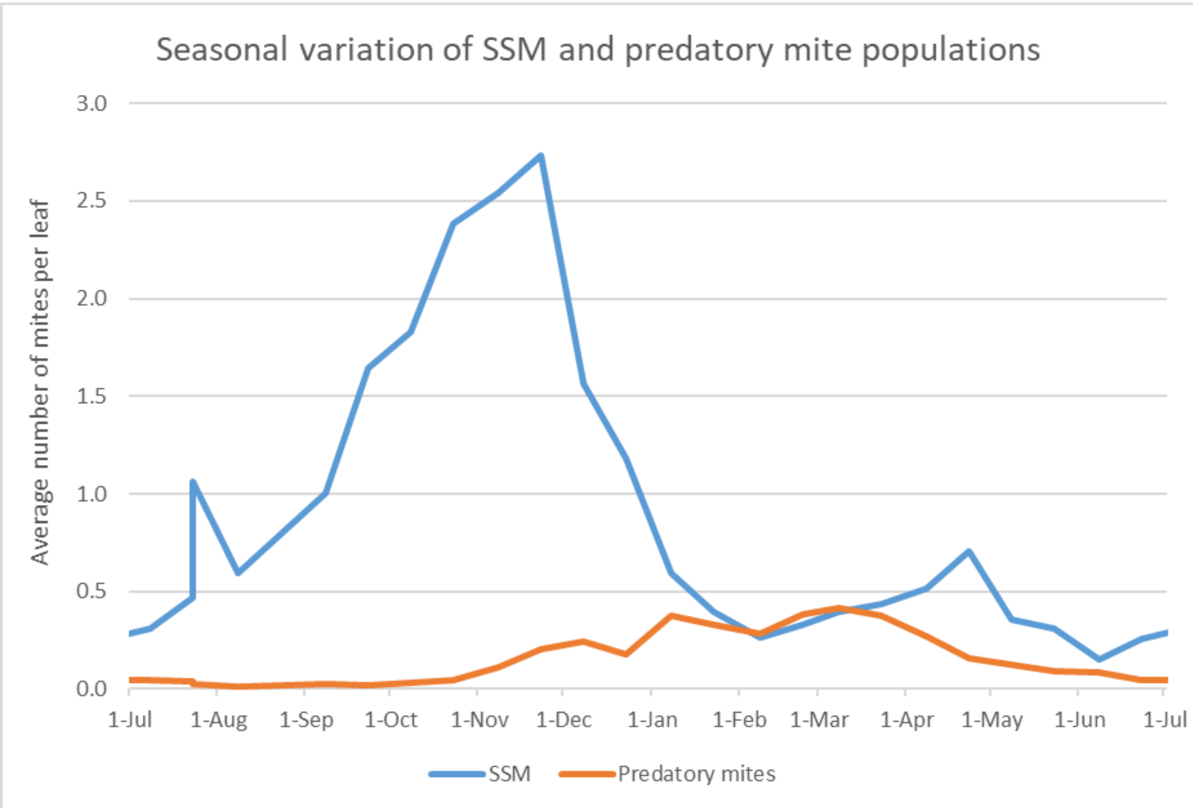

Figure 2: Seasonal patterns of SSM and predatory mite populations measured as the average number of mites per leaf.

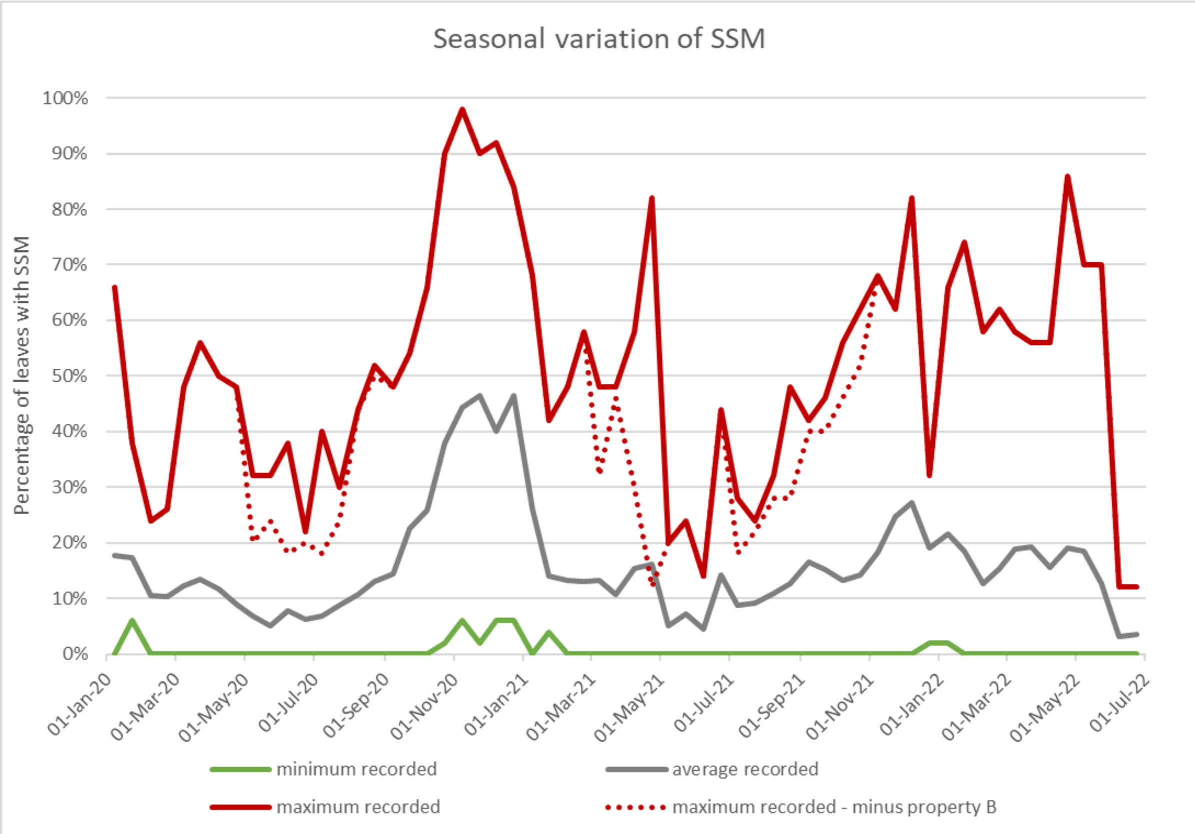

Figure 3: The maximum, average and minimum SSM measured across all unsprayed orchards from January 2020 to June 2022. Property B had consistently higher and outlying SSM numbers over three time periods, the maximum of all other orchard blocks has been included for these periods to give an indication of a more 'usual' maximum.

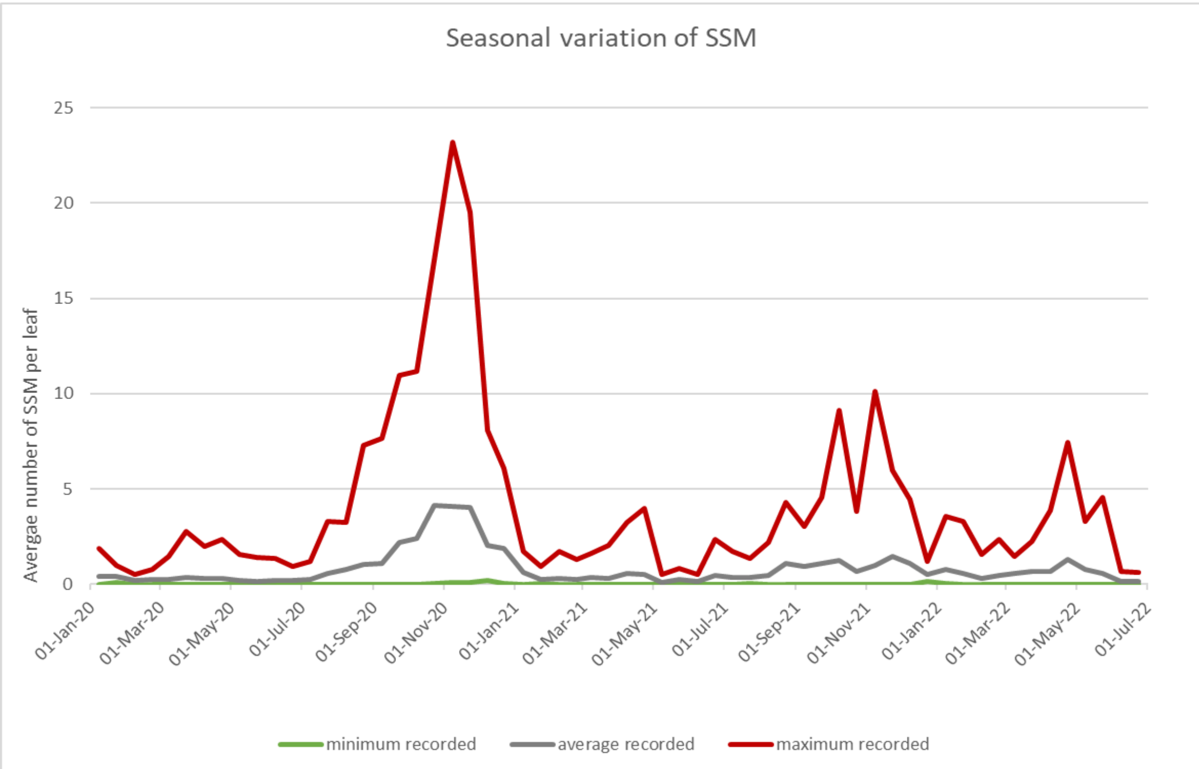

Figure 4: The maximum, average and minimum SSM measured across all unsprayed orchards from January 2020 to June 2022.

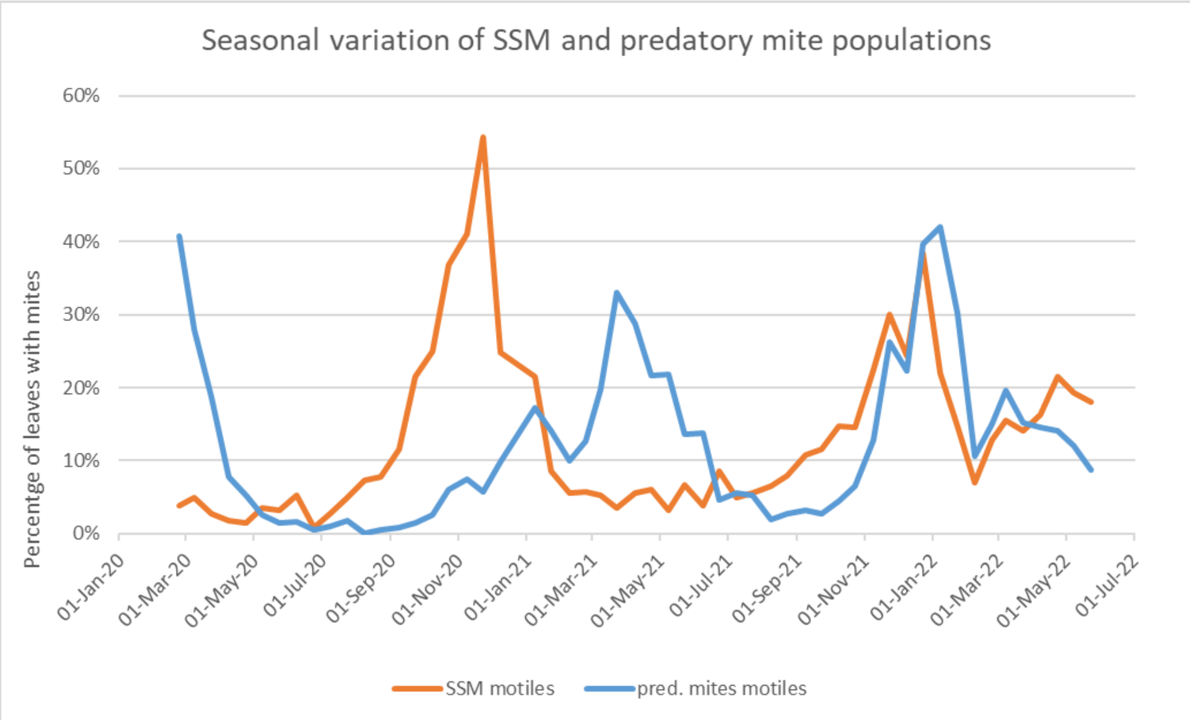

Figure 5: Seasonal patterns of SSM and predatory mite populations taken from only eight entirely unsprayed orchard blocks.

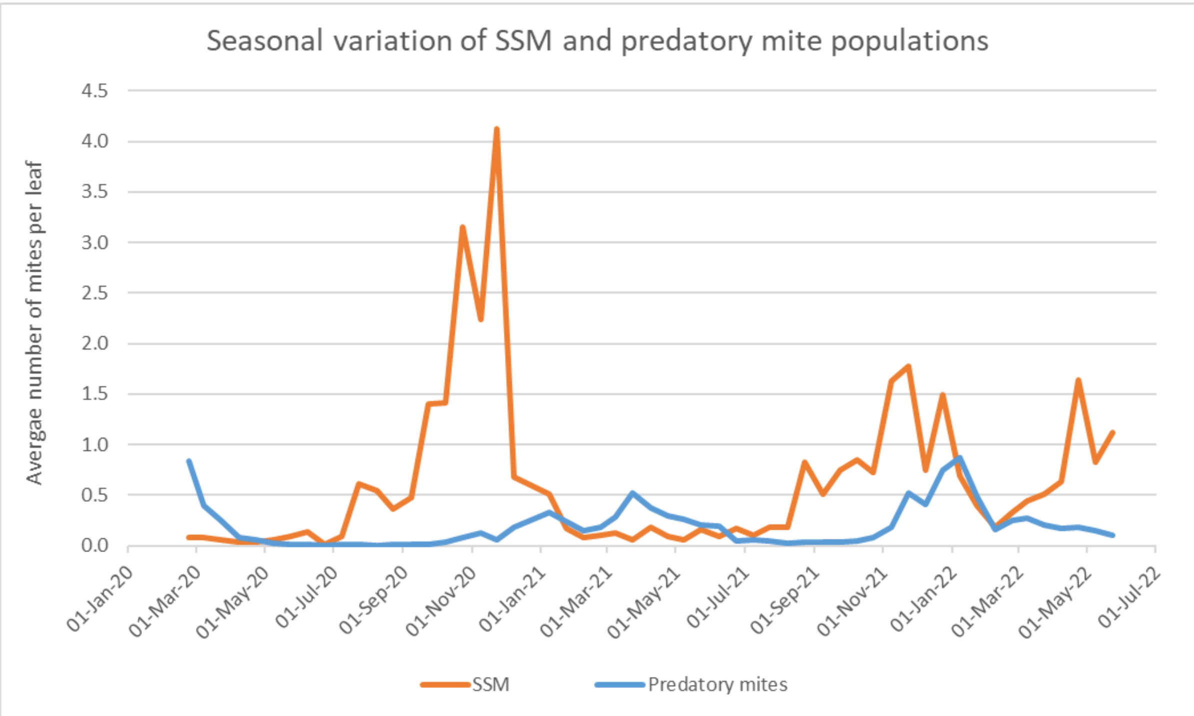

Figure 6: Seasonal patterns of SSM and predatory mite populations taken from only eight entirely unsprayed orchard blocks.

There were also differences in weather between the two seasons. Other than the month of September, 2021 had higher monthly rainfall for all months from April to October, receiving 1386mm total in this time compared to 2020 when 1026mm fell. However, 2021/22 had a drier summer, receiving only 51mm from November to January compared to 151 in 2020/21 (figure 7).

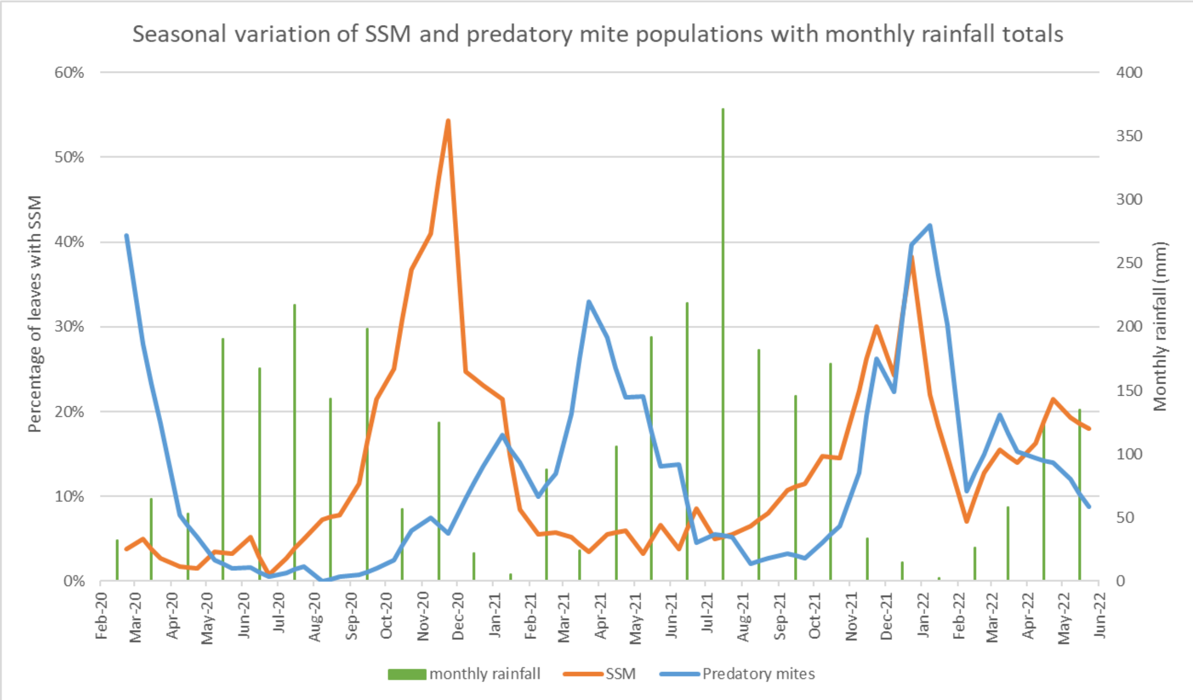

Figure 7: Seasonal patterns of SSM and predatory mite populations taken from only eight entirely unsprayed orchard blocks with monthly rainfall totals for Pemberton.

Studies over more seasons would be needed to determine if the wetter winter in 2021 led to fewer SSM and/or a later peak the following spring or played a role in the earlier and higher predatory mite peak and if this information could be used to predict SSM outbreaks.

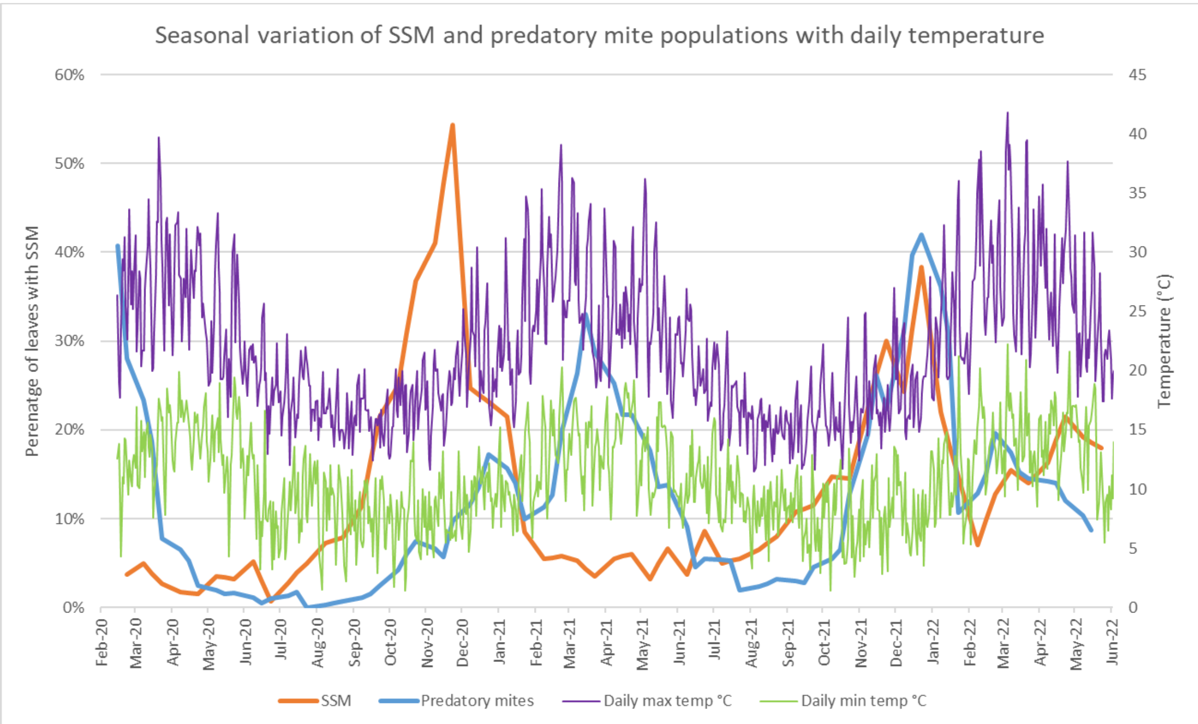

Figure 8: Seasonal patterns of SSM and predatory mite populations taken from only eight entirely unsprayed orchard blocks with daily maximum and minimum temperatures for Pemberton.

SSM numbers in 2020 and 2021 were similar in August, as were maximum and minimum temperatures. September temperatures were also very similar for both years, yet SSM numbers started to increase in early September in 2020 with 25% leaves infested by the first week of October, in 2021 only 15% of leaves were infested at that date. November was warmer in 2020 compared to 2021 but by this time SSM were already twice as high in 2020 compared to 2021 (figure 8). Area scale temperature does not appear to have a direct correlation with the rate or magnitude of SSM populations increases.

Canopy distribution

Background

To accurately and reliably monitor for SSM, the distribution of mites within trees must be understood so that leaves are sampled from areas that give the best representation of the current mite population. Of particular interest to avocado growers has been the validity of sampling from ground level. Avocado trees in mature orchards regularly reach over 8m in height with some more than 12m tall. When sampling from the ground only leaves up to 2m above ground are taken. Concern was expressed by growers that these leaf samples may not be representative of the tree as a whole and lead to inaccurate monitoring results. Similar concerns had been expressed by growers in New Zealand (Brookbanks and Steven 2002).

Mites are often not randomly distributed within crop canopies (Huffaker et al 1970). Through experience and observation monitoring recommendations for mites in avocados in other geographical areas include instructions on what leaves to check. When monitoring for tea red spider mite in Queensland it is recommended to check mature leaves, not the new flush (Broadley 1992). The New Zealand AvoGreen protocols says that leaves used for SSM monitoring must be recently mature, from both the inside and outside of trees and from 5-10 points around each tree (Avocado Industry Council Ltd 2018).

Method

Twenty-four leaf types were sampled from each tree based on leaf age and position.

- Age – recently mature and young 'soft' leaves
- Height – 1.5m, 3m and 4.5m
- Side of tree – received the most sun (north) and least sun (south)
- Canopy position – inner and outer

On some occasions not all leaf types could be sampled. Young growth was not always present, some trees sampled were lower than 4.5m and not all trees had an inner canopy at all heights and leaf ages.

Samples were taken on 10 occasions in spring and early summer in 7 different blocks on 5 different properties across two years, blocks CD-A to CD-J. Samples were taken once in autumn from a single block in 2021, block CD-K. Initially three leaves per tree position and 5 trees per block were sampled. This was increased to six leaves per position and 6 trees per block due to high levels of variation in mite numbers found.

Leaves were picked and placed in paper bags with like leaves and kept cool until SSM motile stages were counted with a stereomicroscope within 48 hours of collection.

For each of the eleven datasets, ANOVA was performed on a square root transformation of the average number of six spotted mites. The square root transformation was to give more equal variance as required by ANOVA. Individual trees were the blocking factor, while the treatment structure was a full factorial of Age, Height, Side and Canopy; or some subset of these factors as described below.

For seven of the datasets; CD-B, CD-C, CD-D, CD-E, CD-F, CD-G and CD-J, there was no or very limited data for the inner canopy position at 4.5m height. Therefore, two analyses were done, each on a fully balanced subset of the data, the first subset excluding 4.5m height and the second subset excluding inner canopy.

For the three datasets, CD-A, CD-H and CD-I there were only either mature or young leaves sampled. A single analysis was done with the impact of Age not possible to be assessed. For the CD-A dataset, height 4.5m was also excluded due to limited data.

Significance refers to statistical significance at a 5% level ($p<0.05$) unless otherwise indicated.

Results and discussion

In spring in four of the seven datasets that both young and mature leaves were collected, there were significantly more SSM in mature leaves. In two of the remaining datasets the difference between young and mature leaves was not significant. Only one dataset had significantly more SSM in young trees, this orchard had a very high SSM population at the time. In the autumn dataset there were significantly more SSM in the mature leaves (table 1).

There were significantly more SSM at height 1.5m in seven of the 11 datasets compared to 4.5m, including the autumn dataset. Only one dataset had significantly less SSM at height 1.5m.

In five of the ten spring datasets there were significantly more SSM on the south side. One dataset had significantly more SSM on the sunnier side/northern side of the tree. There was no significant difference between north and south sides of trees in the autumn dataset.

Table 1: The average number of SSM per leaf for each leaf position for each sampling occasion. Statistically significant results are highlighted in green.

Orchard	Age of leaf		Height			Side of tree		Canopy	
	young	mature	1.5m	3.0m	4.5m	south	north	inner	outer
CD-A	0.8	-	1.0	0.7	-	0.9	0.6	0.7	0.8
CD-B	10.1	7.8	11.2	7.8	6.0	9.1	8.8	9.4	8.7
CD-C	16.6	14.7	14.5	18.2	10.7	15.4	15.9	14.7	16.6
CD-D	1.0	1.2	1.3	0.9	1.0	1.4	0.8	1.2	1.0
CD-E	3.3	6.7	1.71	2.55	2.32	5.8	4.5	5.8	4.7
CD-F	0.7	0.5	0.7	0.6	0.4	0.7	0.5	0.8	0.4
CD-G	0.1	0.5	0.5	0.3	0.3	0.2	0.5	0.5	0.3
CD-H	-	6.7	9.8	6.6	3.9	8.2	5.2	7.1	6.3
CD-I	-	9.3	12.5	5.6	6.6	10.9	7.8	7.9	10.7
CD-J	2.5	3.6	3.9	2.4	2.8	3.5	2.6	3.0	3.0
CD-K	3.5	5.5	3.3	3.6	2.5	3.3	3.2	3.2	3.2

There was no significant difference between inner and outer canopy in eight of the ten spring datasets. In the other two datasets there were more SSM in the outer canopy but only in interactions with other factors which were 1.5m height and south side of the tree in each of those two datasets.

The results show that there is variation in mite densities within tree canopies. These need to be taken into account when monitoring. Growers can now have confidence that sampling from the ground is sufficient. Sampling from higher in the canopy is not needed as there tends to be fewer SSM higher up. The practice of sampling recently mature leaves should remain. It appears SSM do not move onto the new, 'soft', growth in spring except in the case of an orchard with very high SSM numbers. The variation in mite numbers between side of tree is less clear cut. There can be differences in mite numbers between the sunnier and shadier sides of trees, with them more frequently being more prevalent on the shadier southern side. Due to this and the lack of difference between inner and outer canopy we suggest monitoring leaves from several points around each tree, from the inner and outer canopy, and ensure the shadier side is included.

Spatial distribution

Background

SSM are not evenly distributed across trees in orchards. The distribution of mites within an orchard is important to understand so that changes in populations levels are reliably measured and hot spots are identified. By identify features of the surrounding environment that may positively or negatively impact on SSM numbers monitoring can be planned to include areas of interest. This way monitoring and management can be carried out more efficiently, and hot spots are less likely to be missed and localised outbreaks less likely to occur.

A study of distribution of SSM within avocado orchard blocks was conducted in New Zealand in 2002-03. They found that SSM were irregularly distributed but tended to be more evenly distributed at higher population levels (Brookbanks and Steven 2003).

Pest mites are often more abundant on plants in dusty areas (Agriculture Victoria 2021) such as adjacent to unsealed roads and laneways. No studies have looked specifically at six-spotted mite distribution in relation to dust, but we received feedback from growers that they had observed more mites in dusty areas and Fleshner (1958) stated that pests, including mites, were more prevalent in avocado trees impacted by dust due to the dust inhibiting beneficial insects.

On a broader scale, in California SSM are only a problem in more humid coastal areas with moderate temperatures (Ebeling et al 1959, Bailey 1985) that are not impacted by drying winds (University of California 2017) as these conditions are more favorable for development (Jeppson 1952 in van de Vrie et al 1972). It is not known if orchard level mircoclimate variations would impact on SSM distribution, but it is plausible.

The surrounding vegetation has also been known to impact on SSM numbers in avocados, it is not uncommon to find them infesting avocado groves when downwind of lemon groves (Bailey 1985, Bailey and Olsen 1990), another host of SSM.

Method

Snapshot monitoring

To determine if local landscape features impacted on SSM numbers and could be used to direct monitoring to potential hotspots, intensive grid monitoring was carried out in three different orchards with moderate to high SSM numbers across the Manjimup/Pemberton area.

In spring 2020 as per Brookbanks and Steven (2003) one off "snap-shot" samples were collected from each orchard block. A sub-section of each block was selected for sampling, chosen due to its proximity to surrounding features that may influence mite numbers, primarily gravel roads, wind breaks and native forest. Each sampling area contained between 120 and 234 trees. Six leaves per tree were collected. Leaves selected were the 2nd to 4th most recently mature leaf, 1-2m off the ground, from the inner and outer canopy and from random points around the tree. Leaves were placed in paper bags and kept cool until SSM and predatory eggs and motile stages were counted with a stereomicroscope within 48 hours of collection. The characteristics of each site are given below.

<u>Block A</u>

120 trees sampled, Hass variety planted in 2012 on a 4.5m x 9m spacing, north-south running rows.

The block slopes down to the north. It is a windy site. There is native forest on the western boundary that acts as a significant wind break with prevailing winds from the west. The rows closest to the bush were not included as they are significantly younger than the rest of the block. The laneway to the south of the block is heavily grassed, so does not produce dust (figure 9).

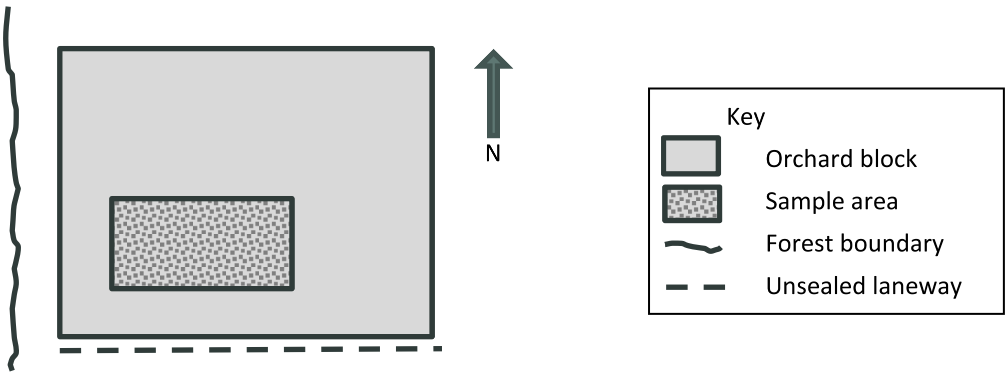

Figure 9: Schematic diagram of Block A showing the orchard block boundary, sample area and local landscape features of interest.

Block B

234 trees sampled, Hass variety planted in 2013 on a 5m x 9m spacing, ENE-WSW running rows.

There are two gravel laneways bounding the block on the south-eastern and south-western sides. There is also a large shed and house area to the south-west with several associated unsealed driveways and access lanes. There is a small windbreak to the southeast for the neighbouring block, this was not thought to have much impact on the avocado block in regards to wind as the prevailing wind of from the west (figure 10).

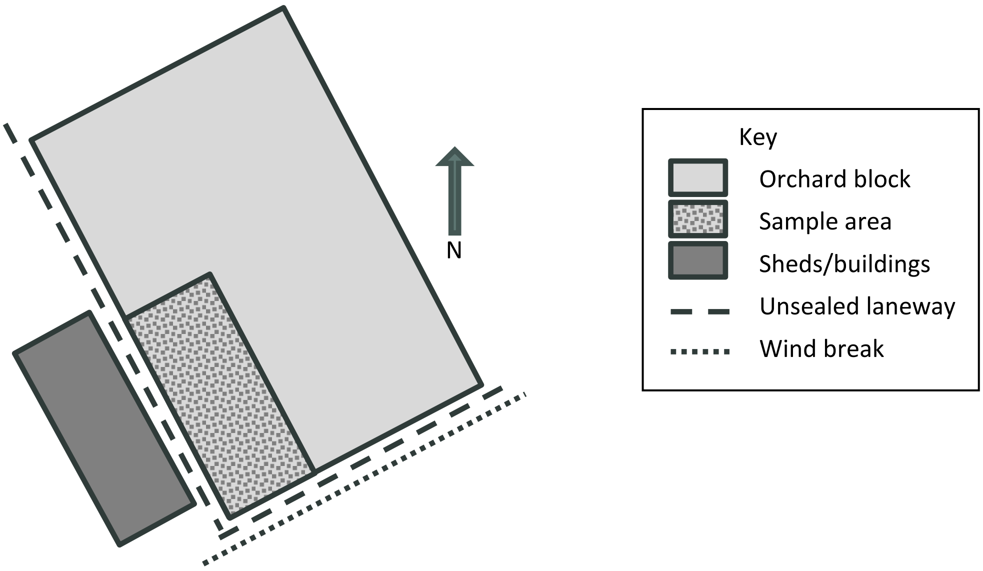

Figure 10: Schematic diagram of Block B showing the orchard block boundary, sample area and local landscape features of interest.

Block C

150 trees sampled, Hass variety planted in 2000 on a 3m x 7m spacing, north-south running rows.

To the northeast of the block is a gravel driveway. To the northwest there is a gravel laneway, then a narrow band of native vegetation, including very large trees and then a gravel public road. In the sample area the block slopes to the southeast with a string of dams in the gully (figure 11).

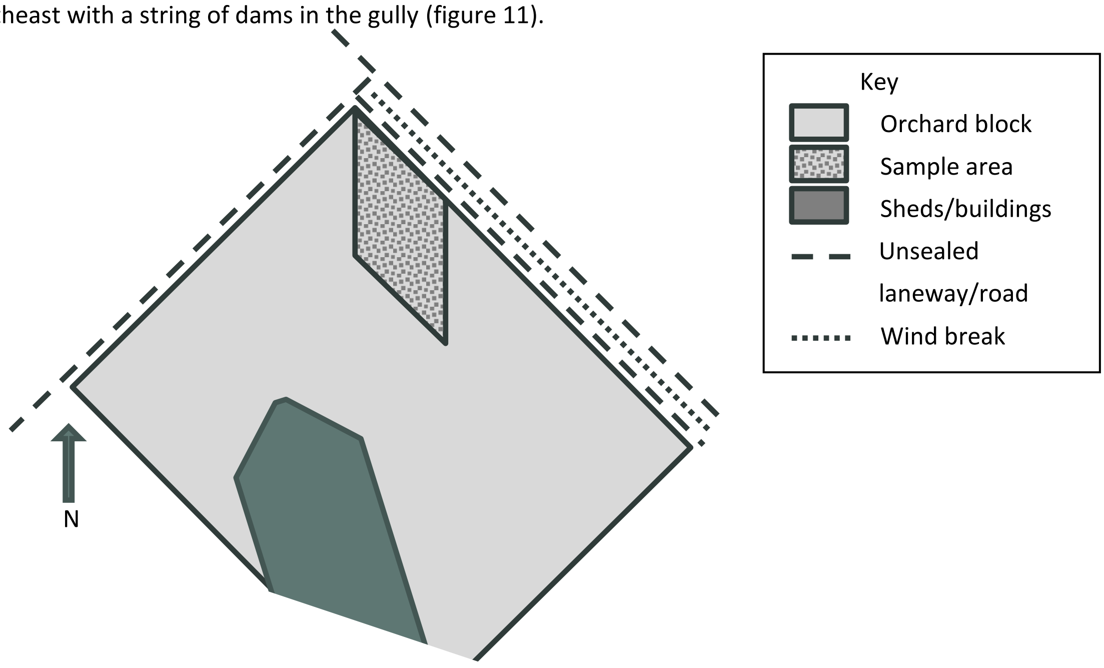

Figure 11: Schematic diagram of Block C showing the orchard block boundary, sample area and local landscape features of interest.

It was intended to return to each block to sample again the following spring to determine if hotspots remained in the same location between seasons. However, blocks B and C were sprayed with a miticide prior to spring 2021 leading to negligible mites being present. In block B no SSM were recorded in September and October, with 4%, 2% and 12% leaves with SSM in the three monitoring occasions in November. In block C only a single SSM was found out of the monitoring done through spring and summer 2021. Due to low SSM numbers the decision was made not to resample the intensively monitored areas to determine special distribution.

The results shown are the average number for the six leaves taken from each tree.

Fortnightly monitoring

To determine if hotspots remained in the same location from one season to the next data was compared for ten trees in eight different orchard blocks that were monitored every fortnight for just over 2 years. Five leaves were collected from every tree on each monitoring occasions and the number of SSM per leaf counted. These eight orchards blocks did not receive any miticide applications during the project monitoring until autumn 2022 allowing comparisons to be made between SSM levels in spring 2020 and spring 2021. The average number of mites per leaf over the whole spring period, September to November, for each tree was calculated. Average SSM levels for spring 2020 and 2021 were compared for each tree.

Results and Discussion

Snapshot monitoring

The following figures are heat maps of the sampled orchard areas. Each tree is represented by a rectangle with the average number of mites per leaf shown and colour coded with green as low and red as high. The tree and row averages show the average number of mites per leaf for that whole row or that tree number across all rows.

In 2020 block A had 22.6% of leaves with SSM with an average of 1.5 mites per leaf (figure 12). The following spring block A had 24.6% of leaves with SSM with an average of 2.6 mites per leaf (figure 13).

Figure 12: Heat map of block A from spring 2020. North is to the top, the highest ground is to the bottom and the bush area to the left.

		Row										Tree average
		4	5	6	7	8	9	10	11	12	13	
N	19	1.8	2.0	0.7	0.7	6.3	0.2	0	0.5	13.5	0.3	2.6
	18	0	0.7	5.5	1.5	8.8	0.2	0.7	6.2	0.2	0	2.4
	17	0	0.2	0	1.3	0	4.5	0	0.2	2.0	3.0	1.1
	16	0.2	0.8	0.2	1.3	1.2	2.0	0	8.3	1.2	0	1.5
	15	1.0	3.2	1.5	6.0	5.8	0	1.5	0	1.0	0.3	2.0
Tree	14	2.3	0	0.2	0	7.2	0	0	0.2	1.3	3.3	1.5
	13	0	1.2	0.5	0.5	0	0.7	1.3	0	1.7	0.7	0.7
	12	2.5	0	2.2	2.7	0	0.3	0	2.8	6.3	6.3	2.3
	11	1.0	2.7	0.2	0.2	0.7	2.7	0	1.3	0.7	0.2	1.0
	10	0	3.7	0.3	1.2	0.5	2.2	1.2	0	0	2.5	1.2
	9	0	0.2	2.3	1.7	0	0	0	0	0	2.2	0.6
	8	0	0	0	0	5.7	0	0	2.8	0	0.5	0.9
Row average		0.7	1.2	1.1	1.4	3.0	1.1	0.4	1.9	2.3	1.6	

Figure 13: Heat map of block A from spring 2021. North is to the top, the highest ground is to the bottom and the bush area to the left.

		Row										
		4	5	6	7	8	9	10	11	12	13	Row average
Tree	19	3.8	11.8	0	1.2	1.3	0.7	0.8	0	6.7	0	2.6
	18	7.8	3.7	0	2.5	0	10.2	0.2	0.7	0	2.5	2.8
	17	1.5	0	0	16.3	0.2	0	4.0	0.8	0	0.3	2.3
	16	0.0	0	0	1.3	7.0	0.3	3.3	0	0	0	1.2
	15	8.7	0.2	3.5	6.5	0.3	14.8	1.3	0.7	0.7	9.5	4.6
	14	0.7	0	3.8	0.2	1.2	9.5	6.7	9.3	0	0.8	3.2
	13	6.5	0.5	0.2	0	3.0	5.7	9.0	9.5	6.7	0	4.1
	12	0	3.0	0	2.5	0.8	0	0	11.7	0.2	3.5	2.2
	11	2.8	7.3	5.0	1.8	4.3	0.8	3.2	0.3	0.3	0	2.6
	10	0.2	1.8	0	3.3	0	2.3	2.7	0	0	1.5	1.2
	9	1.2	0	0.2	4.5	1.0	1.3	6.0	5.7	1.8	0	2.2
	8	0	0	1.7	5.0	1.8	0	3.7	5.8	0	0	1.8
Tree average		2.8	2.4	1.2	3.8	1.8	3.8	3.4	3.7	1.4	1.5	

There is no pattern of SSM distribution across the block in either 2020 or 2021 related to the nearby native bushland, or the unsealed laneway. Nor are there any similarities in location of hotspots between 2020 and 2021. There is a slight trend in both years for there to be fewer SSM on the higher side of the block, the edge where tree 8 is. This may be due to the lower area of the block being more sheltered from the wind and therefore more hospitable for the mites, however the pattern is not distinct enough to draw any conclusions.

Block B had 90.6% of leaves with SSM with an average of 18.58 SSM per leaf. This is a very high SSM population compared to 'normal' and from the literature we would expect the distribution to be more uniform than blocks with fewer mites. There is a pattern of there being fewer mites at the start of each row and more mites towards the end of the sampled area which is towards the middle of the orchard block. This is not what was expected as a busy gravel laneway and shed area run along the edge of the block and it was thought that the dust would results in higher SSM numbers along the edge. Row 1 also has fewer SSM despite also being directly adjacent to a gravel laneway, albeit one that has lower traffic volume. As with block A the area with lowest SSM numbers may be more exposed to the wind, given the prevailing westerlies, while the trees further into the block may be more sheltered. However, this is speculative as no wind, humidity or temperature measurements were taken within the sample area.

Figure 14: Heat map of block B from spring 2020. North is to the top-right hand side, the windbreak is to the bottom and the gravel laneway and shed area to the left.

Row \ Tree	1	2	3	4	5	6	7	8	9	10	11	12	13	Row average
18	5.5	5.0	7.5	13.0	7.5	4.0	7.2	8.7	41.5	36.5	7.2	12.5	10.0	12.8
17	6.5	9.7	28.5	12.2	44.8	21.3	13.8	37.8	27.8	24.5	67.0	24.8	7.3	25.1
16	14.3	11.3	13.3	12.8	10.5	37.2	12.8	27.5	21.5	35.8	30.7	30.5	32.5	22.4
15	18.5	11.7	21.0	9.3	26.0	26.7	51.8	15.8	8.7	29.0	29.7	51.3	16.5	24.3
14	13.7	13.0	29.7	6.5	2.5	22.8	12.2	12.5	18.7	41.0	8.5	45.5	16.7	18.7
13	20.3	25.7	17.2	5.2	34.0	3.2	5.7	68.3	10.2	19.2	11.8	23.8	51.7	22.8
12	7.8		4.2	5.7	12.5	6.8	2.2	6.0	6.2	21.2	8.3	22.3	17.3	10.0
11	8.0	3.0	8.3	18.5	19.8	11.8	37.2	33.5	20.7	14.2	31.7	19.2	3.2	17.6
10	8.7	20.8	14.3	18.0	12.0	9.7	21.3	23.0	37.5	17.5	10.3	23.3	25.5	18.6
9	12.2	12.8	10.5	21.2	23.3	35.8	16.8	23.7	31.5	31.0	24.2	47.5	27.0	24.4
8	3.5	3.0	8.5	8.3	16.2	13.3	29.8	19.2	32.3	34.5	14.5	7.0	13.8	15.7
7	4.2	6.5	19.2	14.3	6.8	16.0	27.3	21.5	24.2	26.3	41.7	40.8	31.8	21.6
6	1.5	6.2	4.3	4.3	8.8	4.0	33.8	68.7	27.3	36.7	67.3	14.7	25.5	23.3
5	0.3	7.0	3.0	5.2	6.0	0.0	4.3	7.3	4.0	2.5		13.8	13.5	5.6
4	23.5	7.2	14.8	5.2	11.2	28.2	25.7	34.2	30.7	29.0	20.8	52.2	44.0	25.1
3	7.5	12.3	14.0	9.7	7.0	69.7	14.0	19.5	24.0	16.8	9.0	43.2	20.3	20.5
2	1.2	16.2	13.2	17.5	21.5	13.7	45.5	22.5	22.0	26.5	5.5	8.8	10.7	17.3
1	0.3	31.7	3.7	5.0	7.7	6.7	14.2	1.7	4.0	2.3	6.5	2.3	4.5	7.0
Tree average	8.8	11.9	13.1	10.7	15.5	18.4	20.9	25.1	21.8	24.7	23.2	26.9	20.7	

Figure 15: Heat map of block C from spring 2020. North is to the top, the windbreak and gravel road is to the top right, the gravel driveway is to the left and the dam is to the bottom.

	Row											
Tree	28	29	30	31	32	33	34	35	36	37	Tree	Row average
1	24											
2	9.8	6.2										
3		13	7.8									
4	21	21	16	14								
5	9.8	55	11	24	11							
6	31	2.3	8.5		7.3	4						
7	12	4.5	9.3	22	13	11	28					
8	15	11	6.3	10	3.8	4	3.2	6.8				
9	8.7	11	6.8	3.3	3	5.5	14	6.5	9.2			
10	3.5	8.8	30	12	1.3	15	7.3	8.8	7.5	19	1	13
11	27	14	7	6.8	4	10	18	6.7	0.8	40	2	14
12	28	3.3	13	1.7	9.2	2.7	3.8	2.5	7	13	3	11
13	40	4.8	4.5	0.2	2.8	14	7.5	40	12	4	4	14
14	11	154	12	5.5	8	13	9.2	7.7	1.7	2.2	5	8.5
15	6.3	2.7	21	2.5	38	3.7	7.3	2.2	0.8	0	6	10
		0	2.5	3.8	14	16	16	1.7	1.2		7	7
			0.7	22	5.3	6.8	7	2.3	0.7	1.8	8	10
				11	0.2	10	34	10	3.2	1.3	9	5.3
						39	11	1.7	1	2.5	10	6.6
						12	0.2	0	0.3	2.7	11	11
							2.8	1.5		4.2	12	11
								1.2	1.5	0.8	13	27
									0	0.8	14	8.2
										2	15	4
Tree average	18	21	10	9.9	8.6	11	11	6.6	3.4	6.8		

Block C had 67.7% of leaves with SSM with an average of 10.7 mite per leaf. This block had the most distinct SSM distribution pattern of the three sampled blocks with a consistent area of low numbers in the south eastern corner of the sample area. However, it is difficult to explain this pattern in relation to surrounding landscape. The gravel road, driveway and laneway appear to have no impact, although the south easter corner is the furthest from the dusty roads all of the higher numbered trees are well back from the roads and yet some of those, particularly in rows 28, 29, 33 and 34 had some of the highest mite numbers. Also, some of the trees in rows 36 and 37 that are relatively close to the gravel road and laneway had low SSM numbers while equivalent trees in other rows had moderate to high numbers. This area with low average SSM per leaf is slightly lower in the landscape and closer to the gully dams, so may be more sheltered and humid, although in those conditions you could expect more SSM.

Overall, while there were some patterns of higher and lower mite densities in the sampled areas none could be clearly linked to features of the local environment that could be used to guide monitoring for potential hotspots in these and other orchard blocks. This is the same result obtained by Brookbanks (2003) who also found high and low density areas "that could not be easily explained by the obvious feature of the local environment".

To determine if there are features of the local environment that influence SSM numbers and if hotspots area recur across seasons more extensive studies are needed. However, the difficulty in conducting these observations is the vast number of leaves that must be collected and analysed in a short timeframe for each block. For blocks A, B and C respectively 720, 1404 and 900 leaves were collected. When combined with the other trials, observations and measurement being taken throughout spring it was not possible to assess any more blocks as part of this project.

Fortnightly monitoring

Trees did not have consistently high or low SSM levels between years (figure 16). For example, in block P1B2 tree 8 recorded the lowest average, 1.2 SSM per leaf, for that block in 2020 and yet have the highest average. 9.47, in 2021. Or P4B2 tree 1 that had the highest average in 2020, 9.8 SSM per leaf, yet recorded and average of only 0.09 SSM per leaf in 2021.

Figure 16: The average number of SSM per leaf recorded for each tree in eight different orchard blocks in spring (September to November) 2020 and 2021. The tree with the highest average for each year is coloured red, graduating through orange, yellow and pale green to the dark green trees that have the lowest SSM average for that year.

Block	Year	Tree									
		1	2	3	4	5	6	7	8	9	10
P1B1	2020	0.00	0.17	0.70	0.00	0.00	0.13	0.00	0.33	0.37	0.20
	2021	0.00	0.03	0.33	0.00	1.07	1.03	0.20	0.10	0.17	0.80
P1B2	2020	2.00	3.80	1.20	0.80	3.07	2.97	4.43	1.20	1.53	3.33
	2021	0.63	1.50	3.90	8.17	1.97	6.83	6.17	9.47	8.53	2.63
P2B1	2020	4.91	1.14	2.91	0.83	1.97	0.37	2.77	1.09	0.69	1.40
	2021	0.91	0.89	0.66	0.49	0.20	0.14	0.63	0.09	0.17	0.03
P2B2	2020	0.54	0.37	0.00	0.14	0.00	0.17	0.03	0.29	0.34	0.14
	2021	0.00	0.09	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.03
P4B1	2020	4.73	2.63	3.70	5.10	1.30	5.30	5.33	3.83	5.80	5.90
	2021	0.43	0.11	0.37	0.06	0.09	0.26	0.09	0.09	0.29	0.17
P4B2	2020	9.80	3.93	7.80	7.47	4.67	4.17	3.70	4.53	3.40	2.63
	2021	0.09	0.37	3.89	0.09	0.43	0.31	1.03	0.46	1.69	0.43
P13B1	2020	0.90	1.70	1.20	1.57	0.63	0.03	0.27	0.50	0.33	2.13
	2021	0.87	1.03	1.17	1.37	0.73	0.23	0.33	0.33	0.10	2.00
P13B2	2020	2.8	0.7	0.2	0.5	0.7	0.4	0.3	0.2	0.7	2.8
	2021	2.1	1.5	2.7	0.5	2.4	1.0	0.3	3.3	0.4	0.7

There were blocks where 'hotspot' trees were consistent between years, namely P13B1 and to a lesser degree P2B1 and P2B2.

These results and those from the Block A snap shots from 2020 and 2021 indicate that hot spots do not remain static from one season to the next. Previous experience may be used by growers to determine areas that are potential hotspots for upcoming season and base monitoring around this but they should be aware that hotspots can arise in new areas. Sampling across a broad area is required every season to ensure that hot spots are not missed.

Optimum sampling

Background

Knowing how many leaves to monitor is important for growers. Monitoring too few leave can give an inaccurate representation of what is actually present in the orchard, leading to unnecessary miticide applications if pest numbers are over estimated or uncontrolled and unexpected defoliation if numbers are underestimated. Alternatively monitoring many leaves is time consuming and may lead to less frequent monitoring or fewer blocks being monitored as individual entities in an effort to save time. A balance must be struck between efficacy and efficiency.

Method

The data sets collected as part of the 'snap-shot' monitoring was used to determine the optimum monitoring. This data was collected in spring 2020, from three orchard blocks. Each sampling area contained between 120 and 234 trees. Six leaves per tree were collected. Leaves selected were the 2nd to 4th most recently mature leaf, 1-2m off the ground, from the inner and outer canopy and from random points around the tree. Leaves were placed in paper bags and kept cool until SSM and predatory eggs and motile stages were counted with a stereomicroscope within 48 hours of collection. The characteristics of each site are given below.

The data was used to simulate different monitoring scenarios, based on different number of trees and leaves sampled, to determine the level of error. The scenario's were as follows.

- Scenario 1: sampling three trees, five leaves per tree. Total 15 leaves
- Scenario 2: sampling six trees, five leaves per tree. Total 30 leaves
- Scenario 3: sampling nine trees, five leaves per tree. Total 45 leaves
- Scenario 4: sampling twelve trees, five leaves per tree. Total 60 leaves

These scenarios were simulated many thousands of times to determine the average error. Taking into account the average error from different sample sizes, the time taken to sample x number of leaves and the need to maintain user friendly monitoring recommendations a recommended sample size was chosen.

Results

The average error of a simulated monitoring sample was reduced as the samples became larger (Table 1). If 15 leaves were sampled from 3 trees there was an average error of 15%. If 60 leaves were sampled the average error is reduced to 5%. This means that if the true percentage of leaves with SSM in a block was 40%, if five leaves were monitored from any three trees within that block results from just those 15 leaves would be within a range of 25%-55% leaves infested. However, if 5 leaves are taken from 12 trees the results would be only 5% above or below the true result, that is in the range of 35%-45%.

Table 2: The number of trees and leaves for each simulated scenario and the calculated average error

Scenario	No. of trees sampled	No of leaves sampled per tree	Total no. of leaves sampled	Average error
1	3	5	15	12%
2	6	5	30	8%
3	9	5	45	6%
4	12	5	60	5%

Discussion

To reduce the average error to a minimum and have to most confidence in the results more and more leaves must be monitored. However, it is a case of diminishing returns, with each additional 15 leaves added to the simulation the reduction in the average error became smaller and smaller. More time could be spent monitoring more leaves, but the benefit in accuracy would not necessarily warrant that extra time. It was decided to recommend to growers to monitor 5 leaves from 10 trees, giving 50 leaves in total. This is a compromise between having a reasonable level of error, only 5-6%, without being overly time consuming. The ten trees across a whole block give a reasonable amount of spread. Also having a 50-leaf monitoring sample makes calculating the percentage of leaves infested very quick and easy.

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Appendix 4: Predatory mites

Background

There is a preference among many growers to use non-chemical control options to manage SSM, as long as they are effective and price comparable. Predatory mites are an alternative management option that warrants investigation. Encouragingly there are other pest mite species in avocado, namely *Oligonychus punicae* and persea (*Oligonychus perseae*) mite in California, that have been shown can be kept below economically damaging levels by beneficial species (McMurtry and Johnson 1966, Fleschner et al 1956).

Due to the limited number of locations worldwide where SSM is considered a pest there is relatively little information available on its management and relationship with beneficial arthropods. The earliest work looking at SSM in avocado orchards came out of California. SSM became a pest when natural enemies, e.g., *Typhlodromus* sp. predatory mites, were eliminated after applications of broad-spectrum insecticides (Fleschner 1954). Without disruption from insecticides SSM were generally maintained at low, non-damaging, levels by beneficial arthropods. On occasions when SSM numbers did flare the predatory beetle *Stethorus picipes* (Casey) increased with them, leading to a subsequent reduction SSM numbers again (Fleschner 1954).

Despite the long period of time that SSM has been present in Californian avocado orchards pesticide use to control them has been minimal (Hoddle et al 1999). Today populations rarely exceed 2 to 3 individuals per leaf and SSM are not considered a major pest of avocado in California (McMurtry 1992, Mark Hoddle personal communication 10th August 2020). They are generally kept under control by six-spotted thrips (Scolothrips sexmaculatus) and phytoseiid mites, such as *Typhlodromus rickeri* and *Euseius hibisci* as well as *Galendromus helveolus* when it is released for control of persea mite (University of California 2017, McMurtry 1990, Bailey 1985, Fleschner et al., 1955, McMurtry 1992). Other beneficials recorded in California avocado orchards include green lacewing larvae, Staphylinid beetles, predatory fly larvae, pirate bugs, and predatory thrips (Fleschner 1954).

In New Zealand predators have been identified in unsprayed unmanaged orchards as well as those following the industries AvoGreen® protocols which can include pesticide application. They may play a role in SSM control given the low populations of SSM in unsprayed orchards but the role is not clear (Logan et al 2022). Stethorus ladybirds, and predatory mites have been observed in orchards in association with SSM (Stevens 2001). Their abundance varies, in one survey phytoseiid mites were found on 13% of leaves while *Stethorus* spp were found on just 0.1% (Logan et al 2022). However, chemical control is currently relied upon for SSM management in New Zealand.

Stevens (2001) acknowledged the promising results with biological control from California but wrote that the "New Zealand avocado orchard environment is much more toxic to natural enemies than would be typical of orchards in California, due to the need to spray for other pests". This is not the case in WA orchards where very few insecticides are applied, particularly after trees are established.

In the preceding project to this one, Pest status and management of SSM (*Eotetranychus sexmaculatus*) in WA avocado orchards, AV15012, mass reared *Metaseiulus (Typhlodromus) occidentalis*, *Neoseiulus californicus* and *Typhlodromus doreenae* were released into orchards. None of these species provided economically significant control or established in orchards (Learmonth 2019). *Euseius elinae* and to a lesser degree *Amblydromalus lailae* were found naturally occurring in orchards indicating that these species are potential biocontrol agents and should be studied further (Learmonth 2019).

Amblyseius spp. are type III generalist predators and *Euseius elinae* is a type IV specialised pollen feeder/generalist predator (McMurty and Croft 1997). In California orchards *E. hibisci* does not provide adequate or consistent control of persea mite, possibly because as a specialised pollen feeder it increases in numbers most when the avocados are producing pollen but this is when perseae mite populations are very low (Kerguelen and Hoddle 1999a, Hoddle & Morse 2013). In Western Australia, however, there is an overlap between when avocados flower and the peak in SSM numbers. *Euseius* species or other pollen feeders have been suggested for control spider mites in greenhouses pollen supplements to increase their numbers (McMurtry and Croft 1997).

Increasing the number of predatory mites available to improve their control of pest mites, can be done by altering orchard conditions to favour predatory mites, known as conservation biological control or by releasing predatory mites into an orchard. Both avenues were trialed in this project.

Phytoseiids have relatively lower rates of reproduction (Huffaker et al 1970) and are not particularly voracious (Janssen & Sabelis 1992). However, their ability to persist and consistently regulate pest populations at low levels in favourable conditions makes them a good choice for biological control in a stable perennial crops situation (Huffaker et al 1970)

In inundative trials of phtyoseif predatory mites to control various spider mite species in perrenial tree crops the numbers released ranged from 500-1000 mites per tree in citrus (Argov et al 2022) to 2000 (Hoddle & Morse 2013, Kerguelen & Hoddle 1999b) up to 4000/tree over two releases in avocado (Maoz et al 2011).

Various release methods have been used for predatory mites including a mist blower with fine mist of water (Hoddle & Morse 2013), or attaching envelopes (Hoddle et al 1999), paper cups (Kerguelen & Hoddle 1999b) or waxed paper bags (Argov et al 2022) containing a predator and vermiculite mix to multiple points around trees. Hoddle & Morse (2013) found five times more predators survived when releasing with paper cups compared to blower likely due to injury after hitting tree or not reaching tree.

There are many ways in which orchard conditions can be altered to suit beneficial arthropods. In this project we looked at the impact of pesticides on beneficial arthropods and the provisioning of pollen and alternative food sources as a potential management tool.

Alternative prey can result in predators becoming more abundant which then gives them a “head-start” over the pest species later in the growing season (Settle et al. 1996 in Lester and Harmsen 2002). Wari et al (2014) and McMurtry and Croft (1997) list numerous examples of pollen providing an alternative food source to predatory mites, with pollen producing ground covers in orchards or adjacent wind breaks leading to greater predator numbers. In avocado orchards predatory phytoseiid mites have been observed when there is a lack of prey but pollen present (Gonzalez-Fernandez et al 2009). Maoz et al (2011) studied the impact of pollen on persea mites and the predatory mite *E. scutalis*. They found that in trees to which corn pollen was applied with an electrostatic applicator population levels of *E. scutalis* tended to be higher, but not statistically so, while persea mite levels were significantly lower than control trees. Trees adjacent to Rhodes grass plantings that acted as source of pollen also had lower *O. perseae* populations and great numbers of *E. scutalis*.

Other species of mites can also act as an alternative food source for predatory mites. A pollen and prey mite mix were used in this project.

The role of the commonly found Tydeid mites in the SSM/avocado pest complex is unknown, possibly interacting positively and negatively in several ways. In New Zealand, avocado orchards with fewer tydeid mites tended to have more SSM and conversely those with less SSM tended to have more tydeids (Tomkins 2002). They may provide an alternative food source for predators that also feed on SSM (steven 2004, Knop and Hoy 1983a, Flaherty and Hoy 1971 in Knop and Hot 1983b). There is also potential for them to be predatory, as although they are thought to be mainly fungi and detritus feeders (steven 2004) in laboratory conditions starved individuals of the tydeid species *H. anconai* have fed on mite eggs (Knop and Hoy 1983b). But it was concluded that their predation of spider mites in the vineyard systems studied, if any, would have little impact on overall numbers (Knop and Hoy 1983b). Tydeid mites could possibly also be a competitor for habitat with SSM as they can occupy a similar niche on avocado leaves (Tomkins 2002). Also, they may have a negative impact on SSM control by acting as preferential prey species for some predatory mite species (Huffaker et al 1970) reducing the number of SSM consumed.

Method

Several aspects of predatory mites were considered as part of this project as either trials or monitoring and case studies.

1. Replicated trials of two treatments applied in commercial orchards:
    a. Release of mass reared *A. lailae* as a means to reduce SSM populations.
    b. Application of a pollen, prey mite mix as a method to increase naturally occurring predatory mites numbers and reduce SSM populations.
2. Monitoring to determine the naturally occurring predatory mites present and seasonal distribution of naturally occurring predators and their relationships with SSM populations.
3. Impact of pesticides on beneficial arthropods that may play a role in SSM management through case studies of pesticide use in monitored orchards and a review of pesticide impact databases.

1. Application of predatory mites and pollen/prey mix

A. lailae and the pollen/prey mix were applied to three different orchards blocks. In each block two adjacent rows were divided into three equal sections of 22 trees each. A treatment was randomly assigned to each section. Treatments were:

1. *A. lailae*
2. Pollen/prey mix
3. Control

The *A. lailae* and pollen/prey mix were received from Biological Services via overnight courier and applied on the day of receival. The *A.lailae* was in a vermiculite mix and was applied to trees by placing 4-6 scoops on branches evenly spaced around each tree. In the spring 2020 and autumn 2021 applications 227mL of the mix containing approximately 5,675 mites was applied per tree, as recommended by Biological Services staff. In the spring 2021 application 57mL of the mix containing approximately 1,425 mites was applied per tree.

The pollen/prey mix was applied with a modified handheld electric blower to achieve a more coverage of the pollen on leaf surfaces. The blower was used at ground level with the applicator walking around each tree. The pollen reached a height of approximately 2.5m up into the tree canopies. 227mL of the mix containing approximately more than 150,000 mites was applied per tree on each application date.

Three trees per treatment section were monitored. Trees were monitored fortnightly in all three blocks for at least seven months prior to the first treatments and one year post treatment. Five leaves were taken from each tree for monitoring. Leaves were placed in paper bags inside plastic bags and kept cool until SSM motiles and eggs, predatory mite motiles and eggs, tydeid mite motiles and stethorus beetles were counted using a stereomicroscope within 48 hours. A record of all miticides applications made to monitoring areas was kept. Predatory mites found in treatment areas were regularly collected and sent to Jenny Beard at the Queensland Museum for identification.

Block BC1 had not been monitored for SSM prior to this project, had no historical defoliation events and had never received a miticide application. There were low to moderate SSM numbers present through autumn, winter and early spring of 2020. SSM numbers rose rapidly in spring, and treatments were applied on 8th October 2020.

Block BC2 had been irregularly monitored for SSM prior to this project. It had never suffered from severe SSM induced defoliation and had never received a miticide application. There were low SSM numbers through autumn and winter 2020. SSM numbers rose rapidly in spring, and treatments were applied on 15th October 2020. SSM numbers were variable through autumn and winter 2021, they steadily increased from August and treatments were applied on 14th October 2021.

Block BC3 had not been monitored for SSM prior to this project, had no historical defoliation events and had never received a miticide application. SSM numbers were high through spring and summer 2020/21. Treatments were applied on 23rd March 2021. A second treatment was applied on 14th October 2021.

2. Monitoring observations

28 orchard blocks were regularly monitored during this project. Trees were monitored fortnightly. Five leaves were taken from each of ten trees in each block. Leaves were placed in paper bags inside plastic bags and kept cool until SSM motiles and eggs, predatory mite motiles and eggs, tydeid mite motiles and stethorus beetles were counted using a stereomicroscope within 48 hours. A record of all miticides applications made to monitoring areas was kept.

Species of phytoseiid predatory mites present

To determine what species were naturally present in orchards where releases were not made as part of this project predatory mites from sampled leaves were collected for identification. Between April 2020 and June 2022, 90 collections of suspected phytoseiid predatory mites were made from 23 of the 26 monitoring blocks. Mites were placed in 80% alcohol and sent to Jenny Beard at the Queensland Museum for identification.

Relationships between arthropods present in orchards

To help determine the role predatory mites, stethorus beetles and tydeid mites might play in SSM management as predators, alternative food sources for predators and/or habitat competitors. The following relationships were analysed

- predatory mites and SSM
- stethorus beetle and SSM
- tydied mites and SSM
- tydied mites and predatory mites

Only monitoring data from orchards where a miticide had not been applied in the previous 12 months was used. It was decided not to include orchard blocks in which a miticide had been applied as it may have unequally impacted on the different species.

3. Impact of miticides on predators

The Biobest Group (https://www.biobestgroup.com/en/side-effect-manual) and Koppert (https://sideeffects.koppert.com/) insecticide impact databases were also interrogated to determine the impact of all registered and permitted products used for SSM control in WA on various beneficials. As per Steinmann et al (2011) the following methodology was used in order to rate the impact of the miticides:

- If data were available for multiple life stages of a beneficial, then the life stage was selected with the maximum impact rank found in the database.
- If the database gave multiple pesticide application methods, then the rank was chosen that was assigned to the spray option.
- If there was variation in the rank levels assigned by the two databases for the same life stage, an average rank was used.

Case studies comparing trends in beneficial arthropods before and after applications of various insecticides were developed for monitoring blocks that received an effective miticide spray. These were not replicated trials and no statistically analysis was conducted.

The four actives registered for use against SSM in WA avocado orchards are as follows, example trade name in brackets:

- Abamectin (Vertimec)
- Bifenazate (Acramite)
- Etoxazole (Paramite)
- fenbutatin-oxide (Torque, Vendex)

Mineral oil can also be used

Results and Discussion

1. Release of predatory mites and pollen prey mix

In block BC1, SSM had risen rapidly from late August 2020. On the 5th of October 2020 all three treatment areas were had 67% to 73% of leaves with SSM and an average of 7.9 to 9.7 SSM per leaf. Treatments were applied on the 8th of October. SSM continued to rise in all three treatments. The *A. Lailae* treated trees recorded 100% leaves with SSM on 19th October and hit a peak of 37.8 SSM/leaf on the 18th of November. The pollen prey and control trees recorded 100% of leaves with SSM on the 2nd of November and reached peaks of 20.4 and 30.9 SSM/leaf respectively. The grower chose to apply a miticide to the entire block on the 19th of November. SSM number reduced rapidly after this and remained at zero until spring 2021, figure 1 and 2

The very high SSM numbers at the time of release were not ideal, with better results achieved when releases are made a lower levels (ref). This may explain the lack of treatment effect in regards to SSM between the release date and the miticide application date. Even if there were no differences in SSM numbers a change in predatory mites number recorded would have provided an indication that the *A. lailae* release and/or the provision of the pollen/prey mix was having an impact, however, this was not the case.

The block recorded high predatory mite numbers in late summer and autumn 2020. They fell to zero across the entire trail area for the whole of winter and early spring. Only a few predatory mites were recorded in the treatments areas between 8th October and 19th November, the most being found in the control area on 2nd November when 13% of leaves had predatory mites and there was an average of 0.13 predatory mites per leaf. Figure 3 and 4.

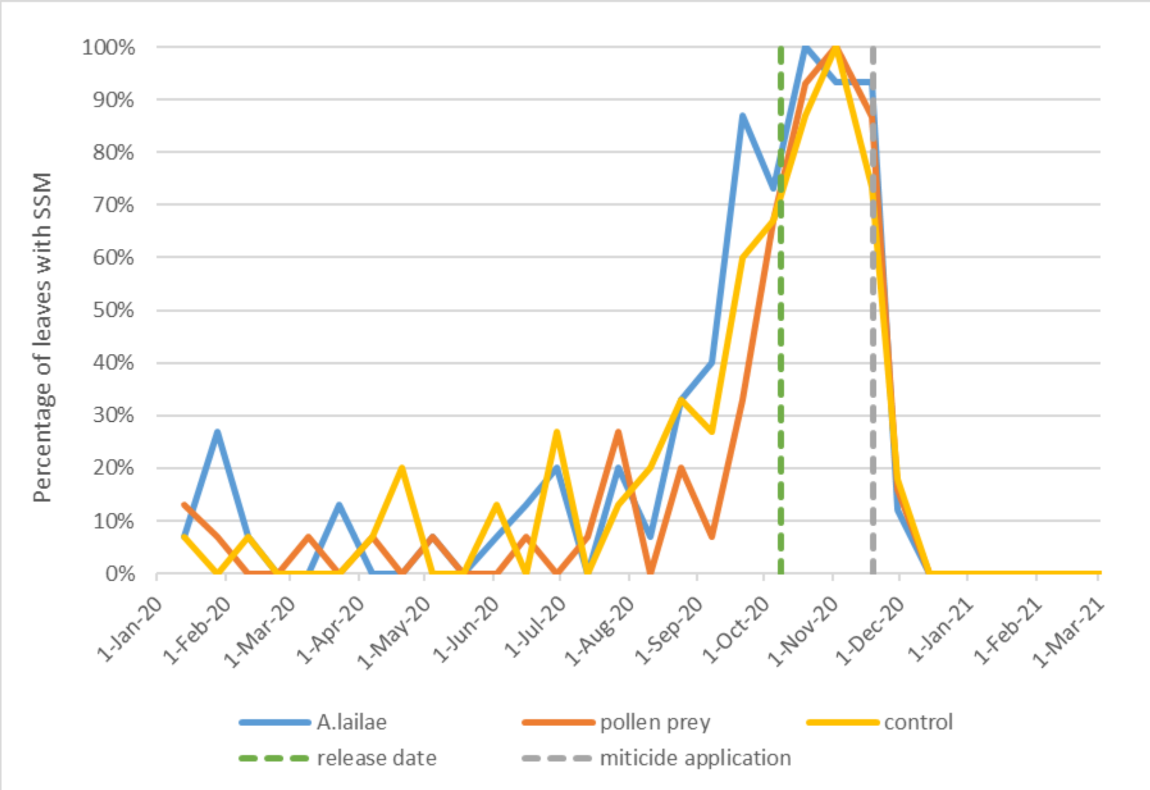

Figure 1: Percentage of leaves with SSM recorded from fortnightly monitoring for the three treatment areas in block BC1. Treatments were applied on the 8th of October 2020, miticide was applied on the 19th of November.

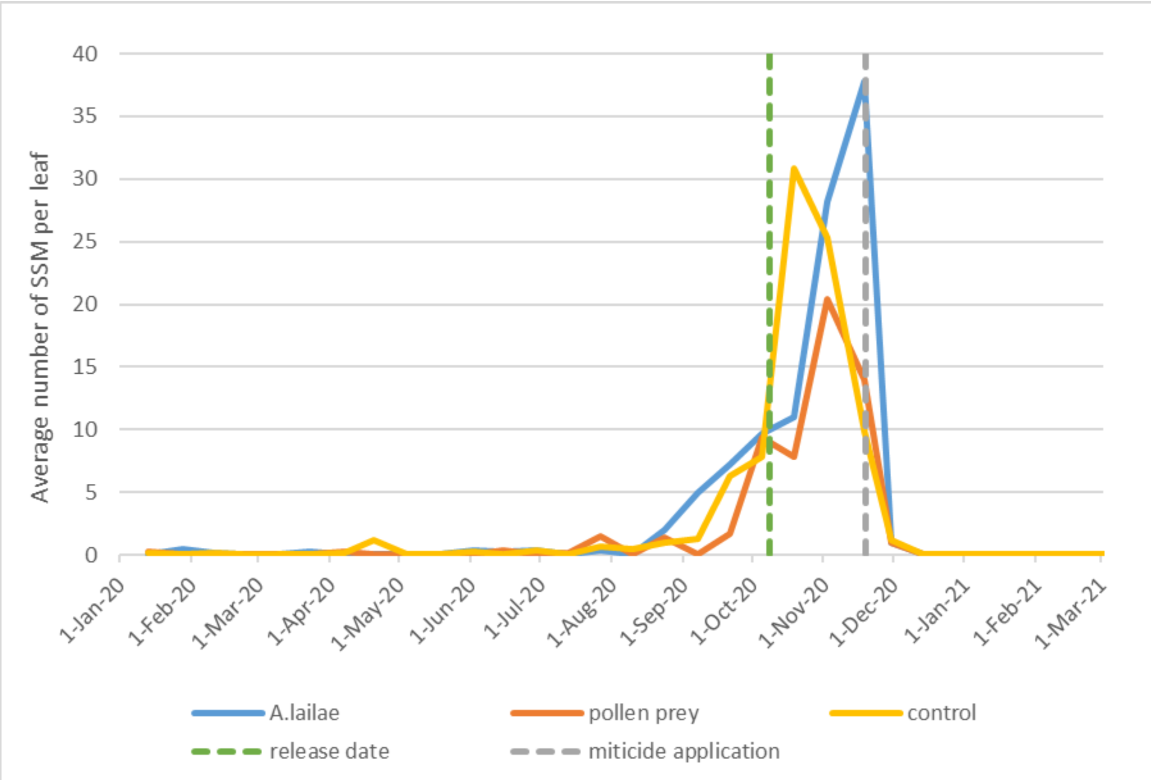

Figure 2: Average number of SSM per leaf recorded from fortnightly monitoring for the three treatment areas in block BC1. Treatments were applied on the 8th of October 2020, miticide was applied on the 19th of November.

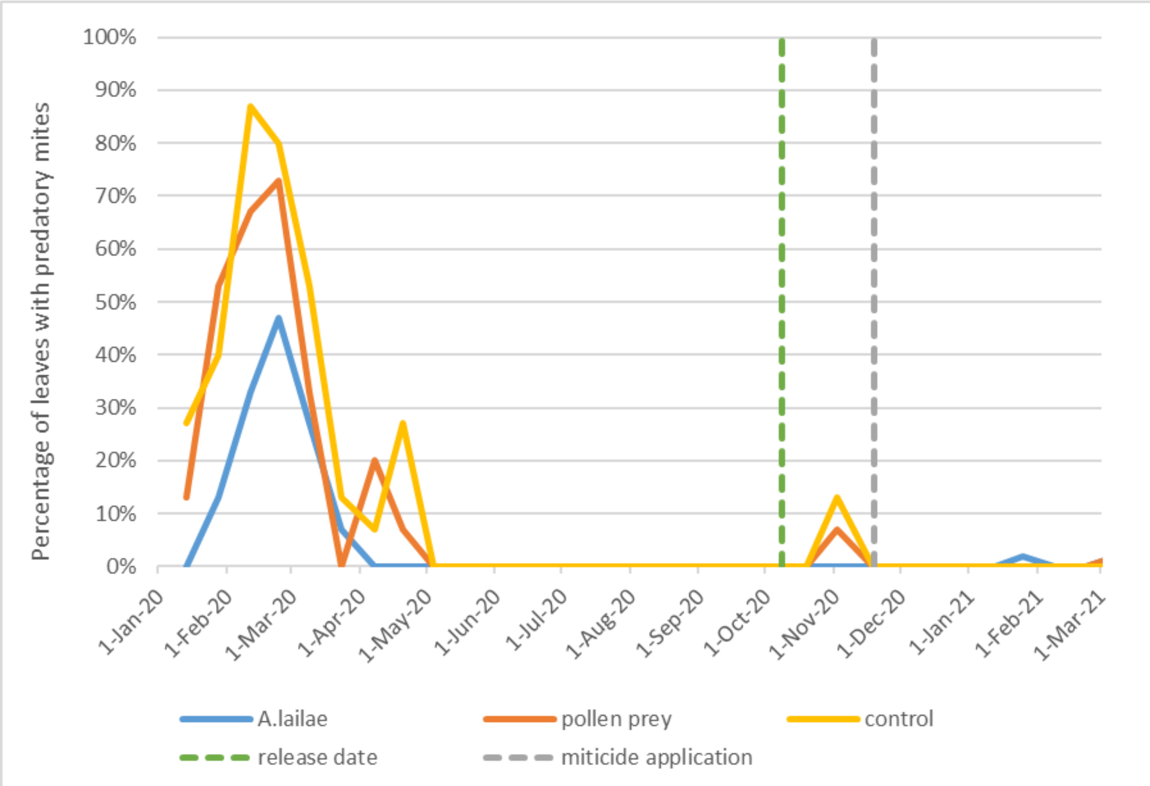

Figure 3: Percentage of leaves with predatory mites recorded from fortnightly monitoring for the three treatment areas in block BC1. Treatments were applied on the 8th of October 2020, miticide was applied on the 19th of November.

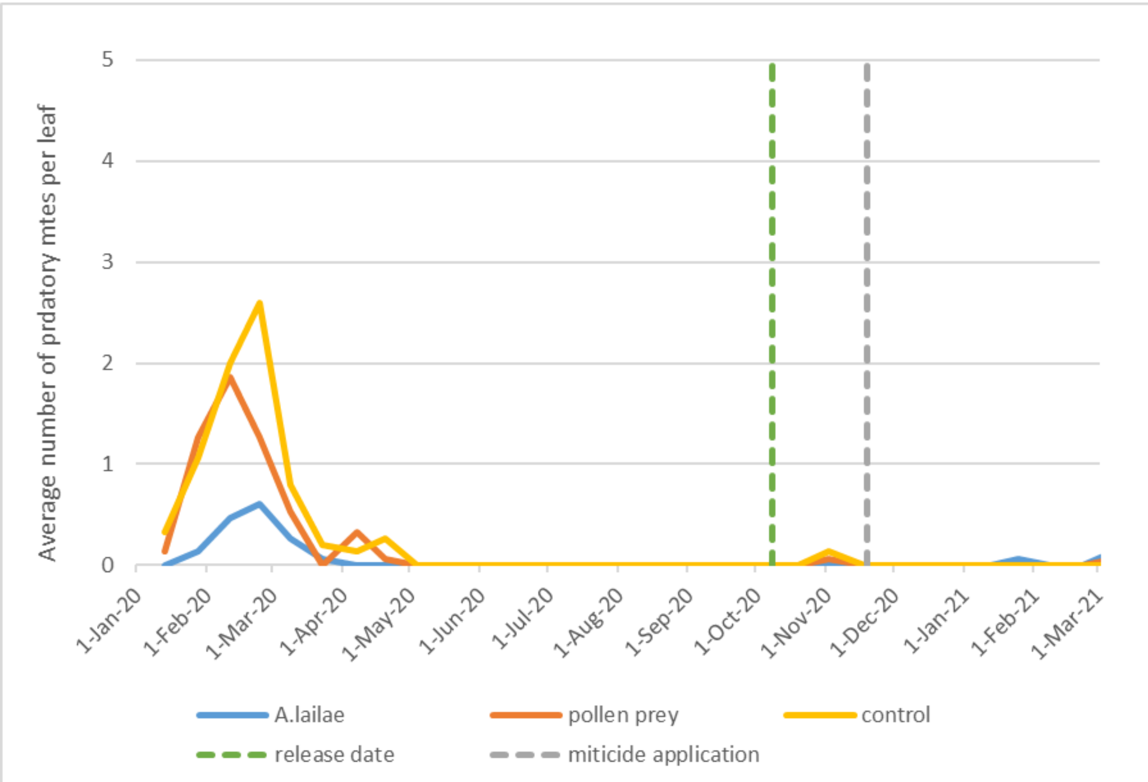

Figure 4: Average number of predatory mites per leaf recorded from fortnightly monitoring for the three treatment areas in block BC1. Treatments were applied on the 8th of October 2020, miticide was applied on the 19th of November.

In block BC2 SSM numbers were low to very low through winter 2020. Numbers started to increase in august and rose rapidly in late September. On the 12th of October, prior to the treatments being applied on the 15th of October SSM and range from 27-40% and 0.8 to 1 mite per leaf. After the treatments were applied SSM numbers fell evenly across all treatments. Figures 5 and 6. Predatory mite numbers were low across the block prior to treatments being applied and remain low until the following autumn and then declined again in winter 2021. Figure 7 and 8

Treatments were applied again on the 14th of October 2021. SSM numbers on 11th October ranged from 27-60% and 0.8 to 5.6. Post treatment SSM numbers rose in all treatments, the smallest rise was in the control trees. SSM numbers fell in all treatments through early summer and remained at low levels in the autumn and winter of 2022. There was no difference in predatory mite numbers before and after treatments.

Collections of predatory mites were made in autumn 2021 and 2022 for identification. All phytoseiidae mites collected from BC2 were *Euseius elinae*. None of the released species *A. lailae* were recovered, suggesting that they were not able to establish within in the block.

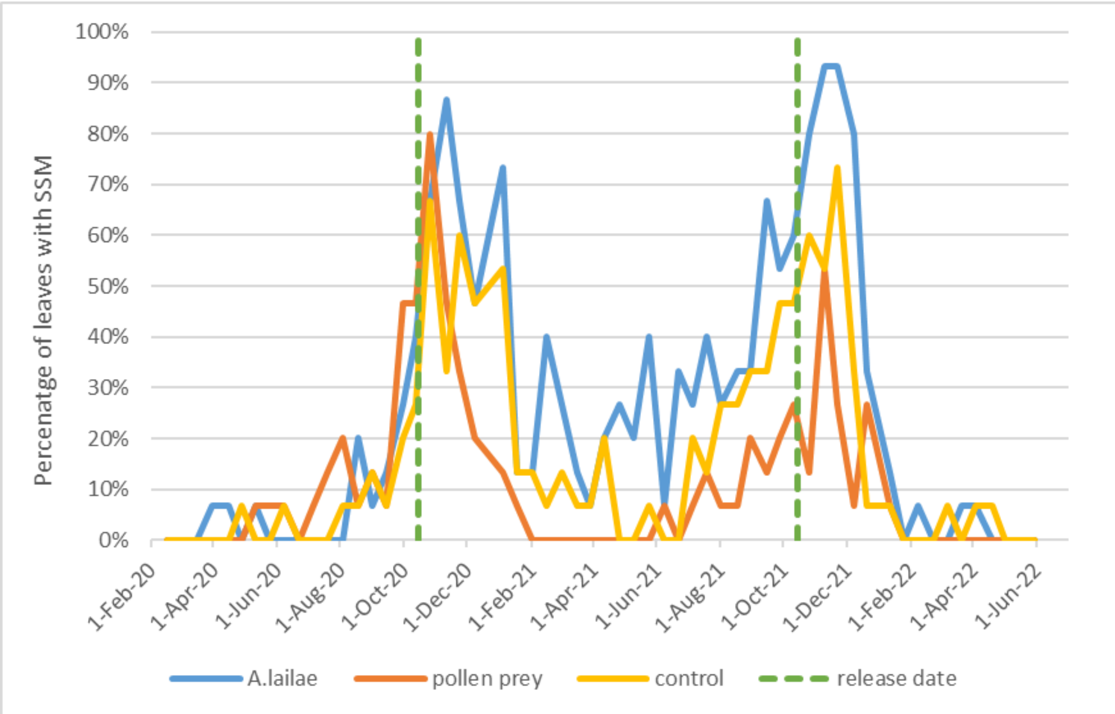

Figure 5: Percentage of leaves with SSM recorded from fortnightly monitoring for the three treatment areas in block BC2. Treatments were applied on the 15th of October 2020, and the 14th of October 2021.

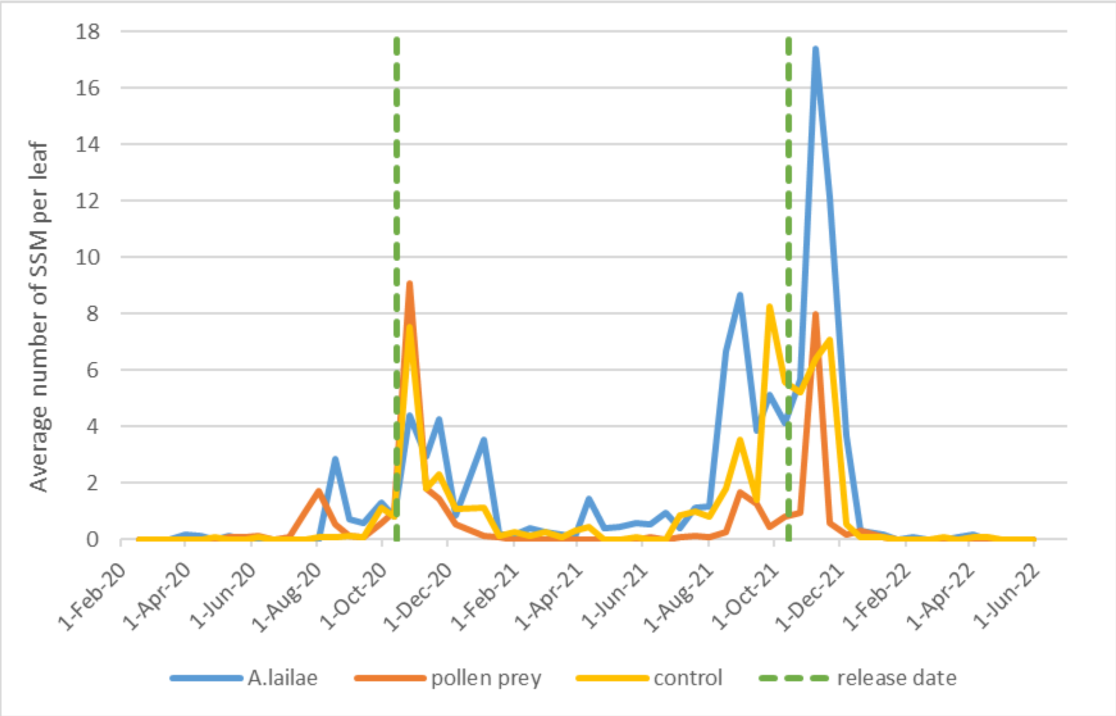

Figure 6: Average number of SSM per leaf recorded from fortnightly monitoring for the three treatment areas in block BC2. Treatments were applied on the 15th of October 2020, and the 14th of October 2021.

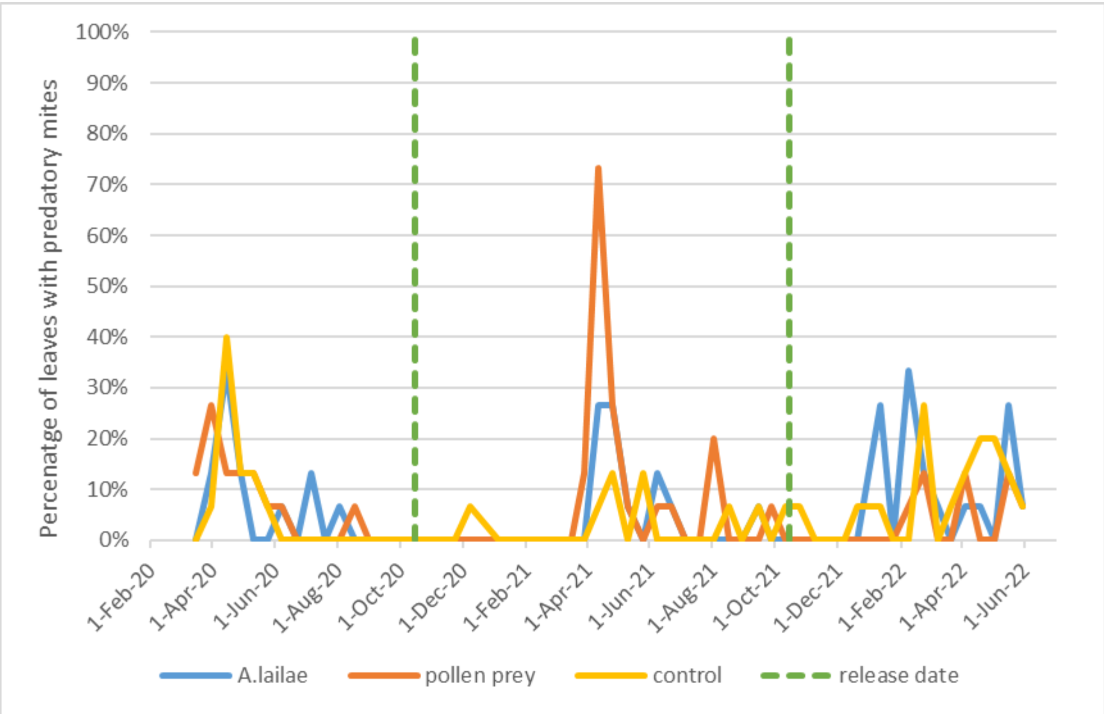

Figure 7: Percentage of leaves with predatory mites recorded from fortnightly monitoring for the three treatment areas in block BC2. Treatments were applied on the 15th of October 2020, and the 14th of October 2021.

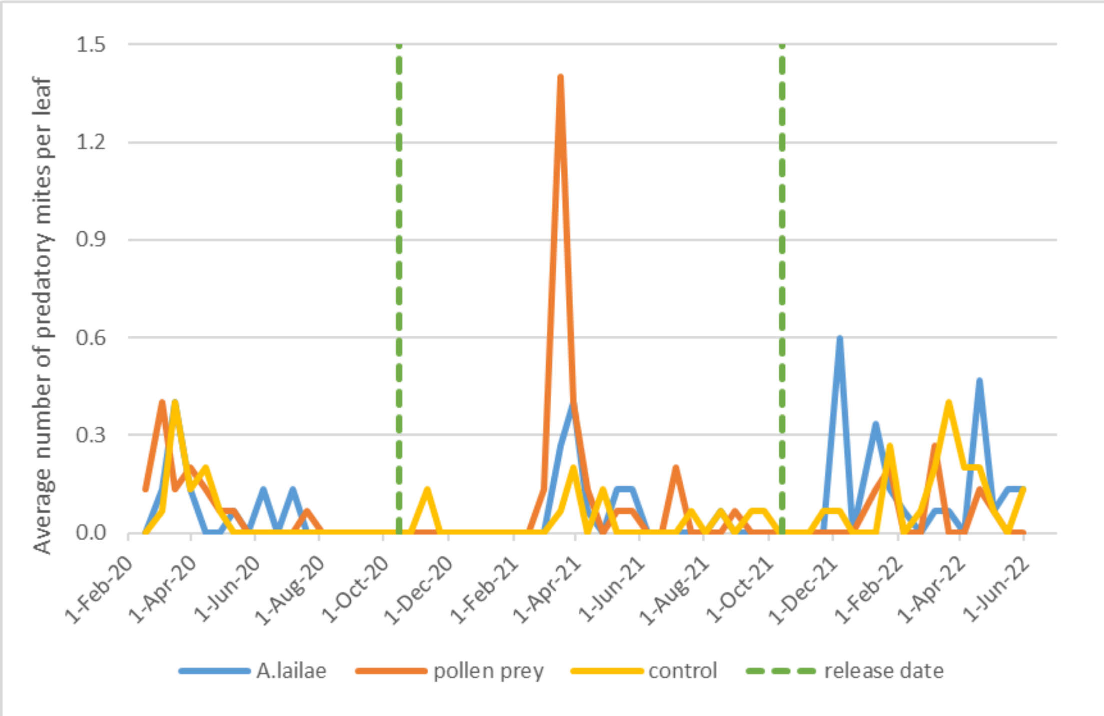

Figure 8: Average number of predatory mites per leaf recorded from fortnightly monitoring for the three treatment areas in block BC2. Treatments were applied on the 15th of October 2020, and the 14th of October 2021.

Block BC3 received treatments on 23rd March and 14th of October 2021. It had the lowest level of SSM at the time treatments were applied. In autumn 2021 the day before treatments were applied an average of zero to 0.13 SSM per leaf were recorded in the three treatment areas. The number of SSM in the A.lailae an pollen prey treatments remained low throughout the following winter and early spring, figure 9 and 10. SSM mites numbers were highest in the control trees after the first application.

There was no difference in predatory mite numbers between the treatments after the March 2020 treatments. This shows that the difference in SSM numbers observed between treatments was not due to a difference in predatory mite numbers post treatment, figure 11 and 12.

After the March 2021 applications SSM and predatory mite numbers were the same for both treatments and the control.

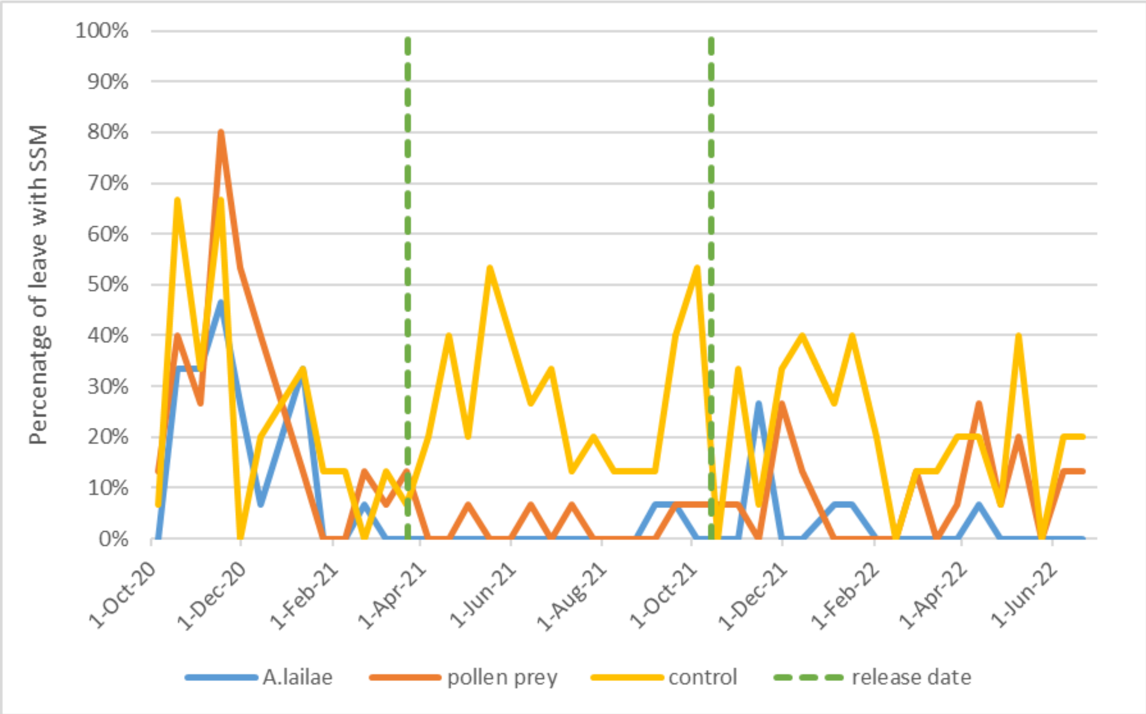

Figure 9: Percentage of leaves with SSM recorded from fortnightly monitoring for the three treatment areas in block BC3. Treatments were applied on the 23rd of March 2020, and the 14th of October 2021.

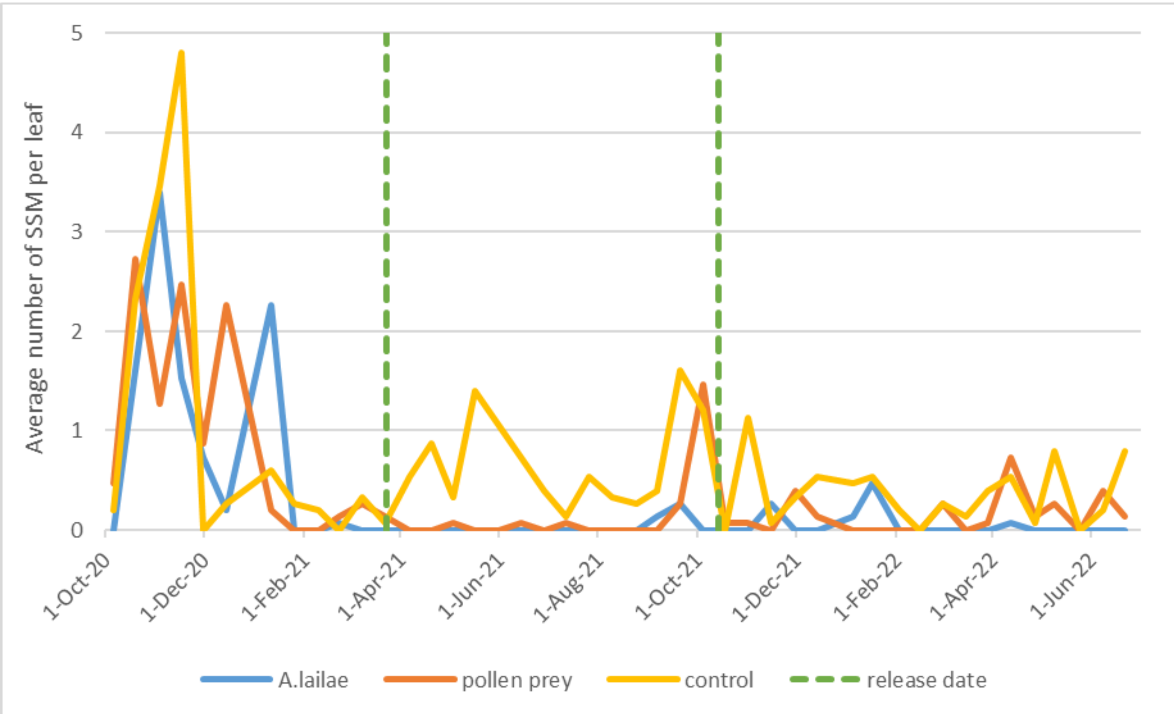

Figure 10: Average number of SSM per leaf recorded from fortnightly monitoring for the three treatment areas in block BC3. Treatments were applied on the 23rd of March 2020, and the 14th of October 2021.

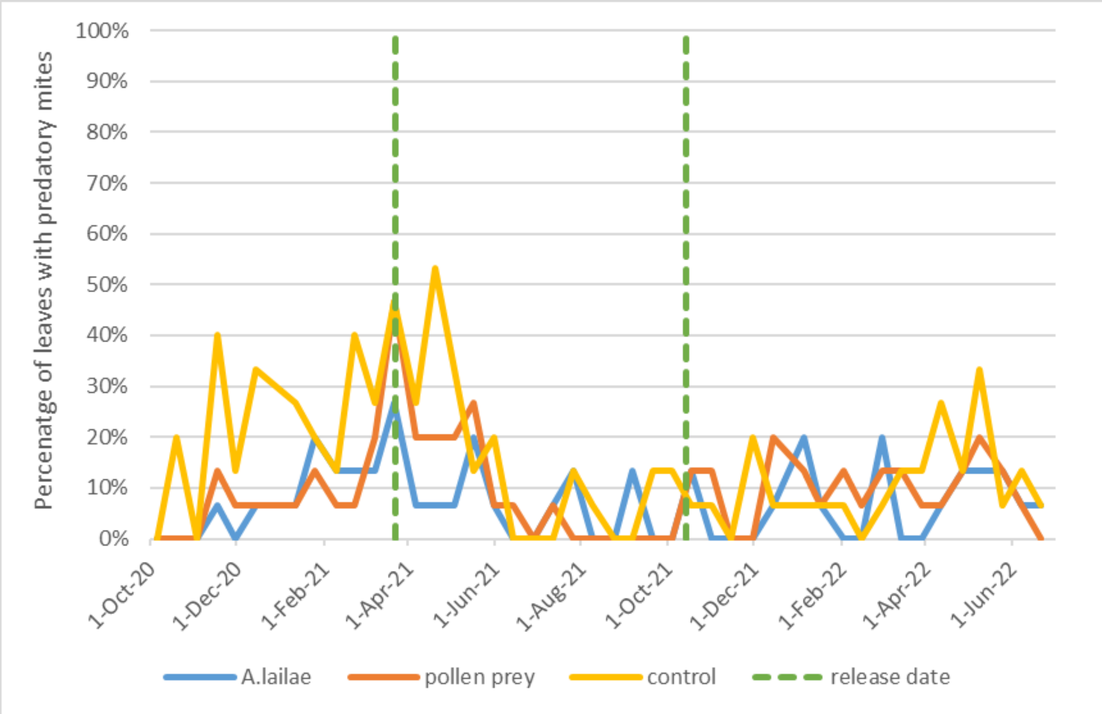

Figure 11: Percentage of leaves with predatory mites recorded from fortnightly monitoring for the three treatment areas in block BC3. Treatments were applied on the 23rd of March 2020, and the 14th of October 2021.

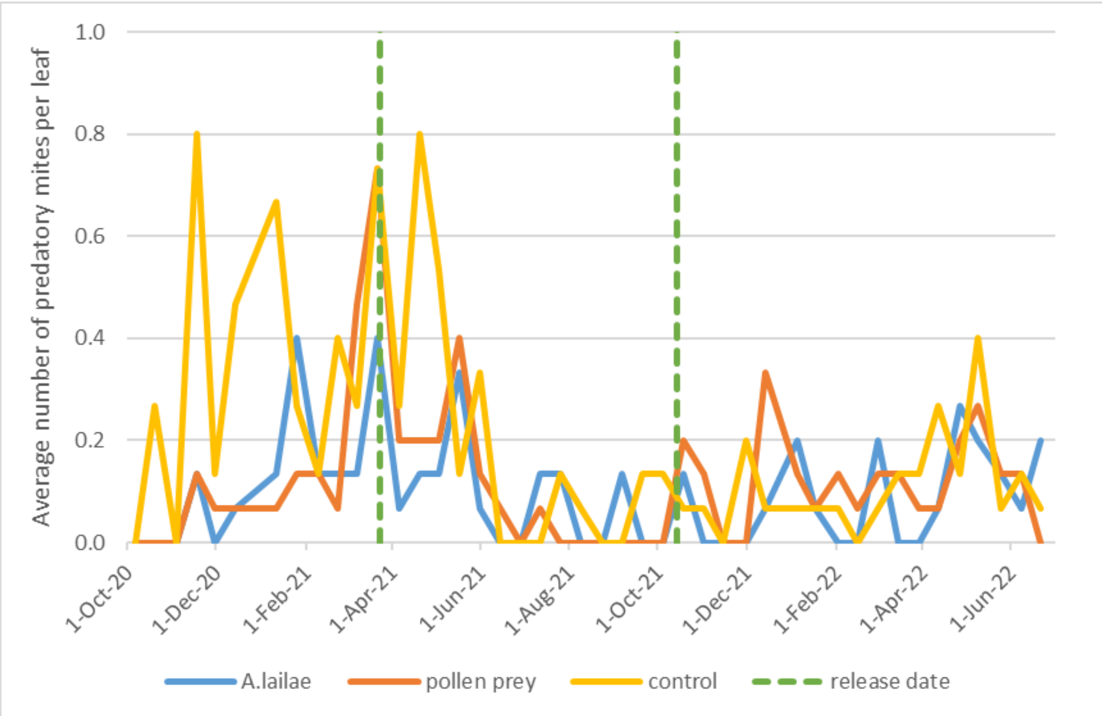

Figure 8: Average number of predatory mites per leaf recorded from fortnightly monitoring for the three treatment areas in block BC3. Treatments were applied on the 23rd of March 2020, and the 14th of October 2021.

Predatory mites were collected from block BC3 for identification in summer 2021, autumn 2021 and autumn 2022. All predatory mites collected from the release area were *Euseius elinae.* None of the released species *A. lailae* were recovered, suggesting that they were not able to establish within in the block. A small number of *Amblyseius* sp. were collected from the control and pollen prey trees.

The mass reared released predator A. Lailae was not able to consistently reduce SSM numbers in either on the release sites that did not receive a miticide application.

There are several reasons while predatory mites do not provide adequate control of pest mites in some horticultural systems:

- Predatory mite numbers do not build up when pest mites increase.
- The predatory mite species' present prefer species other than the pest species.
- The predatory and pest mites occupy different locations on the leaf.
- Low levels of feeding by the predatory mites are unable to reign in high pest mite populations. (Huffaker et al 1970)
- The pest mite population is too high at the time of release (Hoddle 2022)

All of none of these factors may have played a part in this trial. Given that no *A. Lailae* were collected from the release sites suggests that numbers were not able to build up sufficiently to provide control even if these factors were all favourable.

The mass reared released predator A. Lailae was not able to establish in either on the release sites that did not receive a miticide application.

Other trials of inundative phytoseiid mite releases in avocado orchards also resulted in phytoseiid mites not establishing, such as *N. Californicus* in commercial Californian orchards (Hoddle and Morse 2013) and *N. Californicus* in Israeli orchards (Maoz et al 2011). Competition and predation by other predatory mites can lead to predatory mites not establishing (Hergstrom and Niall 1990). Maoz et al (2011) assumed that *N. californicus* did not establish due to negative interactions with the indigenous *Euseius scutalis*. Perhaps a similar scenario occurred in Western Australia orchards with the endemic *Euseius elinae*. Hoddle (2022) released predatory mites at varying pest mite infestation levels and found that they did establish at 50%, 75%, and 95% leaf infestation levels but not at 25% leaf infestation as they were not enough food available. In the *A. lailae* release area of BC2 trees averaged 40% of leaves with SSM prior to the spring 2020 release, this increased to 67% on the first monitoring occasion post release and in spring 2021 there was 60% leaf infestation just prior to release and 80% on the first monitoring occasion post release, suggesting that there was adequate food available in this block. However, in block BC3 there were zero SSM recorded in the *A. lailae* release trees in the fortnight prior to the autumn 2021 release and the week prior to the spring 2021 release. The low numbers of SSM may have contributed to the lack of establishment in that block.

Some other reasons as to why a phytoseiid may not establish is that the species can not subsist in that environment, they reduce the prey mite population through predation to a level that cannot sustain their own population, the condition at and method of release is not favourable and/or they experience population crashes due to unknown causes (Huffaker et al 1970). It is not known which, if any of these factors contributed to the lack of establishment in this case. It is thought that *A. lailae* can sustain itself in avocado orchards as multiple life stages of it has been found in orchards where it has not been released. In BC2 SSM were always present in the release trees and so there was prey present to sustain the predator, although this was not the case in BC3. We do not know what the preferred conditions for *A. lailae* release are. We do know that phytoseiids can be poor dispersers (Huffaker et al 1970) and so in this trial the predators were released at multiple points in every tree as releasing in fewer trees in anticipating of them spreading to other trees is not effective (Hoddle 2022).

This trial and those in the preceding project all looked at individual mite species and the impact of those. Beneficial species complexes are an avenue for future research. Clements and Harmsen (2002) found that a combination of stigmaeids and phytoseiids were more effective over a range of rey densities than either type alone.

2. Monitoring observations

Species of phytoseiid predatory mites present

There were 322 mites in the 90 collections, 300 of which were from the family Phytoseiidae. The vast majority, 84.7%, of those mites were *Euseius elinae*. Other species present in the monitoring orchards in order of number found were

Amblyseius deleoni, Amblydromalus lailae and Typhlodromus doreenae, table 1. Most of the individuals collected were adult females, however, at least one nymph or larvae of each species was collected suggesting that all four species are capable of breeding within avocado orchards.

Table 1: Identification of Phytoseiidae predatory mites collected from orchards blocks that were regularly monitored as part of the project.

Species	Number collected	Percentage of Phytoseiidae collected	Number of orchards found in
Euseius elinae	254	84.7%	11
Amblyseius deleoni	27	9.0%	5
Amblydromalus lailae	8	2.7%	4
Typhlodromus doreenae	5	1.7%	3

These are the same as the top four species identified in the proceeding project AV15012. In AV15012 84% of the Phytoseiidae were *E. elinae* and 12.7% were *A. lailae* (Learmonth 2019). While *A. lailae* made up a lower percentage of the predatory mites collected in this project there were found across more properties, four in this project compared to two orchards in AV15012.

A single specimen each of *Neoseiulella dachanit*, *Typhlodromina musero* and *Typhlodromus dossei* were collected as well as two individuals that could only be identified to genus, *Amblyseius* sp. And only to family.

Relationships between arthropods present in orchards

There was no statistically significant relationship between predatory mites and SSM, stethorus beetle and SSM, tydied mites and SSM or tydied mites and predatory mites, either as percentage of leaves infested of the average number per leaf; figures 13-20.

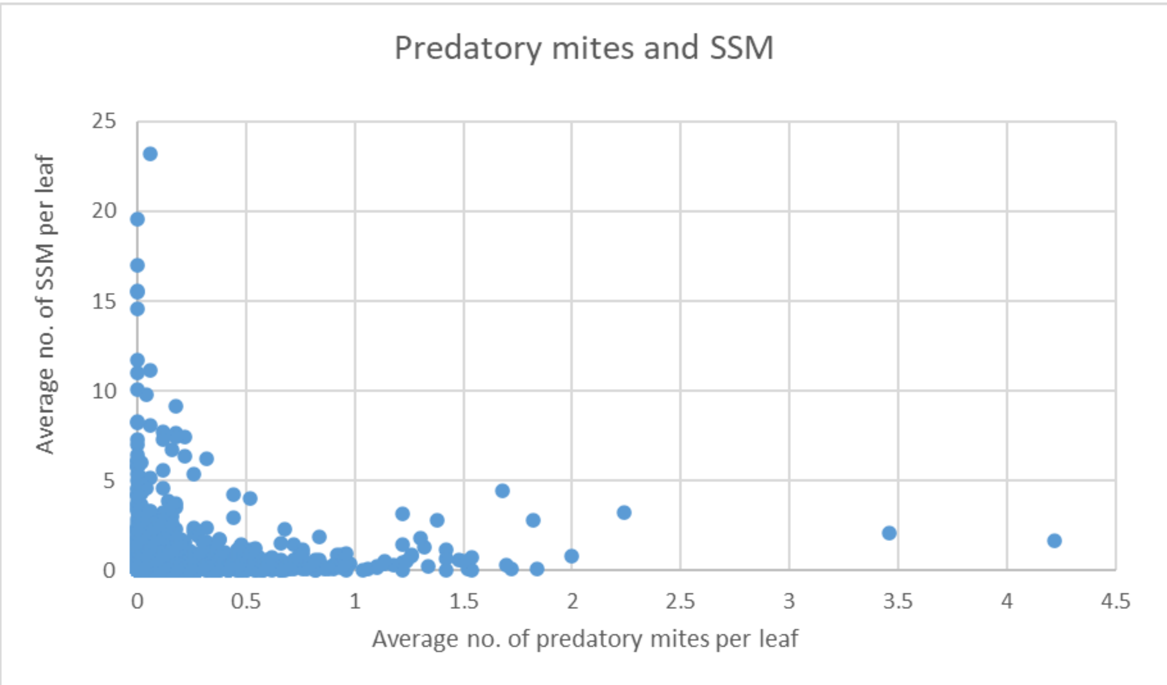

Figure 13: Association between average number of predatory mites per leaf and average number of SSM per leaf. There was no statistically significant relationship between predatory mites (x axis) and SSM (y axis).

Figure 14: Association between percentage of leaves with predatory mites and percentage of leaves with SSM. There was no statistically significant relationship between predatory mites (x axis) and SSM (y axis).

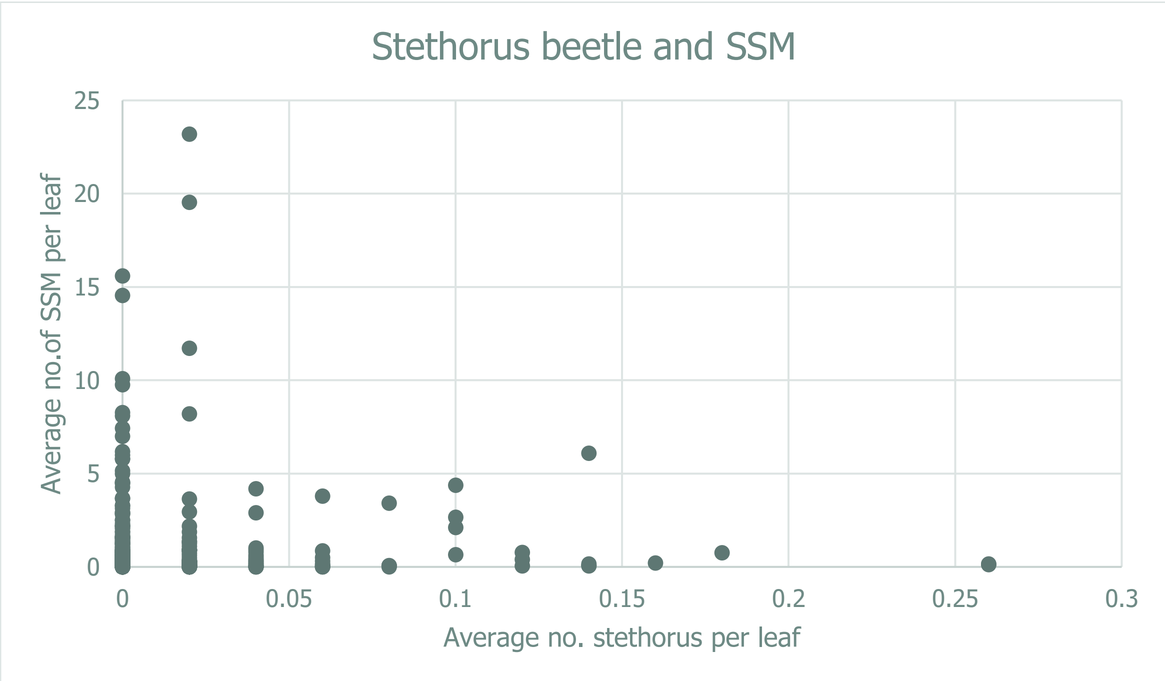

Figure 15: Association between average number of stethorus beetles per leaf and average number of SSM per leaf. There was no statistically significant relationship between stethorus beetles (x axis) and SSM (y axis).

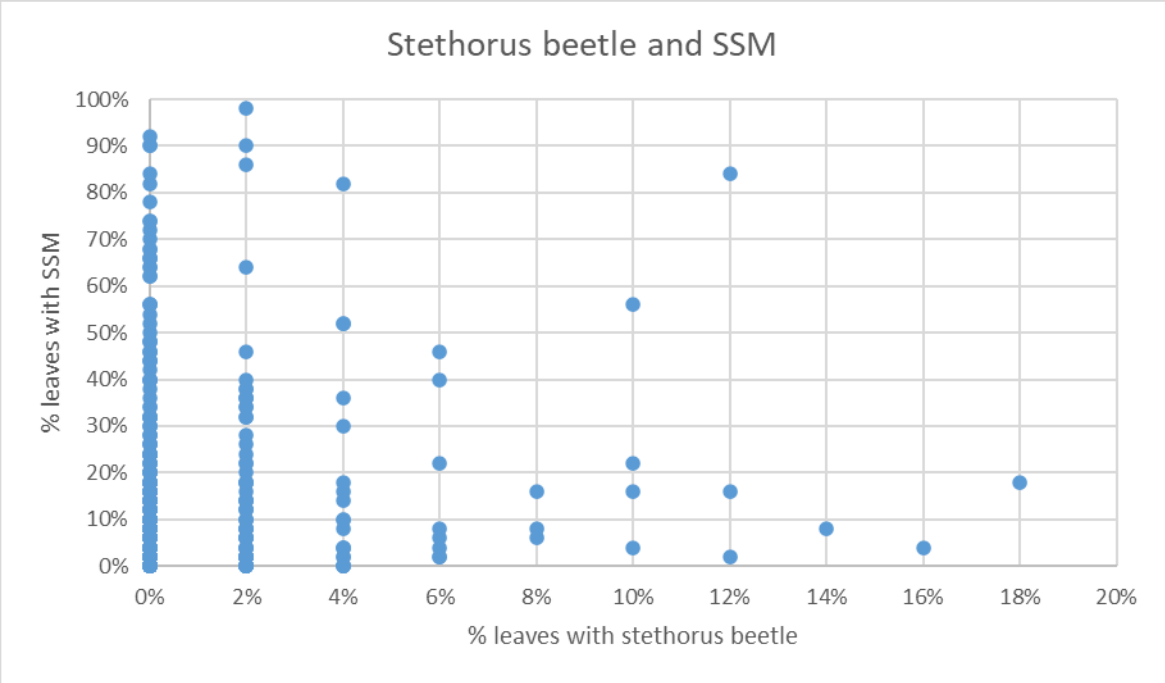

Figure 16: Association between percentage of leaves with stethorus beetles and percentage of leaves with SSM. There was no statistically significant relationship between stethorus beetles (x axis) and SSM (y axis).

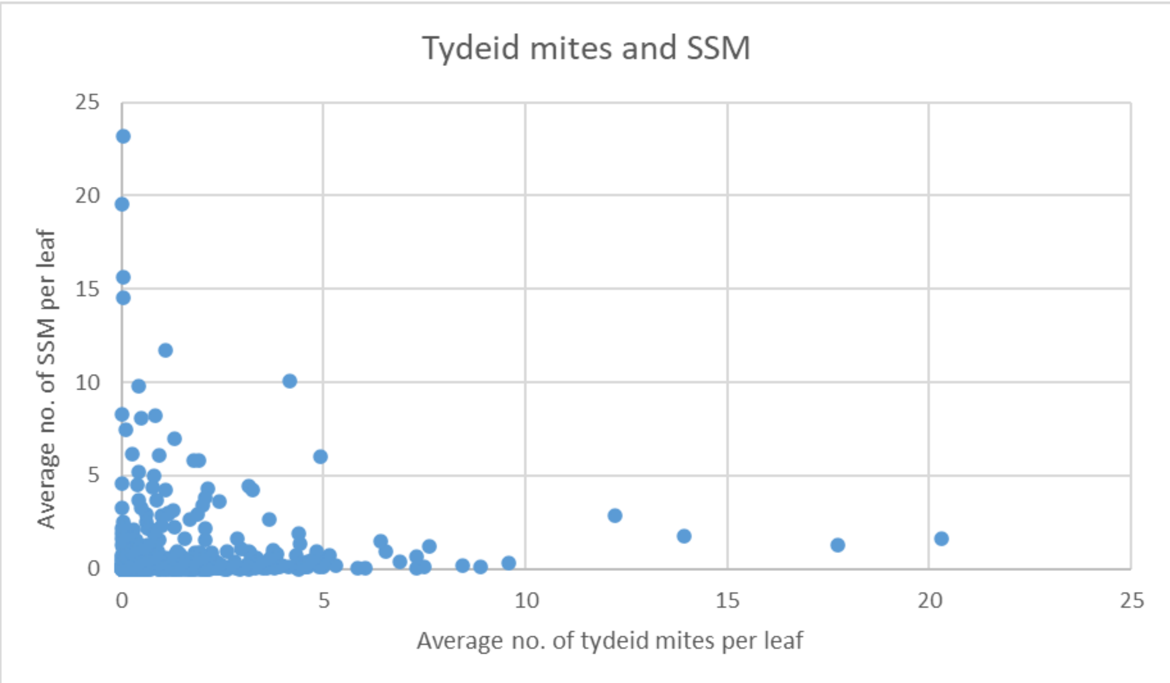

Figure 17: Association between average number of tydeid mites per leaf and average number of SSM per leaf. There was no statistically significant relationship between tydeid mites (x axis) and SSM (y axis).

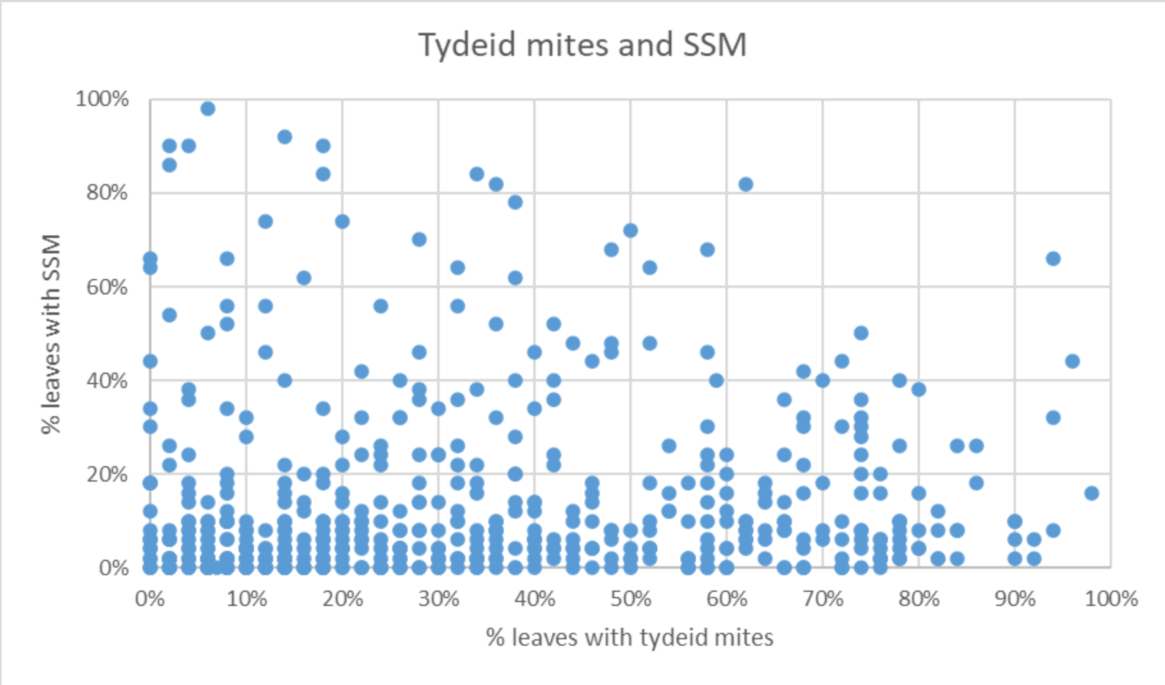

Figure 18: Association between percentage of leaves with tydeid mites and percentage of leaves with SSM. There was no statistically significant relationship between tydeid mites (x axis) and SSM (y axis).

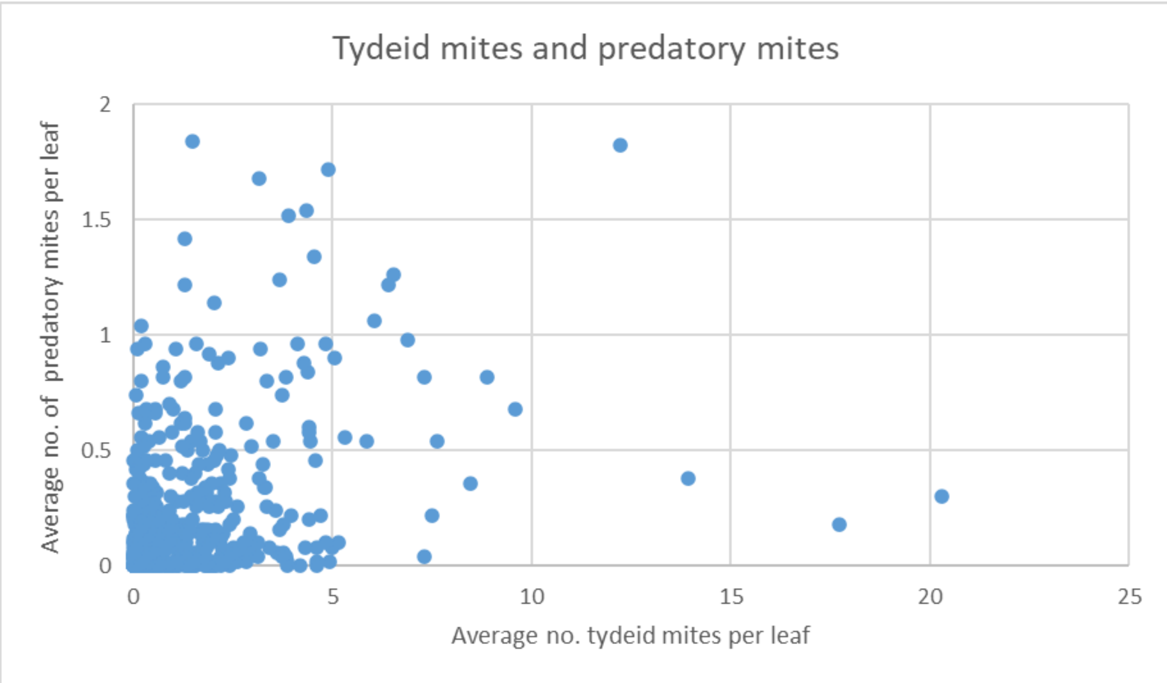

Figure 19: Association between average number of tydeid mites per leaf and average number of predatory mites per leaf. There was no statistically significant relationship between tydeid mites (x axis) and predatory mites (y axis).

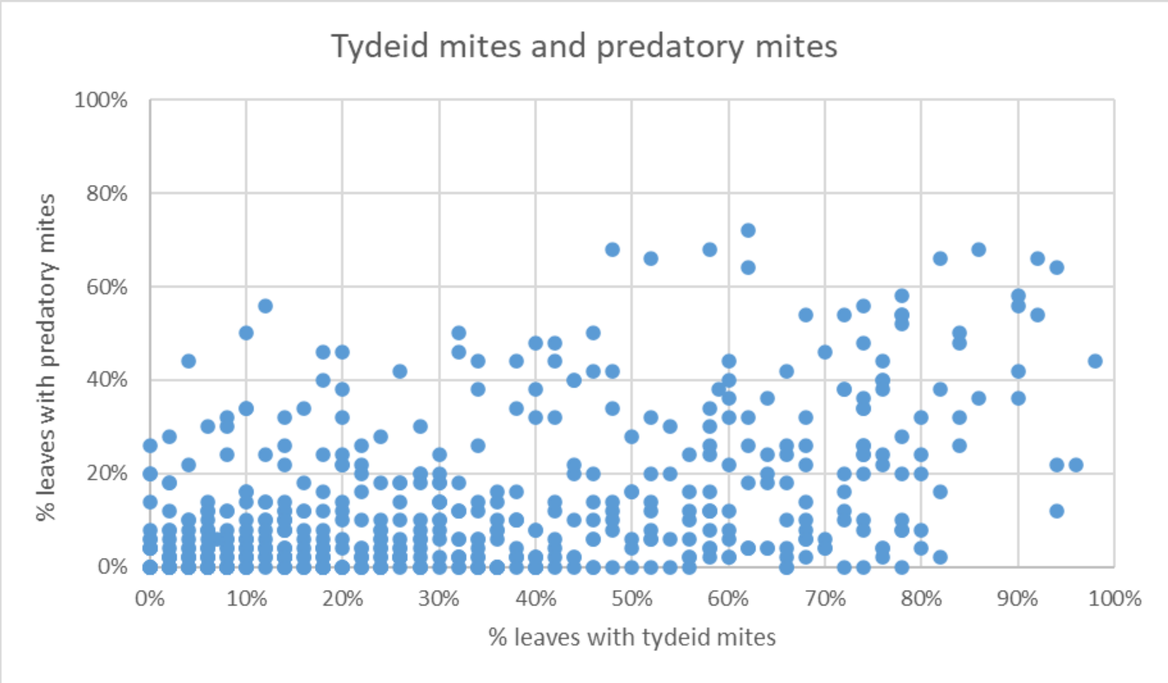

Figure 20: Association between percentage of leaves with tydeid mites and percentage of leaves with predatory mites. There was no statistically significant relationship between tydeid mites (x axis) and predatory mites (y axis).

From these results no management recommendations can be made regarding manipulating predatory mite, stethorus or tydeid mite numbers to alter SSM numbers in orchards. Steven (2004) also found no correlation between numbers of SSM and phytoseids, suggesting that this group of predators generally does regulate SSM populations. Although Fleschner et al (1956) did find fewer spider mites per leaf when predators present.

Predatory mites, SSM and Tydeid mites were found in all monitored orchards blocks. In the orchard blocks where miticides has not been applied in the previous 12 months predatory mites were found on 78% of the monitoring occasions, SSM were found on 81% of monitoring occasions and tydeids 96%. Stethorus were much less common. They were found on only 21% of monitoring occasions, the majority of the time as only a single individual on a single leaf out of the 50 leaves monitored. Only 262 individuals were observed in the abovementioned blocks compared to 5600+ predatory mites and 36000+ tydeid mites. This number may be an underestimate of stethorus actually present in orchards as many insect predators of mites can drop or fly from leaves when they are removed for monitoring (Huffaker et al 1970).

Given that *Stethorus* sp. have been observed as voracious feeder of six-spotted mite E. Barraclough pers. Comm. In Logan et al 2022) and that the above results are based on relatively few observations the potential for Stethorus beetles to be used for SSM management should not be ruled out. This is a potential topic of focus for future research.

Another area of potential future research is to determine how to increase *E. elinae* populations and take most advantage of its presence in orchards. Given the lack of success is establishing other predatory mite species in this and the previous project and that this species consistently makes up a large majority of predatory mites found in orchards makes it a prime subject of research. The pollen prey releases in this project were not successful. However, there are other methods that are worth pursuing, such as the planting of pollen producing plant species in the orchard. These would provide a more consistent supply of pollen for predatory mites such as *E. elinae* but may also have benefits for other beneficial and pollinating species.

3. Impact of miticides on predators

Pesticide impact databases

Both the Biobest or Koppert databases class pesticides from 1-4 as per the table 2. Neither of the databases had information on the most commonly found predatory mite species found in WA avocado orchards, namely *Euseius elinae* or the species released into orchards as part of this project, *Amblydromalus lailae*. Six other phytoseiid mite species were used to gauge the impact of the miticides. There was no *Stethorus* species in either database, information on the impact of the miticides on another ladybird beetle *Cryptolaemus montrouzieri* was included.

Table 2: The categories used by the Biobest and Koppert databases to class insecticides on a 1-4 rating.

	Biobest		Koppert	
Class	Toxicity	Mortality	Definition	Reduction
1	Non-toxic	< 25%	Harmless or only slightly harmful	< 25%
2	Slightly toxic	25-50%	Moderately harmful	25-50%
3	Moderately toxic	50-75%	Harmful	50-75%
4	Toxic	>75%	Very harmful	>75%

According to the databases, of the five actives available to Australian avocados growers for SSM management abamectin is the most toxic to predatory mites. Etoxazole was the next most toxic to predatory mites, followed by mineral oil, then bifenazate and fenbutatin-oxide. Abamectin was also the most toxic to *Cryptolaemus montrouzieri*. There was no rating for etoxazole for this species in either database. The three other products were all in class 1 for their impact on *Cryptolaemus montrouzieri*. Table 3.

Table 3: Class ratings for the five actives available to Australian avocados growers fore SSM management, and examples of trade names for those products; abamectin (Vertimec), bifenazate (Acramite), etoxazole (Paramite), fenbutatin-oxide (Torque, Vendex), mineral oil for various predatory mite species and *Cryptolaemus montrouzieri*

	abamectin (Vertimec)	bifenazate (Acramite)	etoxazole (Paramite)	fenbutatin-oxide (Torque, Vendex)	mineral oil
Neoseiulus californicus	4	1	3	1	2
Neoseiulus cucumeris	4	1	2	1	3
Amblyseius degenerans	4	1	3	1	3
Amblyseius swirskii	4	3	3	2	3
Euseius gallicus	4	-	2	2	-
Phytoseiulus persimillis	4	2	4	1.5	3
Mite average	**4**	**1.6**	**3**	**1.4**	**2.8**
Cryptolaemus montrouzieri	3	1	-	1	1

Case studies

There are no case studies on miticides containing abamectin or bifenazate as only miticides with the active ingredients etoxazole or fenbutatin-oxide were used in the monitored orchards. Miticide applications that were deemed sub-optimal were not included in these case studies because the impact of those applications on SSM was less than expected and so the impact on predatory mites may also have varied from when miticides are applied effectively. For more information on sub-optimal applications see appendix 7 There is also no case studies of the impact of miticides on stethorus beetle as not a sufficient number were recorded in orchards.

Etoxazole was applied effectively to six blocks in spring and eight in autumn. Fenbutatin-oxide was applied effectively to four blocks in spring and none in autumn.

Prior to the spring etoxazole sprays predatory mite levels were very low for blocks P5B1 2020, P5B2 2020, P8B1 2020 and P8B2 2020, often with zero found (figure 21). Levels remained low for these blocks post application, except for P5B2 2020 which had a small peak at 17-21 weeks post application. P3B1 2021 and P3B2 2021 had moderate levels of predatory mites prior to their miticide applications and continued to do so post application. Both blocks increased to high numbers of predatory mites the following autumn, 25+ weeks post application. Figure 21.

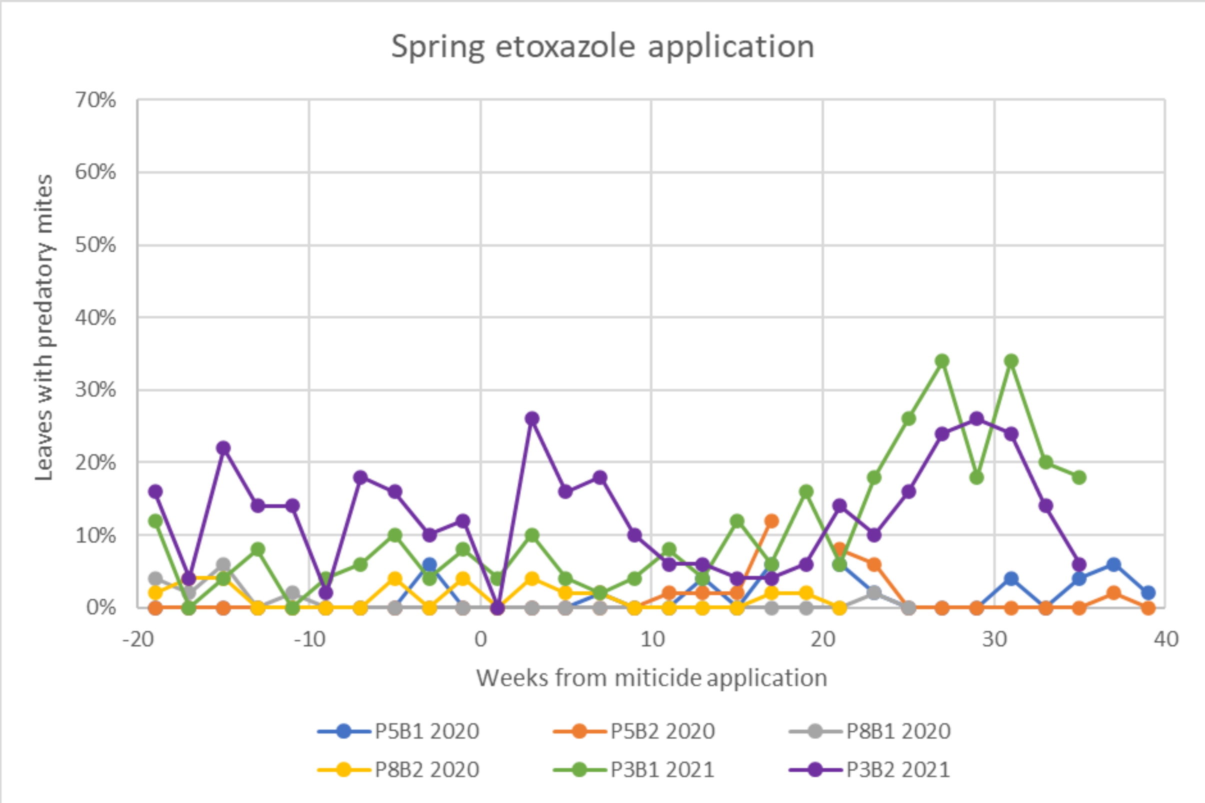

Figure 21: Percentage of leaves with phytoseiid predatory mites recorded fortnightly in six different orchard blocks in the 20 weeks prior and 40 weeks post effective etoxazole miticide application in spring.

Prior to the autumn etoxazole sprays predatory mite levels range from very low to very high across the eight blocks (figure 22). The three blocks with very low mite levels prior to the miticide application, P11B2 2021 P6B1 2021 P6B2 2021, continued to record low levels post application. The other five blocks all had peak predatory mite levels 5-11 weeks prior to the miticide application and numbers were on the decline when the miticide was applied. Predatory mite numbers continued to decline in these blocks, with only low levels recorded in most blocks in the two months post application. Seven of the eight blocks recorded 0-2% leaves with predatory mites from nine to 30 weeks post application. Figure 22.

Predatory mite levels were low in the four blocks that received fenbutatin spray in autumn in the weeks leading up to those applications (figure 23). Numbers remained very low for the next 35+ weeks, with only two recordings of more than 4% of leaves with predatory mites in that time.

There was not a conclusive result from the database review and case studies. Given the rating for etoxazole in the pesticide impact databases it was expected that predatory mite numbers would be more negatively impacted by that active in the case studies, but that was not the case. Etoxazole applied in spring appeared to have no to minimal impact on predatory mite numbers. After the autumn application of etoxazole predatory mite numbers declined and remained very low for a long time. However, numbers were already declining when the miticide was applied and predatory mite numbers also remained very low after the fenbutatin oxide autumn applications. This was not expected as fenbutatin oxide rated lower in terms of impact on beneficial mites.

It should be noted that the average ratings from the databases for *Euseius gallicus* was two, for both etoxazole and fenbutatin oxide. This mite species is in the same genus as the most commonly found predatory mite *Euseius elinae* and perhaps both actives are equally impactful on this species too. The case studies are not replicated trials and so no definitive impacts of these two actives on predatory mites can be drawn. Bioassays would need to be conducted with the actives and specific predatory mite species of interest to determine their impact.

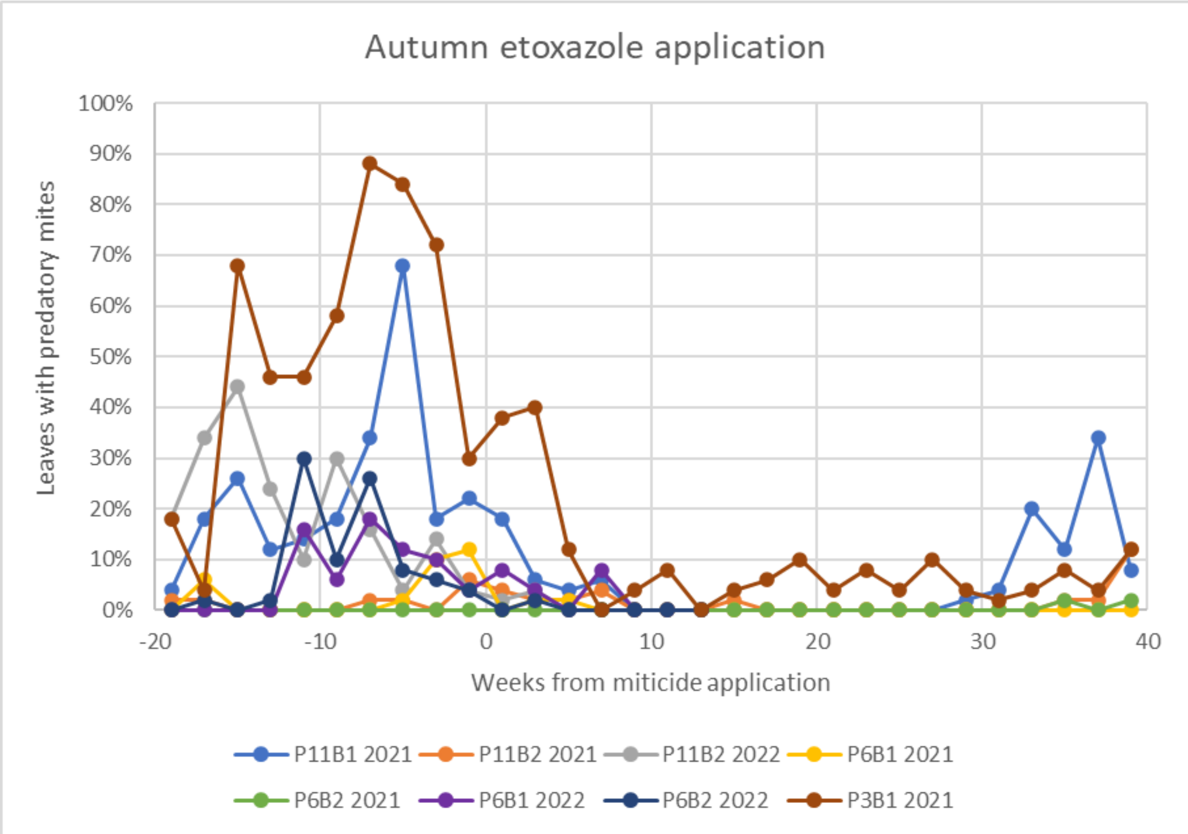

Figure 22: Percentage of leaves with phytoseiid predatory mites recorded fortnightly in eight different orchard blocks in the 20 weeks prior and 40 weeks post effective etoxazole miticide application in autumn

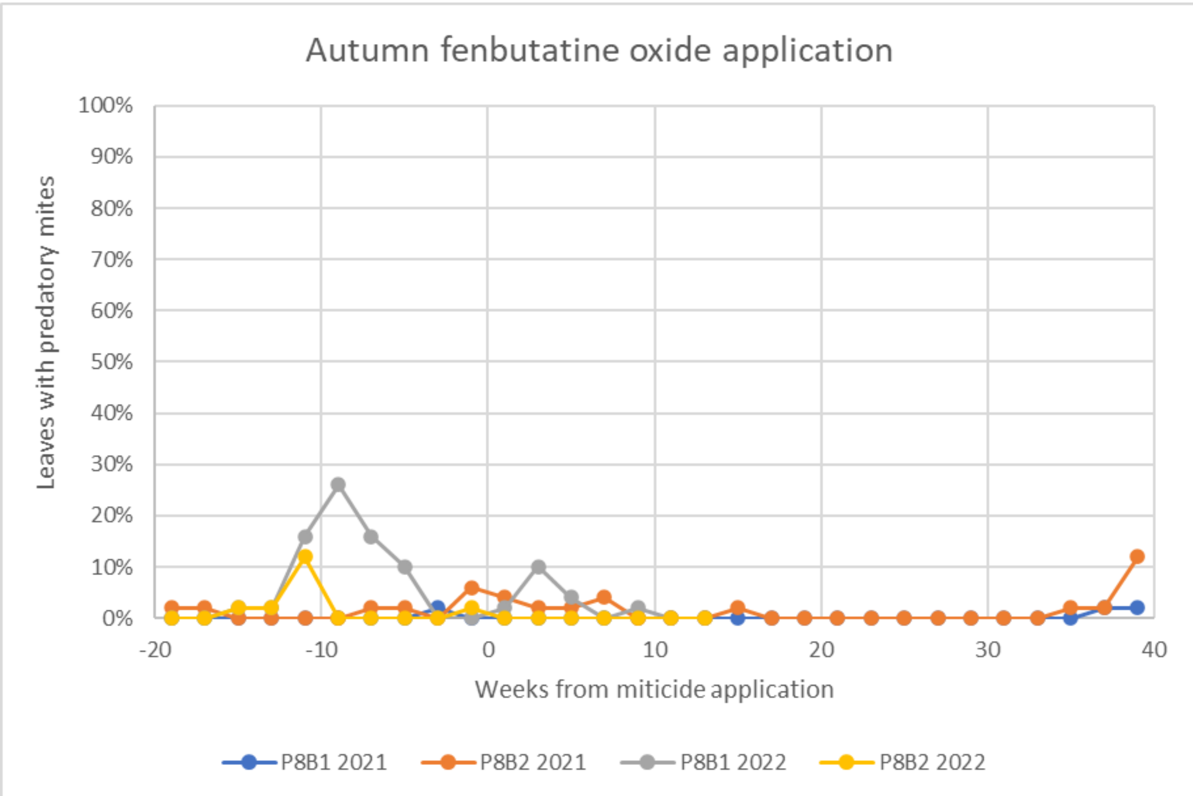

Figure 23: Percentage of leaves with phytoseiid predatory mites recorded fortnightly in four different orchard blocks in the 20 weeks prior and 40 weeks post effective fenbutatine oxide miticide application in autumn

If further studies into the impact of pesticides on beneficial species does take place, then the effect of copper fungicides should also be considered. Copper fungicides have been shown to increase ladybird mortality and decrease predation of soft wax scales in citrus (Lo and Blank 1992 in Stevens and Jamieson 2000)

Recommendations

For growers

- The application of mass reared predatory mite species is not recommended for SSM control.
- Be aware of the different impact ratings of the available actives on various beneficial species and make decisions accordingly.

Future research

- Determine if *Stethorus* sp. play as role in SSM control and if number can be increased to improve SSM management.
- Assess the use of pollen producing ground cover/inter-row species to increase numbers of predatory mites and other beneficial invertebrates.
- Conduct bioassays on the most commonly found predatory mites with the registered actives to determine their impact.
- Assess the impact of copper fungicides on beneficial species

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Appendix 5: Nitrogen and six-spotted mites

Background

There are conflicting results from studies on the influence of nitrogen on population levels of different pest mite species in different crops (Huffaker et al 1970). While there have been no studies looking specifically at the relationship between six-spotted mite (SSM) and leaf nitrogen levels in avocado there are enough studies of other pest crop complexes to suggest that high nitrogen levels may lead to higher mite numbers. Nitrogen fertilisation has even been recommended for consideration as a part of the suite of mite management control options in strawberries (Alizade et al 2016)

In a review Lu et al (2007) found that arthropod plant pests were reported to have developed faster, grown bigger, and survived for longer on plants with higher nitrogen levels in a majority of studies (115/156). In the other 44 studies there was a decrease or no obvious changes in arthropod pest development on plants with high nitrogen content. This is supported by Altieri and Nicholl's (2003) review that also found that there was a positive response in aphid and mite numbers to increased nitrogen fertilisation in most studies.

There have been numerous studies looking specifically at pest mites that have shown a relationship between nitrogen levels and populations, damage and/or reproductive rates. Often it is a positive relationship, but not always (Huffaker et al 1970). Nitrogen deficient plants can be less favourable to mites; however a deficiency can also make them more susceptible to injury from feeding, suggesting there is an optimum nitrogen level where a balance is found between mite numbers and damage from them (Harries 1966 in Huffaker et al 1970).

One hypothesis as to why high nitrogen levels leads to higher pest numbers is that the carbon nitrogen ratio influences susceptibility to pests. When the carbon levels are higher more carbon-based secondary metabolite defence compounds are produced (Bernays 1981 in Alizade et al 2016). When nitrogen levels are increased, the carbon is directed to plant growth, reducing the concentration of defensive compounds (Bryant et al. 1983in Alizade 2016, Tuomi et al. 1984, Hoffland et al. 2000).

Strawberry plants that received less nitrogen had lower protein content and higher phenol, a secondary metabolite, content causing a significant decrease in two spotted spider mites (TSSM) (Alizade et al 2016). The same relationship was found for TSSM in apples, but they could not determine if the protein or phenol levels were the major contributing factor to the change and concluded it was probably a combination of the two (Wermilinger et al 1985, Wermilinger et al 1991).

Increased nitrogen levels may also lead to different growth habits or growth timing (Hoffland et al. 2000), water content, leaf toughness and differences in nitrogen compounds that makes a crop more susceptible (Wermelinger et al 1985).

In avocado Hoddle & Kerguelen (1999) suggested that susceptibility of different cultivars to persea mite was determined by seasonal changes in leaf nutrient levels; with the seasonal outbreaks partly facilitated by the change in leaf chemical composition at that time of year. They suggested there may be a relationship between cultivar susceptibility and nitrogen content of leaves and cycling carbohydrate contents, but there are likely to be other factors involved as well.

In the Avocado SSM pest/crop complex it is not simply the number of mites and the level of direct feeding that impacts crop quality and orchard operations, rather it is the degree of defoliation. There is no doubt that other factors beyond numbers of mites lead to defoliation. One factor may be the concentrations of N in leaves. This may influence both leaf retention and SSM growth and survival. A key research question is whether high nitrogen levels lead to higher SSM numbers in avocado but at the same time contribute to leaf retention. If so. it may be a matter of finding the correct nitrogen balance that does not encourage SSM populations to increase as rapidly but at the same time allows plants to be less susceptible to defoliation.

Field trials were conducted in commercially managed orchards with the objectives to determine if there was a relationship between SSM numbers, leaf nitrogen, flowering, and defoliation. Running trials in commercial orchards does pose issues as not all variables can be controlled and the environment cannot be manipulated to bring on the desired state. It is also not possible to let the mites increase to potentially damaging levels if the grower wishes to control them. There was not scope within this project to undertake a glasshouse trial or replicated field trial examining the influence of various nitrogen fertiliser regimes on SSM fecundity and growth rate and the relationship between infestation levels, leaf nitrogen and lead drop.

Trial 1 – Leaf nitrogen levels in trees that experienced leaf drop

Background

In Trial 1, the aim was to assess SSM numbers and leaf nitrogen levels in trees that defoliated due to SSM in commercial orchards. No defoliation occurred due to SSM in the 26 orchard blocks being monitored fortnightly as part of the project. This was possibly due to active management by the growers involved. They were aware of the SSM levels due to regular monitoring updates and took action to manage them before defoliation occurred. Thus, an alternative approach was used.

Method

Growers in the district were asked to contact the project team if they experienced any defoliation in their trees that was thought to be due to six-spotted mite. Two growers contacted the project team during the project period. An assessment was not able to be conducted in the first orchard as a knockdown miticide had already been applied to the whole orchard. In the second orchard a spray oil application had been made to one block, the most severely defoliated, but it was decided to go ahead with the assessments as it was the last season of the project and it was unlikely another orchard would be identified.

Two blocks within this orchard were chosen for assessment. One block had been sprayed with a pest oil and the other had received no pesticide sprays. Two adjacent rows, near the centre of each block that were representative of the block were chosen. Alternating between the two rows, ten trees equally spaced along the rows were tagged for assessment. Approximately every fourth tree.

On 17th November 2022 five leaves were collected from each tree. The number of SSM motiles and eggs per leaf was counted.

Five mature leaves and five young leaves were collected from each tree and sent to the CSBP Soil and Plant Analysis Laboratory for analysis of total nitrogen, boron, calcium, chloride, copper, iron, magnesium, manganese, phosphorous, potassium, sodium, sulfur and zinc concentrations.

The amount of flowering and leaf drop for each of the twenty trees was rated. Flowering was rated on a scale of one to six, with one being low flowering and 6 being high flowering. Leaf drop was rated on a scale of one to six, with the assumption that leaf coverage had previously been similar on all trees, one was no defoliation and six was total defoliation.

The data was collated and sent to a DPIRD biometrician for analysis to determine if the correlations between variables were statistically significant at a 5% level.

Results

Nitrogen levels in mature leaves ranged from 2.01% to 2.82%. Most (60%) trees in block A were within the recommended range of 2.2% to 2.6% (Avocado Australia Best Practice Resource). All but one of the remainders were over 2.6%. Half (50%) of trees in Block B were in the recommended range, with the other 50% having lower than 2.2% (Table 1).

No SSM motiles were observed on leaves from block B. This is likely due to the pest oil spray.

Table 1: Defoliation, flowering, SSM motiles and leaf nitrogen (N) measured for 20 trees in two commercial orchard blocks in Trial 1.

Block	Tree	Defoliation rating (1-6)	Flower rating (1-6)	Avg SSM motiles/Leaf	Avg eggs/leaf	Total N % Young leaves	Total N % Mature leaves
A	1	2	5	45.0	29.2	2.72	2.19
A	2	1	5	36.0	23.6	2.61	2.65
A	3	1	5	105.0	39.6	2.75	2.59
A	4	1	1	74.8	102.0	2.82	2.56
A	5	1	4	70.4	12.8	2.88	2.47

A	6	1	5	33.2	6.2	2.75	2.2
A	7	1	4	9.0	24.0	2.22	2.66
A	8	1	4	37.6	25.4	2.65	2.43
A	9	2	1	15.2	9.4	2.39	2.32
A	10	1	3	35.6	10.2	2.17	2.82
B	1	5	2	-	16.2	2.61	2.16
B	2	5	5	-	121.8	2.85	2.24
B	3	5	3	-	25.2	2.86	2.12
B	4	2	2	-	43.8	2.87	2.24
B	5	2	3	-	6.6	2.75	2.2
B	6	2	3	-	23.2	3.07	2.35
B	7	4	3	-	27.6	3.06	2.28
B	8	1	1	-	3.6	2.66	2.06
B	9	5	3	-	53.4	2.63	2.01
B	10	1	5	-	11.6	2.72	2.07

There was a significant negative correlation between defoliation rating and total nitrogen in mature leaves when samples from both blocks were considered together ($r= -0.53$, $p=0.017$). The seven highest nitrogen results were all from trees in block A that received a defoliation rating of 1. When only results from trees in block B, where the severe defoliation occuered, were analysed the correlation between defoliation rating and total nitrogen was near zero (-0.03).

There were also significant correlations between defoliation rating and boron, calcium, chloride, iron, magnesium, potassium and sodium levels taken from either young and/or mature leaves (Table 2).

Table 2: Significant ($P \leq 0.05$) correlation co-efficients between defoliation rating and nutrient level in young and mature leaves in Trial 1. N.S. indicates correlations that were not significant.

Nutrient	Young leaves	Mature leaves
total nitrogen %	N.S.	-0.53
Boron mg/kg	0.78	N.S.
Calcium %	-0.50	N.S.
Chloride %	0.61	0.53
Copper mg/kg	N.S.	N.S.
Iron mg/kg	0.63	0.56
Magnesium %	0.60	N.S.
Manganese mg/kg	N.S.	N.S.
Phosphorous %	N.S.	N.S.
Potassium %	0.59	N.S.
Sodium %	0.68	0.68
Sulfur %	N.S.	N.S.
Zinc mg/kg	N.S.	N.S.

SSM motiles were only able to be counted in block A. The trees in this block were all rated 1 or 2 on the defoliation scale and there was no association between average number of SSM per leaf and defoliation rating at a significance level of $\alpha = 0.05$.

There was a significant positive correlation of 0.68 between average SSM per leaf and total nitrogen measured in young leaves, but not it was not significant for total nitrogen from mature leaves.

There was no association between SSM eggs per leaf and total nitrogen in either mature or young leaves, between the average number of SSM eggs per leaf and the defoliation rating or between the flower rating and defoliation rating

Trial 2 – Relationship between SSM numbers, leaf drop, level of flowering and defoliation

Aim

The aim of Trial 2 was to determine if there was a relationship between SSM numbers, leaf nitrogen, flowering and defoliation.

Method

Ten trees were selected in each of three orchard blocks known to have moderate SSM numbers and in which the managers were not intending to apply miticides. Leaf drop, SSM numbers, leaf nitrogen levels and flowering were assessed for each of the thirty trees.

To measure leaf drop three branches equally spaced around each tree and 1-2m from the ground were tagged and the number of leaves on each branch counted. Leaf counts took place in early spring (early October) prior to the defoliation risk period from SSM, in mid spring (early November) during the defoliation risk period and early summer (December) after the defoliation risk period. Each branch had a minimum of 100 leaves on the first counting occasion in October. Only mature leaves were counted, not new spring growth. Defoliation was calculated by comparing the initial leaf counts with those taken in November and December.

To assess SSM numbers ten mature leaves were selected from each tree on the October and November assessments and the number of SSM motiles per leaf counted. Leaves were not removed from the three branches monitored for leaf drop.

In October, 10 leaves per tree were collected and sent to the CSBP Soil and Plant Analysis for total nitrogen analysis.

At peak flowering each tree was rated on a scale of one to six, with one being low flowering and 6 being high flowering.

The data was collated and sent to a DPIRD biometrician for analysis to determine if the correlations between variables were statistically significant or not. Significance refers to statistical significance at a 5% level.

Results

There was a large degree of variability in the percentage of leaves infested, the average number of SSM per leaf, level of flowering and percentage of leaf drop between trees (Table 3). Twenty-one of the 30 trees sampled had nitrogen levels above the recommended range for avocados, which is 2.2-2.6 (Avocado Australia Best Practice Resource), however, the range can probably extend up to 3.0 without result excessive vegetative growth (Declan McCauley personal communications, November 2021) so the high levels recorded are not of concern. One tree's total nitrogen was less than 2.2. The level of defoliation between the first and last monitoring occasion varied from 6% leaf drop to 100% of leaves dropped.

Table 3: Average and range of all factors measured in Trial 2

% leaves infested mean (range)		Avg SSM/leaf mean (range)		Flower rating (1-5) mean (range)	Total N mean (range)	% leaf drop mean (range)		
Oct	Nov	Oct	Nov			Oct-Nov	Oct-Dec	Nov-Dec
25% (0-90)	33% (0-90)	2.33 (0-20.4)	1.91 (0-11.1)	2.40 (1-5)	2.67 (2.12-3.0)	33% (7-80)	69% (27-100)	59% (6-100)

There were no trends in the relationship between either leaf drop or total nitrogen and all other variables measured (Figures 1, 2 and 3).

The following correlations between variables were assessed. None were found to be statistically significant.

- Percentage leaf drop, over all three time periods and leaf nitrogen.

- Average mites/leaf, at both dates measured and leaf nitrogen.
- Percentage leaves infested, at both dates measured and leaf nitrogen.
- Percentage leaf drop, over all three time periods and average mites/leaf, at both dates measured.
- Percentage leaf drop, over all three time periods and percentage leaves infested, at both dates measured
- Percentage leaf drop, over all three time periods and flower rating

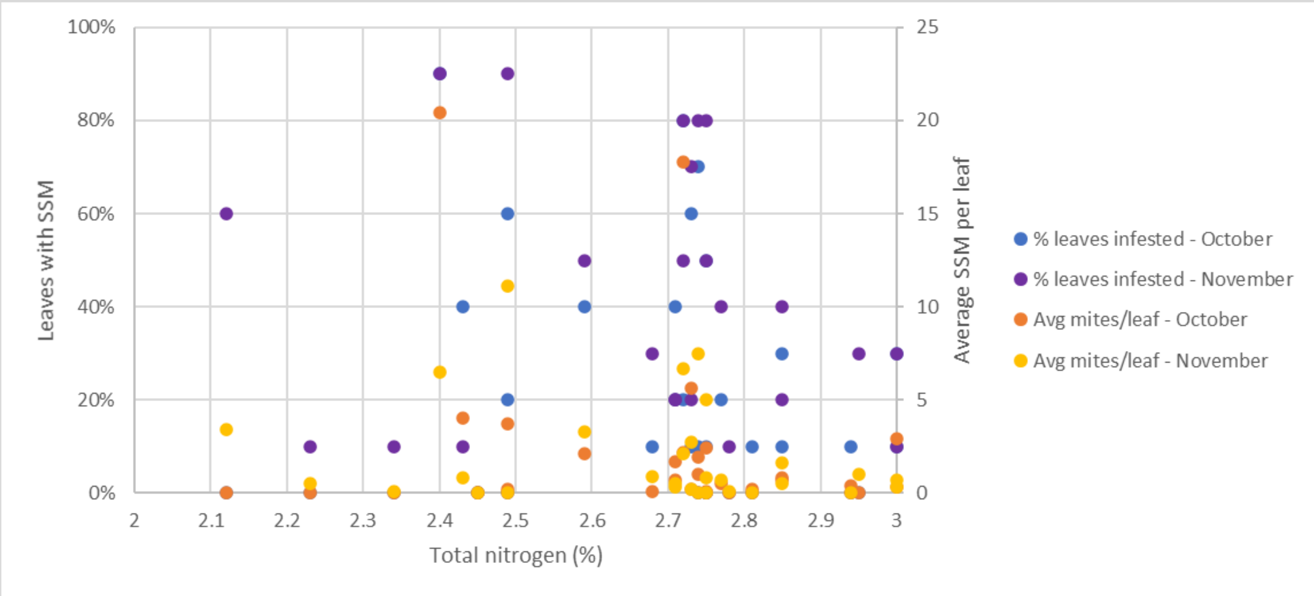

Figure 1: Association between six-spotted mites on leaves and total leaf nitrogen (%). There was no statistically significant relationship between total nitrogen and leaves with SSM (y axis primary) in either October or November or the average number of mites per leaf (y axis secondary) in either October or November.

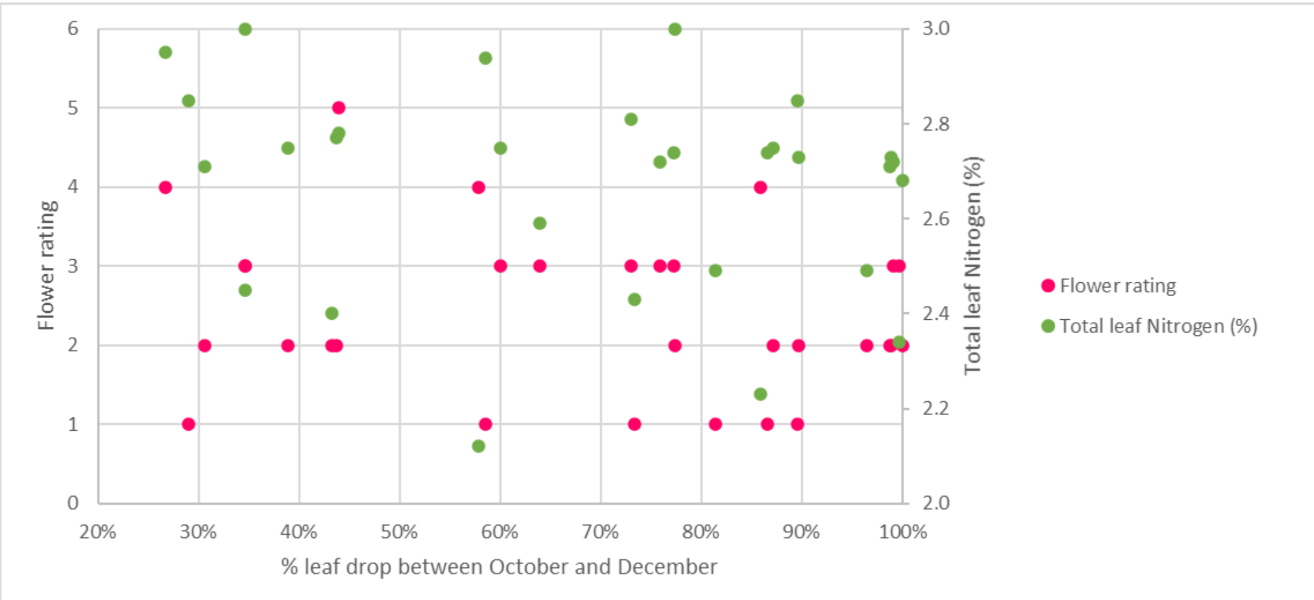

Figure 2: Association between flower rating or leaf nitrogen and % leaf drop. There was no statistically significant relationship between % leaf drop between October and December (x axis) and the flowering rating (y axis primary) or total nitrogen (y axis secondary).

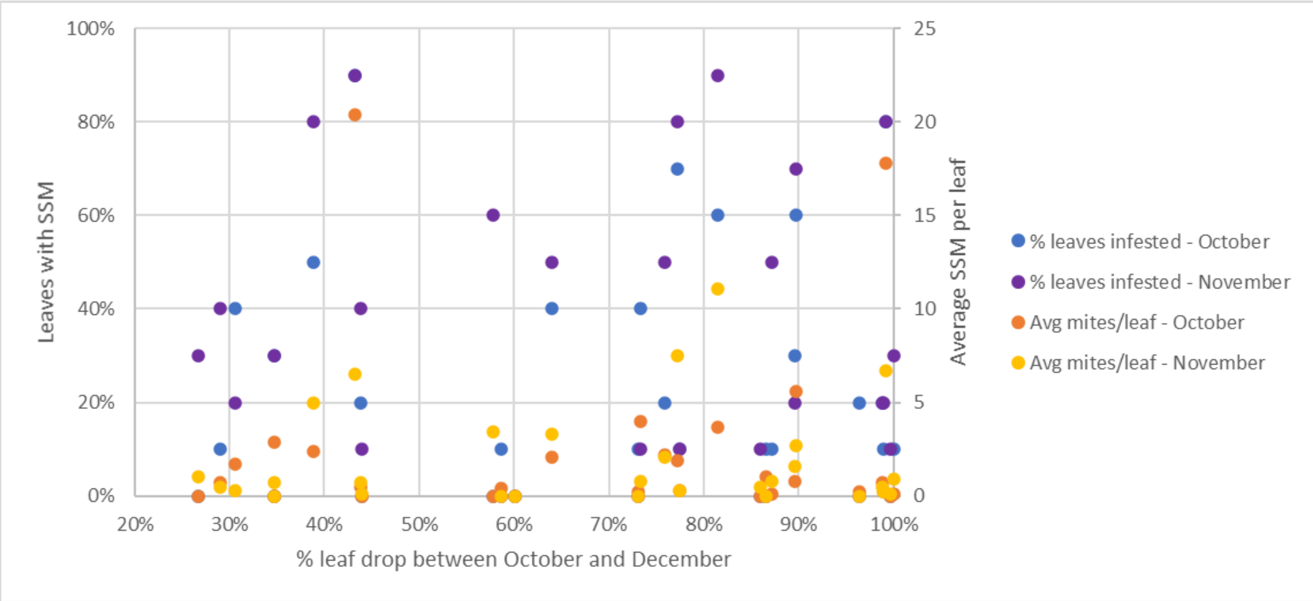

Figure 3: Association between six-spotted mites and % leaf drop. There was no statistically significant relationship between % leaf drop between October and December (x axis) and the percentage of leaves with SSM in either October or November (y axis primary) or the average number of mites per leaf in either October or November (y axis secondary).

Discussion

Two field trials were carried out on commercially managed orchards with the objectives to determine if there was a relationship between SSM numbers, leaf nitrogen, flowering and defoliation. The results from Trial 1 suggests that there were relationships between nitrogen levels and defoliation as well as the density of SSM on leaves. Higher nitrogen levels were correlated with less defoliation but also with more SSM per leaf. From these conflicting results, no recommendations as to how to manage nitrogen levels in regard to minimising SSM populations and defoliation management can be made.

Despite monitoring in trees with wide ranges of total nitrogen, defoliation and mites present in Trial 2 we were not able to determine any relationship between these variables.

While the results from both trials do not provide clear indications of relationships that could lead to management recommendations, they do highlight that there are other factors that influence spring defoliation in avocado trees and that there is unlikely to be a single SSM threshold that will lead to defoliation. Avocados naturally drop some leaves in spring. Less healthy trees tend to drop more and the trees in Trial 2 that dropped the most leaves appeared to have symptoms of dieback and/or general poor health with yellowing leaves and less dense canopies.

What remains to be determined is what the other factors are that influence spring defoliation and to what degree they do. If these factors can be quantified, then they could be measured and included in the decision-making process to reduce defoliation risk, be that a SSM threshold for miticide applications, or cultural practices such as fertilisation.

There are other plant constituents, other than nitrogen, that may play a roll. Along with nitrogen it has been postulated that amino acids, starch, and/or sugars may be related to seasonal susceptibility of Hass avocados to perseae mite (*O. perseae)* (Hoddle & Kerguelen 1999) and carbohydrates may play a role in defoliation as they move away from leaves during flowering, which is when defoliation occurs (Logan et al 2022).

Recommendations

Further research is recommended into the role of amino acids, starch and sugars in defoliation. Replicated trials should play a part in any further projects as the variables can be more accurately controlled and a broader range of treatments applied, making it more likely that causal relationships can be found. Demonstrations in commercial orchards are recommended to increase relevance and uptake to growers. Research into other aspects of tree health and stressors that may contribute to defoliation, such as fruit load and phytophthora exposure are also recommended.

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Appendix 6: SSM Action Thresholds

Background

An economic threshold for a pest is the population or damage level above which it is more economical to treat or managed the pest than not to. The pest still causes damage when present below the threshold but the economic impact at that point is less than the cost of management and so management is generally not advised. Economic thresholds are available for many pest/crop scenarios and are a valuable piece of information for growers that enables them to make informed management decisions. There is currently no economic threshold for six-spotted mite (SSM) in WA avocados.

Being only considered a pest of avocados in very few other locations around the world there are limited other thresholds on which to base a WA threshold on. California and New Zealand are the only other locations that SSM is considered a pest of avocado.

In California SSM is only considered a very sporadic pest of avocados (University of California 2017, Mark Hoddle personal communication 10th August 2020). It is such a minor pest that there is no threshold advised for it, rather the University of California (2017) simply states on their website that they rarely exceed more than an average of 2-3 mites per leaf and this is not a level to be concerned about.

There is currently no research on SSM being conducted in California and has not been for some time (Mark Hoddle personal communication 10th August 2020). More information on SSM came out of California prior to the arrival of persea mite which subsequently became a more serious mite pest of avocados. Bailey (1985) reported there had been numerous cases of "sudden and extensive defoliation of trees" occurring when there were only "a few" SSM per leaf present. In a later article Bailey and Olsen (1990) stated that defoliation occurred when SSM averaged 5 to 10 adults per leaf but there were no data included to inform this threshold.

In New Zealand it is a requirement for export avocados growers to adhere to the AvoGreen® pest monitoring protocols devised and owned by the Avocado Industry Council Ltd, now New Zealand Avocado Industry Ltd. As with California, there is no set threshold. The AvoGreen® manual (Avocado Industry Council 2018) states thresholds "have not been established" and spraying after monitoring "is at the grower's discretion", acknowledging that healthy unstressed trees can tolerate a range of SSM pressure without defoliating. However, there are suggested levels for management decisions, which are referred to as thresholds in the AvoGreen® manual. These suggested thresholds, set in the early 2010s, were based on information out of California as well as local experience and observations (David Logan personal communication). They are now under review to take into account changing climate and management practices.

AvoGreen® SSM monitoring protocols score each leaf monitored according to the number of SSM on them. If there are less than 5 mites on a leaf it is scored as low abundance, 5-10 mites on a leaf are considered moderate and greater than 10 mites are scored high. The suggested threshold is 25% of leaves scored low, or 15% of leaves scored moderate, or 10% of leaves scored high. The AvoGreen® manual also says that the threshold "should vary during the season" but does not provide any further information on what these variations are and when in the year they may occur.

What is common between California and NZ is that defoliation can occur with only low leaf densities (Bailey 1985) and low levels of feeding damage (Stevens 2000). However, defoliation is not predictable. Low leaf densities of SSM does not necessarily lead to defoliation. The experience in New Zealand is that the effect of mites is likely more important in trees that are stressed by other factors.

Even if there were other robust thresholds for SSM, based on research and extensive testing, in avocados industries elsewhere in the world they would not be directly transferable to the WA experience. Thresholds can vary with weather conditions, tree and rootstock varieties, planting densities as well as with canopy and other crop management practices.

The aim of this research was to determine a threshold for SSM in avocados by comparing the amount of leaf drop with mite densities in a broad number of orchard blocks, as Hergstrom and Niall (1990) did with T. utricae (two-spotted mite) in pears.

Method and Results

Twenty-six blocks in thirteen different orchards were monitored fortnightly over two seasons for SSM, predatory mites and other invertebrates of interest. None of the 26 monitored blocks experienced SSM induced defoliation and so no relationship could be determined.

To increase the likelihood of observing SSM induced defoliation and the associated SSM population levels multiple calls were made to the local industry asking them to inform the project team of any defoliation events in the area. Over the course of the project two orchards contacted the project team after defoliation occurred, but unfortunately in both instances a pesticide was applied to the orchard before population assessments could be done. No information from these orchards could be used to help determine a threshold.

In one of the defoliated orchards, however, variability in defoliation between trees with similar SSM levels was observed. Given the numbers of SSM eggs and levels of SSM damage observed after the miticide application it is likely that SSM were similar across the block, yet defoliation was confined to a discrete area. More information on this orchard and other field trials looking into the relationship between nitrogen, SSM levels and defoliation can be found in appendix ?

Maximum leaf densities of SSM recorded in the 26 monitored orchard blocks that did not suffer from defoliation provide a guide to the tolerance of avocados to SSM (Table 1). The table shows the maximum average number of SSM per leaf and the maximum percentage of leaves infested for each spring month for all orchards that did not receive a miticide application that spring. The defoliation risk period is in spring, September to November and none of these orchards suffered leaf drop beyond what is considered normal for that time of year.

Table 1: The maximum average number of SSM per leaf and the maximum percentage of leaves infested for each spring month for all orchards that did not receive a miticide application that spring. Highest maximums for each month of each year are highlighted.

Orchard block	Year	Max. avg. SSM/leaf			Max. % leaves with SSM		
		Sep.	Oct	Nov.	Sep.	Oct	Nov.
P1B1	2020	0.3	0.5	0.1	12%	8%	6%
P1B2	2020	1.6	7	2.9	34%	72%	56%
P2B1	2020	2.5	2.8	2.9	18%	48%	68%
P2B2	2020	0.1	0.4	0.4	4%	10%	10%
P3B1	2020	7.7	7.4	5.4	54%	58%	64%
P3B2	2020	6.1	11.2	6.8	54%	82%	76%
P4B1	2020	2.9	5.8	6.2	52%	64%	78%
P4B2	2020	3.7	8.2	9.8	42%	64%	84%
P13B1	2020	0.2	0.7	3.7	10%	14%	74%
P13B2	2020	0.1	0.7	2.1	4%	24%	44%
P1B1	2021	0.3	0.5	0.6	16%	16%	18%
P1B2	2021	4.4	3.8	10.1	40%	52%	68%
P2B1	2021	0.7	0.8	0.6	18%	18%	16%
P2B2	2021	0.1	0	0.02	2%	0%	2%
P4B1	2021	0.02	0	0.4	2%	0%	30%
P4B2	2021	1.1	0.2	1.3	8%	10%	32%
P5B1	2021	0	0	0.04	0%	0%	4%
P5B1	2021	0	0.02	0.9	0%	2%	6%
P7B1	2021	0	0.02	0.3	0%	2%	10%
P7B2	2021	0	0	0	0%	0%	0%
P8B1	2021	0.02	1.1	0.5	2%	10%	14%
P8B2	2021	0	0	0	0%	0%	0%
P11B1	2021	0	0	0	0%	0%	0%
P11B2	2021	0.1	0	0.2	2%	0%	10%
P13B1	2021	0.2	1.0	1.6	8%	20%	44%
P13B2	2021	0.4	0.9	4.3	8%	24%	50%

In spring 2020, eight of the ten unsprayed blocks had peaks above the Avogreen ‘threshold’ of 25%. Four out of ten had above the 5 mites per leaf stated as leading to defoliation in California (Bailey and Olsen 1990) with all other blocks generally in the 2-3 mites/leaf range which is deemed a level “not to be concerned about” (University of California 2017). The highest recorded levels in the three spring months of 2020 were 54% leaves infested in one in block on September, 82% in October and 84% in November. P4B2 which had the highest reading in November 2020 had 92% of leaves infested in early December. The highest average number of mites per leaf recorded in September was 7.7, 11.2 in October and 9.8 in November.

In 2021 fewer blocks received a spring miticide application, yet more blocks received an autumn application earlier in the year, leading to overall lower levels observed that spring. One block reached peaks of 40%, 52% and 68% leaves infested in September, October and November respectively and averaged over 10 SSM per leaf in November.

The above results from non-defoliating orchards should not be used to infer that all trees can withstand such high population levels without detrimental impact. Avocado trees in WA have suffered from defoliation with SSM levels around 40% leaves infested (Stewart Learmonth personal communication August 2020).

Action threshold

After discussion among the project team, based on observations and experience it has been decided that the level of 40% leaves infested be used as a ‘threshold’ in spring. In addition, an autumn ‘threshold’ of 10% leaves with SSM is also recommended. These are not economic thresholds, but rather a threshold after which action may be considered, such as applying a miticide, while also taking multiple other factors into account. The thresholds were selected based on the following two considerations.

1. Defoliation is likely to be the result of multiple interacting factors

It has been broadly recognized by growers in both Australia and New Zealand that defoliation is more severe and occurs more often in trees that are stressed. The stressors and level of stress that make trees more prone to defoliation in the presence of SSM have not been quantified but the following factors have been proposed:

- Water stress, both over and under watering
- High fruit loads in the current and previous season
- High level of flowering
- Phytophthora
- Inadequate nutrition
- General poor tree health

Other factors that growers must consider before applying a miticide relate to timing and crop and personal factors. They include:

- When has the SSM reached the threshold? Populations naturally decline in summer so if peaking later in the season they may soon decline of their own accord.
- Has the area already been harvested or do the trees have a small crop making a defoliation event less impactful?
- What are the market conditions in terms of price of fruit received and acceptance of lower grade sunburnt fruit?
- Have you experienced defoliation in that area of your orchard under similar conditions and SSM levels? Or have you experienced higher SSM levels in that that area of your orchard under similar conditions without defoliation?
- What is your personal level of risk acceptance?
- Do you prefer to hold off spraying if possible?

2. Percentage of leaves with SSM is a simple method compared with alternatives

It was decided to use percentage of leaves infested as a measure for the threshold to make the monitoring protocol as user friendly as possible. Mites are very small and there are several species commonly found on avocado leaves that can be difficult to differentiate under 10x magnification, particularly for people with less monitoring experience. Currently in

WA there is only one company that provides a crop monitoring service for avocado growers in the southwest. With this project recommending that all growers in the area undertake mite monitoring it is likely that many growers will do their monitoring 'in-house', meaning that often the monitors will be less trained, less experienced, and therefore less likely to be able confidently and accurately count mites on leaves. In New Zealand AvoGreen® monitoring must be done by an accredited pest monitor, who is trained and audited. This can be done in-house but growers often use contract crop monitors who are experienced people that regularly monitor crops and are able to quickly and easily identify and count SSM. It is thought that using a presence/absence scoring system, that provides a percentage of leaves infested, will be simpler and faster for growers doing their own monitoring, compared to having to count mites per leaf, and will lead to greater uptake.

The sole use of percentage of leaves infested without the need to count beyond one mite per leaf differs from both the California and New Zealand thresholds where numbers of mites per leaf are counted. Data from the fortnightly monitoring as part of this project has shown that there is a relationship between the percentage of leaves infested and the average number of mites per leaf all year round as well as in both spring and autumn, the two seasons when monitoring is most critical, figures 1, 2 and 3.

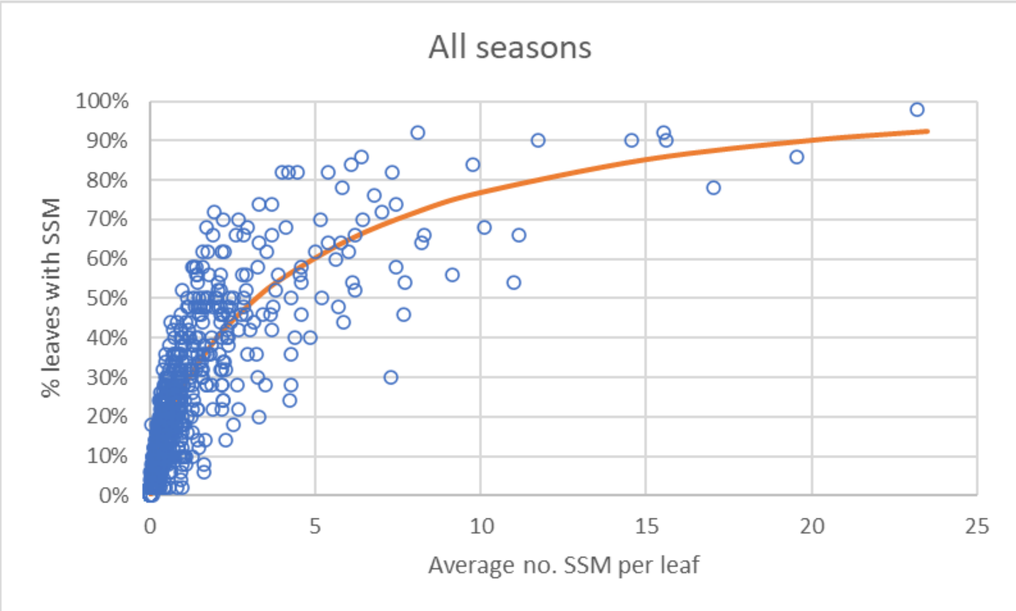

Figure 1: Relationship between the average number of SSM per leaf and the percentage of leaves with SSM from all monitoring data taken fortnightly from 26 orchards blocks from approx. December 2019 to June 2022. y=1-0.72534^(x^0.6578). R^2 81%

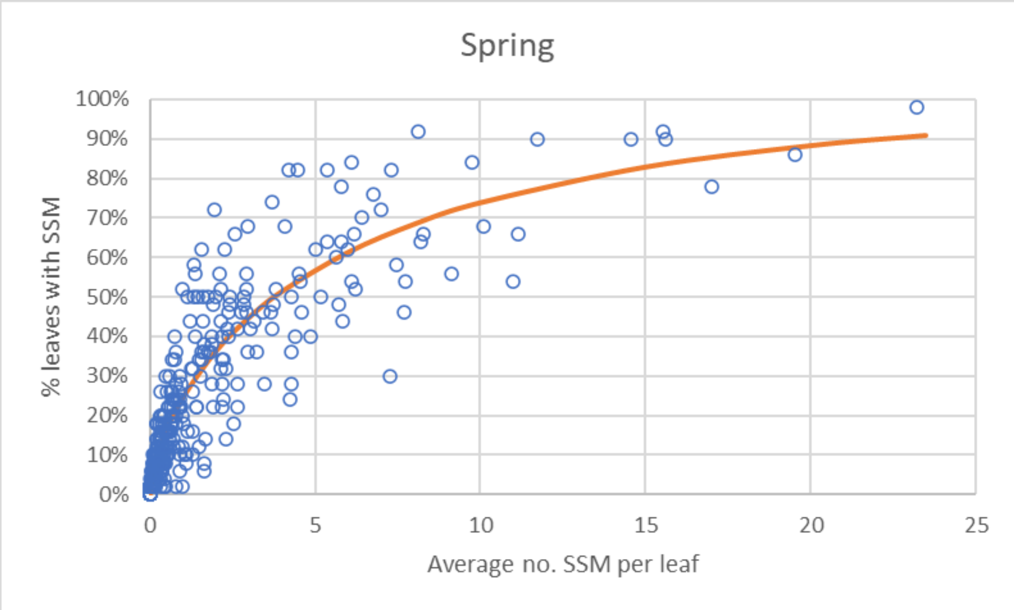

Figure 2: Relationship between the average number of SSM per leaf and the percentage of leaves with SSM from all monitoring data taken fortnightly from 26 orchards blocks over September, October and November in 2020 and 2021. y=1-0.75368^(x^0.6744). R^2 81%

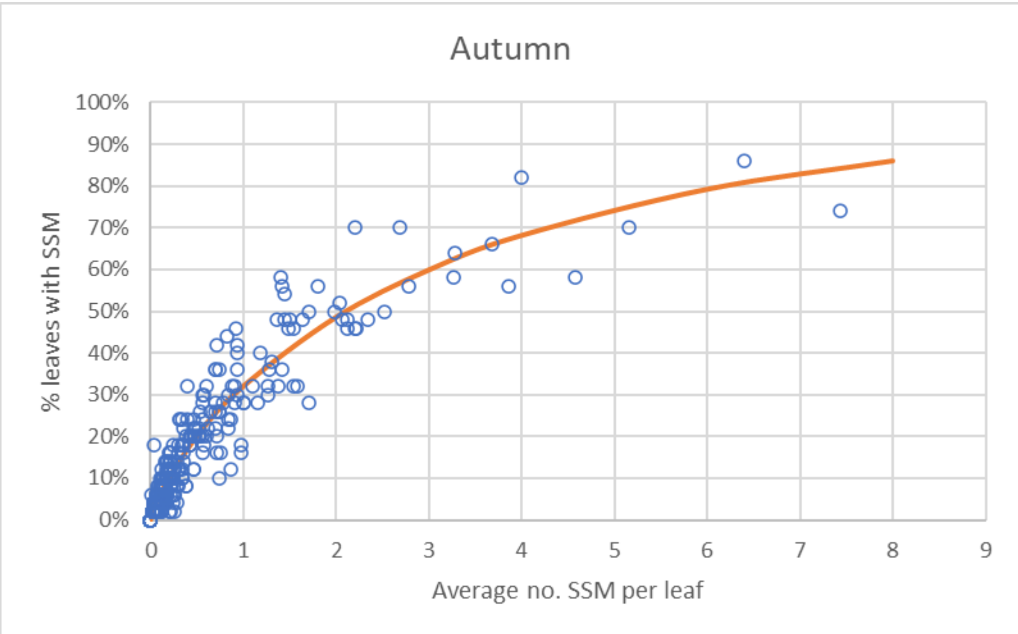

Figure 3: Relationship between the average number of SSM per leaf and the percentage of leaves with SSM from all monitoring data taken fortnightly from 26 orchards blocks over March, April and May in 2020 and 2021. y=1-0.67862^(x^0.7841). R^2 91%

This relationship gives confidence in using percentage leaves infested as a valid monitoring and threshold method. By using the trend line equation, the suggested threshold for WA can be compared with information out of California. 2-3 SSM per leaf is suggested as a level not to be concerned about (University of California 2017), in spring when defoliation generally occurs, in WA this equates to 36-45% leaves with SSM. The level of 5-10 mites per leaf, when defoliation will occur (Bailey and Olsen 1990) equates to 57-74% leaves with SSM. The WA threshold is therefore lower than the rough guidelines currently in place in California, however, perhaps more in line with earlier extension messages from California that suggested “only a few” (Bailey 1985) SSM were needed to cause defoliation.

In comparison the NZ threshold of 25% of leaves with less than five SSM per leaf, while not directly comparable to the WA threshold is lower than the 40% of leaves with any number of SSM. The proposed spring threshold for WA sits between the California and NZ thresholds.

Autumn threshold

In addition to the spring threshold, we propose that an autumn threshold is also required by growers. Autumn is considered as March to May. Over the course of this project autumn miticide applications have shown to be effective in reducing SSM numbers the following spring and therefore are an effective management strategy and preferred option by some growers; as discussed in more detail in the case studies in appendix 7.

The autumn threshold is based on the 40% spring threshold, with the aim of autumn management to prevent numbers reaching 40% the following spring. For properties that did not receive an autumn or early spring pesticide application the maximum percentage of leaves with SSM in autumn was compared with the same measurement the following spring. There were 35 seasonal pairs that were analysed. Only five of the 35 seasonal pairs analysed had 30% or more leaves with SSM in autumn, all of those went on to have 40% or more leaves with SSM the following spring. 81% of the seasonal pairs with more than 20% leaves with SSM in autumn exceeded the spring threshold. 86% of seasonal pairs with more than 10% of leaves with SSM in autumn exceeded the spring threshold. It is suggested that an autumn ‘threshold’ of 10% leaves with SSM be used.

It should be noted that of the 20 seasonal pairs that had fewer than 10% of leaves with SSM in autumn, 12 exceeded the spring ‘threshold’ of 40% of leaves with SSM. For this reason, monitoring should take place in spring even if low numbers are found in autumn.

Discussion

While the preferred outcome for industry would be a clear economic threshold for SSM within avocados in WA this was not possible to produce as part of this project. The disadvantage of working in commercial orchards is that if pests reach high levels the growers are likely to want to control them, as was the case in this project, and as a result no incidences of SSM induced leaf drop were observed. To have the best likelihood of devising such a threshold a more intensive and extensive studies are required. This could include widespread studies of orchards to increase the chances of encountering blocks with SSM induced defoliation, pot studies of trees inoculated with set levels of SSM and blocks of mature trees with various SSM levels that are not controlled with miticides.

Although, given the large variability in SSM levels in anecdotal reports of leaf drop and the frequently reported link between tree stress and SSM induced defoliation it is likely that the relationship between SSM levels and defoliation will not be a simple one. This complexity certainly added to the difficulty in setting a threshold in this project and no doubt also has in California and NZ, hence the lack of thresholds for the Avocado SSM complex anywhere in the world. If an economic threshold is developed in the future, it should not be expected to be a single number for a certain time of year. It could be a variable threshold that incorporates a measure of tree health/stress, therefore similarly incorporating the recommendations developed by this project to take into account factors related to tree stress, crop and market factors.

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Appendix 7: Management Case Studies

Introduction

Case studies of SSM management strategies used in commercial orchards provide a useful tool informing recommendations for future management. Particularly as was the case in this project when replicated trials of various management strategies were not possible.

These case studies are of pesticide applications to reduce SSM numbers. The first group of case studies come from the 26 orchard blocks that were regularly monitored during this project. They include examples of orchards that did not apply any pesticides as well as those that used conventional miticide products for SSM control.

There was also interest from growers in alternative products that may be effective against SSM. A literature review of alternative products was conducted and has been included in this report. Following the review, a case study of spray oil use for SSM control was developed in an orchard that was not being regularly monitored, which is the final case study in this report.

Case Studies

Method

In each monitoring block ten trees were tagged and monitored every fortnight for just over 2 years. On each monitoring occasion five leaves were taken from each of the ten trees in each block. Leaves from each tree were placed together in a paper bag then inside a plastic zip-loc bag and kept cool until arthropods were counted using a stereomicroscope. Arthropods included SSM motiles and eggs, predatory mite motiles and eggs, tydeid mite motiles and other arthropods of interest, such as stethorus. These were counted using a stereomicroscope within 48 hours of leaf collection. Results from this monitoring were regularly provided to the growers involved.

Each grower made their own decisions on whether and when to apply a miticide and how to apply it. After miticides were applied growers provided the following information:

- Application date
- Product used
- Product rate applied
- Water volume applied
- Other products, if any, that were mixed in the tank
- Type of sprayer used

The monitoring results after each miticide application were checked to determine if it was an effective or sub-optimal application. Effective applications were deemed to be those where SSM levels post application declined to negligible levels. Sub-optimal applications were those where SSM levels did not decline, declined less than would be expected or the period of time that SSM levels remained low after application was shorter and not equivalent to observations made in other orchards. When there was a sub-optimal application, all known factors for that application were taken into account to determine where improvement could be made in the future. Factors taken into account were:

- Application rate
- Water volume applied (L/ha)
- Weather conditions on the day of spraying
- Type of sprayer used
- Size of trees
- Any follow-up miticide applications

It must be understood that the reasons for sub-optimal applications proposed here are not definitive. There may be other unknown factors at play, or compounding factors that un-replicated single application examples could not identify. However, the reasons proposed are those considered the most likely reason for the sub-optimal results and are valid and useful examples to understand and learn from to improve future miticides applications for all growers.

No miticide applied

Of the 26 regularly monitored orchard blocks six did not receive any miticide applications over the project period and two further blocks did not receive a miticide application until the second last month of monitoring.

Five of these blocks exceeded the 40% leaves with SSM 'threshold' in both spring 2020 and 2021, P1B2, P4B1, P4B2, P13B1 and P13B2 (figures 1, 2, 3 and 4). Another block exceeded 40% of leaves with SSM in one spring only, P2B1 (figure 5). In some cases, these blocks exceeded the 'threshold' by a considerable amount. P4B2 had more than 90% of leaves with SSM in spring 2020. P1B2, P4B1 and P13B1 had in excess of 70% of leaves with SSM in spring 2020. None of these eight blocks had any SSM induced defoliation over the project monitoring period.

The remaining two blocks, P1B1 and P2B2, had smaller spring peaks of SSM, with less than 25% of leaves with SSM (figures 6 and 7). Despite having low peaks SSM were almost always present over the monitoring period. In P1B1 only very occasionally were no SSM found during the fortnightly monitoring.

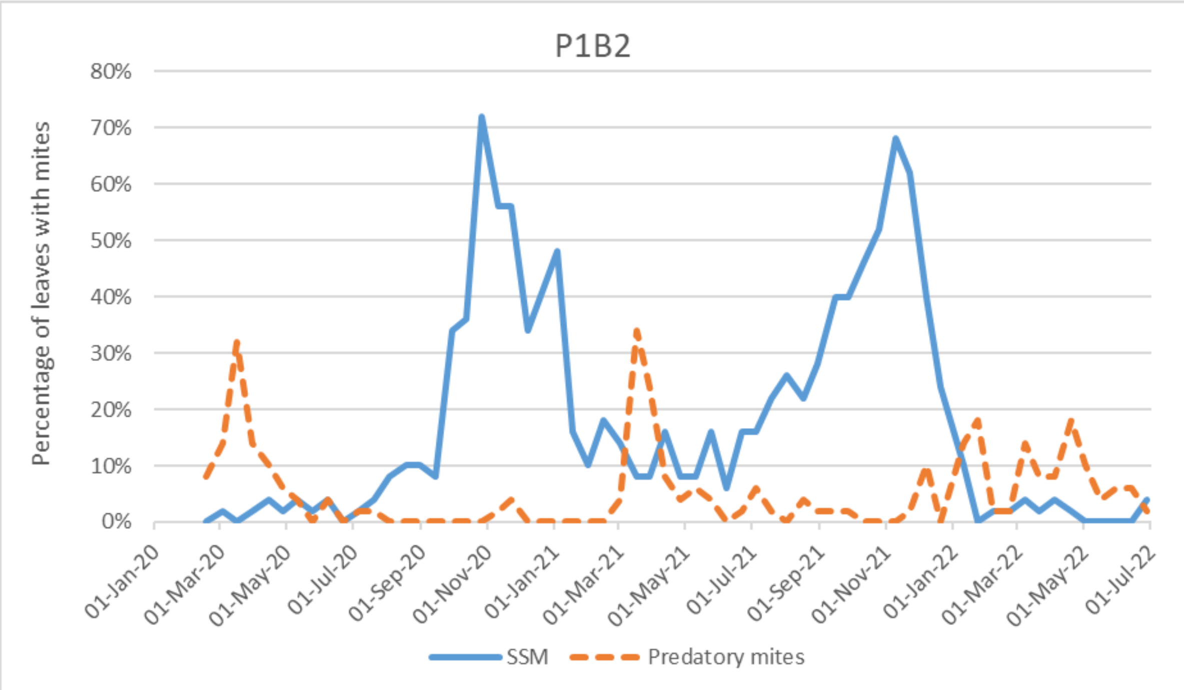

Figure 1: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P1B2 in which no miticides were applied over the project monitoring period.

The percentage of leaves with SSM often decline in early to mid-summer without application of miticides. This occurred in block P1B2 in summer 2021/22, when the percentage of leaves with SSM fell from 62% on the 22nd of November to 24% on the 20th of December and then to 0% on the 24th of January. Similar declines occurred in other blocks. P4B1 had 78% of leaves with SSM on the 4th of November, 56% on the 2nd of December and 6% on the 14th of December. P4B2 had 92% of leaves with SSM on the 2nd of December, 84% on the 14th of December, 36% on the 12th of January and only 8% on the 25th of January. P13B1 also experienced a steep decline in SSM, going from 74% of leaves with SSM on the 23rd of November to 18% on the 7th of December and 8% on the 4th of January. These declines are not as steep as those that occur with effective miticide applications.

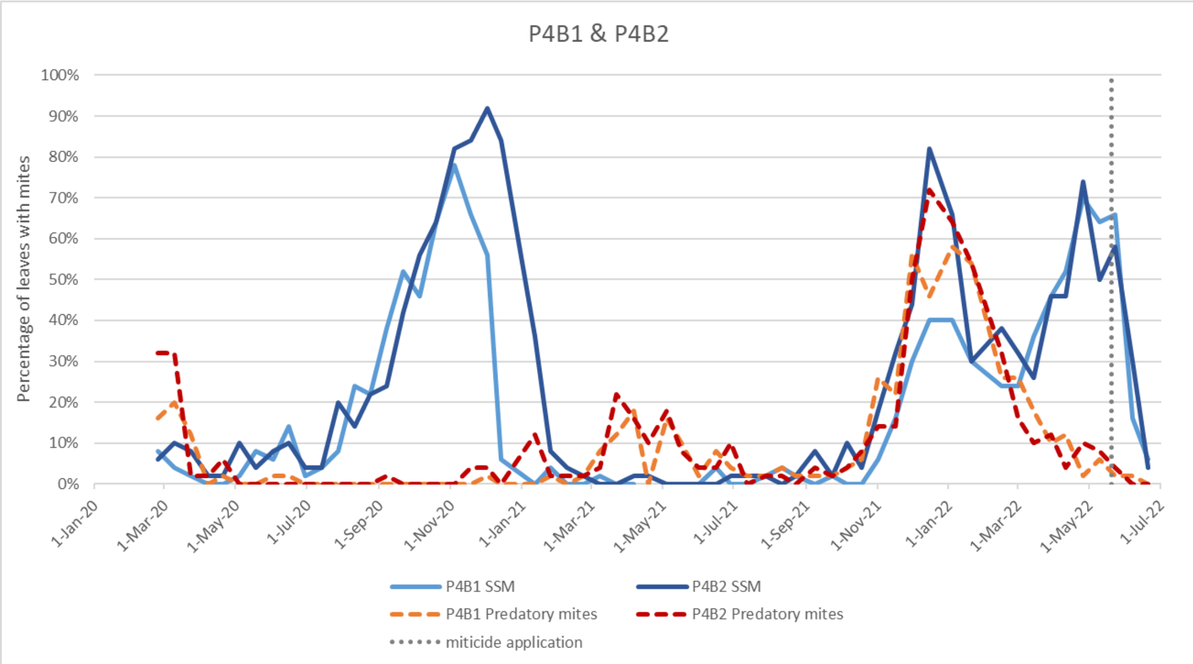

Figure 2: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in blocks P4B1 and P4B2 in which no miticides were applied over the project monitoring period.

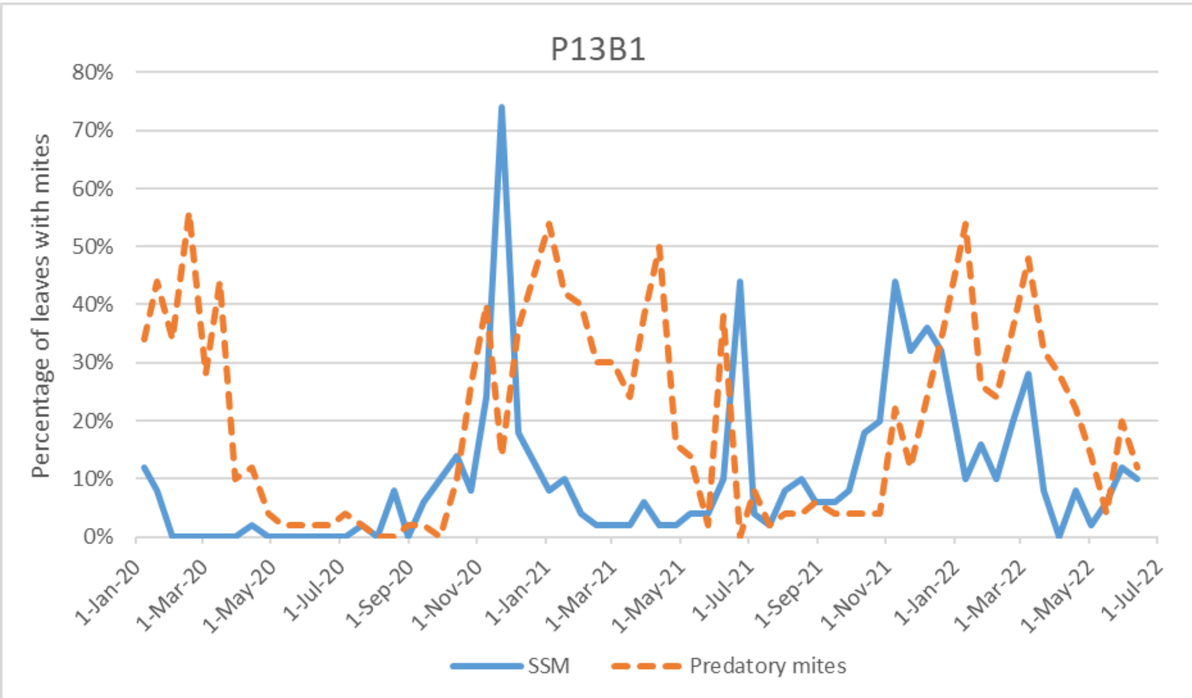

Figure 3:

Figure 3: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P13B1 in which no miticides were applied over the project monitoring period.

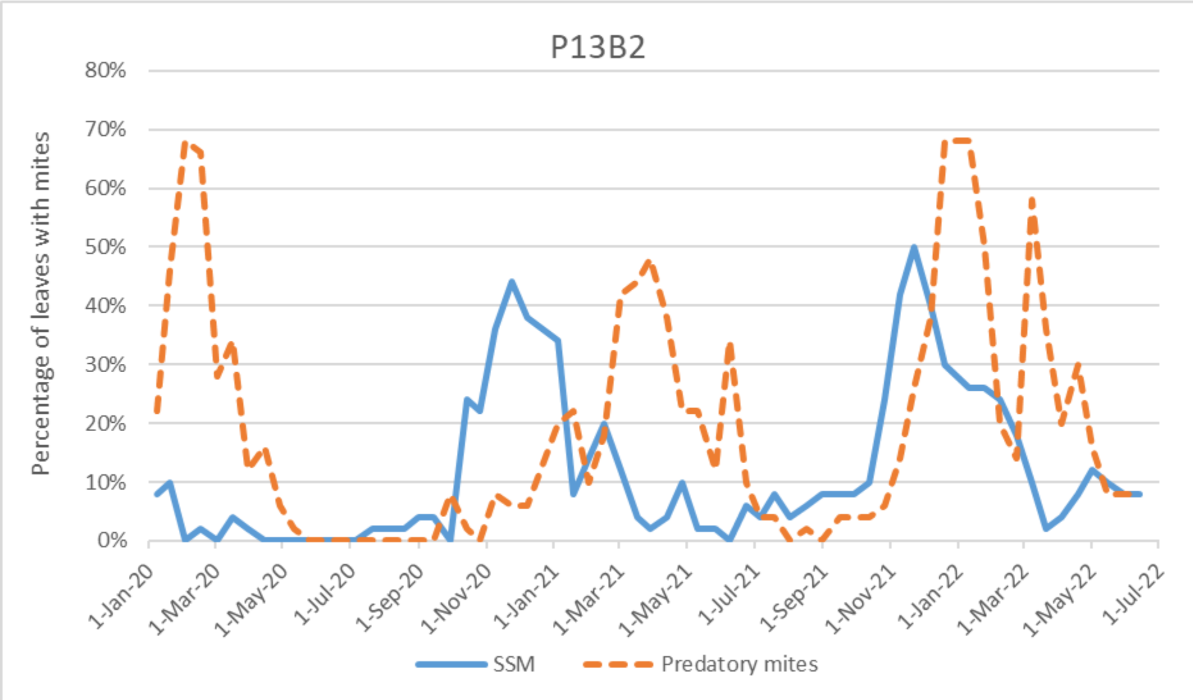

Figure 4: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P13B2 in which no miticides were applied over the project monitoring period.

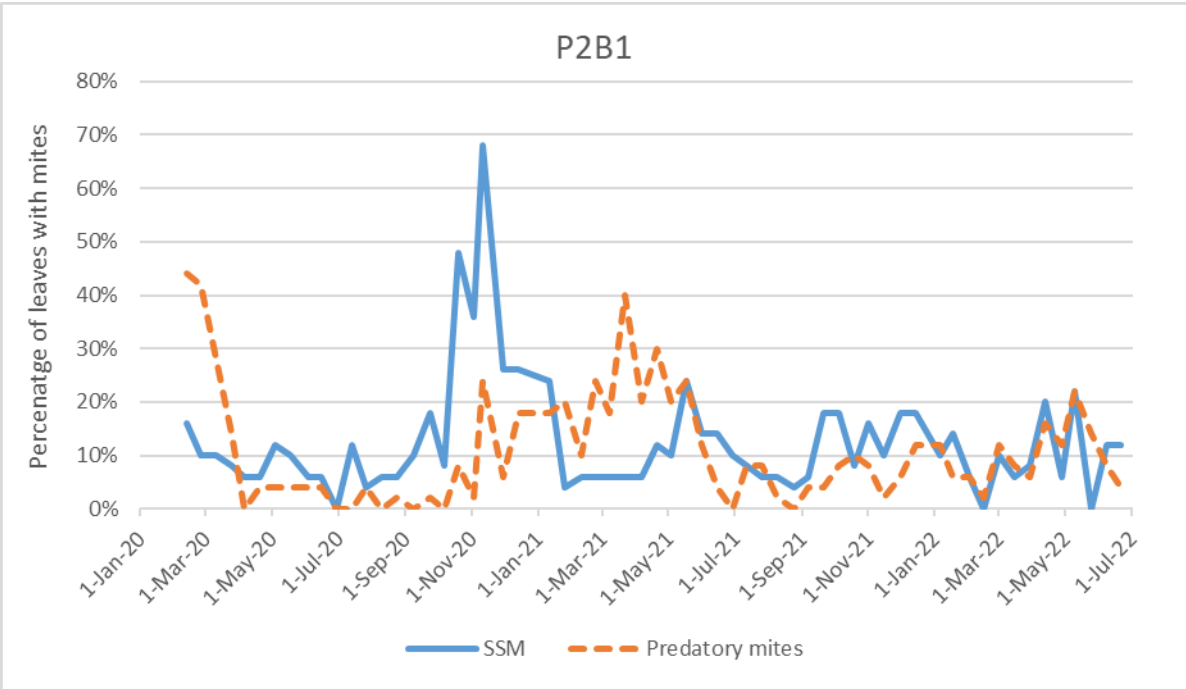

Figure 5: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P2B1 in which no miticides were applied over the project monitoring period.

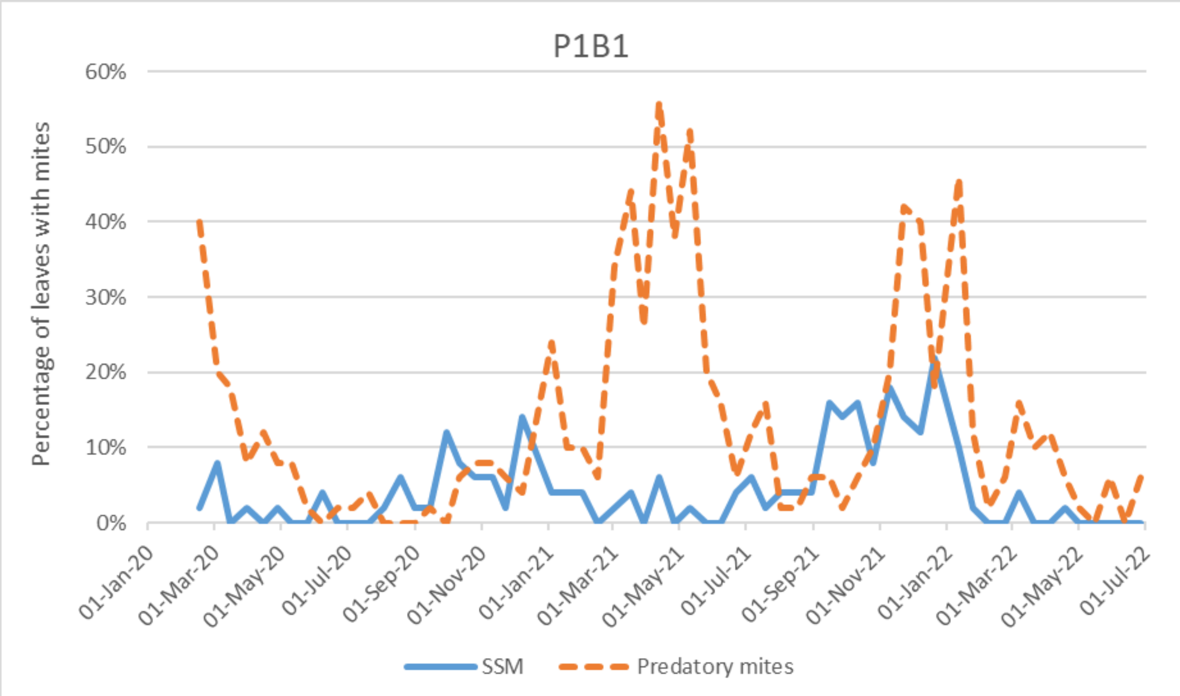

Figure 6: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P1B1 in which no miticides were applied over the project monitoring period.

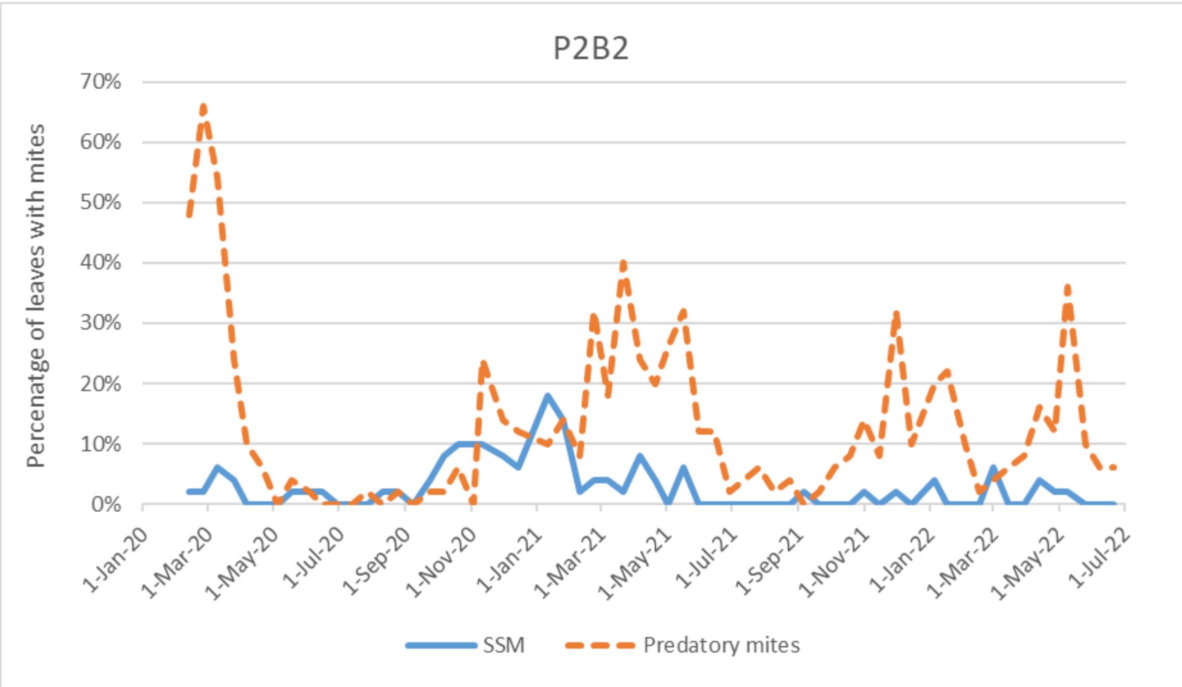

Figure 7: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P2B2 in which no miticides were applied over the project monitoring period.

Three important learnings can be taken from these case studies.

1. High SSM levels in spring do not always lead to defoliation.
2. The presence of SSM does not necessarily lead to the population increasing to potentially damaging levels.
3. SSM populations can fall steeply over summer without intervention.

Management practices should take these learnings into account. Monitoring needs to be done regularly to determine if numbers are increasing, decreasing or remaining stable. If numbers remain low then intervention, such as miticide application, is not required. If SSM numbers do increase, then other factors need to be taken into account before the decision to apply a miticide is made as defoliation will not necessarily occur. There are many other factors that influence defoliation, not all of these are known but are likely to include things that contribute to tree stress, such as high fruit load, a high level of flowering, pressure from disease and other pests, excessive or deficient water and nutrient levels. Beyond tree health and the associated risk of defoliation the decision to apply a miticide must also take into account the time of year and if SSM may decrease naturally soon, the personal/business inclination to spray, as well as the impact a defoliation event would have. Under certain circumstances and in some seasons a defoliation event will be less impactful, such as if the potential income loss from downgraded quality of fruit is minimal or if the crop has already been harvested and so no fruit will be sunburnt due to defoliation that season. The longer term impact of defoliation on tree health and subsequent yield and fruit quality has not been researched.

Effective miticide applications

There are examples of effective miticide sprays applied in both spring and autumn. There are four actives ingredients with label registration or minor use permits for use against SSM; fenbutatin oxide, etoxazole, abamectin and bifenazate. Only fenbutatin oxide and etoxazole were used by growers in this study.

Four blocks from three orchards were effectively sprayed with etoxazole in autumn 2021, P11B1, P11B2, P6B2 and P3B1 (figures 8, 9 and 10). SSM numbers remained low in these blocks through the following spring, so no miticides had to be applied then. No SSM were recorded until early December in P11B1. SSM started to increase earlier in P11B2 than P11B1 but only reached a peak of 12% of leaves with SSM and that was not until mid-December. In P6B2 only a single SSM was recorded from May through to December 2021 and numbers did not reach over 5% of leaves with SSM until February 2022. In P3B1 0-2% of leaves had SSM from June through to October when another etoxazole spray was applied. This application will be discussed later in this section on effective sprays.

SSM numbers increased in autumn 2022 in P11B1, P11B2 and P6B2 and etoxazole was applied again then.

These case studies demonstrate exactly what is being aimed for with an autumn application. SSM numbers generally naturally decline coming into winter. An application of a miticide in autumn, when SSM are still present, can reduce the population substantially so that when the population does start to increase again the following spring it is starting from a lower base leading to a later and lower spring peak. If the population increase is delayed until late spring and/or summer, then only low numbers will be present during the spring defoliation risk period negating the need to spray at that time of year.

There are several factors that can make autumn applications preferable to spring applications:

- With-holding periods are not a concern as harvest is several months away.
- Worker safety and re-entry periods are less of a concern as there are fewer workers in the orchard compared to spring.
- Bee safety of the available active ingredients is less of a concern as the crop is not in flower and hives are not in the orchard.
- There can be more suitable spray days in autumn in regards to temperature, rain and wind conditions. There can also be more flexibility in waiting for a good spray day as harvest schedules and timing of hive deliveries and retrievals do not have to be taken into account.

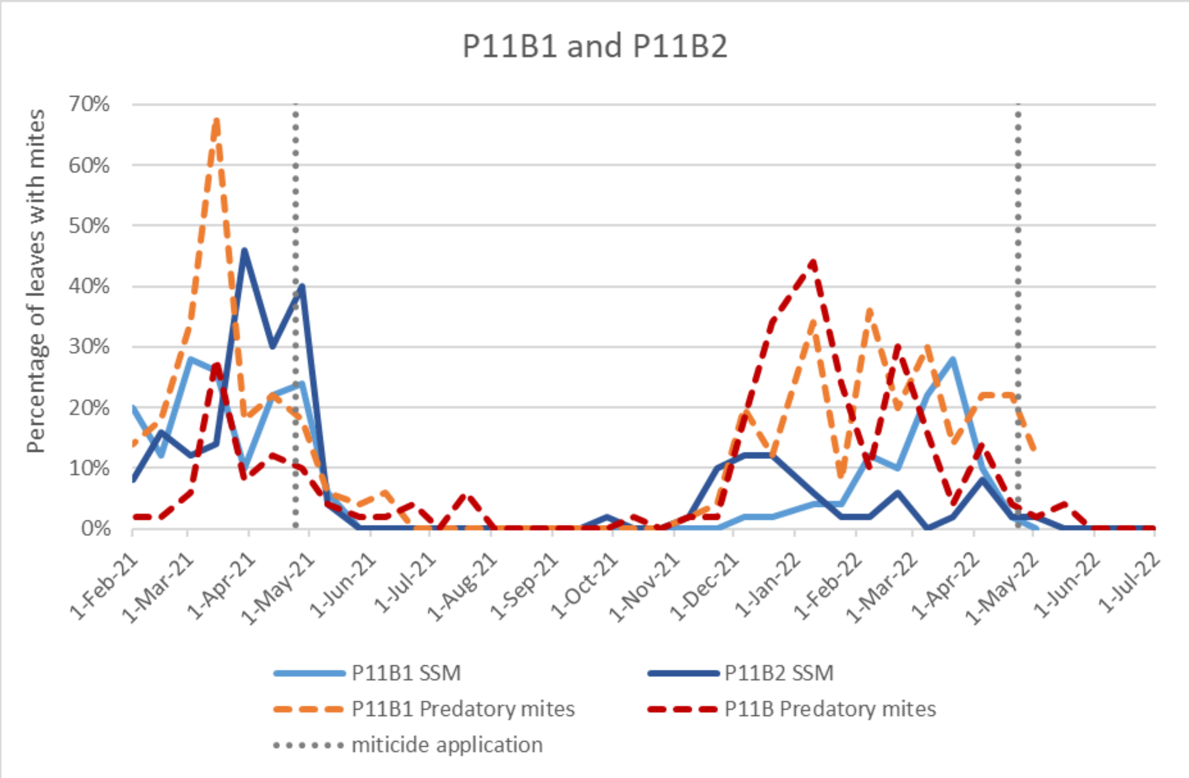

Figure 8: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in blocks P11B1 and P11B2. Etoxazole was applied on the 24th April 2021 at a rate of 35mL/100L and 1500L/ha with a Silvan airblast sprayer.

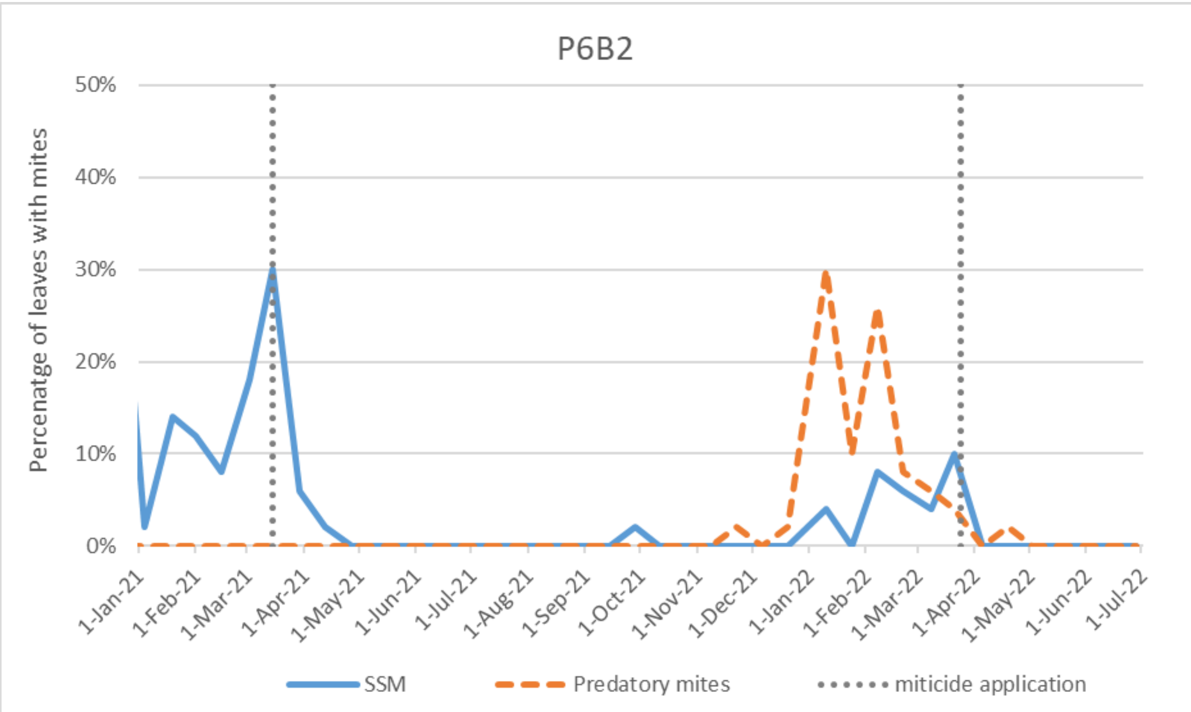

Figure 9: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P6B2. Etoxazole was applied on the 15th March 2021 at a rate of 35mL/100L and 450L/ha with Du-Wett added using a Croplands tower sprayer. Etoxazole was applied on 24th March 2022 at a rate of 35mL/100L and 2500L/ha using a Silvan airblast sprayer.

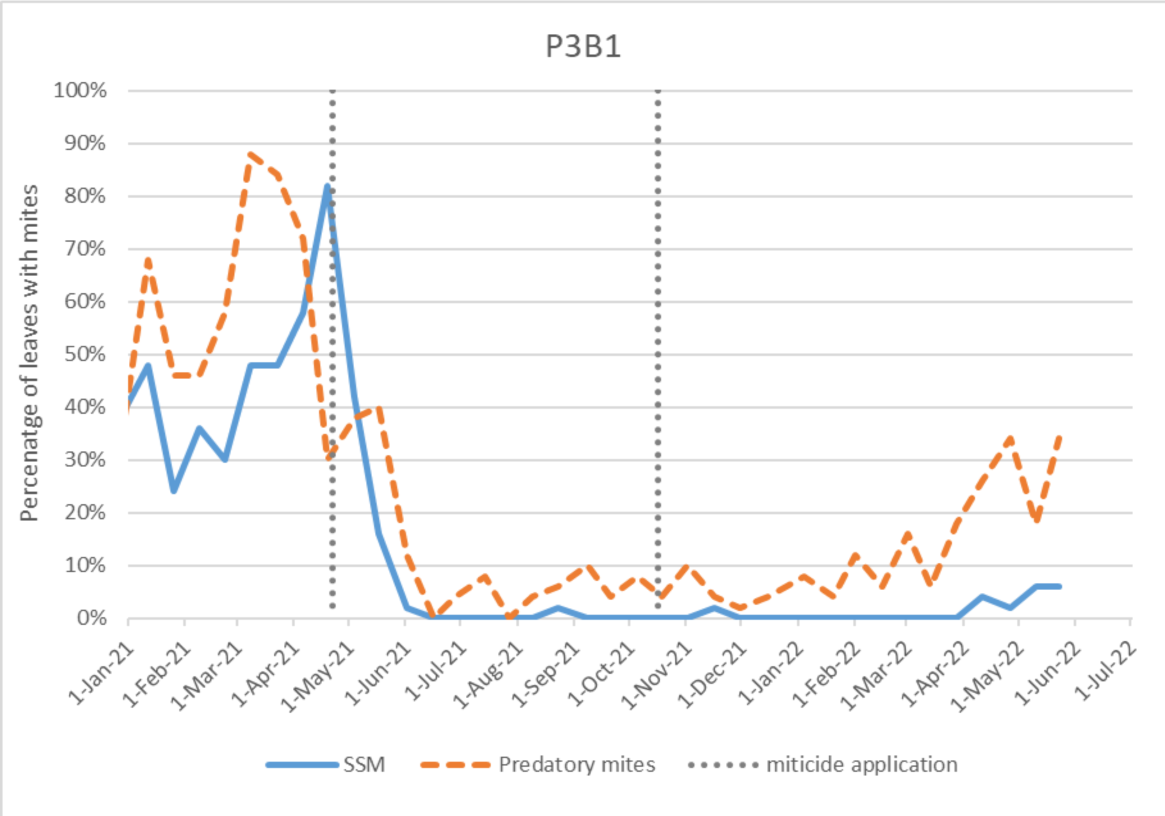

Figure 10: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P6B2. Etoxazole was applied on the 22nd April 2021 at a rate of 35mL/100L and 1000L/ha with a wetter added. Etoxazole was applied on 16th October 2021 at the same rate but no wetter added.

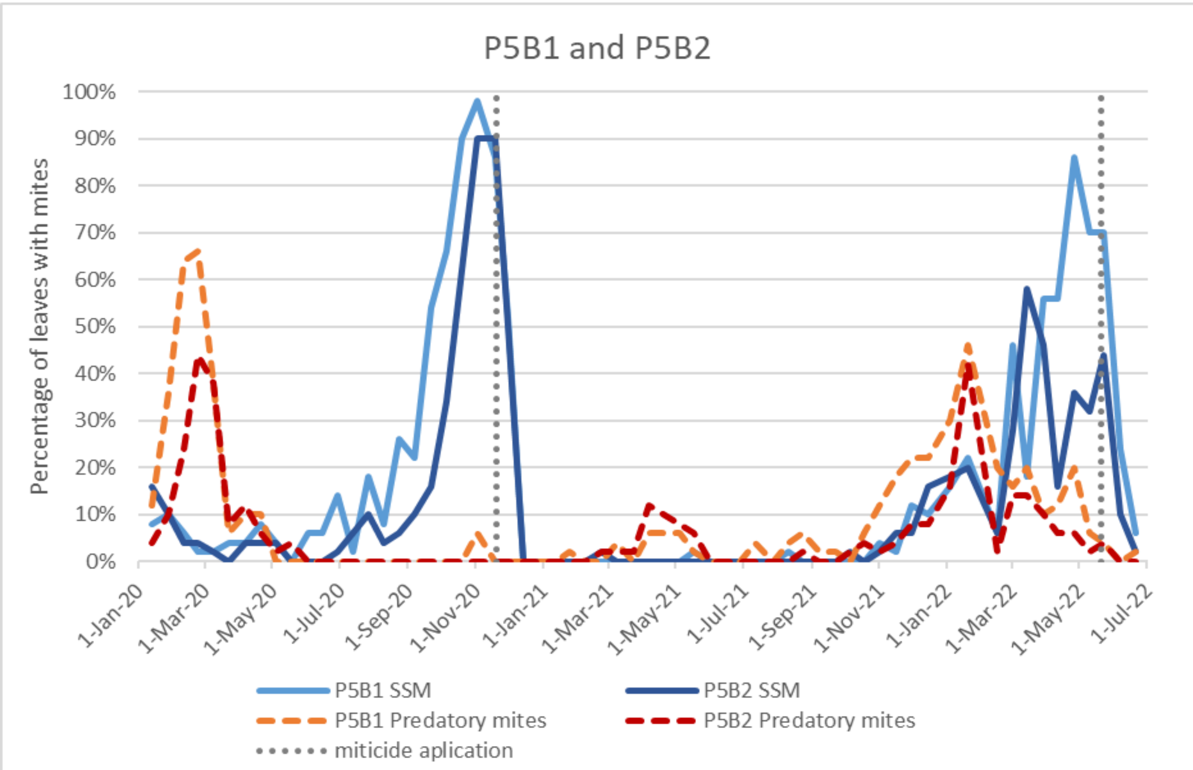

Figure 11: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in blocks P5B1 and P5B1. Etoxazole was applied to both blocks on the 19th November 2020 and 20th May 2022 at a rate of 35mL/100L and 2500L/ha with a Silvan airblast sprayer.

Spring applications are used to reduce SSM numbers and defoliation occurring in that same season. Six blocks from three different orchards, P5B1, P5B2, P3B1, P3B2, P8B1 and P8B2 all received spring applications of etoxazole, that effectively reduced the percentage of leaves with SSM (figures 8, 9, 10 and 11).

There were 86% and 90% of leaves with SSM on the 18th of November 2020 in blocks P5B1 and P5B2 respectively, on the day prior to etoxazole being applied. SSM numbers were 52% and 50% on the 30th of November, respectively and none recorded on the 14th of December. The percentage of leaves with SSM remained very low, often at 0% for the next 11 months. Numbers did start increasing again in November 2021 but remained below the spring 'threshold' and so no miticide was applied until autumn 2022.

These blocks can be compared to P4B1 and P4B2 (figure 2) which are from a neighbouring orchard. They had a very similar increase in SSM in spring 2020 but no miticides were applied. SSM numbers also declined in these blocks in mid to late summer 2020/21. As with P5B1 and P5B1 numbers remained low throughout winter and spring, but not as consistently low, and when they increased in November 2021 it was much more rapidly and with a higher peak.

The etoxazole applications to P3B1, P3B2, P8B1 and P8B2 clearly show that it is not a knock-down miticide. Etoxazole is a mite growth regulator that causes adults to lay sterile eggs and stops existing eggs and nymphs from developing. The SSM will not die immediately, with adults continuing their natural life expectancy, but no further generations will come through. This leads to a slow decline in numbers over several weeks, rather than an immediate drop as would be seen with a knock-down. This gradual decline in numbers needs to be taken into account when choosing which product to apply. The remaining adults are still able to feed and do damage to the crop. If numbers are very high or there is high risk of defoliation occurring soon then a knock-down, such as fenbutatin oxide or abamectin, may be preferable.

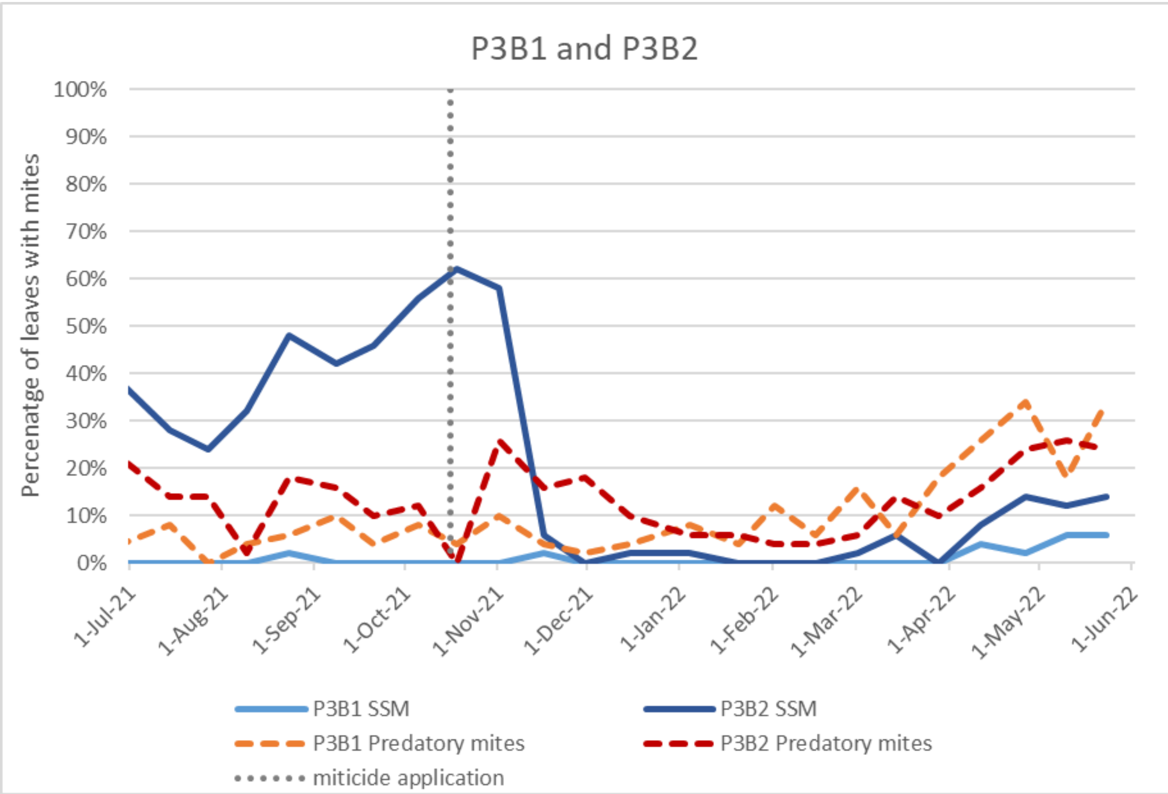

Figure 12 Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in blocks P3B1 and P3B2. Etoxazole was applied to both blocks on the 16th October 2021 at a rate of 35mL/100L and 1000L/ha with a Silvan airblast sprayer.

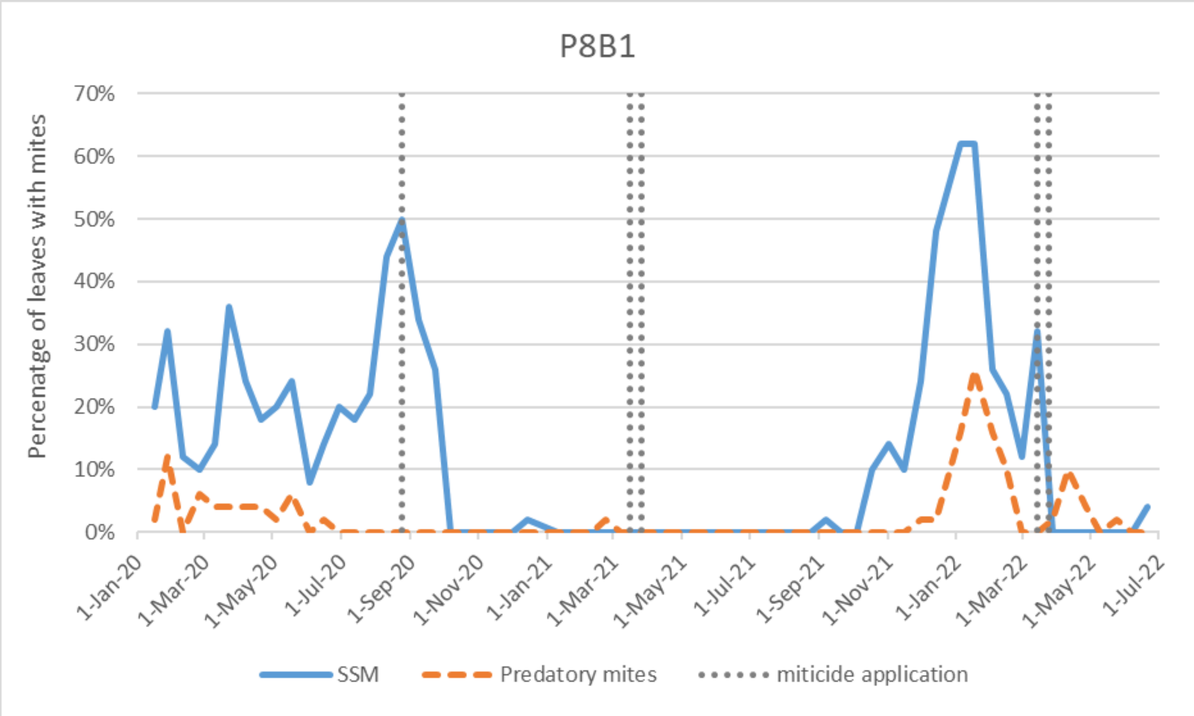

Figure 13: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P8B1. Etoxazole was applied on the 24th August 2020 at a rate of 35mL/100L and 2500L/ha with a Croplands airblast sprayer. Fenbutatine oxide was applied on the 16th and 26th March 2021 and the 14th and 24th March 2022 at 38mL/100L and 2300-2500L/ha.

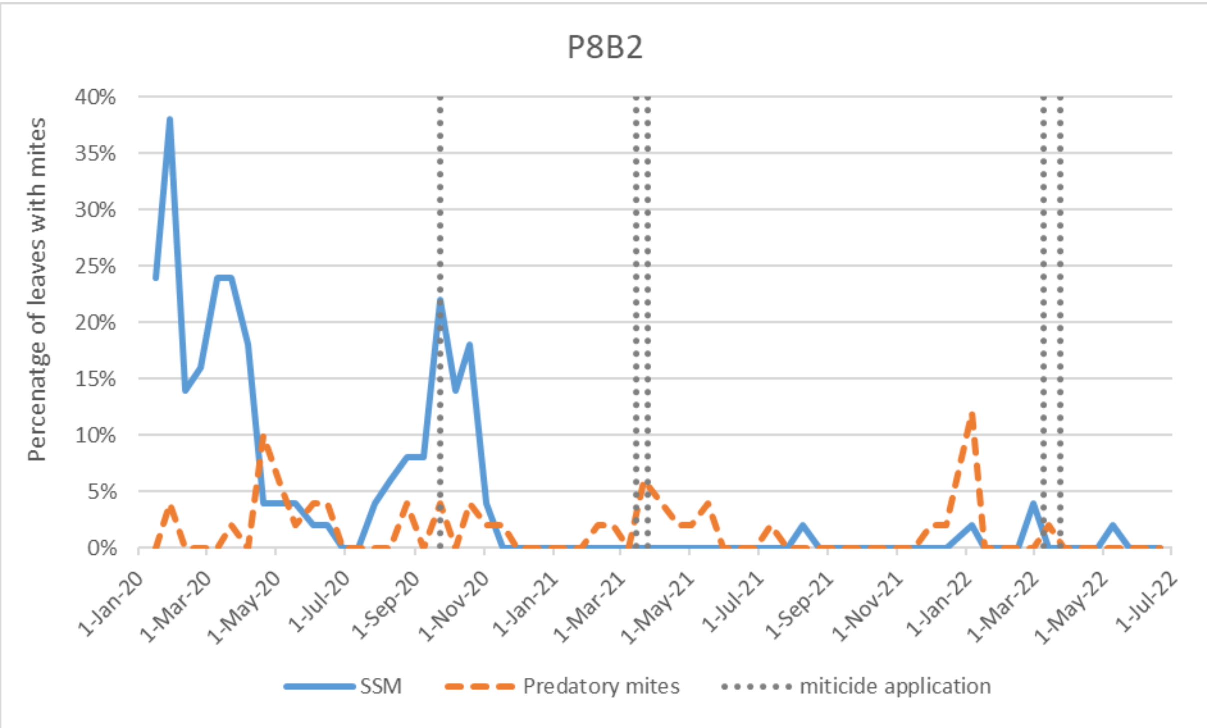

Figure 14: Percentage of leaves with SSM and predatory phytoseiid mites recorded fortnightly in block P8B2. Etoxazole was applied on the 23rd September 2020 at a rate of 35mL/100L and 2000L/ha with a Croplands airblast sprayer. Fenbutatine oxide was applied on the 15th and 25th March 2021 and the 10th and 24th March 2022 at 38mL/100L and 2250-2300L/ha.

P8B1 and P8B2 also received fenbutatin oxide applications in autumn 2021 and autumn 2022. It cannot be determined how effective these applications were as the SSM numbers prior to application were low in all instances except for the autumn 2022 application in P8B1 but monitoring was ceased before spring 2022 when the effectiveness of that spray could be assessed. However, the monitoring data from March through to June from P8B1 are promising that it was an effective spray.

It may look questionable that a total of six miticide sprays were applied in these blocks when the SSM appeared to be so low and there was no apparent justification to spray in March 2021 and 2022. However, it must be noted that the monitoring as part of this project was from ten trees in two adjacent rows, out of an entire block often with several hundred trees. The managers of P8B1 and P8B2 conduct their own regular monitoring more widely over all of their orchards blocks and the decision to spray was made based on this broader monitoring that did show that SSM were present. These examples highlight the need to monitor broadly in all blocks and be aware that the distribution of mites throughout a block is not even. Also, if areas with low SSM levels are consistently being sprayed with miticides due to high numbers elsewhere in the block then perhaps the size of the management blocks should be reconsidered to reduce the time, cost and resistance management impact of applying unnecessary sprays.

P3B1 is another example of a miticide being applied to an area where low mite numbers have been recorded. In this case the neighbouring block P3B2 had high SSM numbers in spring 2021 and it was decided to spray both blocks at the same time despite low SSM numbers in P3B1. Given the positive result from the autumn application and examples from other orchards it is likely that P3B1 would also have maintained low SSM levels through spring and the spring spray was not necessary. This highlights the importance of monitoring and managing each block separately to ensure miticides are only used when necessary to only the areas that require it.

Learnings

1. Both spring and autumn sprays can be effective.
2. Be aware of how each active ingredient works, i.e. is it a knock-down or not, and use the product best suited to your situation
3. With effective sprays a single application round per year, or less, can maintain the population below the ‘threshold’ in the spring risk period.
4. Monitor across a whole block, not just a small area. Keep monitoring records and alter monitoring and management areas if need be.
5. Monitor and manage all blocks separately.

Sub-optimal miticide applications

The case studies of sub-optimal SSM control with miticide use encompass a range of scenarios and possible causes of spray failure, including:

- Lack of follow-up spray
- Temperature at time of application
- Poor spray coverage due to low water volumes, large tree size and/or poor canopy penetration

Lack of follow-up spray

SSM numbers increased in block P11B2 through September 2020, reaching 32% of leaves with SSM on September 29th (figure 14). The grower applied a miticide on the 5th of October. Febutatin oxide was applied at the recommended rate 38mL/100L and at a water volume of 1500L/ha with no wetting agent added using a Silvan airblast sprayer. SSM numbers decreased to 28% on the monitoring occasion immediately following the miticide application but then increased again to 36%. Numbers did not decline to below 10% until mid-January, which can happen naturally at that time of year.

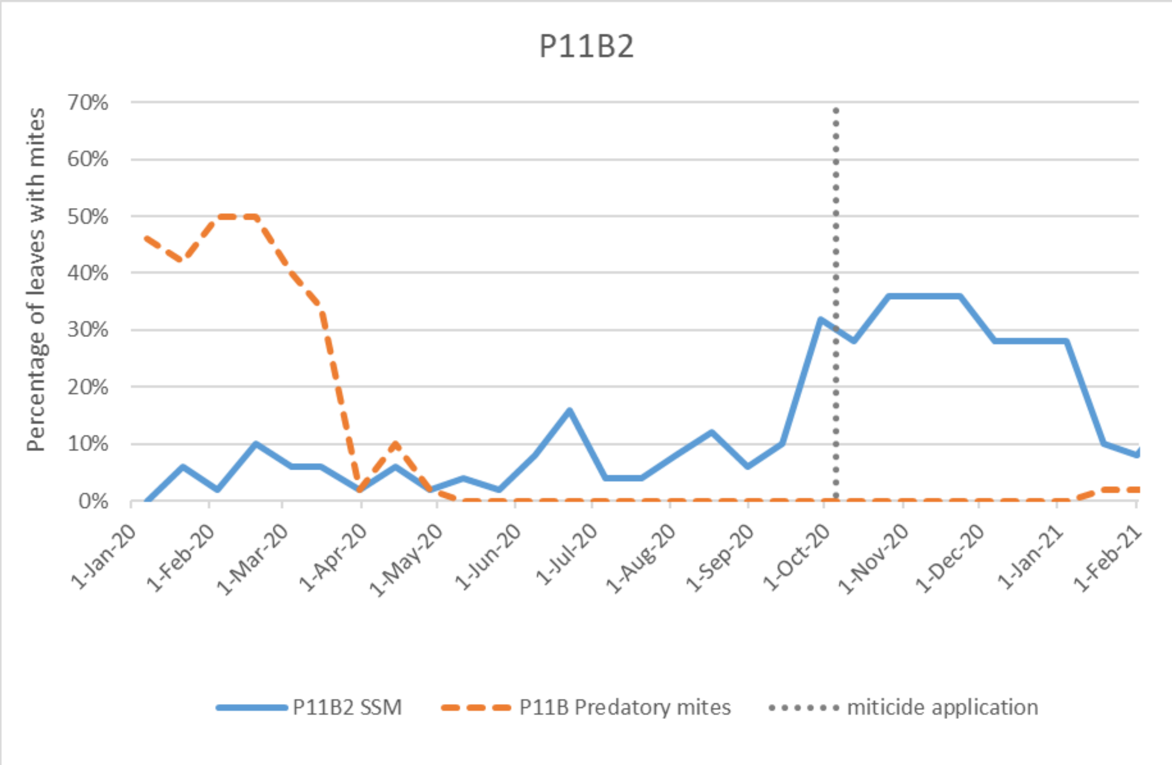

Figure 15: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in block P11B2. Fenbutatine oxide was applied on the 5th of October 2020 at a rate of 38mL/100L and 1500L/ha with a Silvan airblast sprayer.

In this case study the lack of follow-up application is likely to have contributed to the poor result. Fenbutatin oxide kills the adults and nymphs but not the eggs. Even if the first application is effective the unaffected eggs will hatch later and go on to breed and continue the infestation. The label for Vendex, the spray product with Fenbutatin oxide, states that "two applications a fortnight apart is normally adequate to control these pests".

Temperature at time of application and lack of follow-up spray

Blocks P3B1 and P3B2 had uncommonly high SSM levels throughout winter 2020. When monitored on the 27th of July P3B1 had 30% of leaves with SSM and P3B2 14% (figure 16). The grower chose to apply fenbutatin oxide on the 9th of August. The product was applied at the recommended rate of 38mL/100L and at a water volume of 3000L/ha with a wetting agent added. SSM numbers in both blocks continued to rise through spring. P3B1 peaked at 64% on November 2nd and P3B2 at 82% on October 19th.

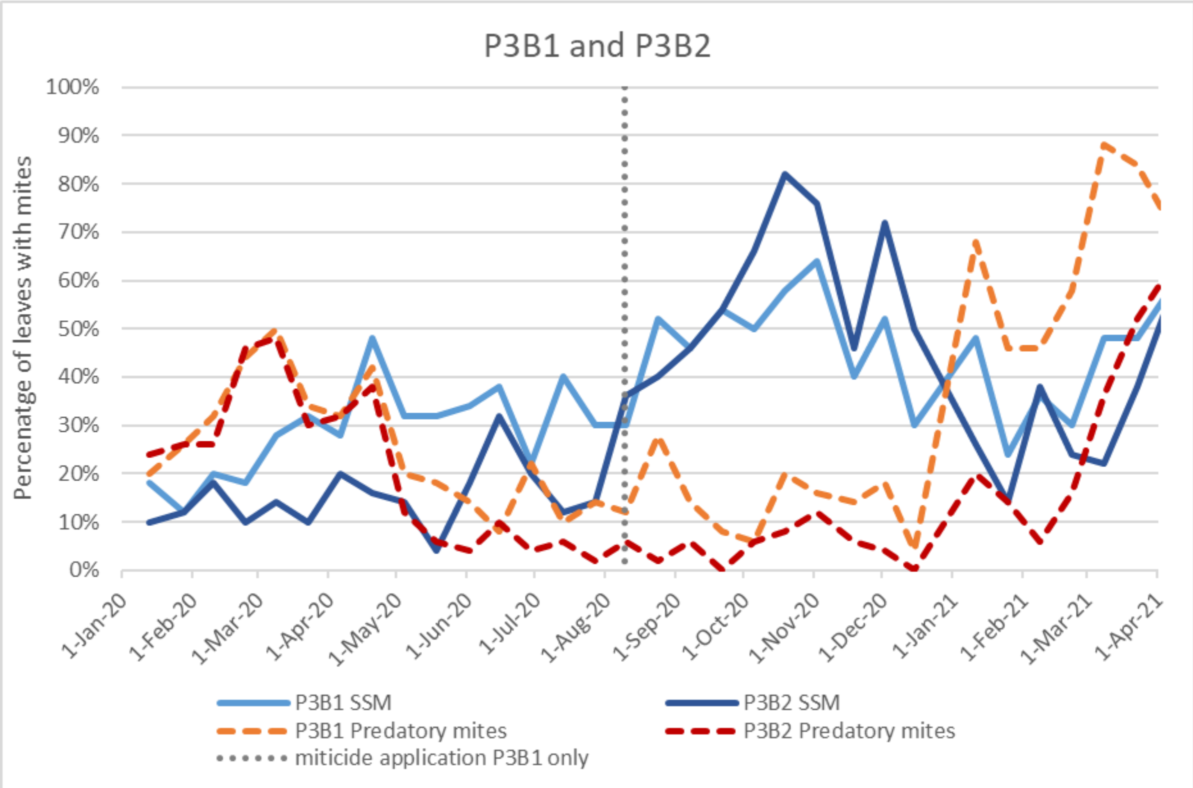

Figure 16: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in blocks P3B1 and P3B2. Fenbutatin oxide was applied on the 9th August 2020 at a rate of 38mL/100L and 3000L/ha with a wetter added.

There was no appreciable impact of the miticide application and there are two factors that likely contributed to that result. Again, only a single application was made and as already stated two applications of fenbutatin oxide are required for adequate control. The other factor was the temperature at application. The Australian label for a fenbutatin oxide product, Vendex, states that "it acts more rapidly in hot weather than in cool weather" but does not state an actual temperature. The USA label for Vendex states it "performs best when the daily maximum temperature at application averages above 70°F. When the daily temperature at application averages below 70°F, performance is reduced". 70°F is equal to 21.1°C. The maximum temperature recorded in Pemberton, the closest town to P3B1, on the 9th of August 2020 was 13.5°C. We have also received anecdotal reports from other growers that have used fenbutatin oxide on cold days that they did not get the expected results from the spray.

P3B2 received another sub-optimal miticide spray on the 22nd of April 2021 (figure 17). SSM had peaked that autumn at 56% of leaves on the 6th of April. They had started to decline, with SSM on 42% of leaves on the 19th of April. Levels continued to decline after the spray, reaching a low of 10% on the 17th of May and 1st of June but then increased again through winter and early spring. Again, the lack of follow up spray likely contributed substantially to the poor result.

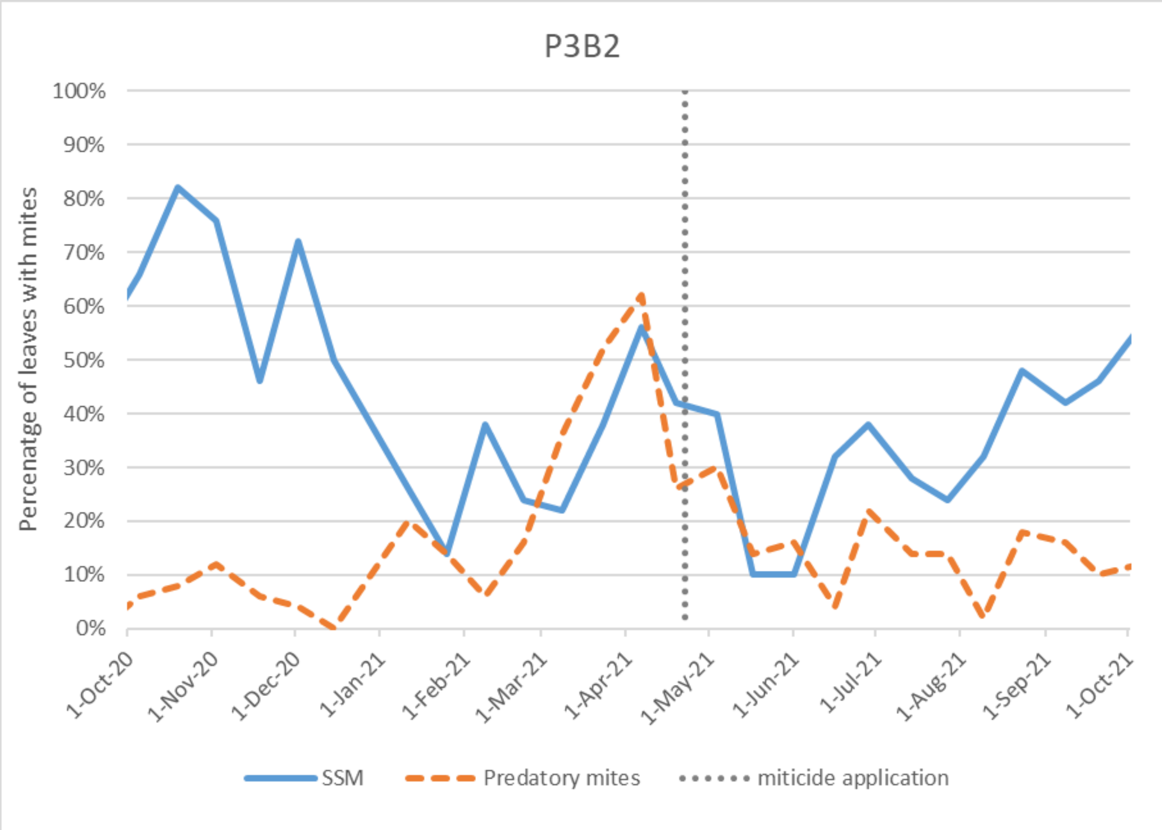

Figure 17: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in block P3B2. Fenbutatine oxide was applied on the 22nd of April 2021 at a rate of 38mL/100L and 1000L/ha with a summer oil added.

Poor spray coverage – Tree size

Block P7B1 was planted in 2005 in an 8m x 4m spacing. The trees are more than 12 metres tall. In the project monitoring period six miticide sprays were applied (Table 1). All applications were made with a Croplands air blast sprayer.

Table 1: The date, actives, rates, water volumes and maximum daily temperatures for all miticides applied to block P7B1

Date	Active	Rate	Water volume	Daily max. temp.
25 August 2020	Etoxazole	35mL/100L	2500L/ha	19.4
17 March 2021	Fenbutatin oxide	38mL/100L	3000L/ha	27.3
29 March 2021	Fenbutatin oxide	38mL/100L	3000L/ha	32.5
10 April 2021	Etoxazole	35mL/100L	2800L/ha	24.5
14 March 2022	Fenbutatin oxide	38mL/100L	3200L/ha	27.9
24 March 2022	Fenbutatin oxide	38mL/100L	3200L/ha	26.0

The etoxazole sprayed in August 25th was sub-optimal as SSM did not start to decline until October and then only remained low for three months before increasing again in February (figure 18). The back-to-back fenbutatin oxide sprays in March 2021 were also not effective as SSM increased after the second spray. A further etoxazole spray was applied that autumn. This spray was effective, SSM numbers remained very low for six months and did not peak until the 4th of January, well after the spring defoliation risk period. Fenbutatin oxide was applied as back-to back sprays in March 2022. These sprays did not reduce SSM numbers.

Unlike previous examples in this orchard fenbutatin oxide was applied with follow-up applications and on warm days. All applications were made with high water volumes which should assist in achieving good coverage. However, the grower suggested that they were not getting sufficient coverage due to the height of the trees and the area of canopy that needs to be covered. There is further discussion of spray coverage below.

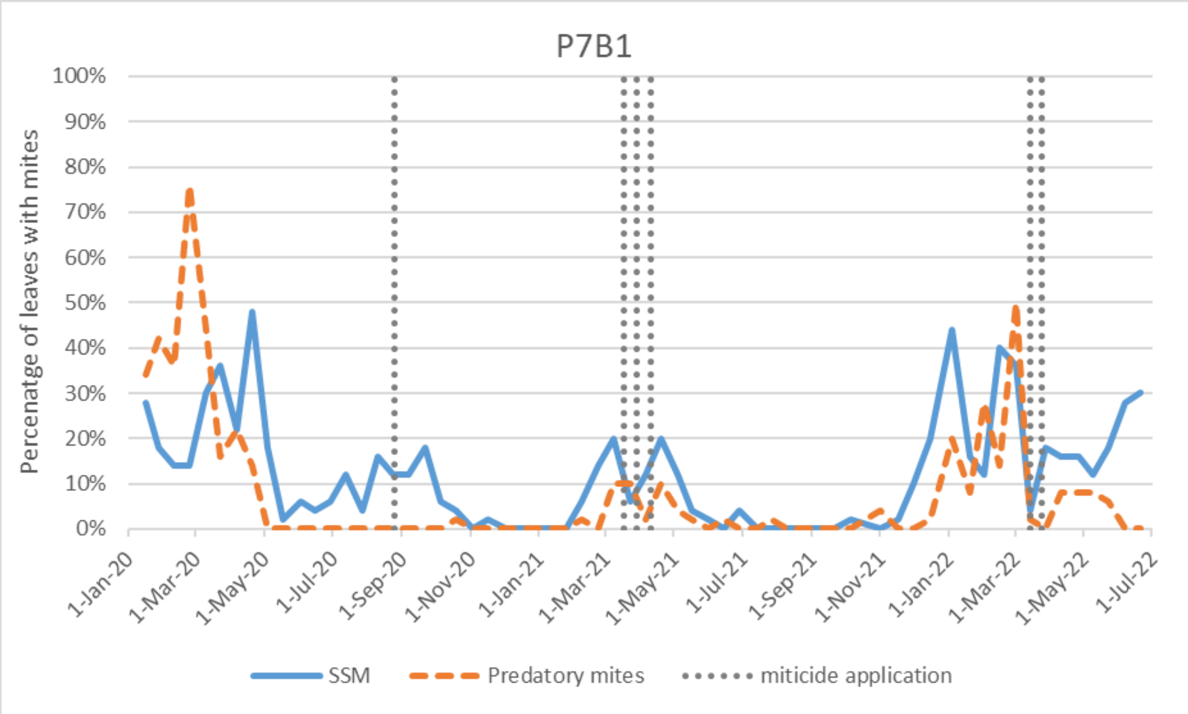

Figure 18: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in block P7B1.

Poor spray coverage – Low water volume

P6B1 and P6B2 are examples of blocks that did receive two applications of fenbutatin oxide, in these cases nine days apart, yet still did not achieve the expected results (figures 19 and 20). The daily maximum temperatures on the application dates were 20.9°C for P6B1's first spray and 20.6°C for the second, 21.5°C for P6B2's first spray and 21.8°C for the second. These temperatures are close to those stated on the USA Vendex label and so temperature is less likely been a factor in the poor result.

Another factor that may have led to the ineffective spray in these examples was the water volume used. At P6B1 the miticide was applied at 700L/ha and 613L/ha at P6B2, with a wetter included at both sites. P6B2 did achieve an effective spray with an even lower water volume (figure 9), but this was an etoxazole application. Etoxazole is translaminar while fenbutatin oxide is not. This means that good coverage, particularly on the underside of leaves where SSM are, is even more critical for fenbutatin oxide and this may not have been achieved with a low volume spray.

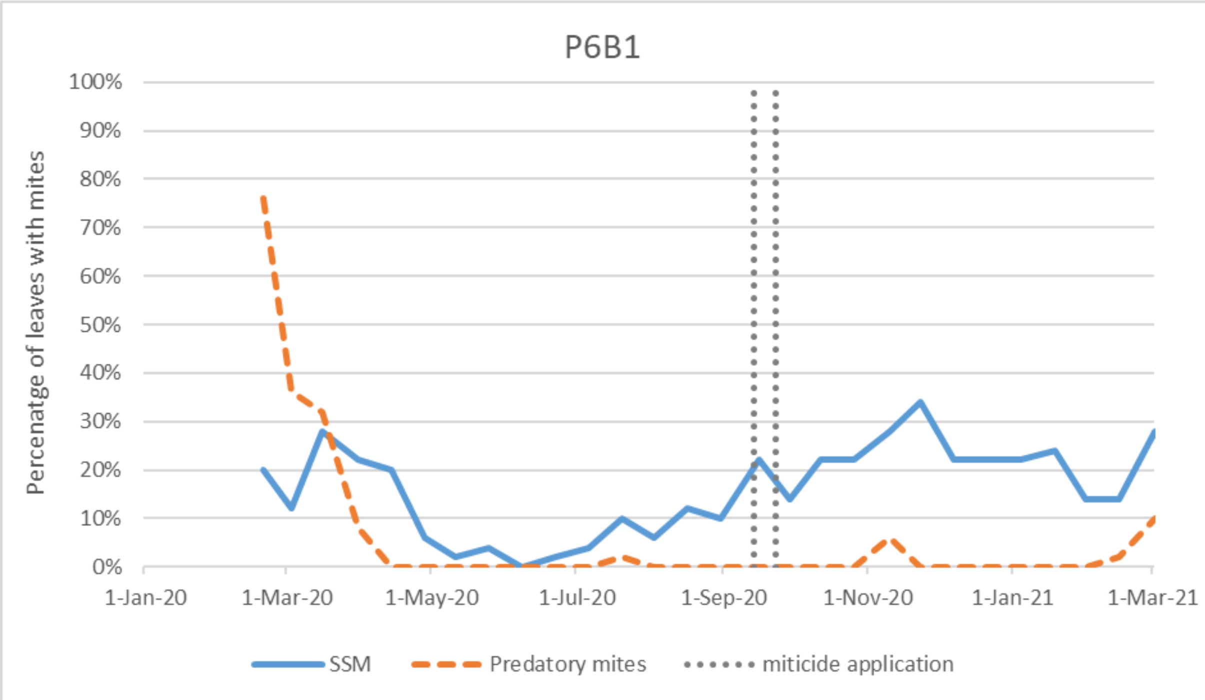

Figure 19: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in block P6B1. Fenbutatin oxide was applied on the 14th and 23rd of September 2020 at a rate of 150mL/100L and 700L/ha with a wetter added.

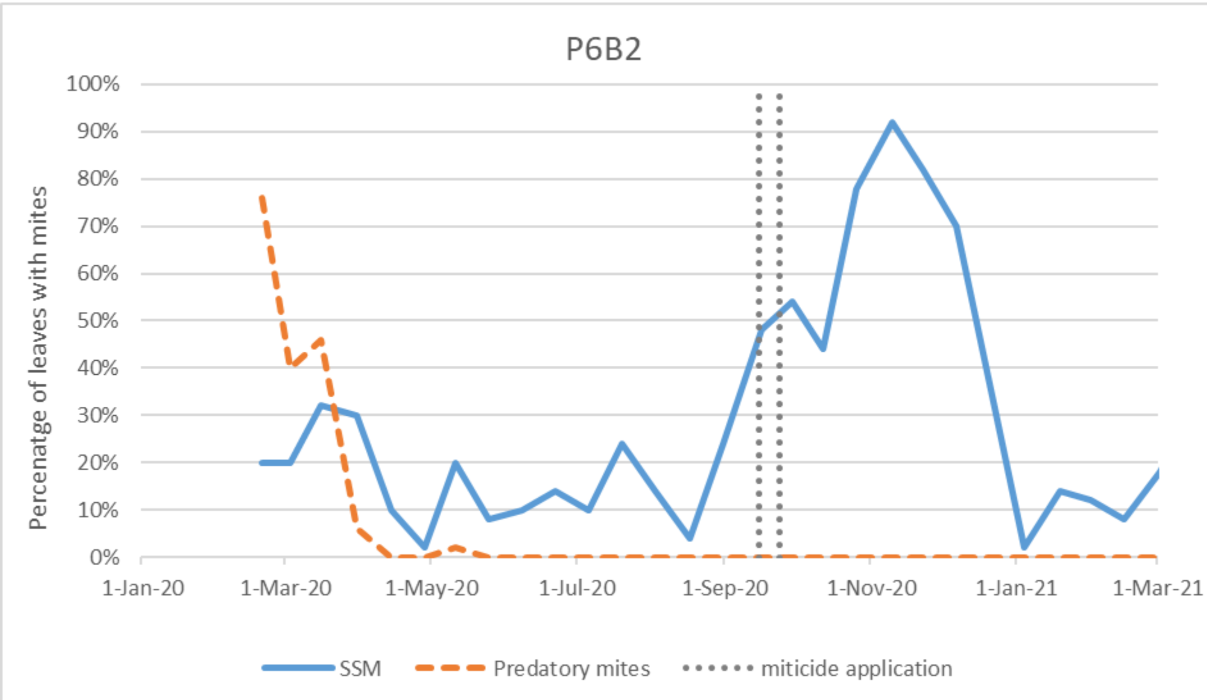

Figure 20: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in block P6B2. Fenbutatin oxide was applied on the 15th and 24th of September 2020 at a rate of 150mL/100L and 613L/ha with a wetter added.

Poor spray coverage – Low water volume and poor canopy penetration

P12B1 and P12B2 suffered a SSM induced defoliation event in spring 2019. The orchard had not previously been monitored for SSM and no damage or defoliation had been noted. Fenbutatin oxide was applied on November 17th and 27th 2019 prior to commencement of monitoring as part of this project. SSM numbers rose sharply in later winter 2020 and etoxazole was applied on 11th September. The SSM population subsequently fell, remained low throughout winter before increasing again the following autumn (figure 21). Numbers increased through late winter and early spring 2021 before another etoxzale application was made on 28th September 2021. A tractor mounted Caffini TPL air blast sprayer was used (figure 22).

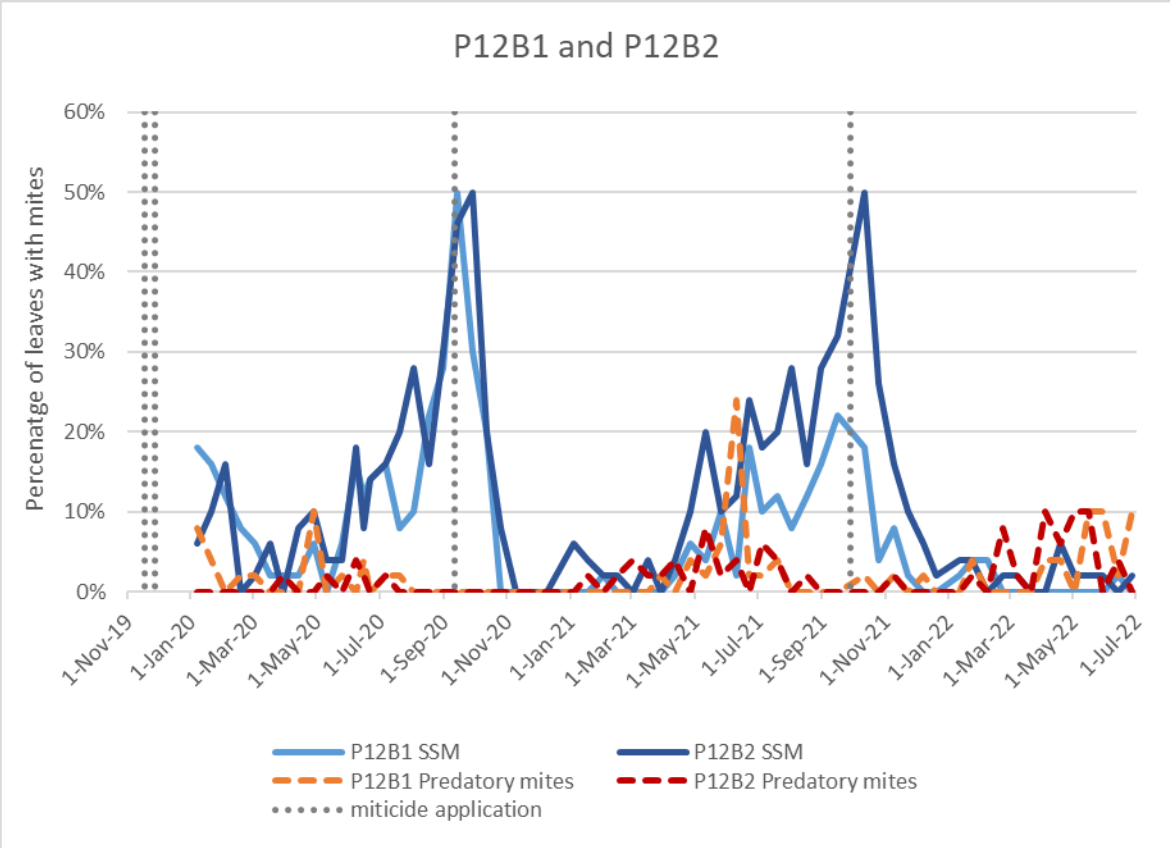

Figure 21: Results of fortnightly monitoring of SSM and predatory phytoseiid mites in blocks P12B1 and P12B2.

Other orchards that applied etoxazole and fenbutatin oxide have achieved much longer-term reduction in numbers. P11B1, P11B2 and P6B2 had etoxazole applied in autumn and had zero SSM recorded for 5 and 8 months respectively following application. P5B1 and P5B2 applied etoxazole in spring and once SSM numbers fell to zero they were not recorded again for another 10 months. P6B1 received febutatin oxide in autumn and near zero SSM were recorded for 6 months following. The applications in this orchard were deemed sub-optimal due to the relatively quick rebound in SSM after the miticide was applied.

The miticides were applied at the recommended labels rates with low water volumes (Table 2).

Figure 22: The tractor mounted sprayer used to apply miticides in P12B1 and P12B2.

Table 2: The date, actives, rates and water volumes for all miticides applied to blocks P12B1 and P12B2.

Date applied	active	Rate (mL/100L)	Water volume (L/ha)
17/11/2019	Fenbutatin oxide	37.5	450
27/11/2019	Fenbutatin oxide	37.5	450
11/09/2020	Etoxazole	35	370
28/09/2021	Etoxazole	35	421

After looking at the known factors for each miticide application, it was concluded that poor coverage due to the low water volume was the most likely factor contributing to the sub-optimal result. A spray assessment was carried out in the orchard to determine the spray coverage. Water sensitive paper was used. The paper turns blue on contact with water. The papers were clipped to leaves in four trees at heights of 0.5m, 1.5m and 2.5m in both the inner and outer canopy. Each paper was folded in half and clipped to a leaf so that half of the paper was on the upper side of the leaf and half was on lower side of the leaf. The sprayer tank was filled with water and the same volumes applied in the same way as per the 2020 miticide application. Due to the small sprayer size the grower only ever sprayed out of one side at a time, driving off-centre in the inter-row in order to be closer to the trees on the spray side. The water sensitive papers were analysed using the SnapCard app to determine percentage of coverage.

The spray assessment confirmed that coverage was not adequate. The water sensitive papers showed there was consistently less coverage on the lower leaf surface compared to the upper. The inner had lower coverage compared to the outer canopy (figure 23). The area to receive the least amount of coverage was the lower leaf surfaces at 0.5m in the inner canopy, where coverage was just 1.1% of surface area (table 3).

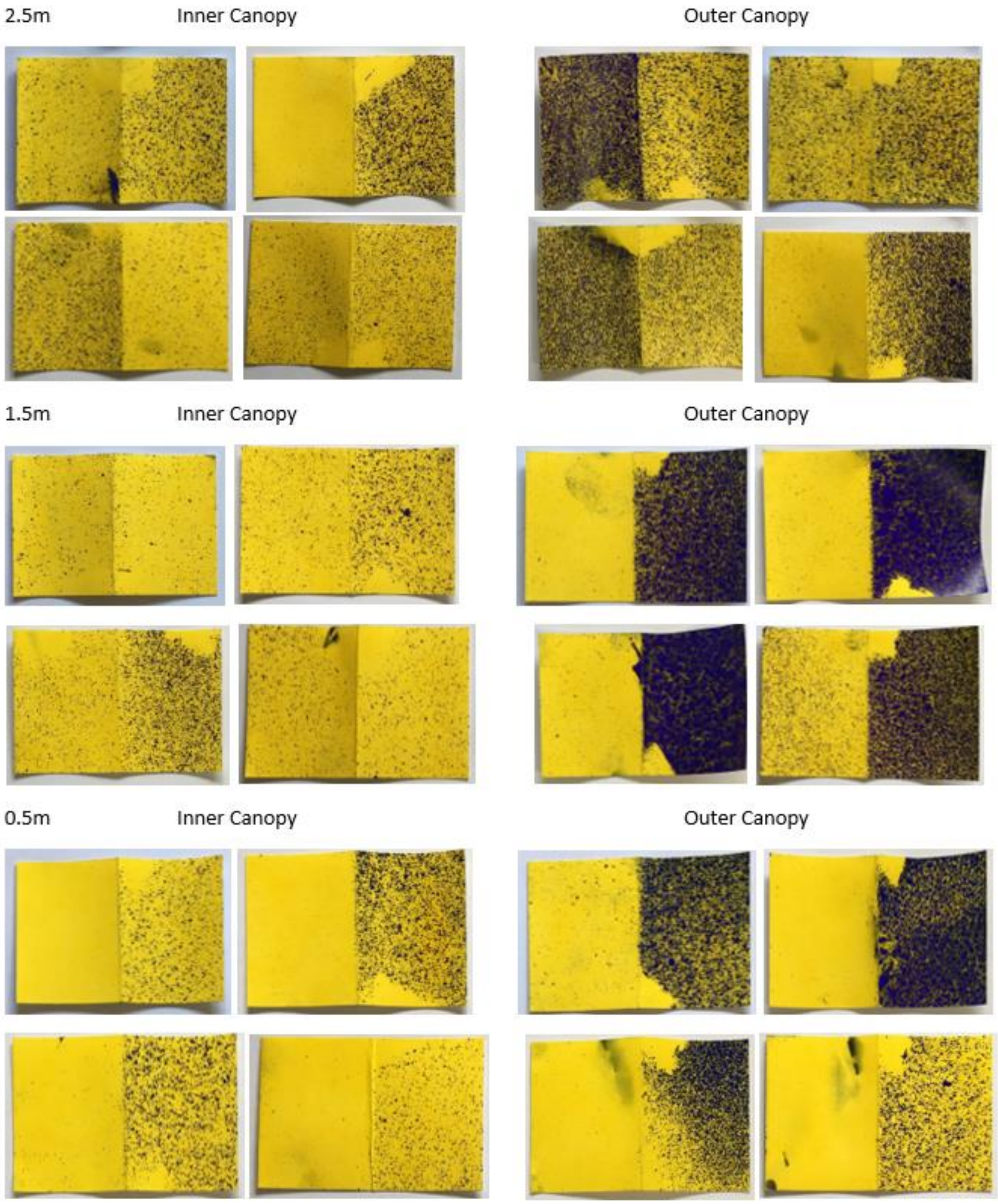

Figure 23: Water sensitive papers placed in four different trees at heights of 0.5m, 1.5m and 2.5m in the inner and outer canopy. Each card shows the spray coverage on the under (left) and upper (right) side of each leaf.

Table 3: Average spray coverage of the four trees for each location as determined using SnapCard.

Height in canopy	Inner Canopy		Outer Canopy	
	lower	upper	lower	upper
2.5m	3.5%	10.1%	17.1%	31.6%
1.5m	2.5%	7.4%	2.2%	55.2%
0.5m	1.1%	10.4%	2.4%	37.1%

After observing the sprayer and pattern of spray coverage not only was also low water volume thought to contribute to the poor result but also the type of sprayer used and weed growth in the orchard. The smaller spray unit used was not able to create enough force and turbulence to push the spray into the canopy and onto the underside of leaves and the tall thick weed growth around the trees intercepting the spray before it reached the tree.

Based on these observations the reasons as to why there was a relatively quick rebound in SSM numbers may be as follows. When leaves are taken for mite counts they are taken from the inner and out canopy at a height of approximately 1.5-2m. Despite being lower than ideal the spray coverage in this height range was sufficient to reduce SSM number. However, pockets of SSM were able to survive in areas that received low spray coverage, particularly lower in the canopy. Over time these mites bred and redistributed over the whole canopy leading to a quicker increase in numbers.

It is not possible to kill every SSM on a tree with a miticide spray. There will always be leaves or portions of leaves that the spray does not contact. However, when more SSM are killed it takes longer for the population to recover. Achieving longer term population reduction as shown in P5B1 and P5B2 led to no miticide being applied the following spring. Fewer miticide applications save time and money and also reduce the risk of resistance development.

Learnings

1. Continue regular monitoring after each miticide spray to ensure the expected result was achieved and to determine when numbers increase again.
2. Read, understand, and follow label comments and instructions in term of rates, follow-up sprays and any temperature requirements.
3. Use water volumes and a sprayer set-up that optimises spray coverage. Alter for blocks with different tree size, canopy structure and density.
4. Assess spray coverage to ensure it is optimal. Make changes if it is not.

There are multiple factors that can reduce spray coverage, as was demonstrated in the case studies. To improve spray coverage higher water volumes may be required. In other circumstances the orchard itself may have to be altered to ensure good coverage can be achieved, such as keeping other vegetation around trees low or pruning large trees so that spray can reach the upper canopy.

Summary

Management	Block No.	No. of applications	40% spring or 10% autumn threshold exceeded (Yes/No)					Leaf drop (Yes/No)
			Autumn 2020	Spring 2020	Autumn 2021	Spring 2021	Autumn 2022	
No applications	P1B1	0	No	No	No	No	No	No
No applications	P1B2	0	No	Yes	Yes	Yes	No	No
No applications	P2B1	0	Yes	Yes	Yes	No	Yes	No
No applications	P2B2	0	No	No	No	No	No	No
Sub-optimal	P3B1	1	Yes	Yes	-	-	-	No
Effective	P3B1	2	-	-	Yes	No	No	No
Sub-optimal	P3B2	1	Yes	Yes	-	-	-	No
Sub-optimal	P3B2	1	-	-	Yes	Yes	-	No
No applications*	P4B1	0	No	Yes	No	Yes	Yes	No
No applications*	P4B2	0	No	Yes	No	Yes	Yes	No
Effective	P5B1	2	No	Yes	No	No	Yes	No
Effective	P5B2	2	No	Yes	No	No	Yes	No
Sub-optimal	P6B1	2	Yes	No	-	-	-	No
Sub-optimal	P6B2	2	Yes	Yes	-	-	-	No
Effective	P6B2	2	-	-	Yes	No	Yes	No
Sub-optimal	P7B1	6	Yes	No	Yes	No	Yes	No
Effective	P8B1	5	Yes	Yes	No	No	Yes	No
Effective	P8B2	5	Yes	No	No	No	No	No
Effective	P11B1	2	-	-	Yes	No	Yes	No

Sub-optimal	P11B2	1	No	No	-	-	-	No
Effective	P11B2	2	-	-	Yes	No	No	No
Sub-optimal	P12B1	2	No	Yes	No	No	No	No
Sub-optimal	P12B2	2	Yes	Yes	Yes	Yes	No	No
No applications	P13B1	0	No	Yes	Yes	Yes	Yes	No
No applications	P13B2	0	No	Yes	No	Yes	Yes	No

*Did receive applications in autumn 2022 but impact was not assessed due to short period before all monitoring ceased.

Spray workshops

From the case studies it was concluded that miticide application practices are an area in which improvements could be made, leading to less miticide being applied. The project engaged with another avocado pest management project, AV19001, that was running concurrently and took part in two spray workshops being run as part of that project in the lower southwest.

At the spray workshops information on SSM pest management was presented, including case studies from this project. The case studies were used to highlight the importance of good application practices and linked to the information given by other presenters.

The workshops also included a practical component. As part of this a spray coverage assessment was done using water sensitive paper. The papers were attached to a pole at every metre and the pole placed approximately a third into a tree canopy of a tree slightly less than 8m tall. The host grower was asked to spray the row with water using the water volumes and settings as they would normally use for a pesticide application (figure 24). Results from the first run show excessive spray was applied at 1m, 2m and 3m. There was slightly less than adequate spray at 4m and far less than adequate at 5m and above (figure 24). The property that hosted the spray day did not have an issue with SSM but if they did this level of coverage would be a concern as coverage in the top half of the canopy was so low. The tree size, canopy structure and sprayer and water volumes used in the demonstration were comparable with industry norms. There are also many older orchards with taller trees that also likely would have difficulty in getting spray to reach the upper canopy.

This poor initial coverage in the upper canopy and subsequent reduced miticide effectiveness at that height would not necessarily by picked up by monitoring as this is done from ground level. Leaves in the 1-2m range that are sampled on the ground had very high coverage and so most mites in the area would be killed, while the surviving mites up higher would not be seen.

After the first spray run, some alterations were made to the sprayer nozzles, tractor speed and angle of the lower air deflectors. This resulted in better spray coverage above 4m (figure 24). There was still room for improvement with this sprayer set-up. More alterations could be made with more time and a wider range of nozzle available that could then be assessed with further spray coverage checks.

The demonstrations highlighted that an over the shoulder check from the cab while you’re spraying is not sufficient to determine effective coverage and just because the targeted litres per hectare are applied it does not mean that are being applied where required in the canopy. It is recommended that all growers regularly check their sprayer to ensure coverage is sufficient and it should be checked in different parts of the orchard where there are different trees sizes and/or shapes and alter spray practices to suit.

A follow-up article including case studies and workshop key messages was written for Talking Avocados after the workshops to extend this information to a wider audeince.

Figure 24: Left to right. The sprayer and trees used as for the spray coverage assessment. The water sensitive paper after the first spray run, numbers indicate height of the card in the canopy. The water sensitive paper after the second spray run.

Alternative pesticide options

Literature review

Spray Oil

Oils are used widely to control mites and a multitude of paraffinic and petroleum oil products are registered in Australia for the control of mites in crops such as pome, stone, ornamental, nut and citrus. There are various oil products registered for use against scale in avocados, with some of those products also registered for use against mites in other crops. Given the legislation in Western Australia growers here would be able to use oil sprays for SSM. Anecdotally, spray oil has been used intermittently in the past for mite management, but it is not common current practice.

There have been trials of oils to control SSM in both New Zealand and California. Bailey and Olsen (1990) stated that oil was historically not considered “entirely effective” for controlling SSM in avocado in California. In their trials it led to reduced SSM numbers seven days after application compared to the control, but still the oil treatments had significantly more compared to some of the miticide treatments. Twenty-one days after application SSM numbers on trees treated with oil were not significantly different to untreated trees. Predatory mites on oil treated trees were not significantly different to untreated trees seven days after treatment.

In 2001 Stevens *et al* conducted bioassays comparing conventional pesticides/miticides and a mineral oil as knock downs and ovicides. The mineral oil led to 22.8% to 35.7% mortality depending on exposure method, significantly higher than the control but less than some of the conventional miticides. Oviposition was significantly reduced, and the oil treatment had the highest percentage of eggs remaining unhatched (80.7%) out of all treatments after 10 days.

In a later study after one application of oil there was no significant difference when compared to the control, however there were fewer adult mites present suggesting that the spray may have had a short-term effect that had worn off by the time the sample was taken four weeks later. After a second application of oil SSM numbers had reduced but were still not significantly different to the control (Steven 2004).

One New Zealand grower described to the project team previous attempts to control SSM in avocados as “spectacularly unsuccessful”.

The inconsistent use of oils in Western Australia and the results from trials elsewhere suggest that control of SSM with oils is not consistent. However, given the regular use of them for mite control in other crops further investigation of their use is warranted.

Erythritol

Erythritol was first shown to have insecticidal properties less than ten years ago (Baudier *et al* 2014) and since then it’s potential as a pesticide has been shown against a range of pests including; termites, ants and the fruit fly *Drosophila suzukii* (spotted-wing drosophila) (Baudier et al 2014, Goffin et al. 2017, Barrett et al. 2020, Caponera et al. 2020).

Only recently has research been published on the potential for it to be used effectively against mite pests. In bioassays erythritol has caused mortality in two spotted spider mite (*Tetranychus urticae*) and pear rust mite (*Epitrimerus pyri* (Nalepa)) while having less impact on the beneficial *Galendromus occidentalis* (Cooper *et al* 2020, Schmidt-Jeffris *et al* 2021). The mechanism of toxicity is unknown, Schmidt-Jeffris *et al* (2021) suggest it could be due to chemical activity or inert effects of the residue, in the same way that films such as kaolin can impact on spider mites.

Erythritol has been shown to have potentially damaging effects on some plant crops, such as tomato seedlings (Scanga *et al* 2018).

There are currently no pesticide products with erythritol as an active ingredient available on the Australian market. For this reason, it was not pursued any further as part of this project. If a product becomes available in the future, further research is warranted.

Molasses

There are numerous home garden focussed websites expounding the use of molasses to control insect pests (Molasses does what? n.d., Marie n.d., Gardening Australia 2009). A DPIRD (2014) webpage on ‘Natural alternatives to synthetic chemicals’ states that “Caterpillars and other chewing insects apparently dislike the taste of leaves treated with this spray” when referring to molasses. But there is no evidence to back up these claims.

There are several theories as to why molasses may work. One is that molasses has a direct impact on pests after ingestion. The other theories are that molasses increases the brix level in the plant making it less palatable to the pest or that it improves soil bacterial health, and this has a flow on effect to overall plant health. However, in one of the few research papers on the use of molasses, it was found to have no impact on the occurrence of, and damage to fruit, caused by *Scirtothrips aurantia* in oranges when compared with treatment that were unsprayed or received water spray only (Thackeray et al 2015).

It was concluded that there was not enough evidence to warrant the trialling of molasses as a direct control method for SSM. However, there is potential for improvements of tree health and manipulation of factors such as brix and carbohydrates to play a part in pest management. This may or may not involve application of molasses. It is suggested that this area be investigated further.

Sulfur

The University of California (2017) lists wettable sulfur as one of the spray options for six-spotted mite. It does come with the comment “Do not treat with sulfur when temperatures exceed 90°F (32°C) to avoid leaf damage. If applied above 32°C leaf and fruit burn can occur (Bender 1993). It does not often reach or exceed 32°C in the Manjimup Pemberton area at the times of year when SSM are sprayed, so the upper temperature threshold is not a concern. However, the lower end of the temperature efficacy range also needs to be met. Sulfur sprays are often not effective in coastal areas where temperatures do not promote fuming action (University of California 2017). Better control is achieved when temperature is in the 80°F (26°C) degree range (Bender 1993). This is why Stevens (2000) suggested that sulfur was not likely to be effective for SSM in New Zealand. The average daily maximum temperatures for Te Puke, a town in New Zealand close to a major avocado growing area, for September, October, November and December are 20.6, 21.8, 24.1 and 26.3 (MetService 2022). The average daily maximum for September, October, November and December for Pemberton is 16.9, 18.9, 21.5 and 24.1 respectively. For Manjimup it is 16.0, 19.0, 22.0 and 25.1 (Bureau of Meteorology 2022). These averages are well below the optimum and would likely result in sub-optimal efficacy.

Some mite species are more susceptible to sulfur than others (Mistric and Rainwater 1952, Abo-El-Ghar and Boudreaux 1958, Jackson and Leigh 1967). Sulfur may not be as effective against SSM as some other species as it tends to work better on the smaller mite species (L. Chillman personal communication, 7th April 2022). Bailey and Olsen (1990) said that sulfur was historically not considered “entirely effective" for controlling SSM in avocados” in California and in their studies found it was effective against avocado brown mite but not SSM.

Care must be taken with sulfur applications as it will kill predator mites (Bender 1993) and when being used as a fungicide multiple applications can result in secondary pest outbreaks of spider mites (James and Prischmann 2010).

There are sulfur products registered for use against various mite pests in Australia for citrus, grape vine, kiwi fruit, mangosteen, rambutan and some vegetables. There are no sulfur products registered for use in avocado.

Spray oils were prioritised over sulfur to be included in this project due poor efficacy against SSM in other studies and the narrow temperature range for it to be most effective. Also, a property on which to conduct a sulfur case study did not become available. Sulfur is a product that could potentially be used in the future when more options are required. Efficacy trials would need to be conducted specific to the pest, host, climate complex.

Other

Steven (2003) trialled the novel chemicals GC Mite (clove oil, garlic and cottonseed oil), Myco-Force (fungal insect pathogen), Neem Azal T/S (neem oil), sucrose octanoate and Thiodan (endosulfan) with none of them having any effect on SSM.

Case study

Field trials of erythritol, molasses and sulphur were not planned for various reasons as outlined in the section above. It was decided to include the use of spray oils in the project. For similar reasons outlined in the miticide case study section above a replicated trial of alternative products was not conducted. Instead, a case study of spray oil use was developed.

The orchard used in this case study was not one of the 13 orchards monitored regularly. The grower contacted the project after experiencing a defoliation event due to high SSM numbers. The orchard was included in the fortnightly monitoring program from that point onwards.

There were three blocks included in the case study. Block A consisted of eight-year-old Hass on Zutano rootstock, Block B consisted of seven-year-old Hass on Reid rootstock, Block C consisted of six-year-old Hass on Reid rootstock. All blocks are planted on 8m x 3.5m spacing. None of the blocks has a history of SSM damage, had been previously monitored for SSM or received miticide applications.

Two adjacent rows within each block that were representative of the block were chosen. Alternating between the two rows, ten trees equally spaced trees along the length of the rows were tagged for assessment. Five leaves per tree were collected every fortnight, giving 50 leaves per block. Recently mature leaves from the inner and outer canopy and multiple points around each tree were picked. Leaves were placed in paper bags with other leaves from the same tree, then placed in plastic snap lock bags and kept cool until being examined under a stereomicroscope within 48 hours.

The defoliation occurred on some trees in B block. High numbers of SSM were confirmed by the grower and an oil was applied on the 11th of November 2021. A follow-up application was applied to block B on the 23rd of November and a single application made in block A on the 28th of November (Table 4). Block C received no spray oil or other miticide applications. The first oil spray was applied before the project was notified, leaves were sampled for SSM monitoring on 17th November and continued fortnightly until June 2022. All sprays were applied with a Silvan air blast sprayer.

On the first monitoring occasion very few SSM were present in block B, with an average of 0.5 mites per leaf overall and SSM found only on 6% of leaves (figure 25). Despite not having data for block B prior to the first oil application we are confident there was a high population previously due to the amount of leaf feeding damage observed and the number of SSM eggs counted on the first monitoring occasion. SSM eggs were found on 90% of leaves at this time. Many of these were likely not viable and did not go on to hatch but this could not be determined at the time and so were counted. From December to mid-March only a single SSM was found on monitored leaves from block B. Through Autumn between 0%

and 8% of leaves had SSM.

Table 4: Spray application details and daily weather information for all applications made to the three monitored blocks.

	Block B 1st app.	Block B 2nd app.	Block A
Date	11/11/21	23/11/21	28/11/21
Active	Paraffinic oil	Paraffinic oil	Paraffinic oil
Product	Biopest	Biopest	Biopest
Rate	2L/100L	2L/100L	2L/100L
Water Volume	2750L/ha	2750L/ha	2750L/ha
Temperature, min-max (C)	9.5 - 19.5	11.4 - 21.4	14.5 - 25.8
RH, min-max	49.3 - 94.9	48.8 - 96.8	59.6 - 93.1
Wind avg, max	5, 31	3, 23	5, 23
Rain (mm)	0	2.6	0

Weather data are from the DPIRD Pemberton weather station, located approximately 13km to the west of the demonstration site and sourced from the DPIRD weather stations website, https://weather.agric.wa.gov.au/station/PM.

Block A had very high SSM numbers on the first monitoring occasion; 92% of leaves had SSM and there was on average 28.2 SSM per leaf. This was the only monitoring event before this block received a spray oil application on the 28th of November. Leaves were monitored the day after the application; 46% of leaves had SSM and there was an average 1.3 SSM per leaf. No further mites were found in this block until late February. SSM egg numbers in block A showed a similar steep, but lagged, drop in numbers and block B.

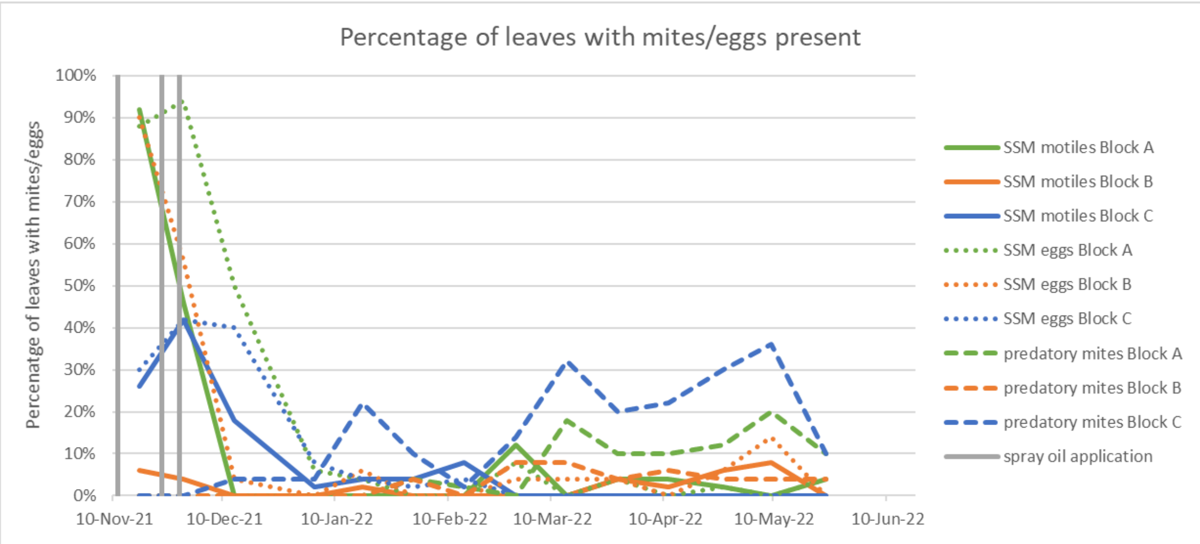

Figure 25: Percentage of leaves with SSM motiles, SSM eggs and predatory phytoseiid mites recorded fortnightly in blocks A, B and C. Spray oil was applied on the 11th and 23rd of November to block B and the 28th of November to block A .Block C received no pesticide sprays.

Block C had moderate SSM numbers on the first monitoring occasion. Numbers peaked on 29th of November when 42% of leaves had SSM. This block was not sprayed and SSM naturally declined through December then remained between 2% and 8% in January and the first half of February from which point onwards no SSM were found.

Predatory mites were consistently higher in block C. All three blocks had zero predatory mites on the first two monitoring occasions. There continued to be no predatory mites found in blocks A and B until the end of January. Throughout autumn block A averaged 0.09 predatory mites/leaf and 10% of leaves with predatory mites, for block B it was 0.06 and 5% and for block C 0.28 and 21% respectively.

This case study gives a positive example of spray oils being used effectively to managed SSM. The grower was able to quickly reduce the population from very high levels to near zero and the low levels remained for the following months. This saw them through the defoliation risk period without the need for any other miticide applications.

It must be noted that thorough coverage is essential for effective control with spray oils as it is contact active. The trees in A and b block were up 5.5m tall.

The grower chose to apply a spray oil, rather than one of the registered miticides, because the affected blocks were scheduled to be harvested within the week and there were beehives present in the orchard. This highlights situations in which oil applications may be preferred. The withholding period for spray oils in avocados is one day compared to 7-14 days for other miticide products. Spray oils are also not harmful to bees. Spray oils may also be preferred in orchards following organic production practices.

A drawback of spray oils is that they do negatively impact on predatory mites. Definitive relationships cannot be drawn from this case study as it was not a replicated trial, however, there is a pattern that suggests the spray oil did reduce the predatory mite population. There were fewer mites found in the block where two sprays were applied, followed by the block that received one application and the block that received no oil applications had the highest number of predatory mites.

Whether or not spray oils are a viable option for autumn spraying has not been assessed. For autumn applications to be effective the SSM population needs to be reduced by a large enough degree to maintain low levels for a longer period, i.e. not just through several weeks of the defoliation risk period, but through all of winter and the following spring. Given the poor longer-term results experienced by Bailey and Olsen (1990) and Steven (2004) autumn applications would have to be assessed in SSM in avocados in south-west WA before they can be recommended.

Further case studies and replicated trials of spray oil applications would greatly add to the foundation of knowledge gained through this single case study, allowing for more tailored scenarios involving, for example, different levels of pest pressure, weather, seasonal timing, budget and spray application.

Conclusions

All the case studies provided useful examples and learnings that all avocado growers can apply to their pest management practices, specifically, but not exclusively to SSM management.

All the learnings that were listed in each case study section are as follows:

1. High SSM levels in spring do not necessarily lead to defoliation. Other factors around tree stress also play a part.
2. The presence of SSM does not necessarily lead to the population increasing to potentially damaging levels. Not every block will experience are large increase in SSM number in spring.
3. SSM populations can fall steeply over summer without intervention.
4. Both spring and autumn sprays can be effective at reducing spring SSM levels below the 40% leaves with SSM 'threshold'.
5. Be aware of how each active works, i.e. is it a knock-down or not, and use the product best suited to your situation.
6. With effective sprays a single application round per year, or less, can maintain the population below the 'threshold' in the spring risk period.
7. Monitor across a whole block, not just a small area, as the SSM levels will vary over an area. Keep monitoring records and alter monitoring and management areas if need be.
8. Monitor and manage all blocks separately as mite numbers can vary greatly between blocks.
9. Continue regular monitoring after each miticide spray to ensure the expected result was achieved and to determine when numbers increase again.
10. Read, understand, and follow label comments and instructions in term of rates, follow-up sprays and any temperature requirements.
11. Use water volumes and a sprayer set-up that optimises spray coverage. Alter for blocks with different tree size, canopy structure and density.
12. Assess spray coverage to ensure it is optimal. Make changes if it is not

If all of this information is applied when managing for SSM then miticide applications could be mor effective, the number of miticide sprays applied to manage SSM could be reduced, and less time and money spent on spraying them.

Recommendations

There is scope for future work in the area of alternative spray products. The efficacy of sulfur could be assessed. If any erythritol products become available, they should be tested for efficacy against SSM. Also, more trials of spray oils should take place to confirm its efficacy and to determine if it is a viable option for autumn sprays.

Given the number of sub-optimal spray applications recorded as part of the fortnightly monitoring as part of this project resources should be put towards improving spray application efficacy, such as spray workshops and one-on-one spray assessments and improvements. This would not only be beneficial for improving mite management practices but also management of all pest, disease and nutritional issues that utilise spray application of products.

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Appendix 8: Extension

Grower monitoring updates

Grower correspondence example 1

4 May SSM monitoring

Alison Mathews
To '[redacted]'

Reply | Reply All | Forward

Thu 6/05/2021 2:43 PM

You replied to this message on 20/05/2021 12:00 PM.

[redacted] - SSM fortnightly monitoring - AV19002.xlsx
268 KB

Hello [redacted]

Attached are this week's monitoring results.

Rows [redacted] - SSM numbers dropped from last fortnight, going from 82% to 42% leaves infested. Predatory mites increased, they were found on 30% of leaves. The result of 82% last fortnight was surprisingly high, and while the results from this week are a lot lower, 42% is still very high for this time of year.

Rows [redacted] – SSM stable at 40% leaves infested. Predatory mites fairly stable too, they were found on 30% of leaves.

Please contact me if you have any questions.

Regards

Alison Mathews | Research Scientist

Grower correspondence example 2

[EXT] - RE: 8 Sept SSM monitoring

[redacted]
To Alison Mathews
Cc [redacted]

Reply | Reply All | Forward

Thu 9/09/2021 4:01 PM

CAUTION: This email originated from outside of DPIRD. Do not click links or open attachments unless you recognise the sender and know the content is safe.

Thanks Alison.

I think the numbers are looking much better than this time last year however

[redacted]

From: Alison Mathews <Alison.Mathews@dpird.wa.gov.au>
Sent: Thursday, 9 September 2021 2:54 PM
To: [redacted]
Subject: 8 Sept SSM monitoring

Hello [redacted]

Attached are this week's monitoring results. Very low numbers again this week.

[redacted] – 0% of leaves with SSM motiles and just a single predatory mite in trees 1-10. In trees 11-20 numbers have started coming up in the last couple of weeks with now 8% of leaves with SSM and 4% with predatory mites, these numbers are still low though.

[redacted] – In block 1 just one leaf with a predatory mite. No SSM or predatory mites or eggs found in block 3.

Please let me know if you have any questions.

Regards

Alison Mathews | Research Scientist

Grower correspondence example 3

6 Sept SSM monitoring

Alison Mathews
To [redacted]

Reply | Reply All

You replied to this message on 22/09/2021 1:33 PM.

[redacted] - SSM fortnightly monitoring -AV 19002.xlsx
334 KB

Hello [redacted]

Attached are this week's monitoring results. Numbers have remained steady, very similar to all other counts over the last couple of months

[redacted] –SSM remained low with 6% leaves infested. Predatory mites found on 4% of leaves.

[redacted] – Just a single leaf (2%) with motile SSM's. Zero predatory mites found.

Regards

Alison Mathews | Research Scientist

Grower correspondence example 4

-----Original Message-----
From [redacted]
Sent: Thursday, 22 July 2021 9:35 AM
To: Alison Mathews <Alison.Mathews@dpird.wa.gov.au>
Subject: Re: [EXT] - Re: 19 July SSM monitoring

Hi Alison
Thanks, that was my plan, and to use paramite again.
We did not apply any autumn mite spray.
Cheers
[redacted]

On 22 Jul 2021, at 9:29 am, Alison Mathews <alison.mathews@dpird.wa.gov.au> wrote:

Hi [redacted]

The numbers we're seeing at your place at the higher end of what we're seeing in other orchards at the moment. If they stay this high then there is definitely the potential for them to build up much faster once the weather warms up. My concern with spraying now is not only finding a suitable day to spray but given the cold the mites will be less active and so some miticides will take longer to work; they may also be moving around less and sheltering more meaning they're less likely to come in contact with any spray.

I've only had experience with one grower doing a winter application and it wasn't effective, but it was fenbutatin oxide which does work better in warmer conditions.

I'd be inclined to wait out the winter, continuing to monitor of course, but be prepared to get out and spray once the weather warms up as they could build very quickly then.

Regards

Alison Mathews | Research Scientist

-----Original Message-----
From [redacted]
Sent: Thursday, 22 July 2021 8:15 AM
To: Alison Mathews <Alison.Mathews@dpird.wa.gov.au>
Subject: [EXT] - Re: 19 July SSM monitoring

Hi Alison
Thanks for these results.
Do you think there is any point doing anything but cruising through the rest of winter with the mite numbers seemingly relatively stable? Not that there have been many opportunities to spray! The one Paramite application last year in early spring, 11/12 September, was very successful.
August could still become quite cold.
Cheers
[redacted]

On 22 Jul 2021, at 8:04 am, Alison Mathews <alison.mathews@dpird.wa.gov.au> wrote:

Hi [redacted]

Attached are the latest mite monitoring results from this week. Very little change from last fortnight.
[redacted] – 12% leaves infested with SSM compared to 10% last fortnight. Predatory mites found on 4% of leaves.
[redacted] – 20% leaves infested with SSM compared to 18% last fortnight. Predatory mites found on 4% of leaves.

Cheers

Alison Mathews | Research Scientist

Extension articles and presentations

Talking Avocados article, spring 2019

Phase 2 of research on managing six-spotted mite in WA avocados

Avocados subjected to heavy infestations of six-spotted mite (SSM) suffer excessive leaf fall and if this occurs in spring, the exposed fruit will be sunburnt and unmarketable. This situation is a challenge for avocado growers in the lower south west of Western Australia.

The Department of Primary Industries and Regional Development (DPIRD) in collaboration with Biological Services and with financial support from the Hort Innovation Avocado Fund completed a three-year project in 2019 to gain a better understanding of how to manage the mite.

This initial study:

- assessed the role of predatory mites
- clarified some aspects of the biology of the mite in WA avocado orchards
- developed tools and ran workshops to help orchardists identify the pest mite and predators
- clarified and made recommendations on the best time to apply miticide to prevent leaf fall in spring.

None of the commercially available species of predatory mite that were released were recovered from the field and therefore were regarded as having no role to play in managing SSM. However, near the end of the project, two other species of breeding populations of predatory mite were identified, in addition to the main species found before the project commenced that could potentially play a part in SSM management.

A new project, phase 2, has just commenced and will carry on and extend the work undertaken in phase 1. The second phase is combining a range of research areas to clarify the identification of the pest and develop monitoring and management techniques for the mite.

The project is being managed by the Department of Primary Industries and Regional Development (DPIRD) Western Australia with collaborators from Biological Services, Queensland Museum and the New Zealand Institute of Plant and Food Research. The project will run for three years and will involve on-farm monitoring, trials and demonstrations across multiple orchards in the south-west region of Western Australia.

By the end of the project, researchers aim to have a SSM integrated pest management (IPM) package for growers, containing information on:

- when and how to monitor for the pest and predatory mites
- the role of both naturally occurring and mass reared predatory mites in SSM management
- the relationship between tree health (nitrogen level), mite numbers and leaf fall, and
- chemical application recommendations that take into consideration resistance management, the impact of chemicals on beneficial species and the impact of timing and application method have on level of control.

More information

For further information on this project please contact Alison Mathews at DPIRD *alison.mathews@dpird.wa.gov.au*, (08) 9777 0122.

Acknowledgement

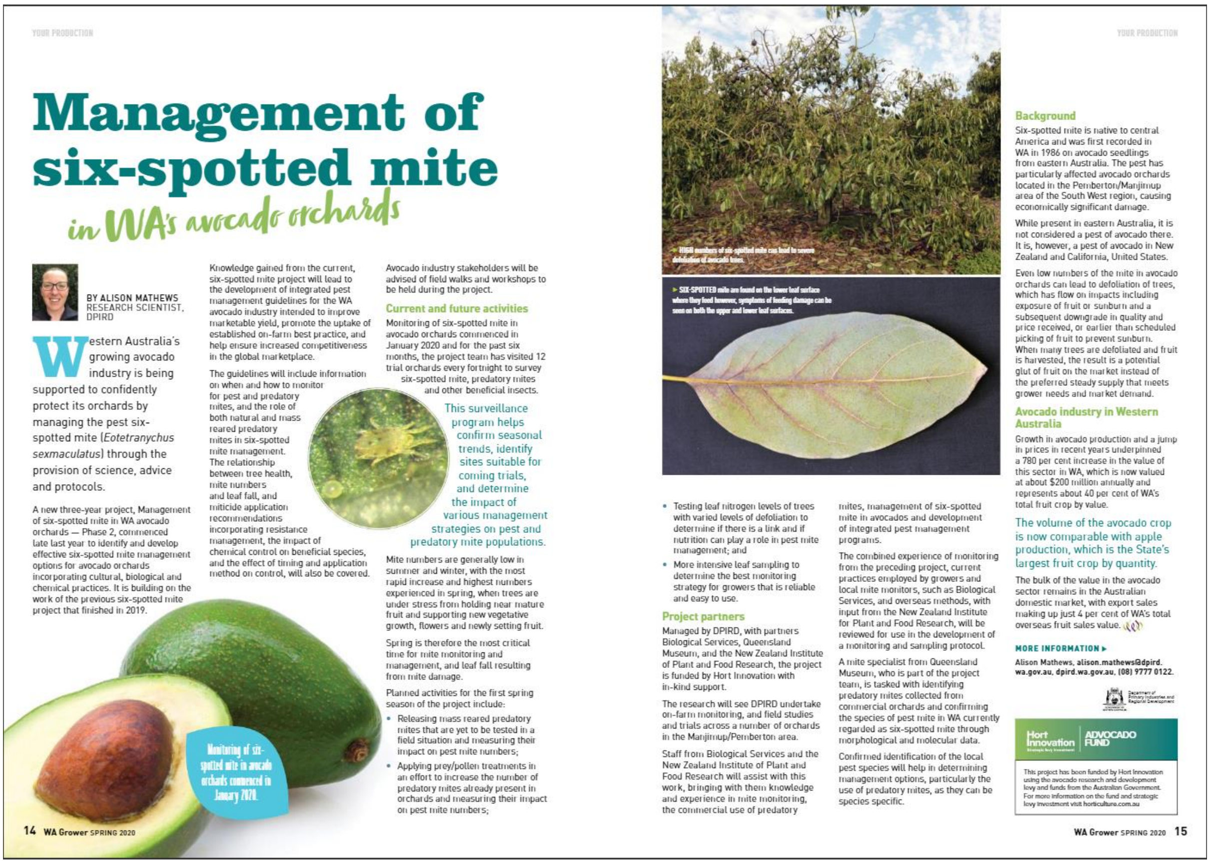
The *Management of six-spotted mite in WA avocado orchards - Phase 2* (AV19002) project has been funded by Hort Innovation using the avocado research and development levy and contributions from the Australian Government.

Hort Innovation Strategic levy investment

AVOCADO FUND

Research and Development

WA Growers article, spring edition 2020



YOUR PRODUCTION

Management of six-spotted mite in WA's avocado orchards

BY ALISON MATHEWS
RESEARCH SCIENTIST, DPIRD

Western Australia's growing avocado industry is being supported to confidently protect its orchards by managing the pest six-spotted mite (*Eotetranychus sexmaculatus*) through the provision of science, advice and protocols.

A new three-year project, Management of six-spotted mite in WA avocado orchards — Phase 2, commenced late last year to identify and develop effective six-spotted mite management options for avocado orchards incorporating cultural, biological and chemical practices. It is building on the work of the previous six-spotted mite project that finished in 2019.

Knowledge gained from the current, six-spotted mite project will lead to the development of integrated pest management guidelines for the WA avocado industry intended to improve marketable yield, promote the uptake of established on-farm best practice, and help ensure increased competitiveness in the global marketplace.

The guidelines will include information on when and how to monitor for pest and predatory mites, and the role of both natural and mass reared predatory mites in six-spotted mite management. The relationship between tree health, mite numbers and leaf fall, and miticide application recommendations incorporating resistance management, the impact of chemical control on beneficial species, and the effect of timing and application method on control, will also be covered.

Avocado industry stakeholders will be advised of field walks and workshops to be held during the project.

Current and future activities

Monitoring of six-spotted mite in avocado orchards commenced in January 2020 and for the past six months, the project team has visited 12 trial orchards every fortnight to survey six-spotted mite, predatory mites and other beneficial insects.

This surveillance program helps confirm seasonal trends, identify sites suitable for coming trials, and determine the impact of various management strategies on pest and predatory mite populations.

Mite numbers are generally low in summer and winter, with the most rapid increase and highest numbers experienced in spring, when trees are under stress from holding near mature fruit and supporting new vegetative growth, flowers and newly setting fruit.

Spring is therefore the most critical time for mite monitoring and management, and leaf fall resulting from mite damage.

Planned activities for the first spring season of the project include:

- Releasing mass reared predatory mites that are yet to be tested in a field situation and measuring their impact on pest mite numbers;
- Applying prey/pollen treatments in an effort to increase the number of predatory mites already present in orchards and measuring their impact on pest mite numbers;
- Testing leaf nitrogen levels of trees with varied levels of defoliation to determine if there is a link and if nutrition can play a role in pest mite management; and
- More intensive leaf sampling to determine the best monitoring strategy for growers that is reliable and easy to use.

Monitoring of six-spotted mite in avocado orchards commenced in January 2020.

HIGH numbers of six-spotted mite can lead to severe defoliation of avocado trees.

SIX-SPOTTED mite are found on the lower leaf surface where they feed however, symptoms of feeding damage can be seen on both the upper and lower leaf surfaces.

Project partners

Managed by DPIRD, with partners Biological Services, Queensland Museum, and the New Zealand Institute of Plant and Food Research, the project is funded by Hort Innovation with in-kind support.

The research will see DPIRD undertake on-farm monitoring, and field studies and trials across a number of orchards in the Manjimup/Pemberton area.

Staff from Biological Services and the New Zealand Institute of Plant and Food Research will assist with this work, bringing with them knowledge and experience in mite monitoring, the commercial use of predatory mites, management of six-spotted mite in avocados and development of integrated pest management programs.

The combined experience of monitoring from the preceding project, current practices employed by growers and local mite monitors, such as Biological Services, and overseas methods, with input from the New Zealand Institute for Plant and Food Research, will be reviewed for use in the development of a monitoring and sampling protocol.

A mite specialist from Queensland Museum, who is part of the project team, is tasked with identifying predatory mites collected from commercial orchards and confirming the species of pest mite in WA currently regarded as six-spotted mite through morphological and molecular data.

Confirmed identification of the local pest species will help in determining management options, particularly the use of predatory mites, as they can be species specific.

Background

Six-spotted mite is native to central America and was first recorded in WA in 1986 on avocado seedlings from eastern Australia. The pest has particularly affected avocado orchards located in the Pemberton/Manjimup area of the South West region, causing economically significant damage.

While present in eastern Australia, it is not considered a pest of avocado there. It is, however, a pest of avocado in New Zealand and California, United States.

Even low numbers of the mite in avocado orchards can lead to defoliation of trees, which has flow on impacts including exposure of fruit or sunburn and a subsequent downgrade in quality and price received, or earlier than scheduled picking of fruit to prevent sunburn. When many trees are defoliated and fruit is harvested, the result is a potential glut of fruit on the market instead of the preferred steady supply that meets grower needs and market demand.

Avocado industry in Western Australia

Growth in avocado production and a jump in prices in recent years underpinned a 780 per cent increase in the value of this sector in WA, which is now valued at about $200 million annually and represents about 40 per cent of WA's total fruit crop by value.

The volume of the avocado crop is now comparable with apple production, which is the State's largest fruit crop by quantity.

The bulk of the value in the avocado sector remains in the Australian domestic market, with export sales making up just 4 per cent of WA's total overseas fruit sales value.

MORE INFORMATION ▸

Alison Mathews, alison.mathews@dpird.wa.gov.au, dpird.wa.gov.au, (08) 9777 0122.

Department of Primary Industries and Regional Development

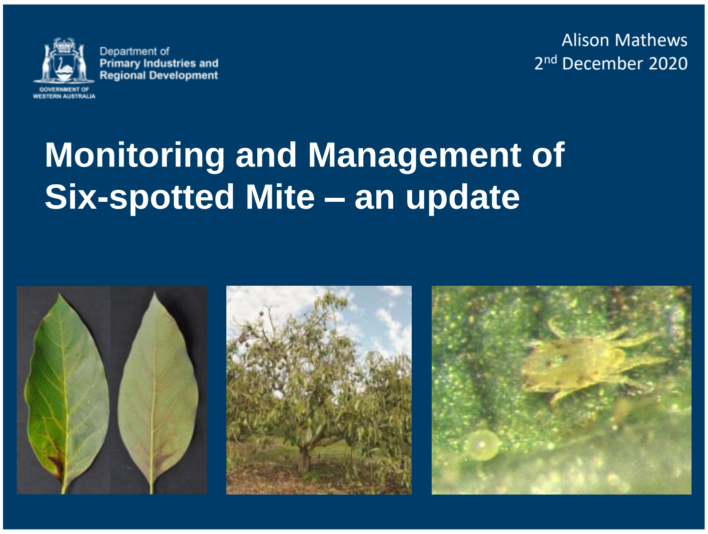
Hort Innovation | ADVOCADO FUND

This project has been funded by Hort Innovation using the avocado research and development levy and funds from the Australian Government. For more information on the fund and strategic levy investment visit horticulture.com.au

14 WA Grower SPRING 2020

WA Grower SPRING 2020 15

Grower presentation, 2nd December 2020



Talking Avocadoes article, summer 2021

Monitoring is key to knowing your mites

Alison Mathews, DPIRD

As we headed further into summer six-spotted mite (SSM) numbers were on the decline as the hot weather continued. Whilst spring is the most critical time for monitoring and management, as it's when numbers can rise sharply and leaf drop is most likely, SSM should not fall off the radar once spring is over. Growers should also be monitoring their orchards and potentially managing SSM in autumn, when smaller peaks can occur.

Monitoring and decision-making for mite management can be a challenge. How, when and where to monitor for these tiny pests are important questions to ask. Learning the answers will provide us with important keys to unlock the toolbox for management of SSM. This is a primary aim of the Hort Innovation funded project, Management of six-spotted mite in WA avocado orchards – Phase 2.

One goal of the project is to develop a monitoring and management package for growers to help with making decisions around SSM. By the end of the three-year project, we'll have sufficient data and insights, gained from multiple years of monitoring and field trials to do this. Even though we're just one year into orchard monitoring for this project, trends and patterns have already emerged that could help growers manage this pest now.

Tools for monitoring

Identification of mites is hard without using magnification. They're small and it's likely you'll find several species of mites, including predatory mites, on your leaves. Having a 10x hand lens in your toolkit provides enough magnification to help with counting and identification.

Learning the characteristics of different mite species known to be present on avocado leaves also allows you to distinguish between them.

Monitor to measure the variability

We've found a lot of variability between seasons, properties, blocks, trees and even leaves of the same tree (examples below). Given the variability, it's important to know what's happening at your place and not base decisions on what's happening in other orchards in your district. The key is to monitor your own orchard, or get someone to do it for you, so you can make decisions and manage it.

We're currently monitoring two blocks in 12 different orchards every two weeks, year-round. We count all of the SSM on each sampled leaf and from this we calculate the percentage of leaves infested. The seasonal variation in SSM numbers can be measured by the percentage of leaves infested – there is a large peak in spring, which declines through summer and a smaller rise in autumn (Figure 1).

We've also noted variability between orchards. The grey line shows the average percentage of leaves infested across all of the orchards being monitored. The green line shows the minimum leaf infestation recorded in any of those orchards and the purple line the maximum. Year round there are very big differences between the orchards, from those with the highest levels recorded and those with the lowest. This highlights the variability and the need to know what's going on at your place.

Monitor different blocks

A high degree of variability is not only present between properties, but also between blocks on the same property.

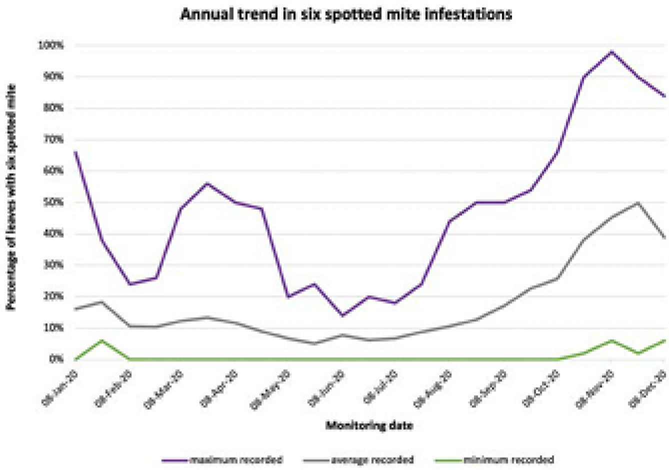


Figure 1. The level of six-spotted mite infestation varies greatly between properties. What might be happening in neighbouring orchards may not necessarily be taking place in yours. The keys times to monitor are spring and autumn, when the two population peaks occur.

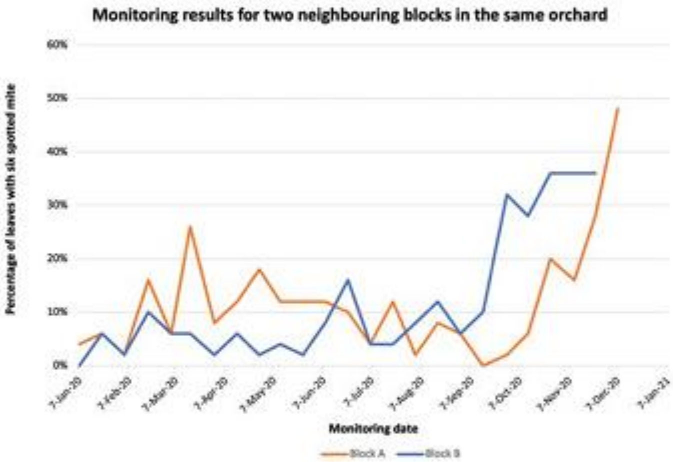


Figure 2. There can be big differences in six-spotted mite populations in different blocks on the same property. By monitoring and managing blocks separately, control measures can be more targeted.

For example, in spring 2020 the SSM population rose rapidly in Block B in mid-September (Figure 2), whilst Block A had a similar steep rise, but not until a full month later. This demonstrates how monitoring in different parts of your property is important, and also managing blocks as different units. In practical terms, if the whole orchard shown in Figure 2 was being managed as one unit and monitoring was only taking place in Block A, then the earlier rise in SSM in the other part of the orchard would have been missed and without treatment, defoliation could result. Alternatively, if only Block B was monitored, then a decision to spray may have been made and Block A would have been sprayed unnecessarily in mid-September, wasting time and money.

You can also see from this example how monitoring results can fluctuate fortnight to fortnight. This reinforces the importance of regular monitoring, as one-off monitoring will not give a clear picture of what's happening compared to trends over time.

Collect samples from multiple trees

When sampling you'll also find that the SSM pressure varies between trees. We've done some intensive monitoring of smaller areas of trees in spring to determine if there was any pattern to SSM distribution. Initial results indicate that there is no pattern, as to where high and low population areas occur across a sub-block, but what the results do show is the variability between trees.

We sampled six leaves per tree, counted all of the SSM and calculated the average number per leaf for each tree. The results for one sub-block are in Figure 3, each square is one tree with its average number of SSM per leaf, the squares have been shaded according to SSM levels, dark green having the lowest and red the highest. The average number of SSM per leaf, in even a relatively small area as this, ranges from 0.3 to 69.7. This demonstrates the need to collect leaves for monitoring from multiple trees in different locations around your blocks to ensure you're getting a more representative sample.

More information

Please contact Alison Mathews, Research Scientist, Irrigated Agriculture Research at DPIRD
alison.mathews@dpird.wa.gov.au, (08) 9777 0122.

SSM motiles

Row \ Tree	1	2	3	4	5	6	7	8	9	10	11	12	13
18	5.5	5.0	7.5	13.0	7.5	4.0	7.2	8.7	41.5	36.5	7.2	12.5	10.0
17	6.5	9.7	28.5	12.2	44.8	21.3	13.8	37.8	27.8	24.5	67.0	24.8	7.3
16	14.3	11.3	13.3	12.8	10.5	37.2	12.8	27.5	21.5	35.8	30.7	30.5	32.5
15	18.5	11.7	21.0	9.3	26.0	26.7	51.8	15.8	8.7	29.0	29.7	51.3	18.5
14	13.7	13.0	29.7	6.5	2.5	22.8	12.2	12.5	18.7	41.0	8.5	45.5	16.7
13	20.3	25.7	17.2	5.2	34.0	3.2	5.7	68.3	10.2	19.2	11.8	23.8	51.7
12	7.8		4.2	6.8	12.5	6.8	2.2	6.0	6.2	21.2	8.3	22.3	17.3
11	8.0	3.0	8.3	18.5	19.8	11.8	37.2	33.5	20.7	14.2	31.7	19.2	3.2
10	8.7	20.8	14.3	18.0	12.0	9.7	21.3	23.0	37.5	17.5	10.3	23.3	25.5
9	12.2	12.8	10.5	21.2	23.3	35.8	16.8	23.7	31.5	31.0	24.2	47.5	27.0
8	3.5	3.0	6.5	8.3	16.2	13.3	29.8	19.2	32.3	34.5	14.5	7.0	13.8
7	4.2	6.5	19.2	14.3	6.8	16.0	27.3	21.5	24.2	26.3	41.7	40.8	31.8
6	1.5	6.2	4.3	4.3	8.8	4.0	33.8	68.7	27.3	36.7	67.3	14.7	25.5
5	0.3	7.0	3.0	5.2	6.0	0.0	4.3	7.3	4.0	2.5		13.8	13.5
4	23.5	7.2	14.8	5.2	11.2	28.2	25.7	34.2	30.7	29.0	20.8	52.2	44.0
3	7.5	12.3	14.0	9.7	7.0	69.7	14.0	19.5	24.0	16.8	9.0	43.2	20.3
2	1.2	18.2	13.2	17.5	21.5	13.7	45.5	22.5	22.0	26.5	5.5	8.8	10.7
1	0.3	11.7	3.7	5.0	7.7	6.7	14.2	1.7	4.0	2.3	6.5	2.3	4.5

Figure 3. The variability in six-spotted mite abundance is seen at individual tree level. Collect multiple leaves from a number of trees around your blocks to get more representative samples.

Acknowledgement

The *Management of six-spotted mite in WA avocado orchards – Phase 2* (AV19002) project has been funded by Hort Innovation, using the avocado research and development levy, and contributions from the Australian Government.

Hort Innovation Strategic levy investment | AVOCADO FUND

Monitoring recommendations

Although a monitoring protocol has not yet been fully developed, there are monitoring recommendations you can take on board now:

- prioritise spring and autumn monitoring
- use a 10x hand lens
- learn to identify SSM and how to tell it apart from the other mite species
- monitor and manage blocks separately, if possible
- record what you find so you can see changes and follow trends in numbers
- collect multiple leaves from a number of trees to get a good representative sample
- continue monitoring after miticide applications to determine effectiveness.

Figure 4. Six-spotted mite.

Grower workshop, 18th March 2021

Grower workshop, 23rd August 2021

Media release, 26th August 2021

https://www.agric.wa.gov.au/news/media-releases/research-manage-mitey-avocado-pest

Taken up by Good Fruit and Vegetables hardcopy magazine and online, plus the Manjimup Bridgetown times newspaper

Good Fruit and Vegetables Magazine, September 2021

Avocado research targets six spotted mite for WA growers

STRATEGIES to help deal with a pest of both avocados and grapevines have been shared in Western Australia.

The three-year research project has looked at six spotted mite which is only considered a pest of avocados in the lower south west of WA and New Zealand.

The pest feeds on the foliage of avocado trees and, in higher numbers, causes the plant to shed its leaves and expose the fruit to sunburn - compromising quality, value and growers' returns.

The WA Department of Primary Industries and Regional Development (DPIRD) is in the final year of the project which is funded by Hort Innovation. The findings so far were shared with south west growers at a workshop at Manjimup last month.

Department research scientist Alison Mathews said the research had already produced some useful insights that would assist the development of an integrated pest management program.

"Very little is known about how six spotted mite performs in avocados so some fundamental research is required to get a better understanding of this pest," she said.

"This includes when and how to monitor for them and best management practices for different times of year."

A key focus of the project has been developing suitable crop monitoring practices to help develop guidelines.

Good Fruit and Vegetables Online, 16 September
https://www.goodfruitandvegetables.com.au/story/7411592/avo-research-targets-pest-for-wa-growers/

HORTICULTURE

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WA research focuses on six spotted mite in avocados

Updated September 16 2021 - 9:10am, first published 2:00am

ON GROUND: DPIRD research scientist Alison Mathews discussed sampling and monitoring techniques with avocado growers at a recent six-spotted mite management workshop at Manjimup.

STRATEGIES to help deal with a pest of both avocados and grapevines have been shared in Western Australia.

The three-year research project has looked at six spotted mite which is only considered a pest of avocados in the lower south west of WA and

Manjimup Bridgetown Times 1 September 2021

Avo go and help prevent orchard damage

BEN LOUGHRAN

DPIRD research scientist Alison Mathews discusses sampling and monitoring techniques with avocado growers in Manjimup.

Avocado growers attended a workshop recently to discuss ways to prevent damage done to the orchards by pests over the picking season.

The workshop, organised by the Department of Primary Industries and Regional Development, was held in Manjimup and showed farmers ways to mitigate the harm done to avocados by the six spotted mite pest.

The workshop is part of a three-year research project by DPIRD, which will conclude at the end of next year, looking into six spotted mites.

Six spotted mites feed on the foliage of the orchard, which can cause the tree to shed excessive numbers of leaves and expose the fruit to the sun, which can ruin the quality and number of avocados.

Department research scientist Alison Mathews said the data collected had already produced some useful insights that would help avocado farmers prevent a loss of product through pest damage.

"We know they are most active in spring, when defoliation is most likely to occur, making it a critical time for growers to monitor for mites," she said.

Ms Matthews said in the last year of the project, it would be important for farmers who were considering monitoring mites for research to keep careful note of how different avocado plants on their properties were affected.

"Mites are very small and this makes the way you monitor them very important," she said. "It's critical to manage different blocks within an orchard as separate units, if possible."

A statement from DPIRD said when the research project ended next year, a management package for six spotted mite in avocados would be formulated to help avocado growers.

Avocado production is now Western Australia's biggest and fastest growing fruit industry, with 33,239 tonnes produced in 2019-20, worth $207 million, from orchards in Pemberton, Manjimup, Busselton, Wanneroo and Gingin.

Talking Avocados article, autumn 2022

Autumn management of six-spotted mite

Alison Mathews, Department of Primary Industries and Regional Development

The impact of autumn miticide applications on six spotted mite (SSM) numbers in avocado orchards was the focus of a case study carried out in 2021 on two Western Australian properties.

The study showed effective miticide applications made in autumn can delay and reduce the spring SSM peak and remove the need to apply miticides in spring. These case studies are from the project, Management of six-spotted mite in WA avocado orchards – Phase 2 (AV19002), led by the Department of Primary Industries and Regional Development.

The application of miticides to control high numbers of six spotted mites (SSM) in avocado orchards are typically applied in spring (if warranted), at which time the mites reach their peak. This is when most leaf feeding damage occurs and the risk of defoliation is highest.

However, spraying in spring can be problematic. Available spraying days can be reduced by spring rain, harvesting and withholding periods must be taken into account and the presence of pollinators may alter the products applied.

A smaller SSM peak can occur in some orchards in autumn. SSM at this time of year doesn't pose a defoliation risk. Although, applying management strategies in Autumn can help knock back the population so that come

Figure 1. An effective miticide application in two blocks on Property A in late April led to very low SSM levels the following spring.

Figure 2. After an effective miticide application in one block on Property B in early April SSM did not reach damaging levels the following spring.

spring, when conditions are right for SSM to breed rapidly, they're starting from a much lower base.

Study outcomes

Observations from two avocado orchards in WA that have been monitored fortnightly throughout the project show the impact of effective miticide applications in autumn.

On Property A, a miticide was applied in late April to two blocks where SSM numbers were high for that time of year. SSM numbers dramatically decreased after the miticide was applied and barely any were seen during monitoring for the whole of winter and most of spring. Numbers only started to increase in late spring and early summer, well past the defoliation risk time and were at very low levels for that time of year.

On Property B a miticide was applied in early April. Again, SSM numbers fell very sharply after this and none were found during monitoring through winter and early to mid-spring. In this case numbers rose a little more through late spring and early summer but did not reach damaging levels before naturally declining again in mid-summer. No spring miticide application was needed on either orchard.

Conclusions

- **Always base spray decisions on monitoring results.** It is important to keep in mind that just because you can spray in autumn doesn't mean you should. Spraying when mite numbers are low wastes time and money and exposes mites unnecessarily to miticides which can accelerate the development of resistance.
- No economic threshold for SSM levels in autumn has been set. However, from monitoring over two years in 26 different orchard blocks we have found that almost 80% of the orchard blocks that had over 20% leaves infested with SSM at some point in autumn went on to reach peaks of at least 40% leaves infested the following spring, a potentially damaging level. 70% of those blocks went on to have at least 50% leaves infested the following spring. If you have over 20% leaves infested with SSM in autumn consider reducing numbers with a registered or permitted miticide.
- **Different blocks in the same orchard should be monitored and managed separately.** SSM numbers vary greatly within and between orchards. Monitoring may show that SSM are high in some blocks and not in others and they should be managed accordingly.
- **Continue spring monitoring.** Monitoring in spring should still be done even after an autumn miticide application to ensure the population remains below damaging levels.

More Information

For further information on this project, please contact Alison Mathews, Research Scientist, Horticulture and Irrigated Agriculture at Department of Primary Industries and Regional Development
alison.mathews@dpird.wa.gov.au

Acknowledgement

The Management of six-spotted mite in WA avocado orchards – Phase 2 (AV19002) project has been funded by Hort Innovation, using the avocado research and development levy, and contributions from the Australian Government. Hort Innovation is the grower-owned, not-for-profit research and development corporation for Australian horticulture.

Hort Innovation
Strategic levy investment
AVOCADO FUND

Spray workshop, May 2022

Manjimup avocado seminar presentation, June 2022

Appendix 9: Avocado six-spotted mite (SSM) management guidelines and Identification guide for mites found on avocado leaves

GOVERNMENT OF WESTERN AUSTRALIA
Department of Primary Industries and Regional Development

Hort Innovation
Strategic levy investment

AVOCADO FUND

Avocado six-spotted mite (SSM) management guidelines

Acknowledgements and contributors

Funding

This Manual is based on research undertaken in the project Management of six-spotted mite in WA avocado orchards - Phase 2 (AV19002). This project has been funded by Hort Innovation, using the avocado research and development levy and contributions from the Australian Government. Hort Innovation is the grower owned, not-for-profit research and development corporation for Australian horticulture.

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Alison Mathews

Project team and contributors

Helen Collie and Lisa Starkie (DPIRD), David Logan (Plant and Food Research NZ), Lachlan Chilman (Biological services), Jenny Beard (Queensland Museum) and Denise Walsh.

Acknowledgements

We thank the growers who provided access to their orchards to enable us to undertake, monitoring, predatory mite releases, development of case studies and spray coverage assessments as part of the project. Without their contribution the project would not have been possible.

Images

The two SSM images on the cover pages, all of the six-spotted mite and tydeid mite images in the mite identification section as well as the second Phytoseiid predatory mite image are © Pia Scanlon, Western Australian Agricultural Authority (Department of Primary Industries and Regional Development) 2020.

All other images used were provided by the project team and DPIRD staff.

Key Points

- Monitor fortnightly in spring and autumn.
- Base management decisions on monitoring.
- Ensure the person monitoring is confident in identifying six spotted mite (SSM) and differentiating between the other mite species that are commonly found on avocados.
- Monitor and manage each block separately as SSM numbers can vary widely across an orchard.
- Keep a record of monitoring results to track mite numbers over time and to measure the impact of any management changes.
- Look for mites on 5 leaves from 10 trees, a total of 50 leaves per block. Calculate the percentage of leaves with SSM.
- Spring threshold is 40% of leaves with SSM. Autumn threshold is 10% of leaves with SSM.
- Take other crop factors into account before deciding if to spray when the thresholds are met.
- Trees can withstand vary levels of SSM before defoliating. Stressed trees are more likely to defoliate.
- Choose the right product for your situation.
- Follow label instructions to improve efficacy and reduce the risk of resistance developing.
- Ensure sprayer is calibrated and good coverage achieved.

Integrated pest management

This guide is for Australian avocado growers to sustainably manage SSM. The monitoring and management guidelines follow the principles of integrated pest management (IPM). IPM combines biological, cultural and chemical practices to managed pests and use monitoring to determine when intervention may be needed. IPM programs look at preventing pests reaching economically damaging levels as a first line of control. Regular monitoring is also undertaken to determine if threshold levels have been reached and if so, targeted management carried out which has the least impact on beneficials and the broader environment as possible.

This guide is based on the research and monitoring conducted as part of the Hort Innovation funded project AV19002 which looked at the effectiveness of various biological, cultural and chemical management strategies.

By following an IPM strategy the number of unnecessary and unsuccessful miticide applications can be reduced. This saves times and money and reduces the risk of pesticide resistance developing. Pesticide resistance can lead to further problems such as environmental and commodity contamination as well as destruction of beneficial agents and secondary pest outbreaks resulting from the need for higher rates and/or more frequent applications, possible cross resistance selection, and the ever-increasing escalation of community concerns around pesticide use.

Damage done

Six-spotted mite are a spider mite, in the Tetranychidae family. They are leaf feeders; they do not feed on avocado fruit.

The leaf feeding causes yellow discolouration to the leaves. This is mainly seen at the base of the leaf and along the veins, where SSM are more often found.

Feeding damage from SSM can be seen on the upper and lower leaf surfaces. It is most prevalent around the veins at the base of the leaf where SSM are more often found.

While the SSM do not cause direct damage to the fruit, under high mite pressure trees will defoliate, exposing fruit, leading to sunburn. Defoliation occurs in spring or early summer in Western Australia, where SSM is a pest of concern. Exposed fruit must be harvested quickly to avoid sunburn and the resultant downgrading in quality and price received. When large areas are defoliated harvest schedules must be altered as large volumes of fruit must be picked from those areas in a short period of time. This can have flow on effects to other orchards' harvest schedules, the consistency and amount of fruit entering the market and potentially prices received. With the effective management of SSM the decline in fruit quality from sunburn and disruption to consistent supply over the season can be avoided.

Defoliation induced by SSM is often sudden and severe, leaving fruit exposed.

Mite identification

A key part to effective SSM management is monitoring. There are numerous species of mites that are found on avocado leaves and it is crucial that people conducting mite monitoring can differentiate between them.

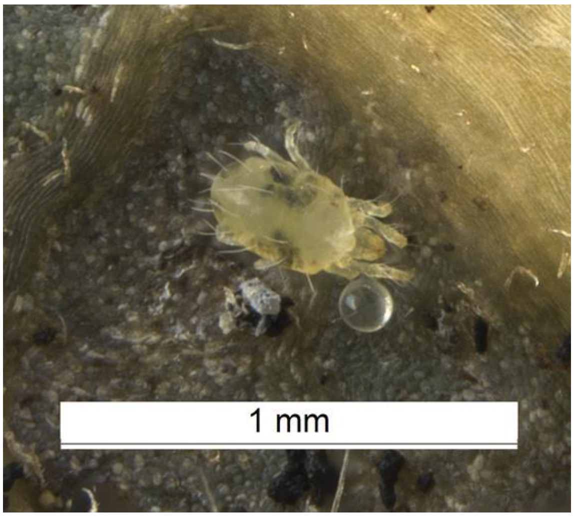
The main types of mites found on avocados in Australia are:

- Six-spotted mite
- Tydeid mites
- Phytoseiid predatory mites
- Stigmaeid predatory mites

All of these mites are similar in size, about 0.3mm long. All monitoring is done based on the motile stages; nymphs and adults. The nymphs and adults for each species are similar in appearance, except that the nymphs are smaller. Mite eggs are not used for crop monitoring as it is more difficult to differentiate between the eggs of different species and the number of eggs observed is not a reliable indicator of SSM levels.

Six-spotted mite

- Body lemon-yellow in colour and blunt oval in shape
- Multiple dark markings on their back, varying in size, shape and number
- Numerous hairs/bristles on their back and legs
- Found more often near veins and closer to the base of the leaf



Despite their common name the number, size and shape of the markings on SSM vary considerably and are almost indistinct on some individuals.

Tydeid mites

- Body often pale yellow to cream in colour but can also be dark yellow or orange
- Angular, ‘coffin’ shaped body
- White legs
- White line along their back, although this is not always distinguishable
- Numerous short bristles on their back
- Move with scuttling motion of the body and jittery motion of the legs
- Often congregate in the leaf vein axis where there are also masses of white discarded exoskeletons

Tydeiids are the mite most often confused with SSM. Their most distinguishing features are the white stripe on their back and their scuttling jittery motion.

Phytoseiid predatory mites

- Tear drop shaped glossy body
- Body various colours including, clear, yellow, orange and red/brown, with usually clear legs
- Move smoothly and quickly over the whole leaf surface, more often moving than still
- Usually found singularly

Phytoseiids are the most commonly found predatory mites in avocados.

Stigmaeid predatory mites

- Body various colours including, bright yellow, orange and dark red
- Legs often different in colour to body
- Angular oval body shape
- Often numerous hairs/bristles on body
- Move smoothly and quickly over the whole leaf surface
- Usually found singularly
- Less common than Phytoseiid predatory mites.

Stigmaeid predatory mites come in a wide variety of colours.

When, where and how to monitor SSM

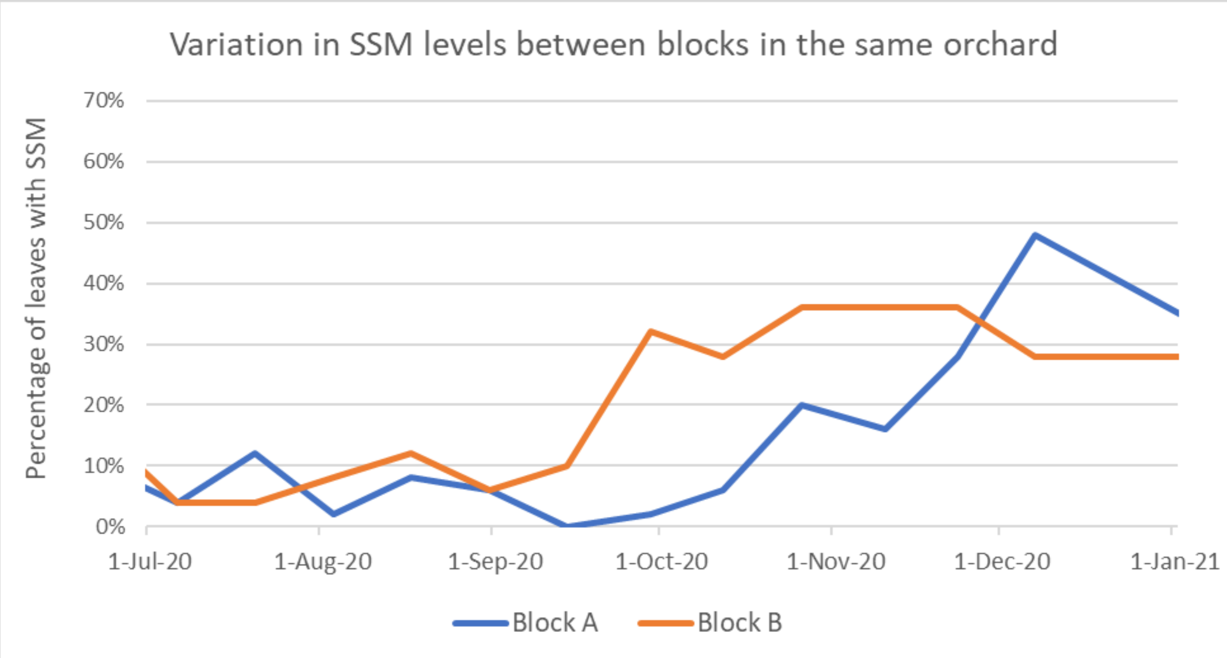
SSM levels can vary widely between blocks.

Every block should be monitored and managed separately

to ensure each area is being managed appropriately. If management is based on a larger area, then hotspots may be missed and areas with low SSM levels may be sprayed with miticides unnecessarily.

If blocks are very large, or with varying tree ages, sizes or spacings or with varying landscape or tree health conditions consider breaking them into smaller areas for pest monitoring and management purposes.

Keep a record of monitoring results to track mite numbers over time as increasing or decreasing trends in mite levels are important. Monitoring records also help you measure the impact of any management changes. This includes continued monitoring after miticides have been applied to determine if the application was successful.



Monitoring results from these two neighbouring blocks in the same orchard demonstrate how SSM levels can vary. In this case SSM numbers began to rise in Block B in September, a full month before they started to increase in Block A.

Monitoring tools

Mites are very small, only 0.3mm long. You will need to use a magnifying tool with 10x magnification to be able to see the mites and differentiate between different types of mites on the leaves.

A ten times magnification tool, similar to those shown, is essential for mite monitoring.

Alternatively, some growers prefer to use an electronic microscope to examine leaves. The advantage of these is that you can easily take photos for your records and future reference or to send to a specialist for identification.

Monitoring times

The key monitoring times are spring and autumn.

This is when SSM are most abundant and effective management can take place.

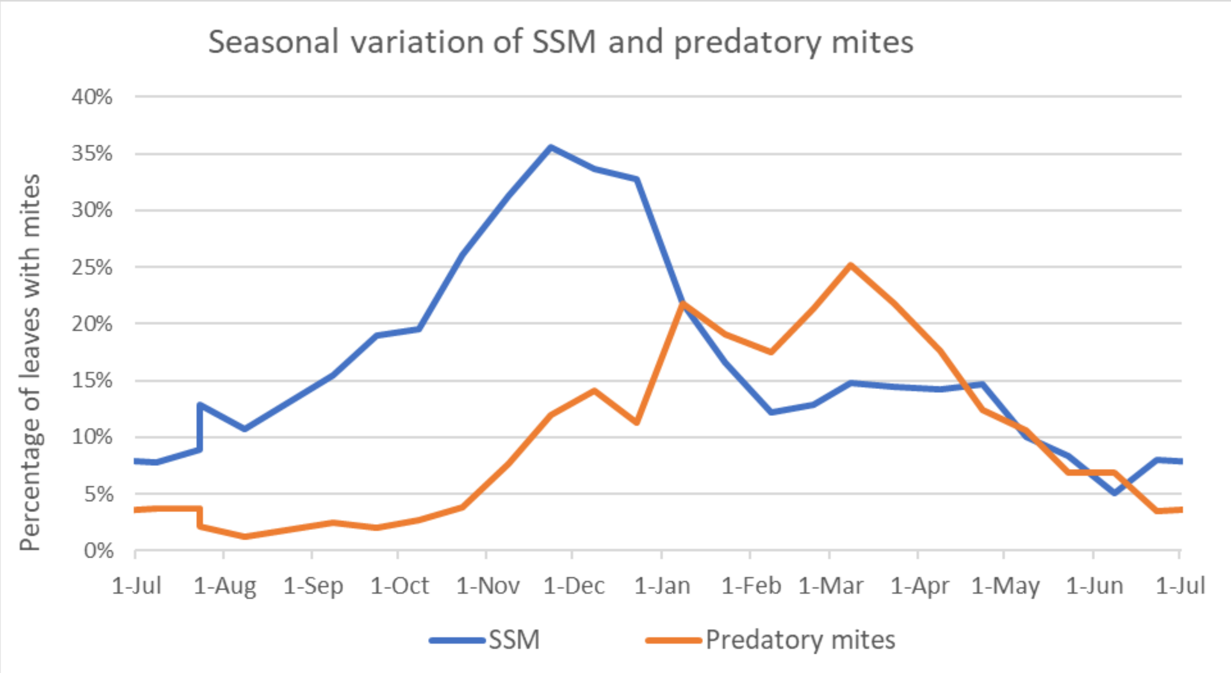
Spring is the defoliation risk period and management at that time may be needed to reduce SSM levels and avoid defoliation that season.

Autumn is an alternative time to control SSM, reducing the population so that they do not reach damaging levels the following spring.

SSM levels can increase rapidly in early spring and decline rapidly in early summer. They are generally low through summer and winter.

SSM can breed quickly leading to rapid increases in population. To keep track of such changes

Fortnightly monitoring is recommended



SSM numbers tend to peak in spring while predatory mite numbers peak in late summer.

Tree selection

SSM are not evenly distributed around orchards, there can be hot-spots, low spots and large variability between neighbouring trees. There is also a lot of variability in SSM numbers found on different leaves of the same tree.

To ensure that you are getting an accurate measure of the level of SSM present in your orchard you must sample multiple leaves from multiple trees.

Sample 5 leaves from 10 trees in every block

The 10 trees you select should be spread around the orchard block. You can choose to sample some trees from known hotspots. You do not need to monitor the same trees every time.

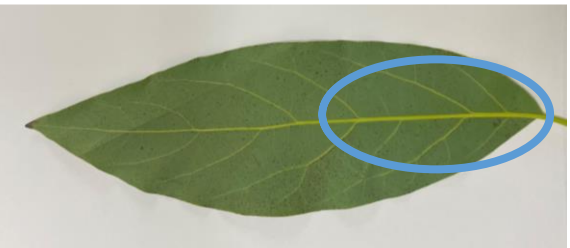
Leaf selection

Sampling of leaves can be done from ground level as numbers are similar at different heights in the canopy.

When selecting the five leaves from each tree always choose recently matured leaves, not soft new growth or old leaves further back along the branch. Look at leaves from the inner and outer canopy and from all around each tree, making sure to include leaves from the shadier southern side when there can often be slightly more SSM.

Walk around each tree looking for mites on recently matured leaves from multiple points.

Look on the underside of leaves. SSM are more often found along the main leaf vein closer to the leaf base, look in this area first.



Look in the circled area of each leaf first. You are more likely to find SSM there.

Threshold calculation

You do not need to count every SSM on every leaf.

Simply look over each leaf and record if SSM are present or not.

After you have examined the 50 leaves from each block calculate the percentage of leaves that have SSM in that block. Management decisions can be based on that percentage.

Thresholds

There is no set economic threshold for SSM in avocados. Trees can withstand varying levels of SSM before defoliating. Trees have been observed to defoliate when 40% of leaves had SSM while others have withstood over 80% of leaves with SSM without defoliating.

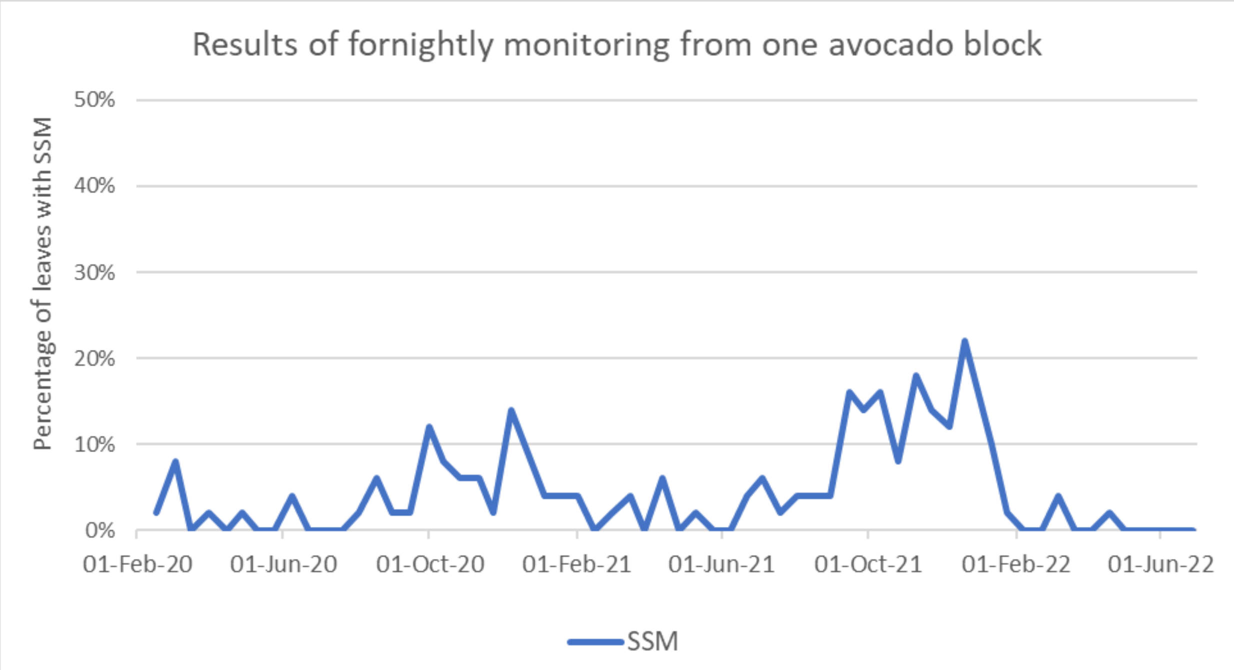
There are thresholds at which point you might consider applying a miticide to reduce SSM levels. These thresholds are:

40% of leaves with SSM in spring and 10% of leaves with SSM in autumn

If SSM reach these levels, there are other factors that need to be considered before the decision to apply a miticide is made.

- Are the trees stressed? Include factors related to water stress, salinity, high fruit loads in the current and previous season, high level of flowering, disease pressure such as from Phytophthora, inadequate nutrition and general poor tree health.
- When has the SSM reached the threshold? Populations naturally decline in summer so if peaking later in the season they may soon decline of their own accord.
- Has the area already been harvested or do the trees have a small crop making a defoliation event less impactful?
- What are the market conditions in terms of price of fruit received and acceptance of lower grade sunburnt fruit?
- Have you experienced defoliation in that area of your orchard under similar conditions and SSM levels? Or have you experienced higher SSM levels in that that area of your orchard under similar conditions without defoliation?
- What is your personal level of risk acceptance?
- Do you prefer to hold off spraying if possible?

Just because SSM are present in your orchard does not mean that they will increase to potentially damaging levels. Levels can remain low year-round.



Some blocks will have SSM present but not reach the thresholds for consideration of treatment.

Cultural management

Given that tree stress is a major factor in defoliation risk when SSM are present trees should be managed to maintain good health.

Factors that can contribute to tree stress include

- Water stress, both over and under watering
- Salinity
- Inadequate nutrition
- Disease pressure, including Phytophthora
- Pressure from other pests
- General poor tree health
- High fruit loads in the current and previous season
- High level of flowering.

Role of predators

Trials in Western Australia showed there was no advantage to releasing mass-reared predatory mites into orchards to assist with SSM control.

However, the Phytoseiid and Stigmaeid predatory mites that are naturally present do prey on spider mites as do other beneficials such as stethorus beetles and predatory thrips.

These beneficials should be maintained and encouraged in orchards. This can be done through minimising the use of pesticides and choosing pesticides that are ‘softer’ on beneficials.

A Phytoseiid predatory mite feeding on a SSM

Predatory thrips found on avocado leaves

A Stethorus larva feeding on pest mites

A stethorus beetle adult feeding on a SSM. They are a very small beetle in the same family as ladybird beetles.

Chemical control

Both spring and autumn sprays can be effective at reducing spring SSM levels to below 40% leaves with SSM and therefore lowering the defoliation risk.

Spring miticide applications are used to reduce SSM levels and avoid defoliation that season.

Autumn miticide applications are used to reduce SSM levels so that they do not reach damaging levels the following spring.

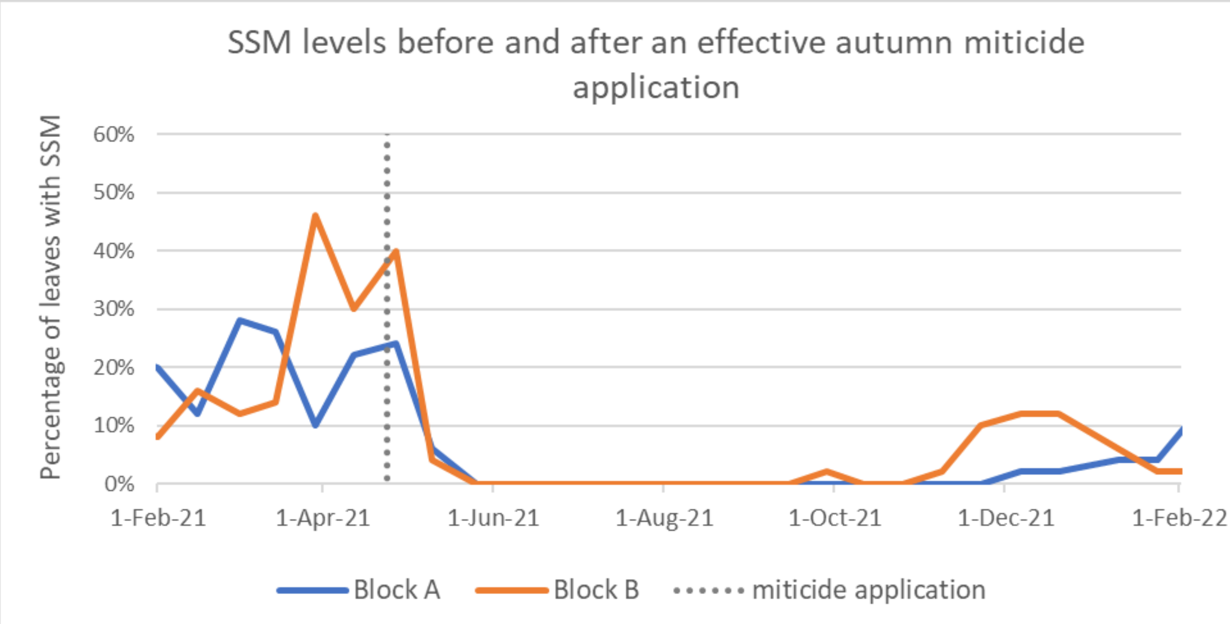
With effective sprays a single application round per year, or less, can maintain a low population in the spring risk period

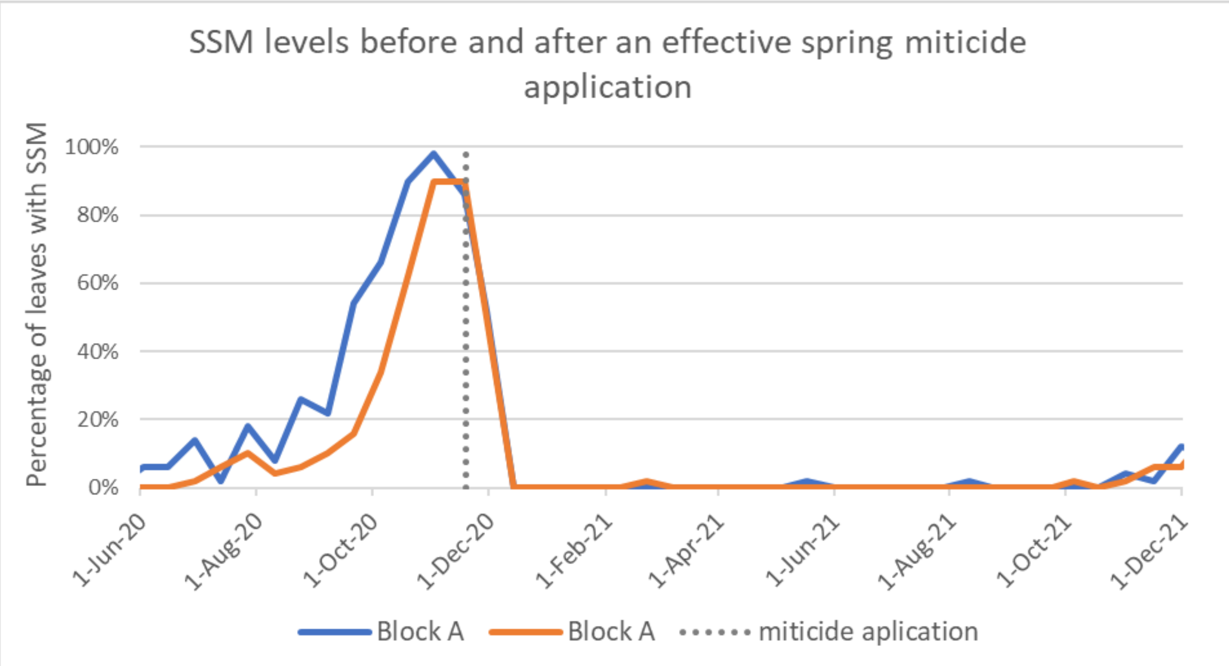
There are several actives that are registered or covered by minor use permits for the control of SSM in avocados.

Spray oil was also shown to be effective in reducing SSM levels as a spring application in a single case study. The benefits of spray oils are that they are not harmful to bees, have a one day withholding period and can be used in organic systems. Spray oils do negatively impact on predatory mites. No demonstrations have been done to assess spray oil efficacy as an autumn spray.

Before choosing a spray product be aware of how each active works, e.g. is it a knock-down, what is its impact on beneficials and bees, what are the withholding and re-entry periods and are there any weather conditions that may impact efficacy. Then use the product best suited to your situation.

For example, Fenbutatin oxide is a knock-down that kills adults but not eggs. After effective application there is a swift reduction in numbers of adults. However, it does not kill eggs. Eggs already present can hatch into viable adults and a follow-up application is required to kill those mites that emerge later. By comparison, etoxazole is a mite growth regulator that causes adults to lay sterile eggs and prevents eggs and nymphs from developing. The adult mites are not killed. This leads to a steady but slower decline in numbers, as the adult mites die-off naturally which may not be suitable if a quick reduction in adult numbers is desired. Only one application of etoxazole is needed. These differences in SSM control will be noticeable in your post-application monitoring.





These examples show how a miticide application in spring or autumn can effectively reduce SSM levels well below the defoliation risk threshold.

Active ingredient	Registration status	Selected exerts from label and permit instructions and critical use comments	WHP (days)	Toxicity to beneficials* (Predatory mites/*Crytolaemus montrouzieri*)
Abamectin	Label registration and Minor use permit PER14618	• Spray in sufficient volume to ensure thorough coverage. Apply in the range of 1000-1500L/ha. • Apply maximum 2 applications per crop. Applications should be applied, 14-28 days apart. • Add 500mL summer oil / 100L water.	14	4 / 3
Bifenazate	Minor use permit PER89167	• To ensure thorough coverage use a spray volume of a minimum of 1000L water/ha • Do not apply more than one application per season	7	1.6 / 1
Etoxazole	Minor use permit PER85167	• Do not apply more than one spray per season • Is a mite growth regulator that causes adults to lay sterile eggs and stops existing eggs and nymphs developing. Is not effective as an adulticide treatment.	14	3 / -
Fenbutatin oxide	Label registration	• Two applications a fortnight apart. • Kills adults and nymphs • Acts more rapidly in hot weather than in cool weather	14	1.4 / 1
Spray oil	Label registration for other pests in avocados		1	2.8 / 1

*Toxicity to beneficials is based on pesticide impact ratings from the Biobest and Koppert databases. Higher scores are more toxic. For more information refer to the project final report.

Always read, understand and follow label instructions before applying a miticide. Choose the active that best suits your situation.

Spray application

No matter which product you use to control SSM, it is essential that it is applied well to achieve an effective spray.

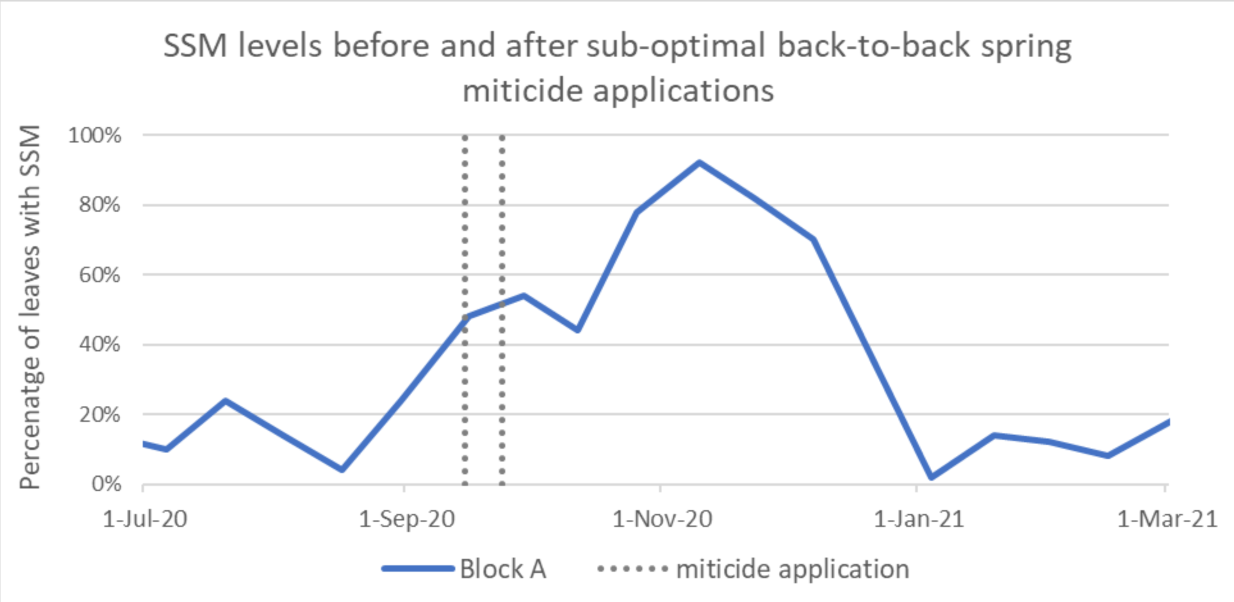
Multiple case studies from the project showed sub-optimal results after miticide applications due to poor application practices.

To get the best from each application:

- Read, understand, and follow label comments and instructions in terms of rates, water volumes, the need for follow-up sprays and any temperature requirements.
- Use water volumes and a sprayer set-up that optimises spray coverage. Alter for blocks with different tree size, canopy structure and density.

Poor application practices can lead to poor control

As shown in the example below. Ineffective applications such as this waste time and money and can have unnecessary impacts on crop residues, the orchard ecosystem and surrounding environment.



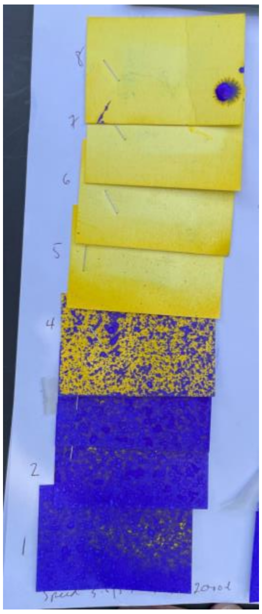
SSM numbers continued to rise after two fenbutatin oxide sprays. The lack of control from the miticide applications in this orchard was most likely due to insufficient coverage.

It is important that sprayers are calibrated to ensure the correct rate per hectare is being applied. However, this does not tell you where in the canopy the product is being applied.

Assess spray coverage to ensure it is optimal. Make changes if it is not

An over the shoulder check is not sufficient. You can not reliably tell from this what your spray coverage is.

Water sensitive papers are an excellent way to assess spray coverage. Place a pole in the canopy with a spray card attached every one metre. The yellow cards turn blue on contact with water allowing you to assess the spray coverage.



In this orchard, with 8m tall trees, water sensitive paper was placed at every metre on a pole within the canopy. Coverage was high up to 4m but poor above that.

On-farm biosecurity

SSM can aerially disperse, spreading naturally between orchards. However, more targeted and widespread incursions into new planting areas and orchards can occur through the spread of SSM on planting stock, machinery and equipment.

The following on-farm management practices are recommended to all avocado growers.

- Always thoroughly check new planting stock for pests, including mites, and control if necessary.
- If sharing machinery and equipment always ensure it is cleaned between properties, this includes bins. With particular focus on plant material.
- If machinery or equipment, including bins, entering your property is dirty or has leaf litter in it, clean it away from your production area.
- All orchards should be regularly monitored for SSM, even if strict biosecurity protocols are followed and no damage has been observed as low population levels can go unnoticed for many years.

Monitoring for mites with a 10x hand lens. Monitoring is an essential part of all six-spotted mite IPM programs

Identification guide for mites found on avocado leaves

Six-spotted mites

- Body lemon-yellow in colour and blunt oval in shape
- Multiple dark markings on their back, varying in size, shape and number. Despite their common name the number, size and shape of the markings on SSM vary considerably and are almost indistinct on some individuals.
- Numerous hairs/bristles on their back and legs
- Found more often near leaf veins and closer to the base of the leaf

Phytoseiid predatory mites

- Most commonly found predatory mites on avocado leaves
- Tear drop shaped glossy body
- Body various colours including, clear, yellow, orange and red/brown, with usually clear legs
- Move smoothly and quickly over the whole leaf surface, more often moving than still
- Usually found singularly

Stigmaeid predatory mites

- Body various colours including, bright yellow, orange and dark red
- Legs often different in colour to body
- Angular oval body shape
- Often numerous hairs/bristles on body
- Move smoothly and quickly over the whole leaf surface
- Usually found singularly
- Less common than Phytoseiid predatory mites

Tydeid mites

- The most often mite type confused with SSM
- Body often pale yellow to cream in colour but can also be dark yellow or orange
- Angular, ‘coffin’ shaped body
- White legs
- White line along their back, although this is not always distinguishable
- Numerous short bristles on their back
- Move with a scuttling motion of body and jittery motion of the legs
- Often congregate in the leaf vein axis where there are also masses of white discarded exoskeletons