Final Report

"Baldwin & Ranking" – Macadamia Inter-row Trial Results

Hort Innovation program title: The IPM program for the macadamia industry – BioResources

Hort Innovation project code: MC16008

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Summary

This project investigates the potential for the development of insectaries through vegetation changes in the inter row via reduced mowing. Adoption of reduced mowing where possible is expected to increase the abundance and diversity of beneficial arthropods by creating more complex food-webs that are vital to pollination and pest suppression. Our aim is to optimise macadamia orchards for the self-regulation of pests by supporting beneficial arthropods with shelter, breeding areas, nectar, alternative hosts/prey and pollen.

You worked with the BioResources team to investigate these ideas from early 2017 to mid 2019.

Your reduced mowing trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk. Industry has been particularly concerned that reduced mowing of the inter row may lead to significant problems such as increased rat activity, invasive weeds and/or increased insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

There were clear benefits associated with having a mohawk with seeding in the inter row on your farm. This included an increase in species richness (diversity) of arthropod communities, particularly those that benefit the health of your macadamia orchard. Insect family diversity was higher in the trial block with a mohawk with seeding when compared to the complete close mow block for all of the main groups of insects sampled including beetles, flies, wasps and true bugs. Flies were comparably more diverse with 38 families represented, many of which are potential pollinators. The most distinct trend we observed overall was an increase in the number of parasitoids and predators. Predators and parasitoids are ecosystem regulators providing virtually free pest control. By contrast, when it comes to potential secondary pests in the orchard, we found for example three times as many thrips in the macadamia tree of the complete close mow treatment block. We speculate that with lower numbers of predators and parasitoids, the complete close mow environment is more favourable to thrips.

The results for your trial are likely to be enhanced farm-wide and into the future where you can maintain a commitment to insectaries throughout your entire orchard. Your farm currently supports biodiversity given your organic management system, areas of native vegetation and relatively relaxed mowing schedules. Your farm enjoys a diverse mix of naturalised weeds, grasses and natives in the inter row with desirable characteristics for an insectary and that are also reasonably easily managed for weediness – with the exception of setaria grass. During the trial we explored seeding options and this and even cover crops can be incorporated into your orchard if you wish to use their features for more targeted benefits from the inter row including improved seasonally-specific resources for pollinators and parasitoids, along with other ecosystem services (see below).

The BioResources team encourages you to read the final report for the *Macadamia IPDM Program – Inter-row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Introduction

This project proposes that reduced mowing in the macadamia inter row may increase vegetative diversity, increase floral resources and reduce habitat disturbance. This may in turn increase the presence of beneficial arthropods in the orchard. More broadly, the proposed changes in plant ecology may increase arthropod populations in general, leading to more complex food webs and better orchard self-regulation of economic pests. Furthermore, this enhanced nutritional food-web will benefit birds and micro-bats, which also have a role in pollination and pest suppression. In comparison it is estimated that beneficial insects provide 5-10 times the pest control in agricultural ecosystems compared to chemical applications[1], as these processes are occurring all the time. By encouraging more diverse ecosystems within the orchard the likelihood and/or intensity of pest outbreaks decreases.

You worked with the BioResources team in this investigation from early 2017 to mid 2019. We compared two (approximately) 1 Ha blocks. A control block was managed as industry standard with regular mowing (**Photo 1**, below). A treatment block was managed with reduced mowing, sustaining a centre mohawk and seeding for most of the trial period (**Photo 2**, below).

Photo 1: "Baldwin & Ranking" – complete close mow October 2018 ***Photo 2: "Baldwin & Ranking" – mohawk with seeding October 2018 including a mix of broad leafed parsley, Queen Anne's lace, marigold, calendula, phacelia, cosmos, buckwheat, lucerne, red clover, dill.***

As you will recall, with each site visit the BioResources team sampled each block for arthropods in three separate rows using yellow stick traps (YSTs), placing one YST in the inter row and one YST in a tree. We assessed the vegetation in the inter row at those three points (a quadrant of approximately 10m x 20m). The three data collection points were at least 30m apart and 50m from any block edge. We also spent

[1] Pimentel, D., Stachow, U., Takacs, D.A., Brubaker, H.W., Dumas, A.R., Meaney, J.J., Onsi, D.E., Corzilius, D.B., 1992. Conserving biological diversity in agricultural/forestry systems. BioScience 42, 354-362.

time with you discussing the trial and any observations that you may have made in relation to rats, weeds, insect pests in the inter row vegetation and/or any challenges with reduced mowing.

The objective of the trial has been to provide growers with practical experience in reduced mowing options on-farm with monitoring to quantify results.

BioResources first worked with growers to consider practical options for reduced mowing that are compatible with the seasonal demands of orchard management. It has then sought to provide information on any relationship between reduced mowing and the potential for increased rat, invasive weed and/or arthropod pest presence. Finally, the trial has sought to monitor association between changes in inter row vegetation management and changes in orchard beneficial/pest arthropod ecology.

Reduced mowing in the inter row at "Baldwin & Ranking"

Reduced mowing and potential problems

	Throughout the trial, BioResources regularly monitored for and consulted with Sue Ranking, on the following issues:
Rats	The project team did make occasional observations of evidence of rat activity in the mohawk during some site visits late in the growing season. This included some shell or burrows here and there. It was noted that this block was especially susceptible to rat incursions because that end of orchard is adjacent to the bush on 3 sides (unlike the complete close mow block). Where setaria grass became very dominant it did provide some habitat. You reported regular concerns that the reduced mowing area may increase your rat issues in the orchard. You provided observations that leading into harvest for 2018 some nut was washing/rolling into the mohawk area and potentially attracting rats. You also observed that unmown areas may provide cover for rats. You observed more rat damage in the reduced mow area in 2018. You increased mowing in that area for harvest and then reduced mowing later in the year. You also reported that as an organic grower you were likely to have access to some additional methods for rat control in the foreseeable future and this provided much stronger rat management for you overall. Mowing more regularly resolved concerns relating to the trial. You also mowed areas specifically when you were managing rats using your Cheetah Rat Control machine. Towards the end of the trial you reported that during the life of the trial rat activity was generally much higher than usual in your area and on neighbouring farms.
Problem weeds	The project team did observe a couple of potential problems with setaria grass becoming dominant in reduced mow areas. Setaria limited the overall vegetative diversity of the trial block and created some additional mowing burden. It also had the potential to provide rats with habitat and shelter from predators. By the end of the third season it was noted however that the power harrowing and seeding was starting to reduce the dominance of setaria in the seeded mohawks. You reported that woody weeds were starting to establish in reduced mow inter rows and you consequently increased mowing frequency and were happy with the result.
Major insect pests of macadamias	The project team monitored vegetation in the inter row for the presence of major macadamia pests including Macadamia Nut Borer, Green Veggie Bug and Fruit Spotting Bug. Plant species typically found in the inter row trial blocks at your farm were not observed to host these pests. You did not report observations of insect pests in the inter row vegetation.
Management of the inter row	There were a number of iterations of the reduced mowing schedule in order to find periods of time that best allowed vegetation growth for insectary but also limited issues with difficult to manage growth-rates and volumes, and possible association with rats, and general pre-harvest clean-up. A combination of unusually wet weather and reduced mowing created some challenges for harvest (mostly because you could not get machinery on to the orchard), but you found a number of solutions including increased mowing as required and a more narrow mohawk for harvest. You noted additional future refinements including: leave the mohawks long until the nut shells harden, the Fruit Spotting Bug high risk time and wasp releases are past.

	Then mow and keep short for a month to two before pickup starts and to deter the rats. The seed mixes selected for your trial did not demonstrate especially strong establishment. As a result, we did not see strong increases in plant species diversity and floral resources. This provided a very useful insight because these plant species are widely recommended for insectaries. Your trial results have helped the project to identify other new and more promising seed mixes suitable for the macadamia inter row.

Outcomes

Your trial has provided several useful insights into the practicalities of reduced mow options in macadamia orchards and especially the mohawk and seeding. Industry has been especially concerned that reduced mowing of the inter row may lead to significant problems with increased rat activity, invasive weeds and/or insect pests. Your trial gives other growers reassurance that a mohawk can be incorporated into existing orchard inter row management and with basic monitoring and management will not lead to other problems.

Some trial farms, including yours, found through time that maintaining a mohawk in the orchard in parallel with standard orchard operations was difficult. This was a result of a combination of row width and available machinery and was particularly a problem leading into harvest. This is an important finding, and the project team and participating growers including you, formed the opinion that alternate row mow outside of harvest may be a more suitable reduced mow strategy in such circumstances.

Over the life of your trial there were a number of challenges to the consistent incorporation of a control and a reduced mow with seeding treatment option into the inter row. There were cumulative impacts from some irregular mowing; wet weather conditions especially in 2018 prevented you from mowing the control block, while management issues with the mohawk meant that you mowed this area out, all of which will have introduced confounding factors into the experimental data. Despite this, data collected for your trial in terms of the benefits of reduced mowing for beneficial arthropods in your orchard are promising and suggest that mohawks with seeding can complement your organic system and native vegetation areas in the promotion beneficial arthropods that can provide ecosystem services.

Abundance of arthropods was higher in the mohawk with seeding (3206 specimens) than in the close mow treatment (2771 specimens), with the most difference in abundance being in samples taken from the inter row and slightly higher in samples taken from the macadamia tree.

Insect family diversity was higher in the mohawk with seeding treatment for all the main groups of insects caught on YSTs (beetles, flies, wasps and true bugs). Flies were comparably more diverse with 38 families represented. The mohawk with seeding block had a higher diversity of flies, with nine extra families. The mohawk with seeding had a greater number of predatory flies both in the inter row and macadamia tree

The mohawk with seeding treatment block had higher nectarivores (potential pollinators), parasitoids (wasps and flies) and predators than the complete close mow block.

There were five parasitoid wasp families absent from the complete close mow block that were present in the mohawk with seeding block. No wasp families were found only in the complete close mow block.

There is not much difference in parasitoid abundance in the macadamia tree in the two treatments, However, parasitoid numbers were double and triple in the mohawk with seeding treatment block in 2018 and 2019 respectively. There were twice as many Trichogrammatidae (including MacTrix) in the mohawk with seeding, but only in the first period of 2019, so this might have been confounded by the release points of MacTrix In other sampling periods there was little difference of MacTrix between treatments.

True bug diversity is greater in the mohawk with seeding treatment block with seven families present there that are not present in the complete close mow block. True bug predators are higher in the row and tree of the mohawk with seeding treatment block.

We found three times as many thrips in the macadamia tree of the complete close mow treatment block. We speculate that it is possible that with lower numbers of predators and parasitoids in the complete close mow environment it could be more favourable to thrips.

For an overview of the potential for inter row insectaries in macadamia orchards, the BioResources team urges you to read the project’s final report, *Macadamia IPDM Program - Inter row Project (MC16008),* which will be available via *Hort Innovation*.

Results of reduced mowing and seeding in the inter row

Vegetative diversity

Vegetative diversity refers to the number of plant species present. Changes to regular mowing and the incorporation of seeding can change plant species diversity. This can in turn be associated with diversity of arthropod species. **Chart 1** presents an average count of plant species observed in the inter row by treatment through time.

In this trial we anticipated that reduced mowing with seeding will increase the number of plant species present in the orchard. As we can see in **Chart 1**, this is consistently the case for the life of your trial, where reduced mowing with seeding and the retention of a mohawk result in an inter row with more plant species. This can be characterised as an area with "managed vegetative diversity".

In experimental terms, you will note however that the distinction between the values recorded for the control and treatment is not strong on a number of the assessment dates – the mohawk with seeding has increased species to a maximum of 2-3 additional species on four out of eight assessment dates. This result is linked to the species selected for seeding, which project records indicate were not consistently strong in establishment. Likewise, reduced mowing was unable to consistently and substantially increase the number of plant species present. At the same time the plant species diversity in the control (complete close mow) was in fact reasonably good. This is good news for your farm, which has good existing plant diversity in the weeds, grasses and local natives already present. But the lack of distinction between the two blocks will have somewhat diminished the arthropod results discussed below, where we sought to investigate an experimental comparison between two different types of inter row management.

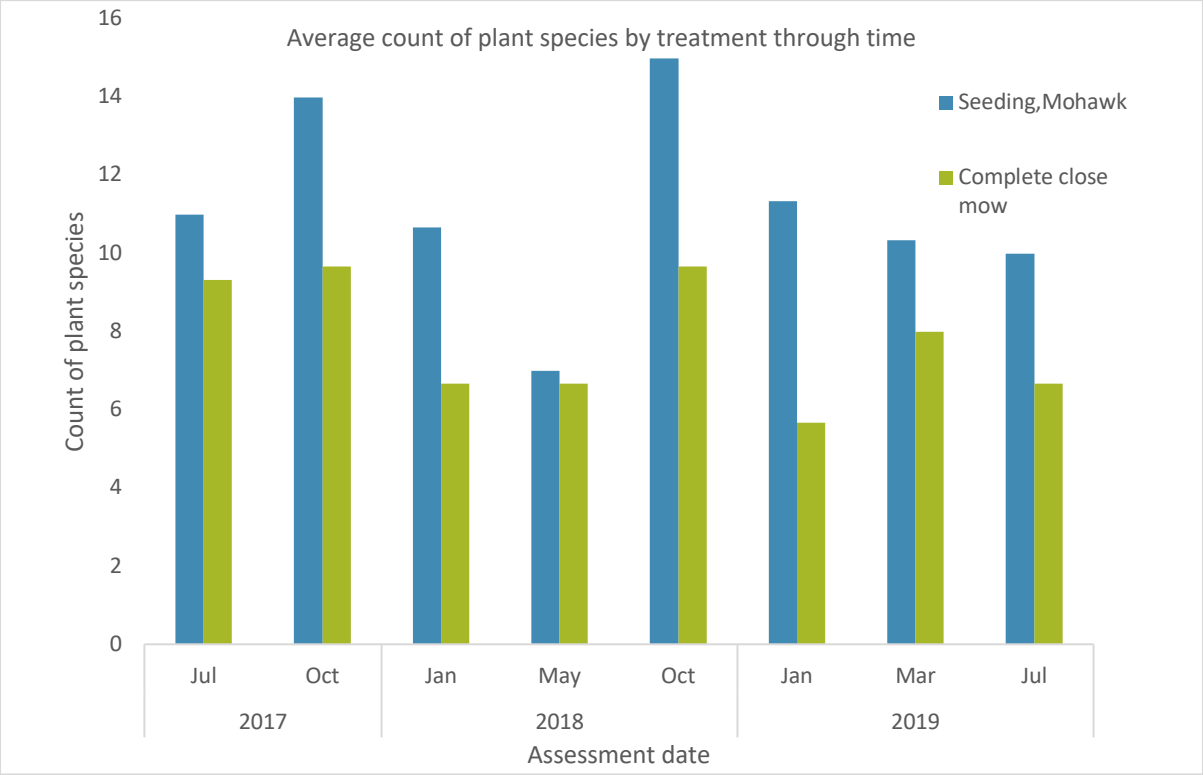

Chart 1: Average count of plant species by treatment through time. This is an average of counts taken at the three assessment points on each block.

Floral resources

Floral resources provide a food source for many beneficial arthropods and will encourage them to remain active in the orchard. **Chart 2** provides an average count of the plant species flowering at the time of the site visit. There were always flowering plant species in both blocks (with the exception of May 2018); but there was always a larger number of flowering species in the mohawk block. In conjunction with this, we also see that these flowering species produced a larger volume of flowers as a percent of biomass in the mohawk block as compared to the complete close mow block (with the exception of October 2018, when prairie grass was especially vigorously flowering in the control block (**Photo 1**)(**Chart 3**). These results are a consequence of the mix of plant species present in the trial block and seeding, which demonstrate a number of favourable characteristics for plants in an insectary. By contrast, the complete close mow block could generally only sustain occasional and very limited floral resources (**Charts 2** and **3**).

Again, in experimental terms, you will note however that the distinction between the values recorded for the control and treatment in **Chart 2** is not especially strong for a number of the assessment dates. The mohawk with seeding increases the number of flowering species in a range of 2 to 3 additional species in most cases. Despite this, in **Chart 3** we see that the flowering species in the mohawk with seeding have significantly increased the availability of floral resources for beneficial arthropods.

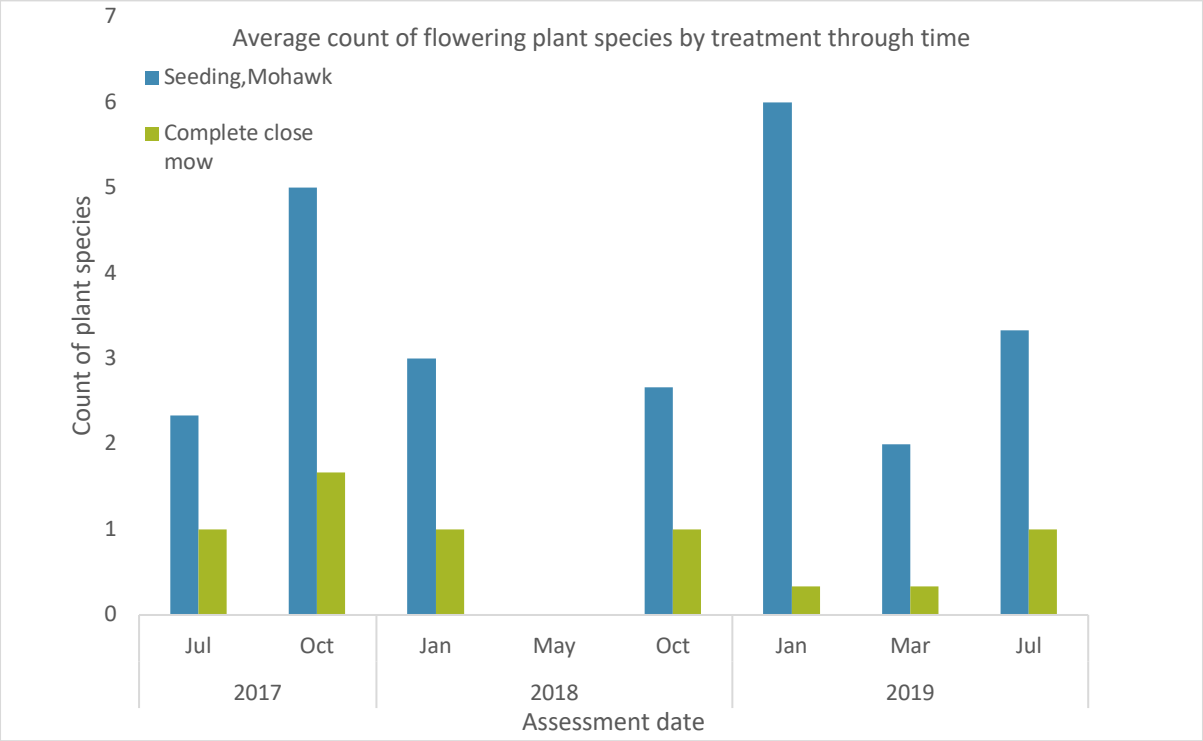

Chart 2: Average count of plant species with floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

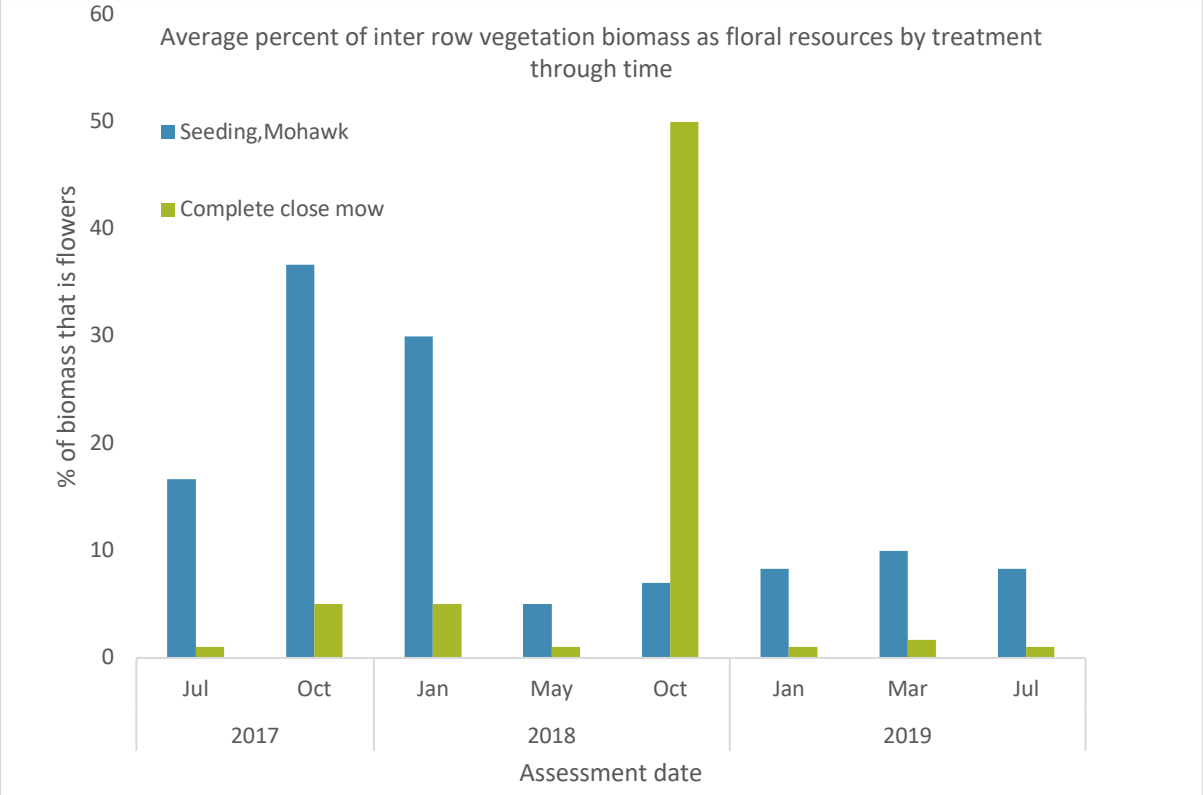

Chart 3: Average percentage of inter row vegetation biomass as floral resources by treatment through time. This is an average of counts taken at the three assessment points on each block.

Habitat disturbance

Areas of reduced mechanical and chemical disturbance can serve as favourable habitat for beneficial insects. Undisturbed areas may also provide a refuge for beneficial arthropods for faster recovery after spraying. The measurement of height provides a good indication of rates of mechanical disturbance. **Chart 4** reports the height in centimetres (cm) of vegetation in the inter row by treatment through time. Retention of a central mohawk on your farm allowed for greater height of vegetation, and hence less disturbance in the inter row for the life of the trial. By contrast, the complete close mow block was more regularly and heavily disturbed.

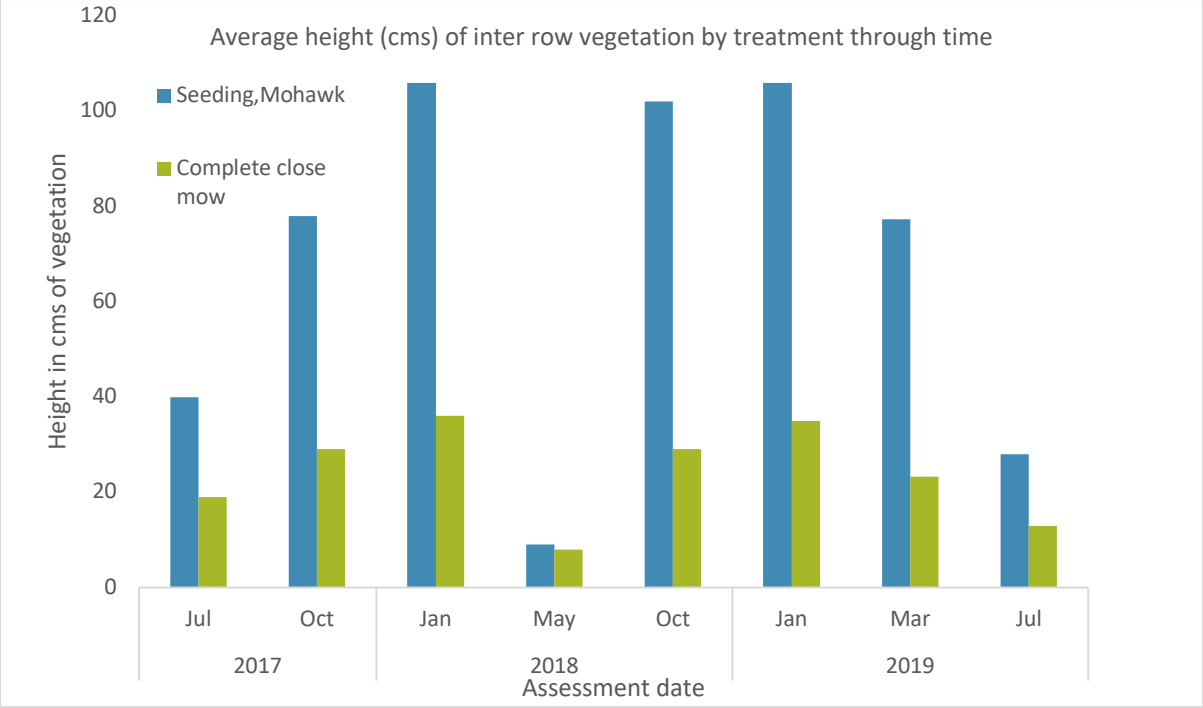

Chart 4: Average height (cm) of inter row vegetation by treatment through time. This is an average of counts taken at the three assessment points on each block.

Results of arthropod evaluation

General arthropod abundance

From March 2017 to July 2019 we identified 5,977 arthropods over 8 sampling dates (approximately every 4 months) using yellow sticky traps (YSTs). YSTs best capture flying insects such as flies, true bugs (including aphids), wasps and thrips. However non-flying insects and those not attracted to yellow are seldom caught (ants and spiders for instance). In **Chart 5,** we have collated all the arthropods over the sampling period into broad order level classification and compared the inter row and macadamia tree habitats. Most arthropod orders are similar in both treatments except for wasps (most of which are parasitoids), which are almost twice the number in the inter row of the mohawk with seeding treatment block. Booklice where higher in the trees of the mohawk with seeding. Thrips are modestly higher in the inter row (502 vs 455 specimens) but are found less in the tree where there is a mohawk with seeding (75 vs 110 specimens). Proportionally, over the years, thrip abundance in the macadamia trees was relatively high in 2017 and 2019, but similar in 2018. This could have been influenced by the block mowing alterations in 2018.

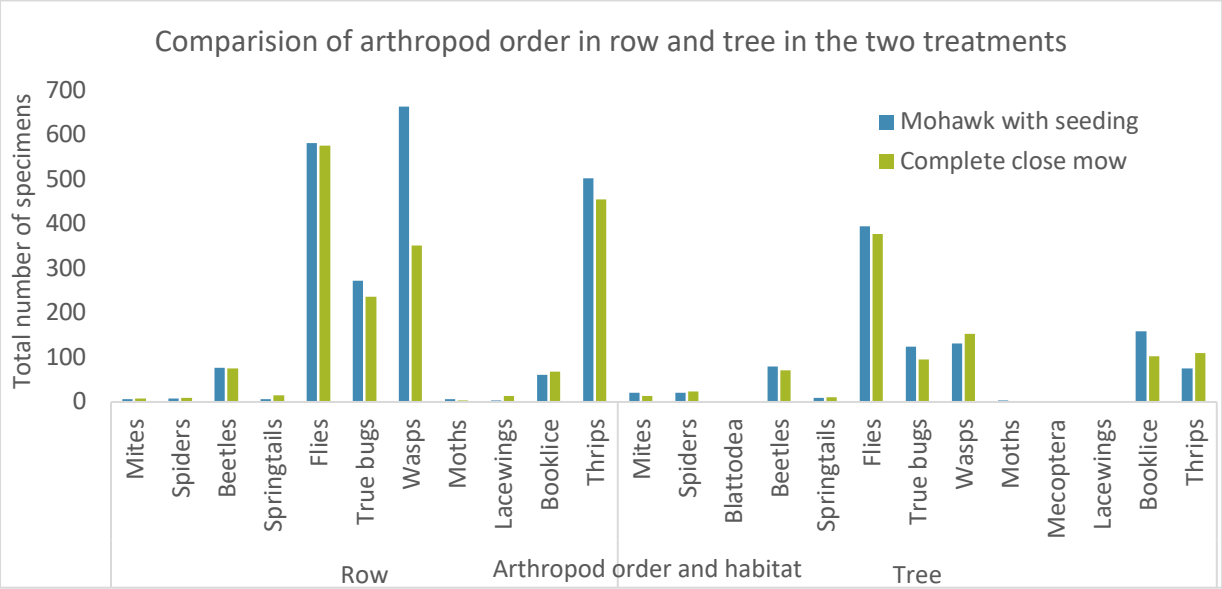

Chart 5: Abundance of arthropods divided into order level classification, comparing the mohawk with seeding and complete close mow treatments over the total sampling period.

Arthropod abundance was higher in the mohawk with seeding block (3206 specimens) compared with the close mow treatment block (2771 specimens) over the three years of the survey. **Chart 6** compares total arthropod abundance in the two habitats over the sampling period, demonstrating that the abundance was higher in the inter row of the mohawk with seeding over time. In the macadamia tree there was slightly higher arthropod abundance in 2017 in the close mow block. This changed in 2018 when higher overall abundance was observed in the mohawk block. In 2019 both treatments had similar arthropod abundance in the macadamia trees.

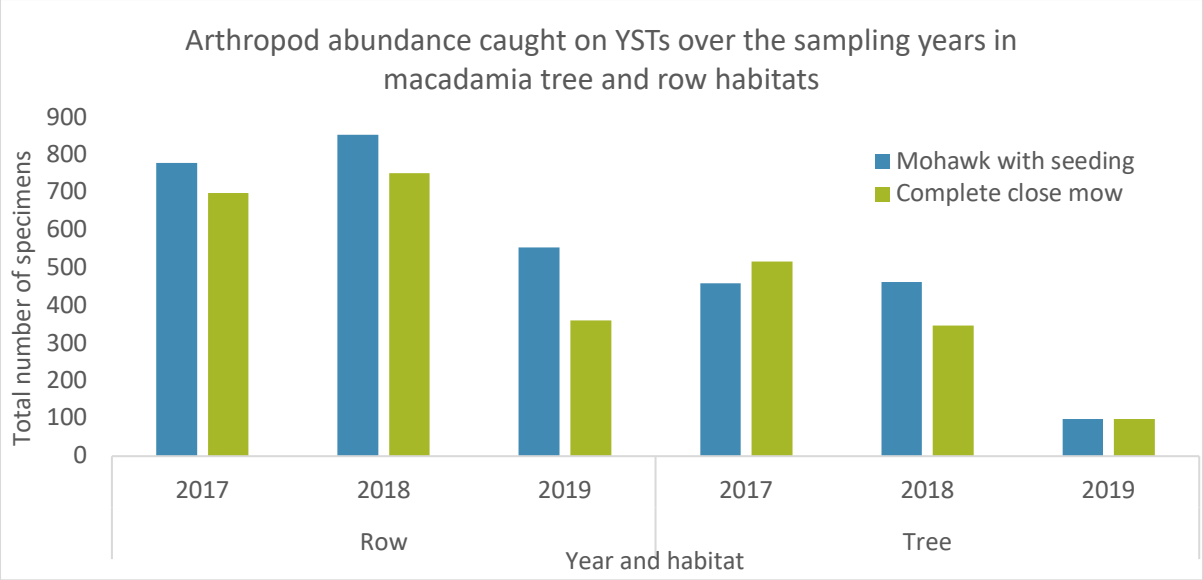

Chart 6: Total arthropod abundance of specimens collected by YSTs over the sampling period combining both the inter row and macadamia tree habitats.

Another broad level of comparing treatments is to examine the diversity of insects between treatments. In **Chart 7** we have listed the most diverse groups that we identified to family level classification. On your farm, flies are diverse, consisting of 38 families (out of 111 found in all Australian environments). In the four main insect groups, the mohawk with seeding block had more diversity of families. Prey diversity is important for the year-round nutrition of predators and parasitoids.

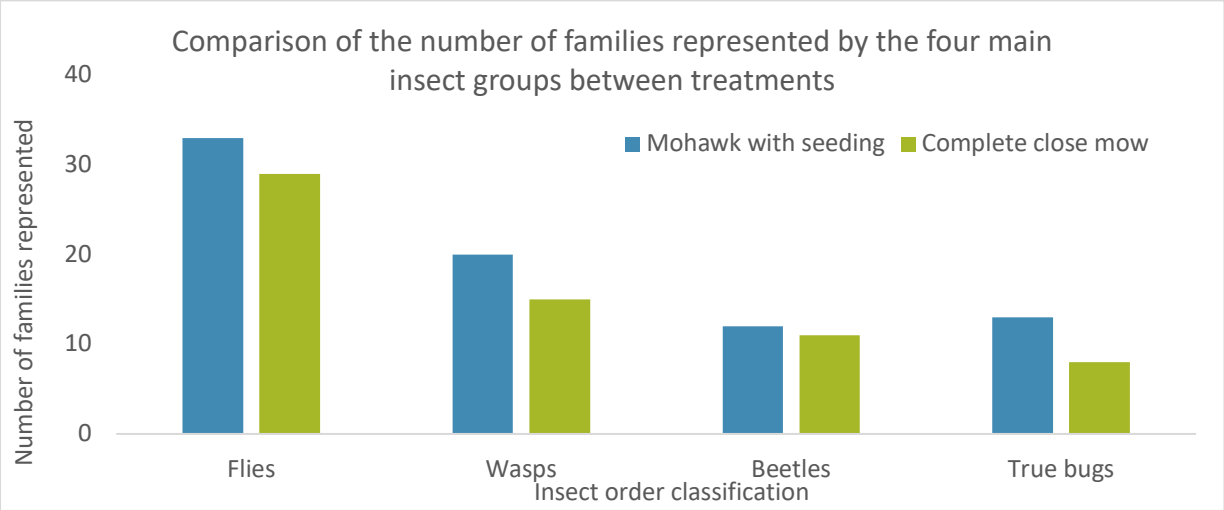

Chart 7: Comparison of the number of families represented by the four main insect groups between treatments.

Feeding Guilds

To better understand the nature of food webs on macadamia farms we have identified most insect species to family level classification, allowing us to determine the feeding guild structure of insect assemblages. The guild concept has been widely utilised by ecologists; a guild is any group of species that exploit the same resources. For instance, most insect herbivores are selective feeders, they may be specialised as leaf chewers, sap suckers, stem borers, root borers, gall formers, leaf miners etc. Beneficial insects feed as predators and parasitoids. Other important arthropod feeding groups are pollinators via

nectar feeding (nectarivores). This is a good way of examining species richness and how it relates overall to farm food webs. **Chart 8** summarises the total number of arthropods grouped by feeding guild. The mohawk with seeding treatment block had higher nectarivores, parasitoids and predators than the complete close mow block.

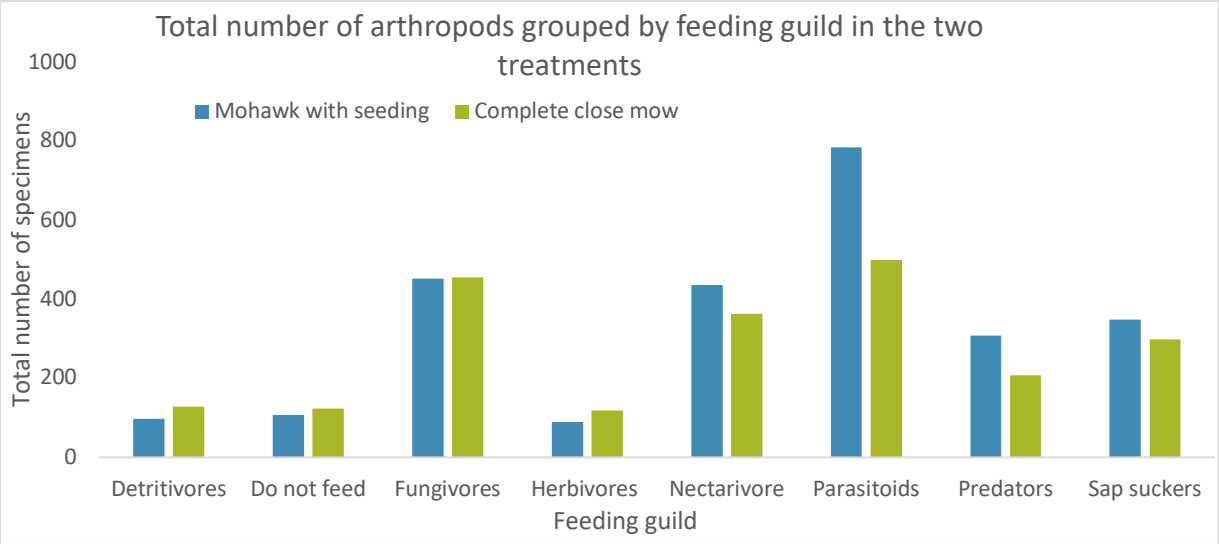

Chart 8: Total number of insects and their respective feeding guilds caught on YSTs from March 2017 to July 2019 in the two treatment blocks.

To simplify our results, by classifying all insects as prey and then separating nectivores (potential pollinators), predators and parasitoids, as four broad categories, we can compare treatments comparatively in proportions. By combining tree and inter row abundance counts between mohawk with seeding and complete mow treatments (**Chart 9**), there is a slightly greater proportion of prey in the mohawk (54%). The proportion of predators and parasitoids in the mohawk block is greater (60 and 61% respectively) than in the complete close mow block. Nectivores are modestly greater in the mohawk (55%) compared to the complete close mow block (45%).

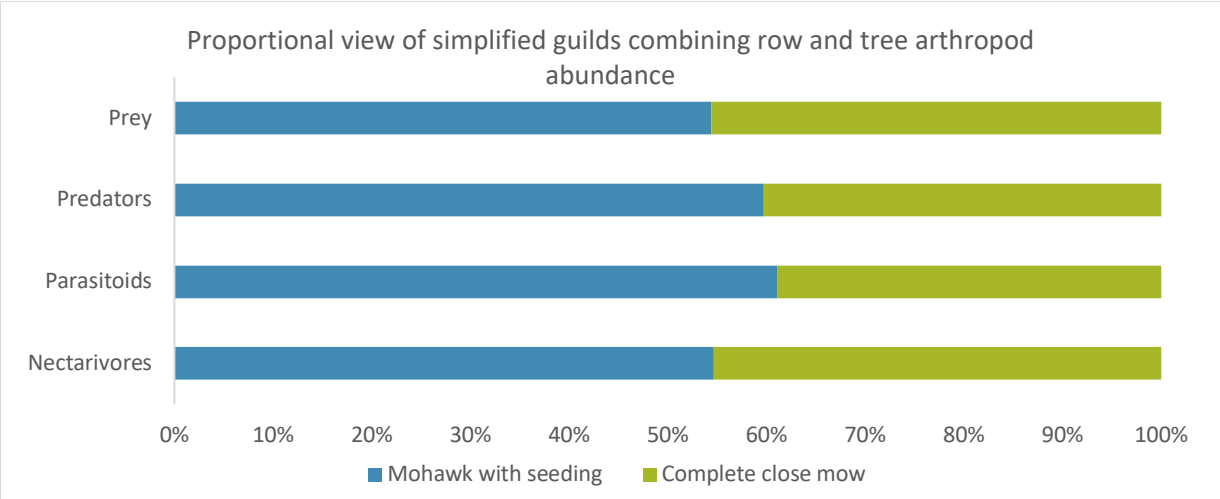

Chart 9: Representation of simplified feeding guilds in macadamia tree and inter row habitats combining all abundance data.

When we examine this ratio comparing the row habitat in mohawk and complete close mow (**Chart 11**), nectarivores have similar proportions (51% and 49% respectively). There is however proportionally

greater abundance of prey in the mohawk (55%). This may account for the greater proportions of predators (61%) and parasitoids (65%) in the mohawk with seeding compared to the complete close mow block.

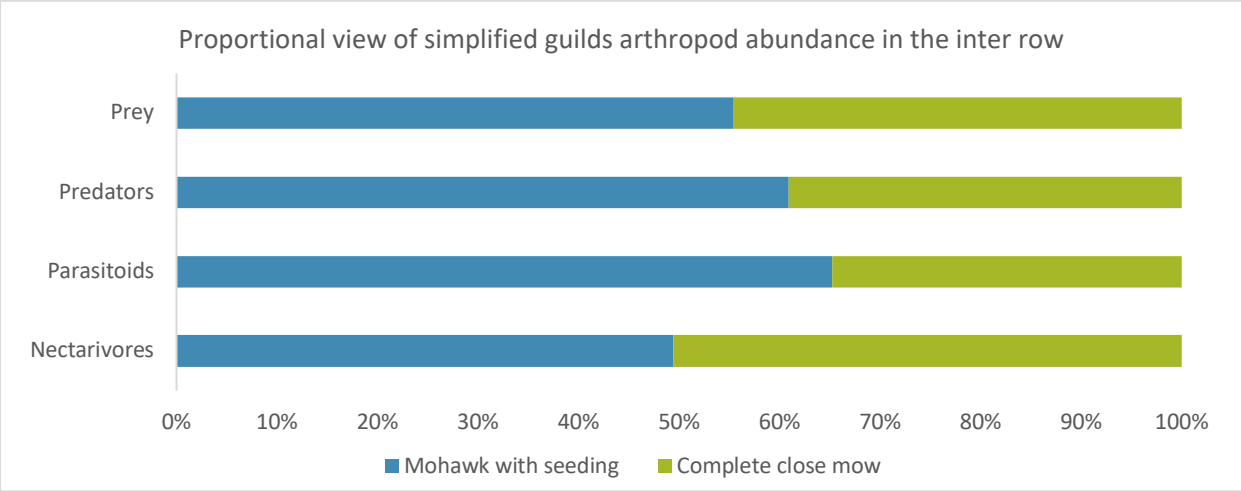

Chart 10: Representation of simplified feeding guilds in the inter row comparing the mohawk and complete close mow treatments.

In the macadamia tree (**Chart 11**) we found a slightly higher prey ratio in the mohawk with seeding (53%, 1890 specimens) to that of the complete close mow (47%, 1702 specimens), and conversely slightly less parasitoids in the mohawk with seeding (46%, 131 specimens) to that of the complete close mow (54%, 153 specimens). Given the low numbers of parasitoids this difference is small. Predators (including species from flies, beetles and true bugs) where higher in the mohawk with seeding (57%) to that of the complete close mow (43%). Nectivores (potential pollinators) were much higher in the mohawk with seeding (61%) to that of the complete close mow (39%).

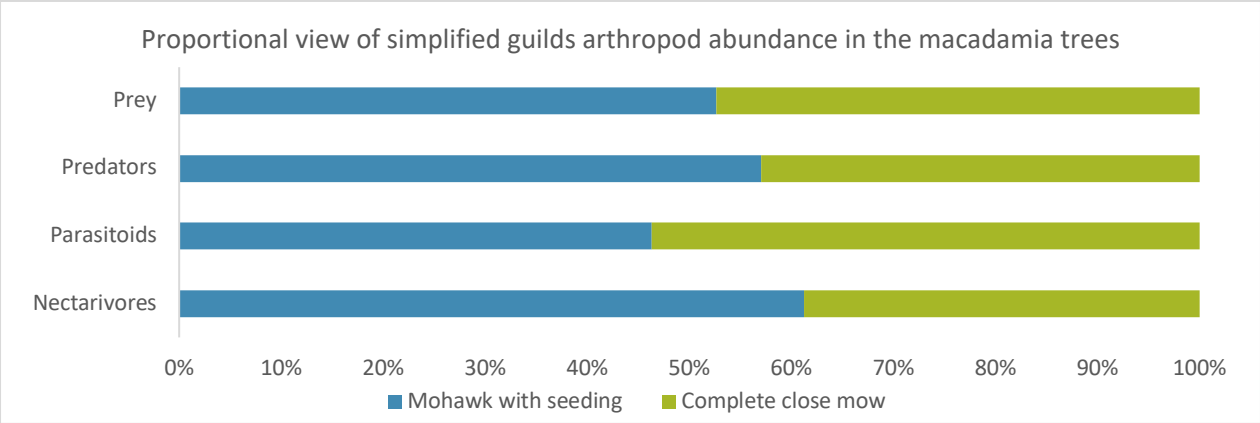

Chart 11: Representation of simplified feeding guilds in macadamia trees comparing mohawk and complete close mow treatments.

Flies as pollinators

In many ecosystems, including agricultural ones, flies are very important pollinators. Of the 150 families of flies worldwide, almost half, 71, have been shown to feed from flowers (mainly nectar) and thus in principle transmit pollen from one plant to another. This is currently an expanding area of behavioural

research as we discover more about their pollinating abilities. A famous example is that we would be a world without chocolate without pollination by the chocolate midge (family Certopogonidae).

Nectivores are the most abundant flies in the orchard and there are more in the mohawk with seeding block in the macadamia tree (**Chart 12**) and these are represented mainly by phorid and sciarid flies. Conversely there were more nectarivores counted in the complete close mow block in the inter row. Sciarid species are known to be pollinators however they are generally poorly studied in Australia, as they are particularly difficult to observe in the field, and thus their roles as pollinators are probably not fully appreciated. Phorids are a very diverse family and many are important pollinators particularly in forest habitats. The most numerous Phorid genus on your farm was *Megaselia* which has over 1500 species worldwide. Some Phorids species are also known to be aphid predators. Phorid species have also been identified in northern NSW that parasitise macadamia seed weevil and fruit spotting bug.

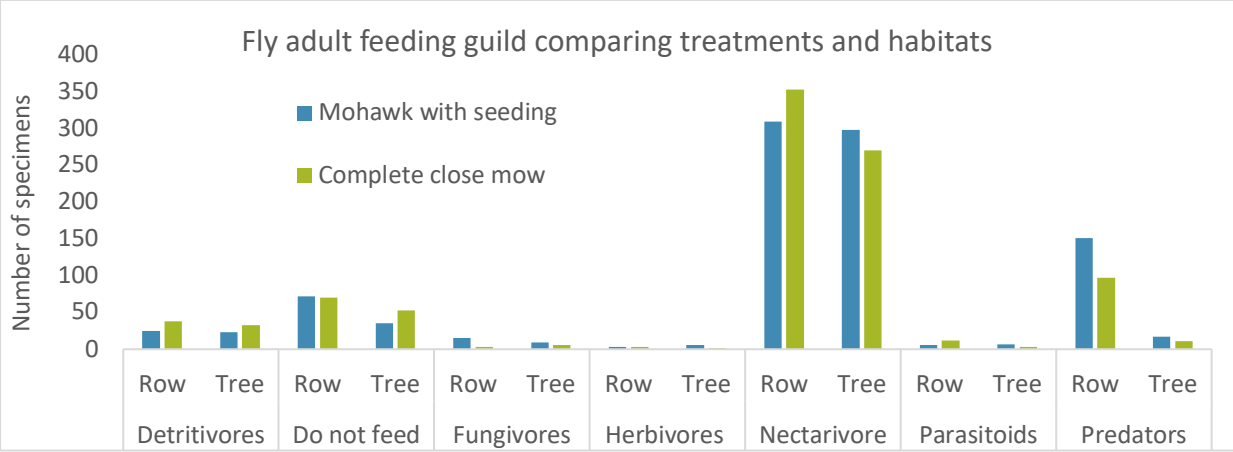

Chart 12: Fly feeding guilds structure in mow treatments in the row and trees over the sampling period.

There were large differences in the inter row where there was double the abundance of phorids in the mohawk with seeding (132 specimens) than the complete close mow (67 specimens). There were somewhat higher levels of phorids in the macadamia trees in the mohawk with seeding (129 specimens) than the complete close mow (115 specimens). Phorids where not collectively placed in the predatory guild as they are very diverse and occupy various feeding guilds as adults and larvae including scavengers, predators, herbivores, fungivores, parasitoids, and true parasites. Other nectivores included lauxaniid and conopid flies. Detritivores and fungivores were higher in the complete close mow in both tree and row habitats. Parasitoid flies were few but were more numerous in the row of the complete close mow (12 vs 6 specimens) however more numerous in the mohawk with seeding tree habitat (7 vs 3 specimens).

We identified 1,929 flies from 38 fly families on your farm. In **Chart 13** we show the total abundance of each fly family caught on YSTs over the 8 sample dates from March 2017 to July 2019. The mohawk with seeding block has a higher diversity of flies, with nine extra families (**Chart 13**). Of these families four are predators (Anthomyiidae, Asilidae, Empididae, Micropezidae) and another four are nectarivores (Micropezidae, Sciomyzidae, Stratiomyidae, Therevidae); the final family does not feed (Bibionidae). In the complete close mow, there are two parasitoid fly families that are not in the mohawk with seeding block (Conopidae, Pyrgotidae), one fungivore family (Keroplatidae), one nectivore family (Tabanidae) and one detritivore family (Heleomysidae). These families only appeared in 2018 and may be a reflection on experimental protocol modifications in that year/season. The mohawk with seeding had a greater

number of predatory flies both in the inter row and macadamia tree, mostly Dolichopodidae (long legged flies) and other families included Hybotidae (dance flies) and Rhagionidae (snipe flies) (**Chart 13 and 12**).

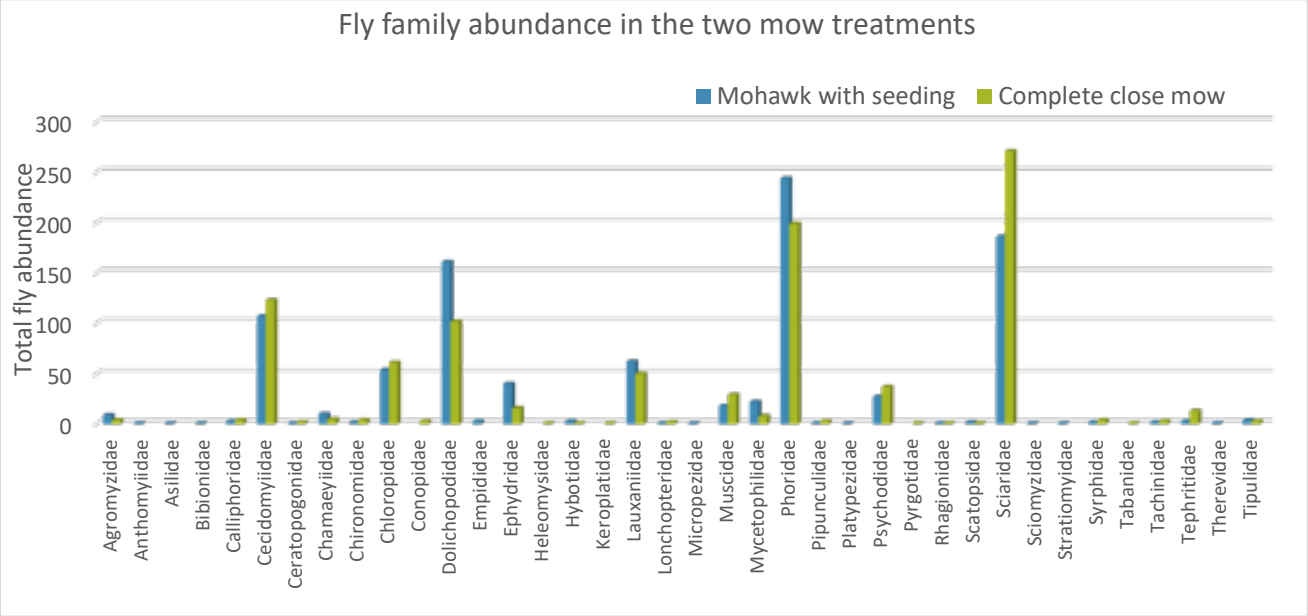

Chart 13: Total fly abundance in each fly family caught on YSTs over the 8 sample dates from March 2017 to July 2019

Wasps as parasitoids

We identified 470 specimens of wasps (Hymenoptera) on your farm, comprising of 20 families out of 77 families found in Australia, almost all of which were parasitoids. Most (90%) of the wasps caught on YST on your farm were chalcids (Superfamily Chalcidoidea). Chalcids are very important in biological control of herbivorous crop pests because they are predominantly parasitoids of lepidoptera, aphids and beetles. There were more chalcids in the mohawk with seeding (492 specimens) than the complete close mow block (336). For the first six survey dates the chalcids were not identified to family, but for the last two sampling dates they were to explore this superfamily more. In **Chart 14** we have compared the wasp families other than chalcids from 2017-2018 to better compare less numerous families. The Chalcid families from 2019 are (Encyrtidae, Eulophidae, Eupelmidae, Eurytomidae and Mymaridae). Encyrtidae is the most numerous in the mohawk with seeding block (74 specimens) compared to the complete close mow (19 specimens). Trichogrammatidae are also chalcids and include mostly MacTrix egg parasitoids, we separated them as they were released on the farm. There were twice as many Trichogrammatidae in the mohawk with seeding (105 specimens) compared to the complete close mow block (51 specimens). These numbers might be influenced by the position of any MacTrix releases. The next most numerous family is the Diapriidae; they typically attack larvae and pupae of a wide range of insects, especially flies. They were generally more numerous in the mohawk with seeding (34 specimens) than the complete close mow (28 specimens). There were several parasitoid wasp families absent from the complete close mow block (Figitidae, Mymaridae, Pergidae, Tenthredinidae and Torymidae) that are present in the mohawk with seeding block. No unique families were found only in the complete close mow block.

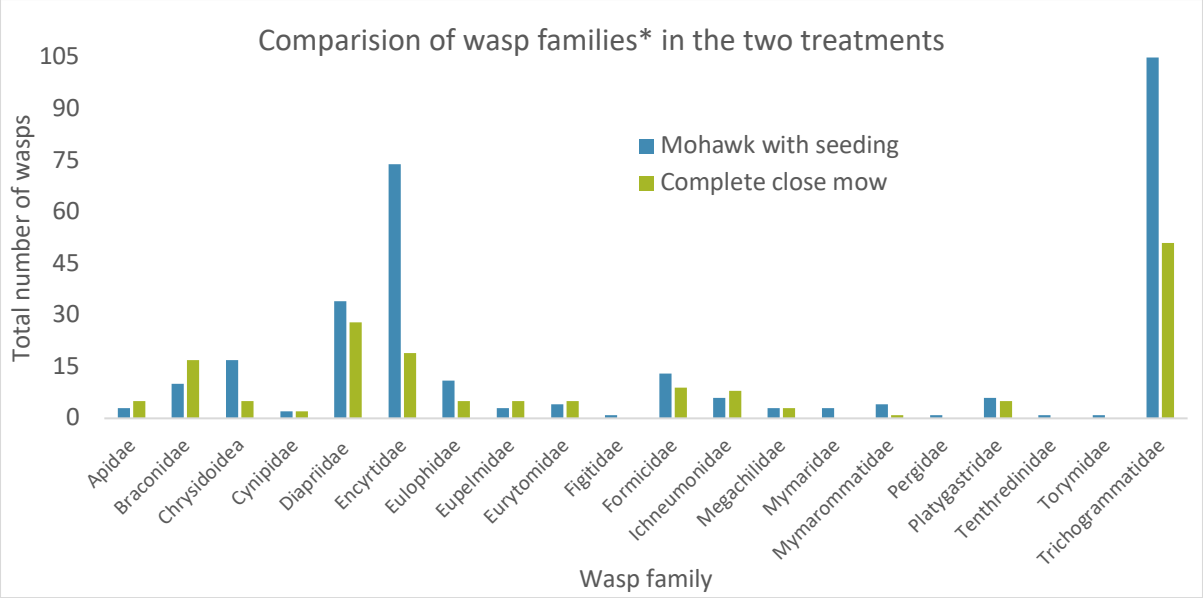

Chart 14: Comparison of the number of parasitoids caught on YSTs from March 2017 to July 2019 in row and tree * excluding the superfamily Chalcidoidea from 2017-18 dates to better compare less numerous families.

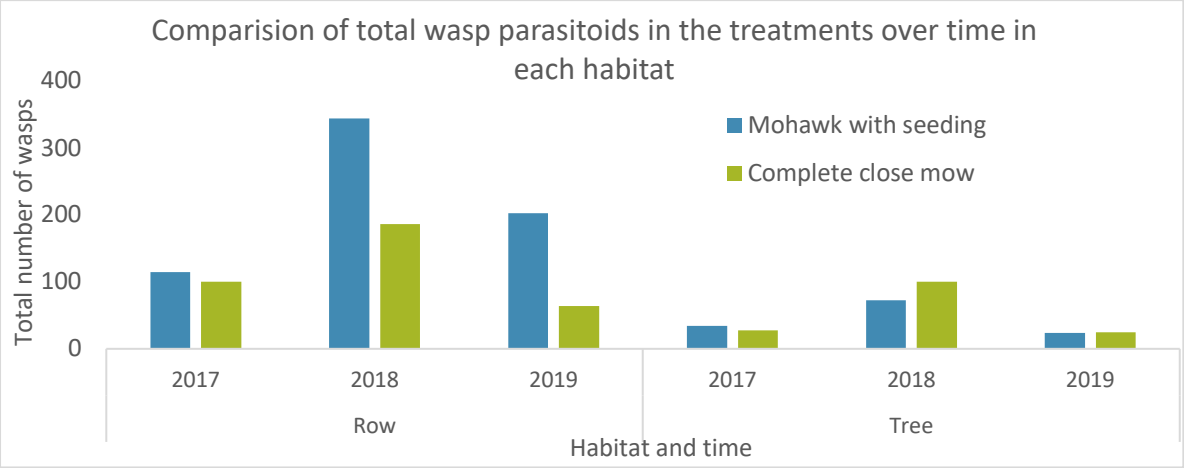

Chart 15: Comparison of abundance of wasp parasitoids in the two treatments over time in each habitat.

There is not much difference in parasitoid abundance in the macadamia tree in the two treatments (**Chart 15**). In the 2017 sample dates there was also little difference in the treatments in the inter row. However, in 2018 parasitoid numbers were double (345 vs 187 wasps); they were triple (203 vs 64) in 2019 survey dates in the mohawk with seeding treatment block.

If we examine the families in the macadamia tree (**Chart 16**), there were several families only present in the mohawk with seeding treatment including; Torymidae, Platygastridae, Mymaridae, Megachilidae and Apidae.

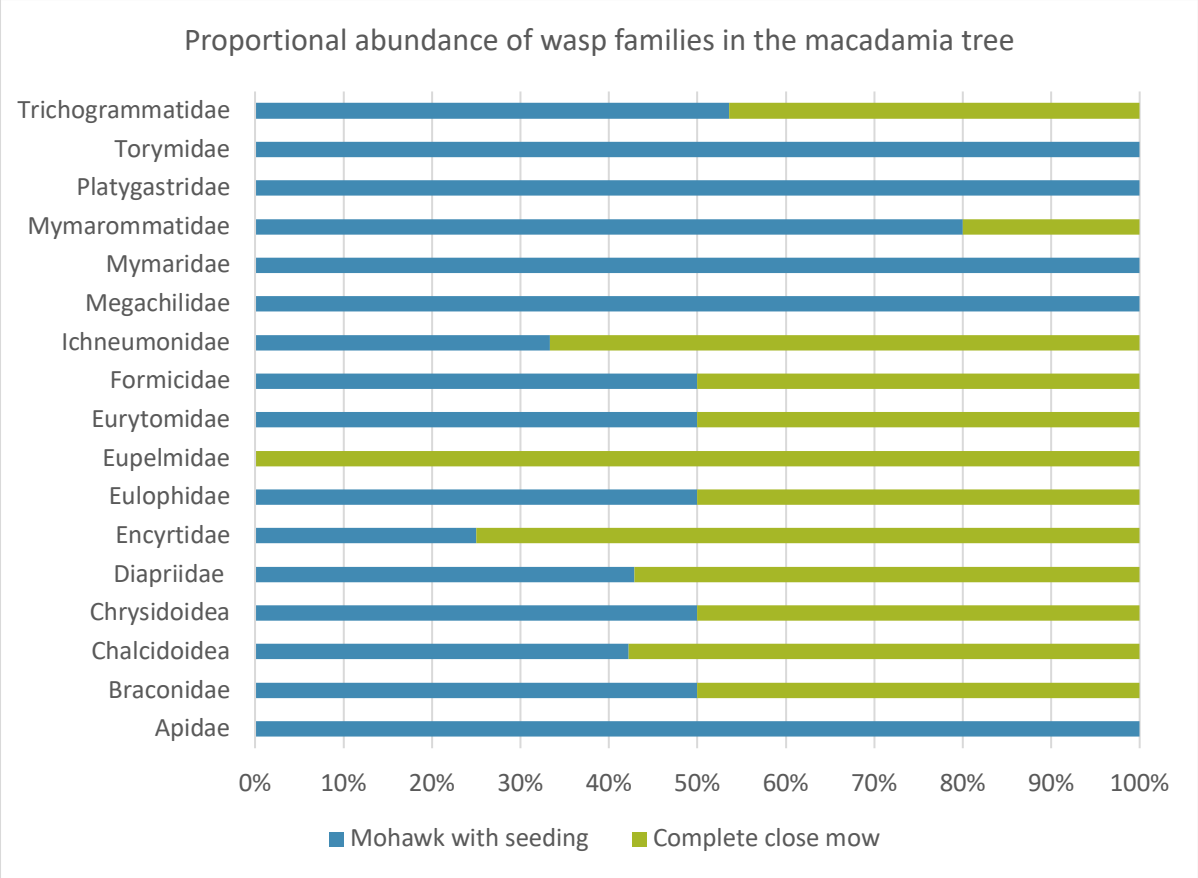

Chart 16: Proportional abundance of wasp families in the macadamia tree in the two treatments over the sampling period.

Similarly, in the inter row, there are several families that are only present in the mohawk with seeding treatment block (**Chart 17**) (Tenthredinidae, Mymaridae, Pergidae and Figitidae). Apart from Mymaridae these parasitoids were not present in the macadamia tree.

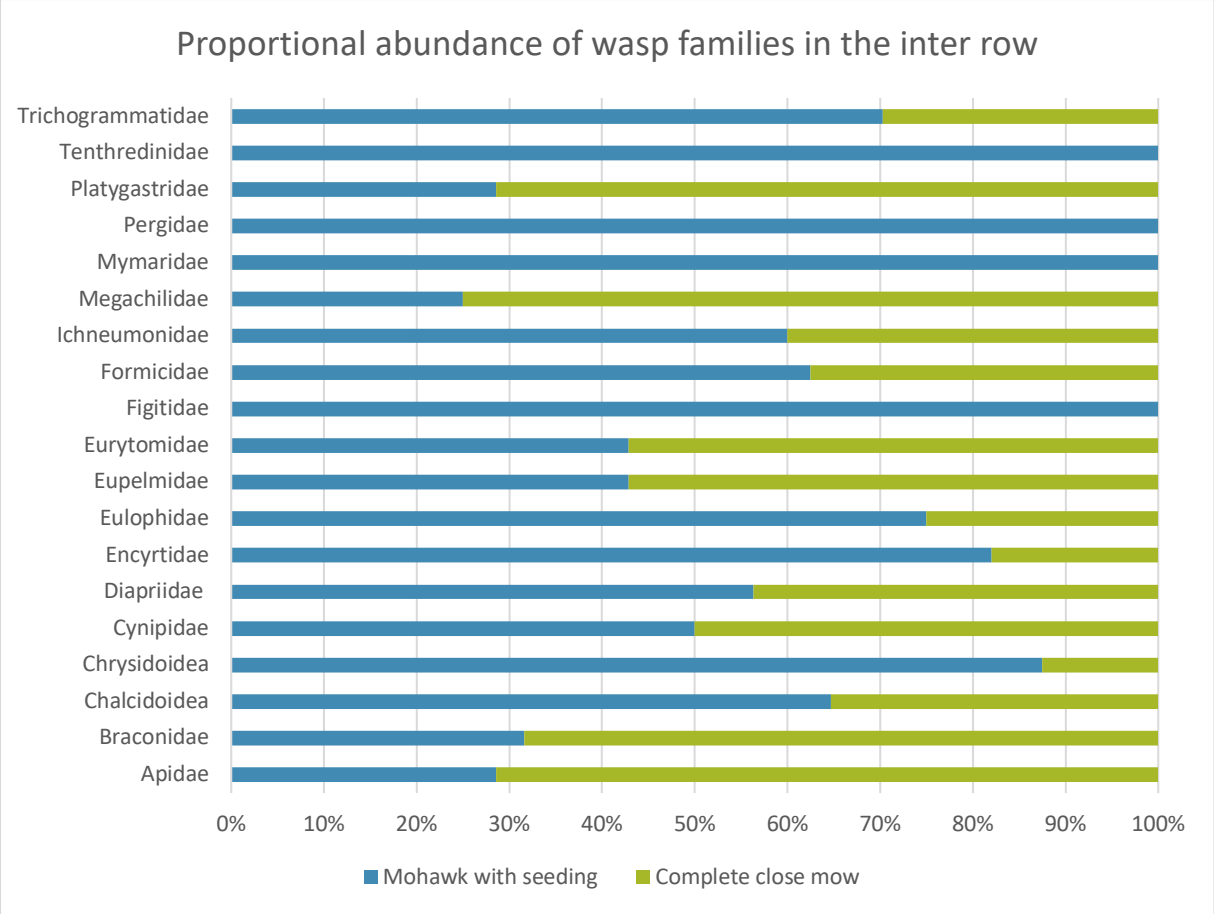

Chart 17: Proportional abundance of wasp families in the macadamia tree in the two treatments over the sampling period.

Thrips

Thrips had a higher abundance in the macadamia tree in the close mow treatment (110 specimens) than the tree of the mohawk with seeding treatment (75 specimens) (**Chart 18**), and proportionally this was greater in 2017 and 2019 sampling dates.

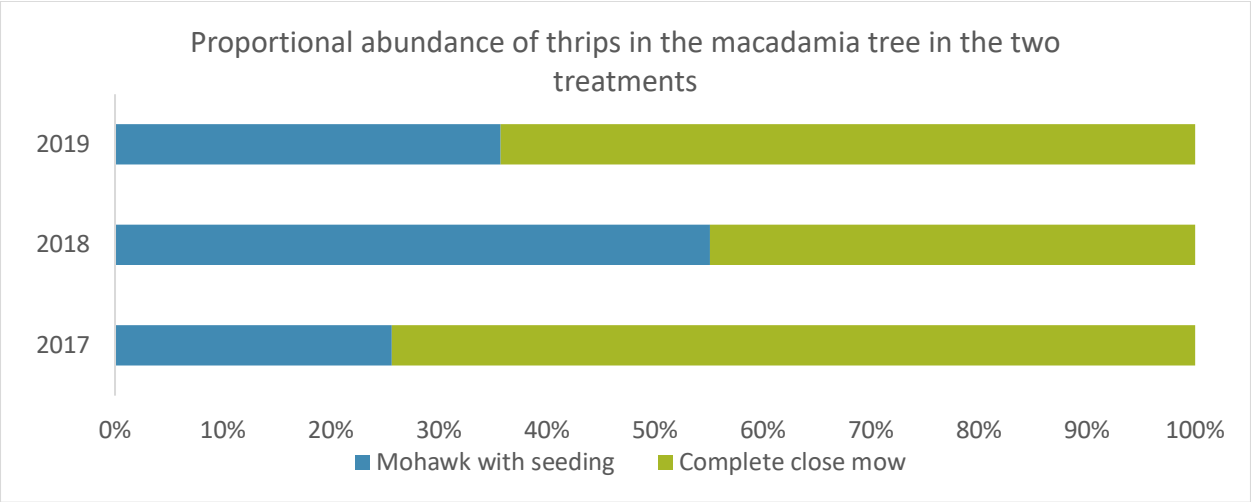

Chart 18: proportion of thrips in the macadamia tree comparing the two treatments over time.

When comparing thrip abundance in the two treatments (**Chart 19**), there are three times as many thrips in the tree of the close mow (61 specimens) as in the mohawk block in 2017. This is interesting as in the same period in the inter row thrips are twice as abundant. In 2018 thrip numbers are only slightly higher in the mohawk trees (49 specimens) and the complete mow (40 specimens). By contrast, they are twice as abundant in 2019 in the complete mow (albeit at low numbers). In 2019 thrip abundance was significantly higher in the inter row of the complete close mow compared to the mohawk with seeding block.

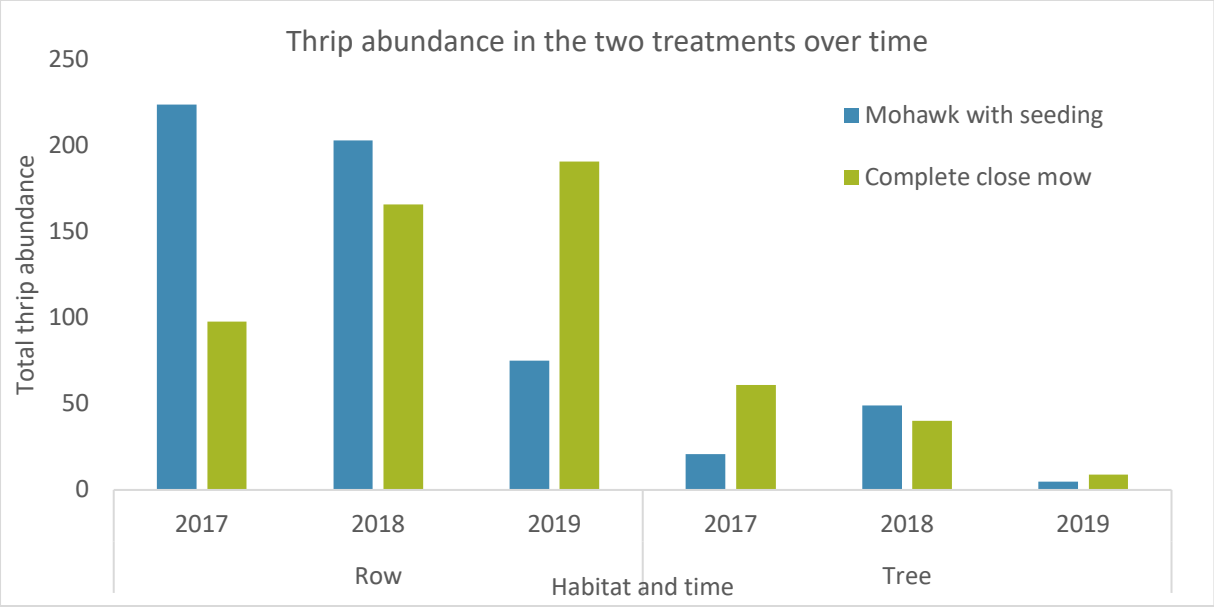

Chart 19: Total thrip abundance caught on YSTs in the two treatments over the sampling period March 2017 to July 2019.

True bugs

True bugs (Hemiptera) is an order of insects that has over 6000 species in Australia and includes species such as cicadas, aphids, scale insects and planthoppers. YSTs are not an ideal trapping method for population estimates and overall, this group is poorly represented by this technique. However, for the Hemipteran insects that we caught, they can be divided mostly into two feeding guilds (**Chart 20**). Predators are higher in the row (15 vs 7 specimens) and tree (32 vs 26 specimens) of the mohawk with seeding treatment block. Predators are from the Anthocoridae and Reduviidae families. Sap suckers (mostly aphids and leafhoppers) are somewhat more abundant in the row and tree in the mohawk with seeding block, however on any given year there are fluctuations where the complete close mow treatment block has more (2017 and 2018 inter row) and in the tree in 2019.

Diversity is greater in the mohawk with seeding treatment block (**Chart 21**) with seven families present there that are not present in the complete close mow block. However, two pest species Lygaeidae (seed bugs) and Miridae (mirids or plant bugs) were not recorded in either the tree or inter row in the mohawk with seeding treatment block, while they were recorded in the complete close mow block.

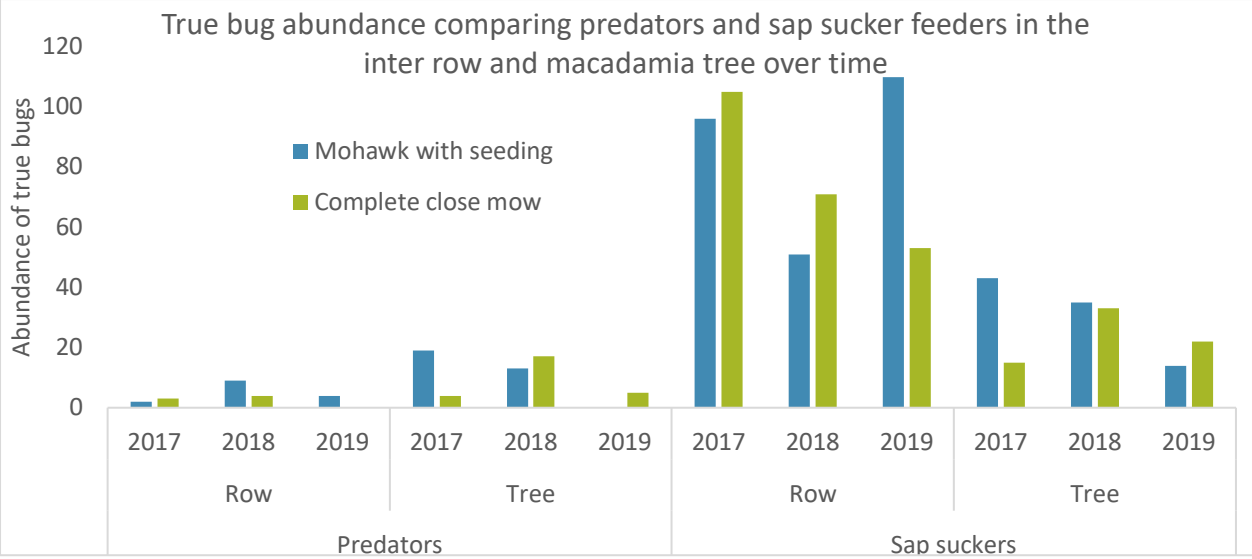

Chart 20: Comparison of true bug (Hemiptera) abundance in the two treatments in each habitat separated by the main feeding guilds over the sampling period caught on YSTs.

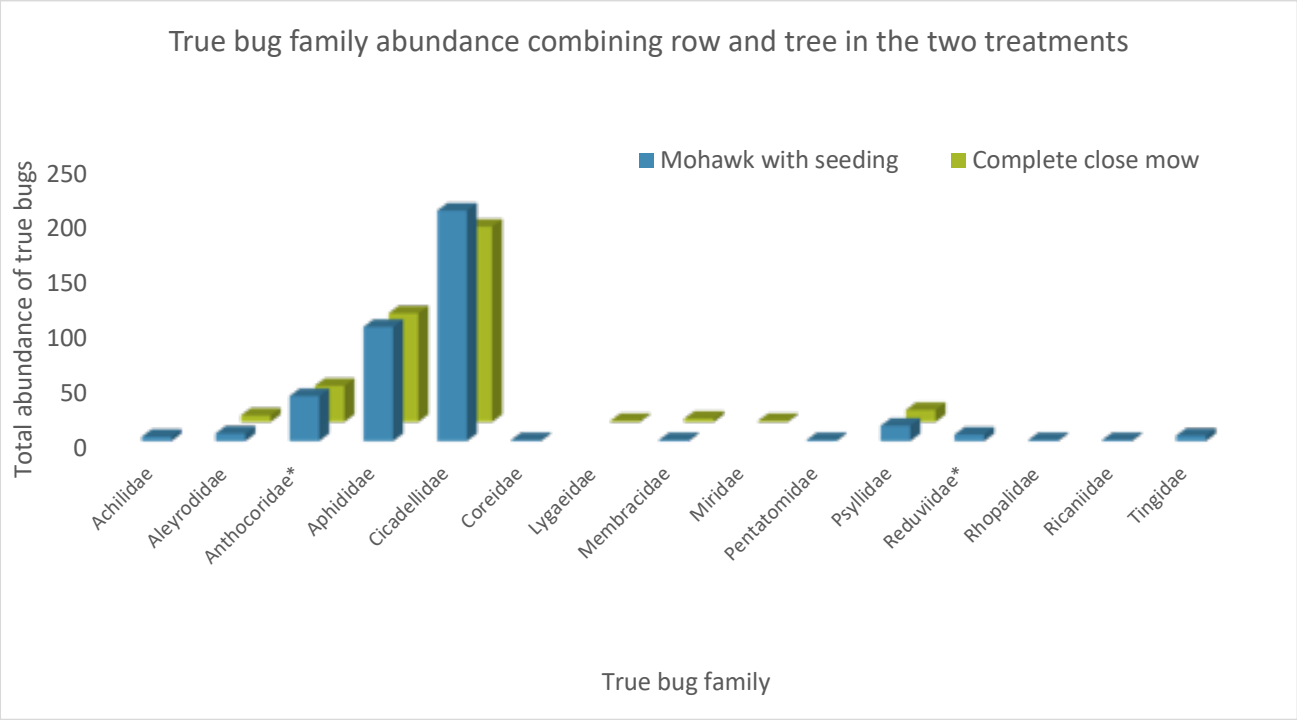

Chart 21: True bug abundance in the two treatment blocks for each family. Asterix identifies the families that are predatory.

Findings and recommendations

Your trial of mohawk with seeding has provided the inter row project with a number of useful insights into the practicalities of incorporating insectaries into the inter row. It has provided a valuable opportunity to better understand seed mix options; and suitable periods between mows to ensure appropriate rat, weed and vegetation growth-rate management. There are advantages to sustaining a mohawk during harvest if it is feasible: it keeps an insectary viable year-round especially during winter when growth slows down, and particularly in dry years. Other trial farms that removed the mohawk during harvest took many months to re-establish insectary vegetation. Optimal benefits from insectaries are possible when they are in place ahead of macadamia flowering and the annual intensification of crop pest pressure. On balance, and by the end of your trial you had found however that an increase in mowing leading into and during harvest was necessary.

It is worth noting that findings from other trial farms and other industries indicate that alternate row mow may be a reduced mow management strategy for you to consider. This involves mowing every second row on a rotating schedule, allowing all rows to "grow out" somewhat across the year but providing opportunities for mowing and management as required. This reduces the overall disturbance of beneficial arthropods, ensuring a refuge remains in place at all times for them. Beneficial arthropods will always have undisturbed areas around your farm for habitat. But it also provides opportunity to schedule removal of vegetation for rat monitoring and management. Likewise, there is opportunity to monitor and manage any "weediness" or dominance of vegetation and encourage regrowth and flowering. For your farm, this would allow you to incorporate insectaries in the orchard but give you more control over seteria dominance, potential rat problem areas, and nut drop into the reduced mow areas as the canopy continues to close over.

There were some promising increases in arthropod abundance and diversity in the mohawk with seeding trial block. In some groups such as wasp parasitoids there seems to be potential to increase their abundance and diversity further, as overall we expected more families to be represented and the overall population to be higher (excluding Mactrix) compared to more northern orchards. This maybe related to temperature differences, however further wasp parasitoid monitoring might show increases over time in conjunction with the appropriate vegetation management. Conversely fly abundance and diversity was very good (better than northern orchards) and many fly families that are predators and parasitoids were represented and had much higher populations in the mohawk with seeding block. This along with true bugs and beetle diversity increases indicated that there is potential to increase the wasp (parasitoid) abundance and diversity which is important for biological control. It is worth noting that our trial was conducted over 2.5 years, if these practices continue its likely arthropod diversity will increase further.

When the findings from all of the farms that participated in this project are taken into consideration, it is clear that insectaries have meaningful influence on orchard ecology when growers can commit to inclusion of the insectary in the orchard in terms of space allocation and long-term management. The mohawk in the inter row worked very well on your farm given row width. There are other areas on-farm worth considering, including headlands, field margins and so on where changes to management can allow for habitat suitable for beneficial arthropods. Decisions to improve plant diversity with seeding, well-timed seeding and mowing to limit dominance of one species while encouraging new growth and flowering and so on are also very influential.

Finally, the BioResources team encourages you to read the final report for the *Macadamia IPDM Program – Inter-row Project (MC16008)*, which is available via *Hort Innovation*. Here you will find out more on the

benefits of insectaries for macadamia orchards and also the experiences of other trial farms in implementing and managing insectaries. There is also an exploration of the multiple ecosystem services known to flow from reduced mow inter row management practices along with improved arthropod biodiversity, including benefits for soil organic matter, nutrient cycling, water management, erosion control, weed suppression, soil carbon storage, soil microbiology and more.

Acknowledgements and thanks

The project team wishes to thank Baldwin & Ranking family for their participation, and particularly Sue for her contributions and support in providing field reports.