



Integrated Pest Management (IPM) Toolkit

for Avocado and Macadamia Growers

A guide to developing sustainable
integrated pest management systems
for sucking bugs



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Getting started

Acknowledgements

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Editor



Ruth Anita Vaughan, is an IPM specialist and the project lead for AgDevCo's IPM project. Ruth has over 30 years of technical experience in African agriculture, including hands-on management and advisory roles across the continent. She is a strong advocate for reduced pesticide use, soil health and holistic pest management.

Purpose of the toolkit

Sucking bugs can severely reduce avocado and macadamia yield and quality. Overreliance on broad-spectrum pesticides can harm pollinators and natural enemies and accelerate resistance. This toolkit supports growers to implement practical, sustainable IPM programmes that reduce pesticide reliance, protect beneficial insects and maintain long-term productivity and market access.

Growing awareness of the importance of bee stewardship, promoting biodiversity, protecting aquatic systems and the environmental and social sustainability of agricultural production is leading to chemical bans by legislative authorities, certification schemes and market off-takers. This is reducing the number of chemical options available for sucking-bug control and increasing the risk of insecticide resistance build-up.

How to use this toolkit

This document is a toolkit that macadamia and avocado growers can draw on when developing or strengthening on-farm IPM programmes.

It is designed to help guide avocado and macadamia farms to develop a holistic IPM programme from scratch or to fine-tune and add to existing IPM programmes.

The toolkit has been laid out in standalone sections based on the PAN Europe IPM triangle in Section One. There are helpful downloadable Excel forms in relevant sections to help farms get started with record keeping. Useful links and references have been added for managers who want to learn more. There are many areas of overlap between the different sections, but in the interest of brevity we have tried not to duplicate information.

Additional useful handouts have been added in the annexes.

Abbreviations

IPM	Integrated pest management
GIS	Geographic information system
EIL	Economic injury level
ETL	Economic threshold level
HHP	Highly hazardous pesticide
MRL	Maximum residue level
LOD	Limit of determination
SHF	Smallholder farmer
FCM	False codling moth
MoA	Mode of action (insecticides)
IRM	Insect resistance management
EMF	Entomopathogenic fungi

IPM overview

For commercial avocado and macadamia operations, strong IPM is increasingly essential. As key chemicals for sucking-bug control are restricted or phased out, farms need validated alternatives that can be integrated into production systems to maintain compliance and market access.

IPM reduces pesticide use and related regulatory and operational risk, protects workers and consumers, and supports beneficial species that provide natural pest suppression. It also slows resistance development and, as programmes mature, enables more targeted interventions that can lower input costs and improve efficiency.

Resilient IPM depends on on-farm trials, close monitoring and regular evaluation. What works in one region or orchard may not work in another, so programmes should be adjusted using local data as conditions, cultivars and practices change.

For commercial orchards, robust IPM is a strategic necessity to protect profitability, support compliance and secure long-term production.

IPM principles

Integrated pest management (IPM) is defined by the FAO as¹:

“The careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations. It combines biological, chemical, physical and crop specific (cultural) management strategies and practices to grow healthy crops and minimize the use of pesticides, reducing or minimizing risks posed by pesticides to human health and the environment for sustainable pest management.”

With increasing pressure from climate change, shifting pest complexes and tighter sustainability requirements, IPM provides a practical, science-based approach to protecting yields while reducing environmental and social risk.

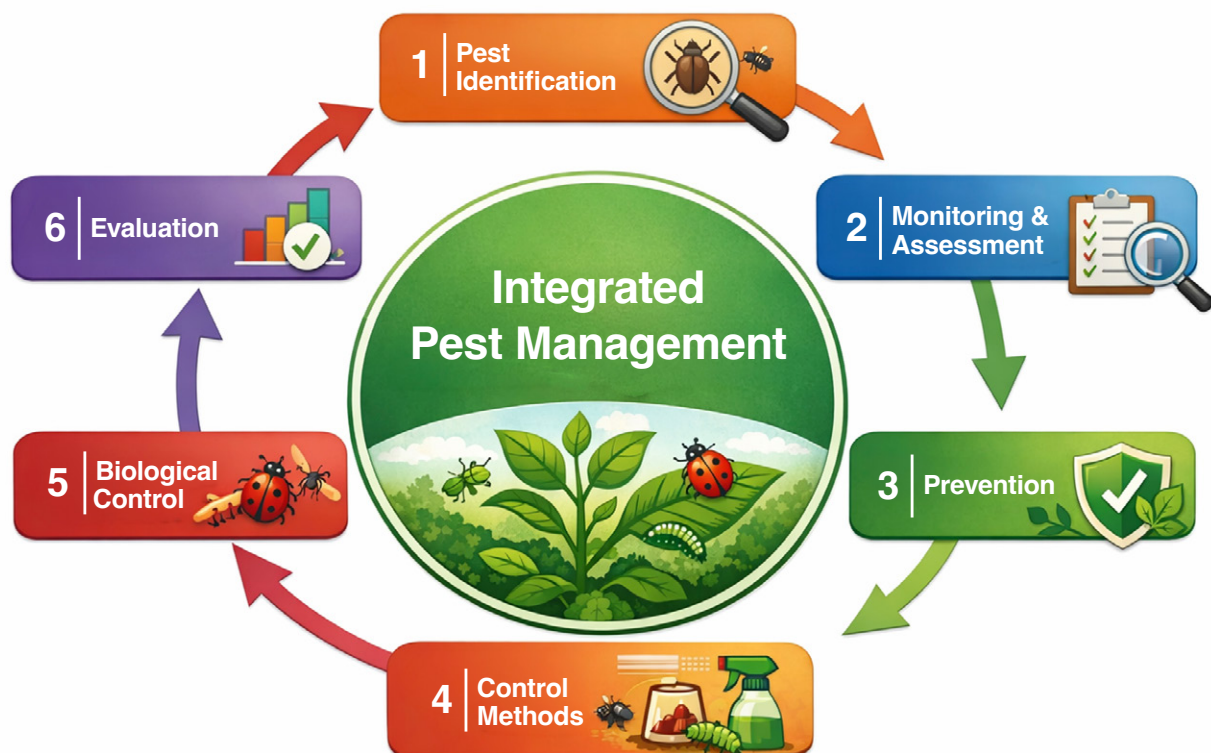
IPM is a dynamic, ecological approach that uses the full range of control options based on economic, environmental and social considerations. It aims to produce safe, healthy crops with minimal disruption to agro-ecosystems by encouraging natural control mechanisms.

IPM helps maintain crop–ecosystem balance by conserving soil, water and biodiversity, and by protecting ecosystem services such as pollination, nutrient cycling, residue breakdown and water purification. This reduces long-term production and climate-related risks.

IPM can also improve profitability by lowering input costs and protecting quality and market access through reduced residues. It strengthens farmer stewardship by building locally relevant knowledge of how the farm ecosystem functions.

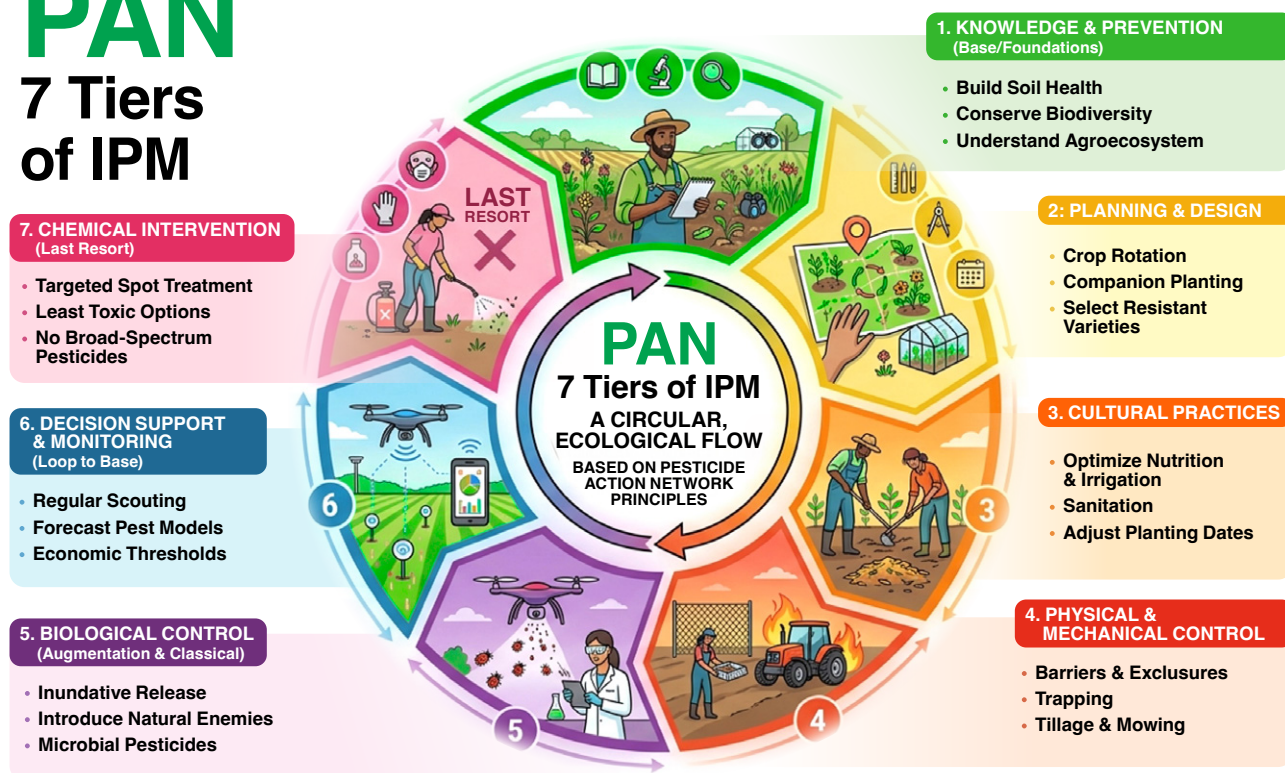
This toolkit draws on the Pesticide Action Network (PAN) Europe IPM triangle¹, which prioritises building a stable agro-ecosystem first. Prevention and other non-chemical measures are used to avoid imbalances; natural and biological controls are preferred when action is needed; and chemical controls are a last resort.

¹ <https://www.fao.org/pest-and-pesticide-management/ipm/integrated-pest-management/en/>



PAN

7 Tiers of IPM



PAN

IPM Principles

Avocado and Macadamia Orchards.

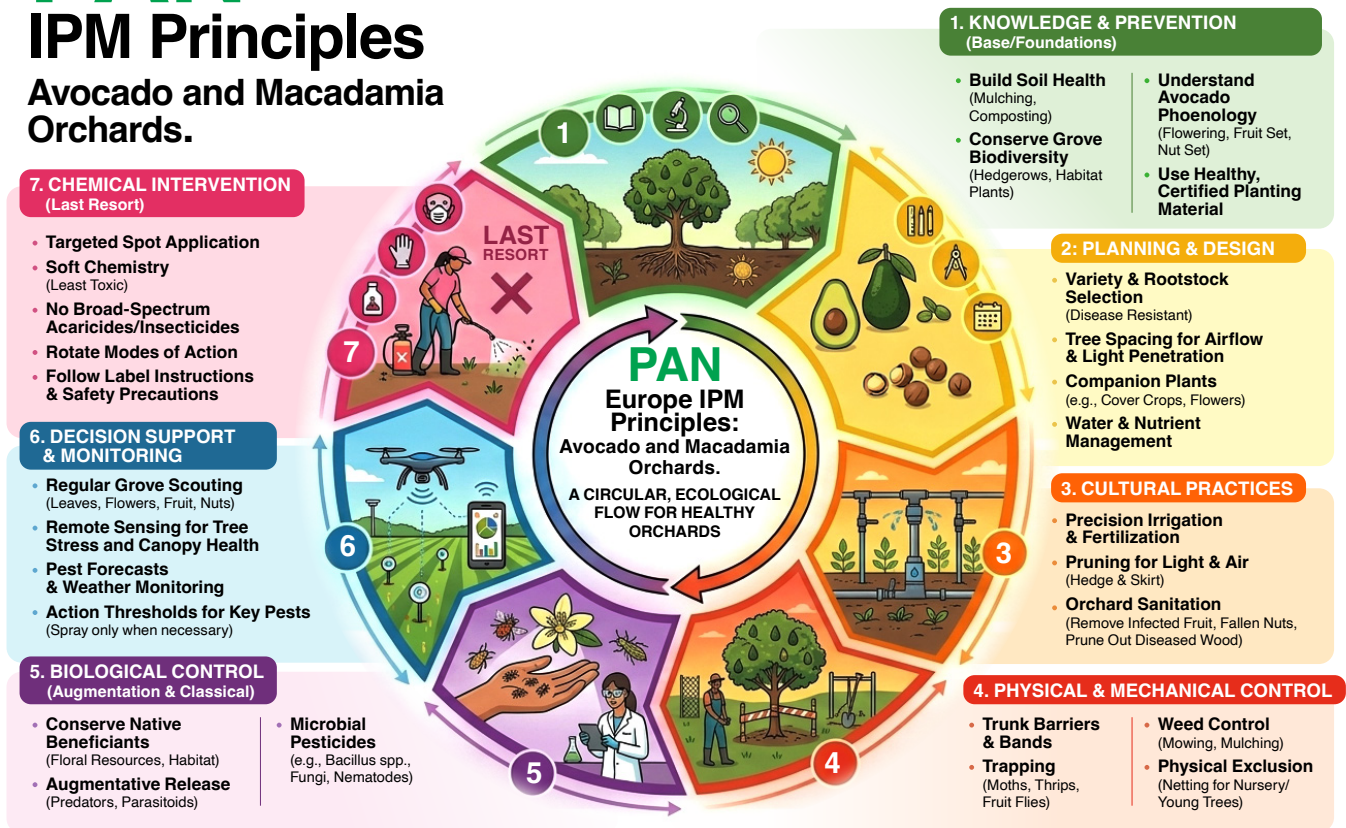


Figure 1: Diagram adapted from the PAN Europe IPM triangle²

The diagram presents IPM as a layered decision-making process: start with prevention, then monitor, act first with natural and biological controls, and use chemical controls only when necessary. Ongoing trials, evaluation and adjustment help keep programmes robust and effective.

IPM is a continual journey, not a destination

² <https://www.pan-europe.info/resources/reports/2021/04/using-cap-turn-ipm-triangle-its-solid-basev>

² <https://www.pan-europe.info/resources/reports/2021/04/using-cap-turn-ipm-triangle-its-solid-base>

Section one:

Preventative agronomic practices



Figure 2: Orchard landscapes vary considerably and this has a big impact on the pest populations.

Reducing reliance on pesticides starts with prevention: building a healthy crop and orchard environment that is less favourable to pests. This means managing the wider ecosystem in and around the farm, including beneficial plants and insects, natural enemies and the local conditions that influence pest pressure. Preventative practices are generally low-cost, durable and compatible with all other control options.

Good agronomy makes crops less attractive and less suitable for pest build-up. Practices such as crop rotation (where relevant), choosing tolerant varieties, balanced fertilisation, appropriate irrigation and strong sanitation reduce plant stress and limit pest habitat. Maintaining areas of natural biodiversity increases resilience by supporting predators and parasitoids. Tools such as hedgerows, intercropping, managed inter-row vegetation, cover crops and flowering strips can strengthen ecological balance. Trap crops, effective weed management and mulching can further reduce pest pressure and support healthier, more resilient agro-ecosystems.

Water management

Irrigation is a critical part of IPM because water status affects plant health, pest behaviour and crop

ecology. Well-managed irrigation supports vigorous trees with stronger defences, while over- or under-irrigation can trigger pest problems. Overwatering depletes oxygen in the root zone and reduces nutrient uptake; water stress during key growth and flowering flushes can produce soft, wilted tissue that attracts sucking pests. Keeping irrigation within the optimal range supports both crop performance and pest management.

In dry regions, irrigated crops create patches of lush vegetation that can draw pests in from the surrounding landscape. Strategically placed perimeter vegetation (e.g., trap crops, flowering bands or pollinator strips) can intercept pests, support pollinators and natural enemies, and act as early-warning areas for scouting. Where appropriate, targeted interventions in these zones can reduce pressure in the commercial crop. Consistent irrigation is needed to keep trap plants attractive and effective.

Rainfed crops usually grow and flower in step with the surrounding environment, but dry spells during vegetative or flowering flushes can disrupt this balance. Under stress, trees often produce soft, wilted shoots that are highly attractive to sucking insects. Understanding these dynamics helps anticipate pest risk and time monitoring and responses appropriately.

Soil and plant nutrition

Healthy, living soils with balanced physical, biological and chemical properties support vigorous plants that are naturally more resilient to pests and disease. Biologically active soil, rich in diverse microbes, helps buffer climate variability, regulate nutrient supply, improve water infiltration and storage, and suppress some pest and disease pressures.

Soil biodiversity underpins resilience. A stable soil food web supports ecological balance: many organisms compete with, prey on, or disrupt soil- and litter-dwelling pest stages, helping keep populations below damaging levels and improving the system's ability to recover from stress and disturbance.

Microbes also drive nutrient cycling – nitrogen, phosphorus, carbon and sulphur – by breaking down organic matter and converting nutrients into buffered plant-available forms. This supports steadier nutrition, reduces leaching risk and helps sustain growth through the season.

Good soil structure (stable aggregates or crumbs) improves aeration, root development, infiltration and moisture retention. These conditions reduce plant stress and form a strong foundation for IPM by improving tree health and tolerance to pest and disease pressure.

Over-application of nitrogen can drive lush growth that attracts sucking bugs and creates dense, shaded foliage that increases humidity, hides pests and reduces spray penetration. Nutrient imbalances can make trees more attractive to insects. Aim for balanced fertilisation especially appropriate nitrogen levels based on regular soil and leaf analysis. Adjust rates for tree age and size and account for nutrient removal in harvested fruit, nuts and crop debris.

Landscape and habitat management

Landscape management treats the farm as part of a wider ecosystem. Designing orchards and surrounding areas to support ecological balance can reduce pest pressure, improve soil health and strengthen crop performance. Layered vegetation within blocks, between rows and along margins creates habitat for beneficial organisms and helps prevent pest outbreaks.

Pollinator strips (flowering bands within or alongside blocks) provide nectar and pollen through the season. They support pollinators (bees, hoverflies and butterflies) and attract natural enemies (e.g., ladybirds, parasitic wasps and lacewings). Aim for continuous flowering. Other options include banker plants, selective grass cutting and targeted weeding, as well as structures such as bee hotels, bat houses and water features that attract dragonflies and birds. Stone mounds can provide refuges for lizards.



Figure 3: (a) A well-managed, row-planted, drip-irrigated planting of Wild Basil around a macadamia orchard in Zimbabwe attracts a range of insects and is scouted alongside the macadamia crop. It is used as both an indicator plant and a trap crop. (b) Pollinator strips in orchard inter-rows are often difficult to manage: they can obstruct equipment, be shaded by the trees and generally require extra irrigation.

Trap crops (e.g., basil planted at row ends or around the orchard) can draw pests away from the main crop and act as indicator plants for early detection. Regular scouting of these plants provides early warning of pest build-up and supports targeted intervention before pests reach damaging levels, reducing broad-spectrum spraying and conserving beneficial insects.

Natural diversity at orchard edges (native vegetation, buffer zones and hedgerows) strengthens resilience by providing habitat, refuge and overwintering sites for beneficial insects, birds and other wildlife. These areas act as ecological “shock absorbers”, supporting predators and disrupting pest movement. Managed as part of the farm design, they are a practical, low-risk tool for stable, productive IPM.

Plant selection, clones and rootstock

Select varieties, clones and rootstocks suited to local climate and soils – not only for market preference. Well-adapted planting material reduces tree stress, improves growth and increases tolerance to insect damage.

Avoid mixing early- and late-flowering clones within the same orchard where possible, as this can extend the vulnerable period and allow pest populations to build up, often concentrating damage in later-flowering varieties.

Root architecture can differ by propagation method. Seedling rootstocks typically form a taproot with deeper lateral roots, which can improve tolerance to stress. Clonal rootstocks, produced from cuttings, often develop shallower, more spreading root systems with finer roots, and may be less tolerant of heat and moisture stress.

IPM in the nursery

Introducing new plants into an orchard system is a critical moment for IPM, and careful handling at this stage can prevent serious problems later. The guiding principle is simple: start clean.

New plants should always be quarantined in a biosecure area and monitored closely before being planted out. This helps ensure that no hidden pests (or their eggs, spores or pathogens) are inadvertently introduced into the orchard.

Early detection in a controlled quarantine area allows for timely intervention and avoids the much larger costs and complications of managing pests once they become established in the orchard.

When plants are small and close together in a protected nursery environment it is an ideal time to apply biological control agents and predatory mites. The quantities required are lower, making treatment cheaper; beneficial mites can be applied more uniformly and disperse more easily when plants are touching; and nursery structures typically offer shade, reduced wind, and higher humidity – conditions that enhance the establishment, survival, and performance of many biological control agents.

Predatory insects and mites released in this environment can be exceptionally effective at finding and consuming small insect pests, including early-stage nymphs that are often difficult to detect and even harder to manage with conventional insecticides. Contact sprays frequently struggle to penetrate dense foliage or reach tiny pests hiding in protected plant tissues, while predators such as predatory mites and soil-dwelling *Hypoaspis* species actively seek out their prey.

Soil health and insect resistance can be enhanced before the plants leave the nursery by seeding the potting mix with entomopathogenic fungi such as *Beauveria*, *Metarhizium*, *Trichoderma*, and *Mycorrhiza*. Introducing these microbial allies early increases the likelihood that they will establish successfully once the plants are transplanted into orchard soil. As these beneficial fungi colonise the root zone, they contribute to long-term pest suppression, improved nutrient cycling and greater overall resilience of the orchard ecosystem.

Top tip

Starting with plants that are clean, protected and biologically enriched lays a strong foundation for sustainable IPM throughout the life of the orchard.

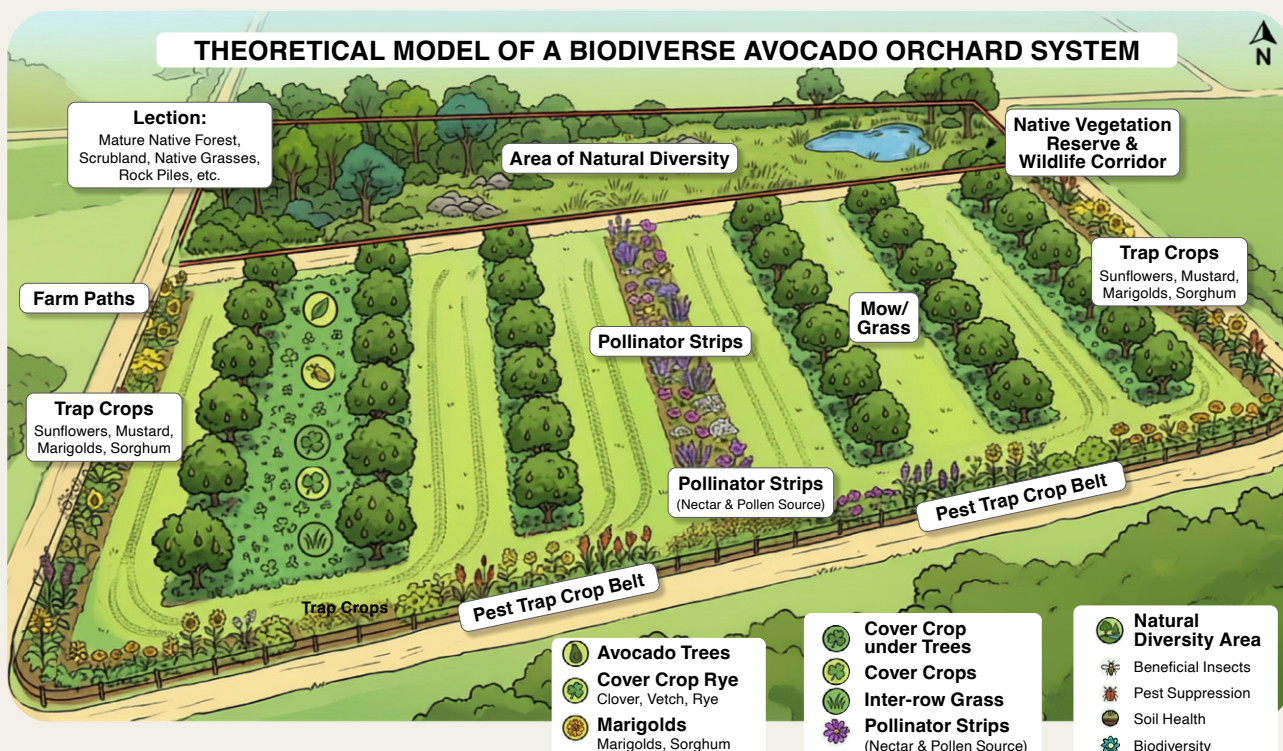


Figure 4: Diagram of a theoretical orchard with inter-row vegetation, under-tree planting, surrounding trap crops and an area of natural diversity. Together, these cultural practices create a healthier, more balanced production environment, strengthening the resilience of the cropping system and supporting long-term sustainable pest management.

Orchard design and layout

Orchard layout and design choices – including tree orientation, tree density, raised beds, orchard-floor and under-tree management, cross-pollinating cultivars, intercropping, inter-row vegetation, weeds and wildflowers – all affect resident insect populations in orchards.

Packhouses and managing rejects

Packhouses play a larger role in IPM than many growers realise. They aggregate fruit and nuts from multiple blocks (and sometimes neighbouring farms), creating a high-risk point for pest movement. Pests can hitchhike on produce, crates, clothing and machinery, spreading quickly across the farm and bypassing natural barriers. Packhouses should therefore be treated as key biosecurity zones.

Packhouse placement can also reduce pest spread. Locating the packhouse at or near the main entrance limits vehicle and staff movement through production blocks and helps keep traffic at the farm perimeter. Combined with strict sanitation, controlled traffic flow and good reject handling, this significantly reduces the risk of moving pests into clean blocks and strengthens the overall IPM programme.



Figure 5: Electric insect traps placed strategically around the packhouse and reject-storage area attract and kill flying pests.

Rejects can introduce or amplify pests. Fruit or nuts rejected for insect damage may contain larvae, pupae or eggs. If rejects are dumped near the packhouse and left exposed, they can quickly become a source of new outbreaks. Rejects should be contained securely and removed promptly, for example through sealed or controlled composting systems, or deep burial (where permitted). Good hygiene, frequent equipment cleaning and clear waste-handling protocols are essential parts of packhouse IPM.

Section two:

Monitoring and forecasting

Monitoring, forecasting, early warning systems and area-wide management are foundational to effective IPM. Robust programmes typically include five elements:

- **Pest and crop knowledge:** Know key pests and their life cycles, crop/cultivar vulnerability, crop phenology, when damage risk is highest, and the local conditions that favour pest development.
- **Monitoring and reporting (scouting):** Collect consistent field data on pest identity, life stage, location, population level and crop injury. Where possible, also note beneficial insects, weeds and host plants. Use these records to guide control decisions and anticipate outbreaks.
- **Dissemination and communication:** Provide timely, consistent updates so managers and decision-makers receive clear status reports, warnings and recommendations in a usable format.
- **Preparedness and response:** Develop practical short- and long-term management response plans, and maintain the capacity to act quickly when monitoring shows increasing risk.
- **Forecasting, early warning and area-wide management:** Link pest data with weather, crop phenology and landscape context to predict when and where pressure will rise. Where pests are highly mobile (e.g., sucking bugs, FCM and fruit flies), sharing information through local grower groups supports coordinated, area-wide strategies that can reduce pressure across the whole production area.

Developing pest knowledge

To build knowledge of the pests that may affect your crop, consider the following steps:

- Research the crop, cultivar and rootstock. Ensure that the climate, soil type, water quality and agricultural zone are suitable for your plants. List the major pests and diseases known to affect your crops. Understand pest life cycles and what the pests look like at each life-cycle stage.
- Talk to your neighbours, agricultural suppliers, IPM input suppliers, produce aggregators and market off-takers, to understand the main pests and diseases in the locality.
- Join relevant grower organisations and use their technical resources, where available, such as Macadamias South Africa (SAMAC)³, the South African Avocado Growers' Association (SAAGA)⁴ and the Avocado Society of Kenya (ASK).⁵
- Contact government extension agencies, where available, for local support and advice.
- Scout existing plants and the surrounding landscape to observe the current pest profile.

Sucking bug populations are complex: multiple species may be present, they feed on many host plants, and numbers are often low but highly seasonal, particularly around flowering and early fruit set. Their distribution in orchards is typically heterogeneous (*patchy*), with high numbers on some trees and few or none on others. This should be considered when designing scouting. Population dynamics also shift with season and crop phenology.

In South African macadamias, winter and summer sucking-bug complexes occur. The species present in these complexes vary according to the surrounding landscape, climatic zone, local weather conditions, orchard landscape and stage of nut development.

³ <https://samac.org.za/>

⁴ <https://avocado.co.za/>

⁵ <https://kenyaavocados.co.ke/>

Mapping

Landscape mapping

Mapping surrounding land uses (e.g., annual and perennial crops, hedgerows, fallow land, riparian zones and woodlots), is a key step in building a scouting plan. These habitats can act as pest sources, refuges or dispersal corridors, and may also support natural enemies (predators, parasitoids and pollinators). Adding farm features (block boundaries and roads), as well as topography and prevailing wind patterns, helps identify likely entry points and hotspots. A landscape-informed plan supports more targeted sampling locations, appropriate scouting frequency and better-timed IPM interventions.

Case study: Avocado orchard

The farm has rich, deep soils and large mature trees. The inter-rows are covered in grass and flowering weeds, which are mown regularly, and the soil under the trees is heavily self-mulched. The farm no longer sprays highly hazardous pesticides (HHPs), preferring to promote beneficial insects and use pheromone trapping as far as possible. Softer chemicals are sprayed only when necessary, and in response to scouting reports and pest threshold levels. The farm supports a wide range of beneficial insects in and around the avocado trees.

The landscape around the avocado blocks varies considerably and affects insect populations in the individual fields. Using a GIS scouting app and appropriately located pheromone traps can help build understanding of how the local landscape, in combination with weather, affects pest population dynamics.

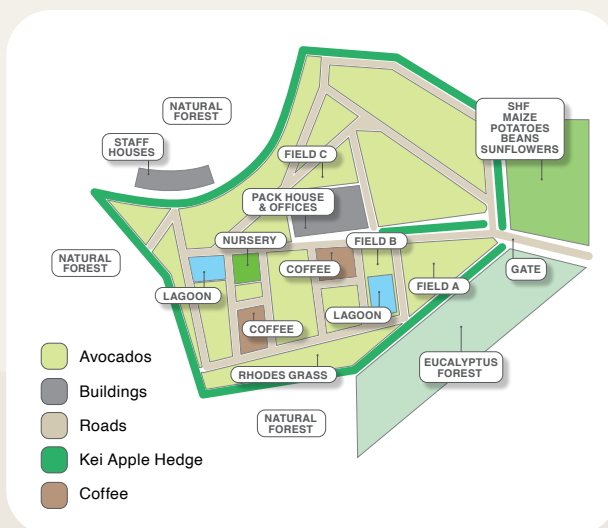


Figure 6: Schematic layout of an avocado farm.

Monitoring orchard edges with pheromone traps helps track pest movement in and out of the fields.

On this farm, the blocks with the highest sucking-bug pressure and reject rates border the main access road. Blocks across the road are partly shielded by a kei apple (*Dovyalis afra*) hedge and have lower pressure. Field C, behind the packhouse and adjacent to the reject area, has higher false codling moth (FCM) and fruit fly pressure, so extra traps are used there.

When Rhodes grass is mowed in the dry season, stink bugs and leaf tippers can move into neighbouring irrigated avocado trees.

Figure 7: Enhanced trapping along the field boundary after Rhodes grass has been mown.





Figure 8: Boundary with a grass strip, kei apple hedge, eucalyptus trees and smallholder intercropped maize, beans and sunflowers. Sucking bugs move out of the orchards when the sunflowers are in full flower, and move back into the orchard when the smallholder crops dry out and are harvested. Monitoring the orchard edge with pheromone traps helps track pest movement.

Placing pheromone-enhanced sticky traps along the boundary helps intercept these mobile pests and reduce crop damage.

Along one boundary, a smallholder co-operative grows maize, beans, potatoes and sunflowers. After the rains, when these crops flower, sucking bugs often move out of the orchards into the crops. As the crops dry and are harvested in the dry season, bugs can move back into the avocado trees.

A kei apple hedge borders much of the farm and the main road. It provides unsprayed habitat and alternative food for sucking bugs and their predators, so it should be included in scouting. It can also be a suitable area for releasing stink bug predators.

One boundary is a mature eucalyptus forest, which can be a source of thrips and sucking bugs after flowering. Increase scouting and trapping along this boundary as flowers dry, and use boundary sprays only if necessary.

Figure 9: The orchard boundary on the left has Rhodes grass in full flower and Napier grass, both of which provide a source of stink bugs and leaf tipper bugs when cut. The other boundary is indigenous forest, which provides habitat for mammalian pest control. The baboons in the background eat fallen fruit, helping to neutralise pest larvae, pupae and eggs, including FCM. At night, large populations of bats feed on night-flying insects such as stink bugs and FCM.





Figure 10: Dropped fruit can be a source of FCM and fruit flies. If scavenged by baboons or small buck, it can reduce pest pressure.



*Figure 11: An upsurge in mealybugs in the coffee resulted in a large population of predatory *Cryptolaemus*, which moved into the avocados and reduced the mealybug and heart-shaped scale pressure.*

After the rains, lagoons can support large numbers of adult dragonflies. Dragonflies are strong predators that capture many flying insects (e.g., mosquitoes, flies, stink bugs, mirids and moths) mid-air, making them beneficial for reducing pest pressure.

Along roads, especially at junctions, spider mite populations can build up in the dry season. Reduce pressure by managing dust through watering roads, controlling speed or applying hay and, where practical, washing dust from leaves.

Orchard layout

Orchard layout strongly influences microclimate, pest movement and scouting effectiveness. Row orientation – north-south, east-west, and relative to prevailing winds – affects sunlight, temperature and moisture patterns, creating warmer and cooler zones that can favour different pests or beneficial insects. Use these patterns to prioritise scouting in higher-risk areas (e.g., shaded or cool sides, warm edges and windward entry points).

Figure 12: Year-round flowering weeds within a perpetually green grass inter-row provide a year-round source of pollen for beneficial insects and pests. This creates a balanced micro-ecosystem that is more resilient to incoming pests.



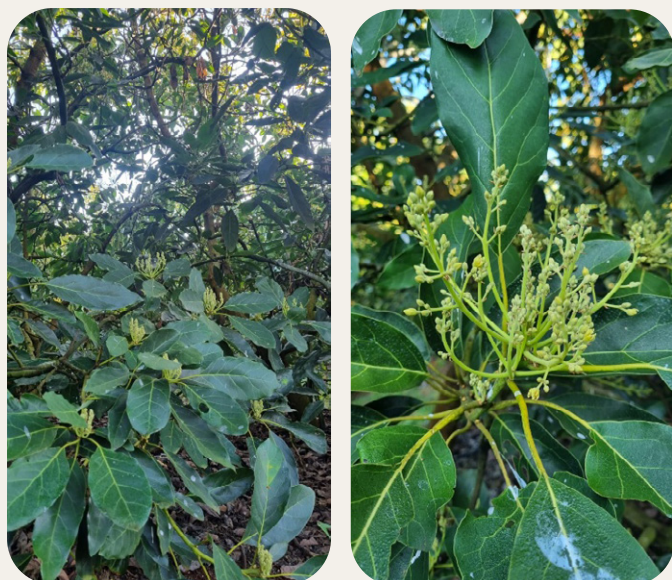


Figure 13: (a) Cool side and (b) warm side, taken on the same day. A significant difference in flowering stage between the cool and warm sides increased the flowering season in this block by five weeks. This provided an extended food source for *Taylorilygus* (avo bugs) – allowing several generations to breed. As a consequence, populations and associated fruit damage were much higher in this block.

Tree age, tree density and canopy density

Tree density, age and canopy structure affect pest build-up and control efficiency. Dense or poorly pruned canopies create humid, sheltered conditions that favour pests and diseases, reduce scouting visibility and limit spray penetration. Open canopies improve airflow, reduce humidity and increase the coverage and efficacy of targeted sprays or biological products. In older, taller orchards, reaching the upper canopy can be difficult, increasing the risk of incomplete control and resistance development. Regular pruning and thinning help reduce this risk.

Prioritise monitoring in high-risk zones (dense canopies, shaded rows and edges near pest source habitats). Combining orchard design observations with landscape mapping supports more targeted, timely and efficient pest management.

For hectares with square or rectangular spacing:

$$\text{Tree density (trees/ha)} = \frac{10,000}{(\text{in-row spacing (m)} \times \text{between-row spacing (m)})}$$

Tree age, variety, cultivar, rootstock, plant distribution, planting density and orientation can be captured in the file below. Recording and mapping these important characteristics helps with IPM evaluation.

Farm	Block	Crop	Variety	Rootstock	Area (ha)	Planting Year	Tree Age (years)	Inter-row spacing (m)	In Row Spacing (m)	Tree Density (trees/ha)	Tree Height (m)	No of Trees	Row Orientation
	1	Avocado	Hass	Dusa	1			8	4	313			North South
	2	Avocado	Pinkerton	Own root	3			7	3	476			East West
	3	Avocado	Carmen		2			12	5	167			South East to North West
	4	Avocado	Fuete							#DIV/0!			
	5	Macadamia								#DIV/0!			
	6									#DIV/0!			
	7									#DIV/0!			

Table 1: Excel Tree Mapping Template. [Download it here](#)

Pruning

Pruning is a cornerstone of IPM for macadamia and avocado trees because it directly alters the orchard microclimate and can help discourage pest and disease outbreaks. By opening up the canopy, pruning increases sunlight penetration and airflow, reducing the high humidity levels that fungi, such as those causing anthracnose or *Phytophthora*, need to thrive. A well-managed canopy also helps

organic or chemical sprays reach the inner leaves and fruit, significantly improving treatment efficacy. Removing dead or overcrowded wood eliminates “bridge” structures that pests such as thrips, mites, and borer beetles can use to hide and reproduce, allowing natural predators to find and manage these populations more easily.

Scouting

Designing an effective pest scouting programme for orchards involves creating a systematic, regular routine to detect insect pests before pest levels are high enough to cause economic damage. A robust programme typically divides the orchard into manageable sections and selects approximately **10 out of every 100 trees** for random inspection, with additional focus on high-risk areas, including sunny or dusty corners, orchard borders, dense trees and areas identified through landscape mapping.

Monitoring should take place at least **weekly** during critical periods such as flowering and fruit set, and can be reduced to fortnightly during low-risk periods. Scouts should use specialised techniques such as tapping flowers over a white sheet to detect thrips, using a magnifying lens to inspect the undersides of leaves for mites and their nests, and deploying pheromone or sticky traps to monitor adult pests and flight activity. Comprehensive record-keeping, including the pest life stage and infestation severity, is essential for identifying seasonal trends and timing management actions effectively.

Effective pest management begins with a structured scouting plan that monitors pests, damage and beneficial insects over time. Combine visual inspections, trapping and standardised sampling to generate consistent, comparable data that supports decision-making. The plan should specify which pests and natural enemies to monitor, which methods to use, and how results will be recorded and reviewed.

Frequency and timing of scouting

Adjust scouting frequency according to crop phenology and periods of high susceptibility. In avocados, flowering and early fruit set often require more frequent inspections. Continue regular monitoring outside peak periods to detect early infestations and track beneficial populations.

Also consider daily activity patterns: some pests are easiest to detect at specific times. Mirids such as the **avo bug** are most active early in the morning (while dew is present) and in the evening, so midday scouting may miss them.

Scouting blocks

Divide farms into manageable blocks that can be monitored and managed as units. Consider roads and natural boundaries, topography and slopes, irrigation zones and valves, cultivars, rootstocks and planting dates.

Management blocks are ideally up to 5 ha (maximum 10 ha). As a minimum, scout approximately 1–1.5% of the trees in a block, increasing intensity to 10% in boundary blocks, susceptible orchards and during high-risk crop stages.

Sampling design: trees and movement patterns

Use representative walking patterns (e.g., a zig-zag route) across the block, with higher sampling density at boundaries to detect early incursions. Fixed monitoring points, such as traps, reference trees or “sacrificial trees”⁶, add consistency over time.

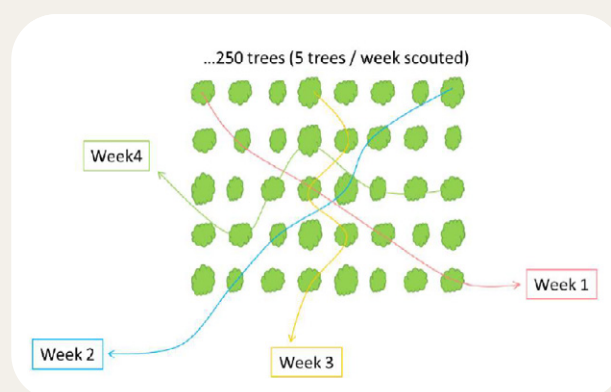


Figure 14: A typical random scouting pattern in an orchard.

Standardise what you inspect and how you count (e.g., eggs on specific leaves, insects on panicles/flowers, or insects dislodged onto a white tray), so results are comparable between scouts and dates.

Scouting supervision

Effective supervision of scouting helps ensure that field data is accurate, timely and directly applicable to pest-management decisions. Supervisors are responsible for auditing the quality of scouting by performing random “double-checks” on recently scouted trees to verify that pests were identified and counted correctly. This oversight includes

6 Sacrificial trees should be marked and fitted with insect-specific pheromones. These should be left for 24-48 hours to attract the pests into the tree, before the tree is sprayed with a quick knockdown spray.



Figure 15: (a) An FCM trap placed at the top of the canopy, where adult FCM are more likely to be caught because wind can carry the pheromone further. (b) Visual scouting of tall trees or dense orchards can be difficult, making attraction and trapping a more reliable option.

ensuring scouts follow standardised sampling patterns, such as the “W” or “M” formation, to prevent bias towards obviously damaged areas. Modern supervision increasingly relies on **digital scouting apps** which allow supervisors to track scout locations via GPS, review real-time photographic evidence of pests and monitor data-entry timestamps to check that the orchard is being covered thoroughly.

Key supervisory responsibilities include:

- **Quality auditing:** Randomly re-inspecting 5-10% of scouted sites to check count accuracy and proper pest identification.
- **Equipment verification:** Ensuring scouts have functional 10x hand lenses, beating sheets, and properly maintained sticky or pheromone traps.
- **Data analysis:** Reviewing weekly scout outputs to identify “hotspots” and comparing pest-to-predator ratios to assess whether biological controls are working.
- **Training and calibration:** Organising regular “calibration sessions” where scouts identify pests together to support consistent reporting across different personnel.
- **Scheduling:** Adjusting scouting frequency based on crop phenology – such as moving from fortnightly to weekly inspections during critical **flowering and fruit-set** periods.

Figure 16: (a) Recent insect feeding damage on an avocado fruit with white sap. (b) Dissecting the damaged area helps identify which insect caused the damage.

Scouting methods

Scouting methods range from traditional field observations to advanced digital technologies.

Visual observation

Visual observation involves regular, systematic inspection for insect pests, beneficial insects and their life stages (eggs, nymphs/larvae and adults), as well as damage symptoms, including feeding damage, yellowing, wilting and sooty mould. Use a hand lens (10–15x) and tools such as sweep nets and beating trays. During vegetative flushing and flowering, shaking panicles over a white card or tray can improve detection and counting. In dense or very tall orchards, visual scouting may be unreliable, so trapping can be a better option. Rotate scouting staff periodically to reduce observer bias.





Figure 17: Collecting fallen fruit in macadamia orchards and cutting open the husk to identify feeding damage: (a) stink bug feeding damage; (b) coconut bug feeding damage; (c) early kernel damage with sunken lesions; and (d) late kernel damage – note the white internal lesions and nuts with an oily appearance.

Nut or fruit dissection

Cut open prematurely aborted or fallen nuts or fruit to check for internal damage and identify the cause, such as stink bug lesions, macadamia nut borer, fruit fly damage or FCM.

Mark 10–20 fruit per tree with bands, for example white for undamaged and yellow for damaged fruit. Scout weekly and add a yellow band to any newly damaged fruit or nuts, recording this as new damage and noting fruit size, nut stage and fruit or nut drop.

Monitoring fruit or nut damage in orchards

A practical method for tracking insect damage is to monitor marked fruit or nuts as they develop. Select 10 random trees per plot and mark them with tape.

As avocado fruit enlarge, they become less susceptible to sucking-bug damage, often around 30 mm or “chicken egg” size, depending on the pest complex. After this stage, control is often unnecessary, even if bugs are still present.

Farm _____
Scout _____

Date _____
Block _____

Tree No	# White Tagged Fruit (undamaged)	#Yellow Tagged Fruit (damaged)	# Newly Damaged Fruit	#Fallen Fruit (White)	#Fallen Fruit (Yellow)	Fruit Size (mm)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Comments _____

Table 2: Avocado Fruit Damage Scouting Template. [Download it here](#)

Figure 18: A simple template for scouting damaged fruit and nuts in orchards.



Figure 19: Insect eggs can be laid singly on (a) unopened flower buds or (b) the upper surface of leaves near the flower panicle, or as (c) egg masses on the upper surface of an avocado leaf.

Scouting for eggs

Monitoring specific areas of the trees (such as the basal 3 m of the main trunk, the underside of leaves near the flowering panicle, or unopened flowers), for eggs or egg masses can be a key method for identifying peak laying periods and timing contact sprays effectively.

When avocados and macadamias flower, pollen, nectar, young fruit and expanding shoots provide abundant food for sucking bugs. Adults often arrive early and lay eggs on or near buds as they expand. These are referred to as “pre-egg laying adults”. If incoming egg-laying adults can be trapped and/or eggs identified and managed at this stage, subsequent pest populations and damage to young fruit can be substantially reduced. It is important to train scouts to quantify eggs that can be identified in the field, as this information can be used to predict future problems and plan proper timing of appropriate control measures.

Knockdown scouting

Knockdown scouting uses a quick knockdown spray or high-pressure water jet on selected trees, with insects collected as they drop onto a sheet placed under the canopy (ideally laid out the day before). Alternatively, branches can be shaken to dislodge insects. Specimens are then identified and counted to estimate pest and beneficial insect presence. Limitations include the reduced availability of suitable knockdown products due to restrictions and bans, and the highly patchy distribution of sucking bugs, which can lead to missed detections. Where appropriate, shaking branches and catching the insects that fall may be a simpler alternative.

Attracting and trapping insects

Many orchard pests are hard to see in tall, dense canopies and may hide or drop when disturbed, such as stink bugs. Some are active outside working hours, such as mirids early morning or evening; and FCM at night. Attractants and trapping systems can therefore complement visual scouting by working 24/7 and improving data on pest presence, timing and movement. Insects can be attracted by colours, scents or baits, lights and sound, and captured using glue, water traps, funnels or nets. Position traps to account for orchard layout, wind patterns and proximity to likely pest-source habitats.

Coloured sticky traps

Sticky traps use different glues to trap insects and are available in many sizes and colours. Different colours target specific pests:

- **Yellow** attracts whiteflies, aphids, fungus gnats, thrips, and leaf miners.
- **Blue** is best for thrips and leaf miners. In a trapping trial on stink bugs in macadamia, blue traps caught twice as many stink bugs as yellow traps.
- **Red** targets fruit flies (like *Drosophila suzukii*).
- **Black** catches *Tuta absoluta* (tomato moth) and is a good neutral colour to use with pheromones for stink bugs and mirids.
- **White** attracts Lygus bugs, or mirids.
- **Clear** sticky traps are neutral and can be used with pheromones.

Lessons learned with sticky traps

- Sticky traps should be changed when they are full, dirty or have lost their stickiness.
- Sticky traps can be covered in clingfilm plastic to allow for counting in the office. They can also be photocopied to help with counting. Several apps can assist with insect counting from photographs, for example Trap View and Koppert.
- In hot weather, the glue on the sticky traps can melt, especially on black traps, and may no longer catch insects. Be alert to this.
- Birds quite often peck insects or pheromone lures off sticky traps.
- Blue, yellow and red traps caught many beneficial insects and bees.

Choosing the right colour is key. In trials, yellow, blue and red traps also caught many pollinators and beneficial insects, so they should be used carefully. Trap height and placement affect catches; in dense, dark orchards, traps may be less visible and pheromones may not travel far. Trap size and materials also matter: large plastic sheets that vibrate in the wind have been observed to increase stink bug catches, possibly due to sound or vibration.

Semiochemicals – attractants

Semiochemicals are chemical signals released by organisms (insects, plants and animals) that influence behaviour or physiology in other organisms. In IPM, they are used to monitor, attract or disrupt pests without direct toxicity, offering low-risk alternatives to conventional pesticides.

Semiochemical research is advancing quickly, with new lures and deployment methods emerging for scouting and control. The Pherobase database provides up-to-date information on many semiochemicals and their uses⁷.

Pheromones are semiochemicals that signal between members of the same species, known as intraspecific. They can be mating attractants (sex pheromones) or signals for aggregation or alarm.

They are the most widely used semiochemicals for pest management. Pheromones are species-specific chemical lures used to detect insect arrival, movement and population build-up. They can be used for baiting and mating disruption to reduce population levels. Pheromones may target only specific life-cycle stages or sexes; for example, FCM pheromones attract only flying male adults. Pheromones attract insects to traps, and different traps are used depending on the type and nature of the insect.

Allelochemicals are semiochemicals that signal between different species. They may be added to pheromones to increase the attraction and efficacy of the lure.

Case study: Stink bug trapping

Species-specific pheromones often attract both the pest species and the beneficial insects that prey on them. This provides a useful way to monitor beneficial insects in the orchard.



Figure 20: (a) Trap scouting in avocados using a stink bug-specific pheromone enhanced with the synomone eugenol on a large plastic black sticky trap was effective for trapping most stink bug species, except the two-spotted bug. These green stink bugs were caught within five minutes of deploying the trap. (b) The stink bug lure also attracted tachinid flies, which are important natural enemies and parasitoids of stink bugs. Pheromones can be very helpful for understanding insect cycles and activity patterns.

⁷ <https://www.pherobase.com/>



Figure 21: (a) This solar light trap has holders at the base for pheromone lures to support enhanced trapping, as well as a water trap to catch the insects. (b) At night, it emits black light that attracts many insects.

Lessons learned

Adding detergent helps break the surface tension of the water and drown the insects.

Stink bugs are strong swimmers and can crawl out of water traps.

Water traps attract mammals, which may knock them over. Bees and other beneficial insects may also drown, so alternative water sources should be provided where possible.

Light traps

Phototaxis is an insect's response to light and is used for foraging, navigation and shelter. Insects are drawn to specific light wavelengths emitted by the traps; UV or black light is commonly used. Once near the lights, insects can be trapped using sticky glue boards, electric currents, soapy water reservoirs, or funnel systems that guide them into a collection chamber.

A wide range of solar-powered light traps with different wavelengths is available. Trapping efficiency depends on the wavelength, species, life-cycle stage and condition of the insects, trap placement, moon phase and the time the light comes on. Electric insect zappers should be on a timer switch so that they operate only at night, reducing the risk of killing bees and other beneficial insects. Ideally, lights should be placed on the orchard perimeter and outside the trees to avoid attracting pests into the crop.

Sound

Vibratory signals play an important role in how many species communicate. Laser vibrometry can be used to measure these vibrations in detail. For example, many insects communicate using substrate-borne signals. Some insect sounds are quite loud, such as cicada song, while others are ultrasonic and cannot be heard by humans. Some insects are so small that their signals are transmitted mainly through plant tissues rather than through the air. Researchers can use laser vibrometry to record these acoustic communication signals. Characterising such signals can improve understanding of the ecology and evolution of a species.

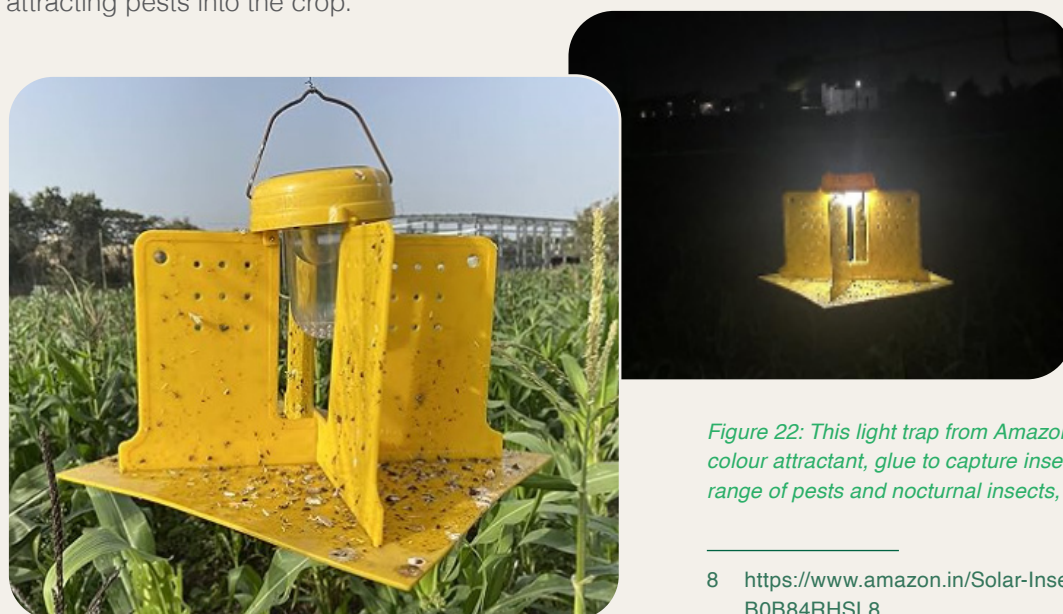


Figure 22: This light trap from Amazon India⁸ combines a yellow colour attractant, glue to capture insects and solar light to trap a range of pests and nocturnal insects, such as moths.

8 <https://www.amazon.in/Solar-Insect-Trap-Day-Night/dp/B0B84RHSL8>

In some circumstances, once an acoustic signal has been characterised, it can be used to manage unwanted organisms, for example by disrupting communication.⁹

In our trials, we found that large, stiff sticky traps that vibrated in the wind had higher catch rates for stink bugs. One trial involved recording stink bug calls and playing them back on large subwoofer speakers to assess whether the sound attracted or repelled pests. The trial was not completed because the researcher retired.

Digital tools and AI

Mobile scouting apps, such as Natutec Scout¹⁰, automated detection systems and camera traps can streamline data capture, provide near real-time alerts and support remote monitoring.

Choose tools that are easy to use, affordable and able to show trends and spatial patterns using GIS. Spot Ag¹¹ is an affordable GIS-based scouting app with avocado and macadamia pest and disease databases, crop phenology and satellite imagery integration.

Automated detection systems and camera traps often use pheromones, colours or light to attract insects. For example, Magic Trap¹² uses a camera to photograph trap contents at intervals, sends images to a phone and automatically analyses catches in the app.

Counting apps such as Trap View¹³ estimate insect numbers from photos taken on a phone.

Farm management software

Good farm management software can integrate planting, irrigation, fertiliser application, scouting, remote sensing, spraying, yield and quality reports to support holistic farm management and easier data interpretation.

9 <https://www.pherobase.com/hi-tech-products/laser-vibrometer/>

10 <https://www.koppert.com/natutec-scout/>

11 <https://spot.ag/login>

12 <https://magicscout.app/en/magictap>

13 <https://trapview.com/scouting/>

Remote sensing

Remote sensing in agriculture uses drones, also known as UAVs, satellites and aerial imagery to detect stress, diseases, pests, nutritional deficiencies, canopy cover and density from a distance. This acts as an early warning system, identifying hotspots of stress due to changes in chlorophyll content, water content and plant structures weeks before they become visible to the human eye, allowing for targeted, proactive and localised early intervention.

Advantages include rapid, remote scanning of large areas, reduced manual scouting costs, 24/7 monitoring potential and reduced chemical use. However, high-resolution imagery can be costly, cloud cover can cause problems and data may require expert interpretation.

Remote sensing can help with yield prediction, irrigation management, variable-rate application maps for targeted pesticide spraying, plant counts and orchard stand evaluation to identify gaps.

NDVI satellite imagery

NDVI, or Normalised Difference Vegetation Index¹⁴, is a remote-sensing method that uses the reflectance of light in the visible and near-infrared (NIR) wavelengths to determine the amount and health of vegetation in an area. NDVI is widely used in agriculture, forestry and ecology to monitor vegetation growth and health, and to identify areas of stress or damage. NDVI values can also be used to map and classify vegetation types and detect changes in vegetation cover. To understand plant health, the absorption and reflection values of red and near-infrared light need to be compared.

Modern scouting

Modern scouting often integrates multiple data sources. For example, a satellite might identify a potential stress area (using NDVI), after which a drone (UAV) or scout can be deployed for a high-resolution, close-up inspection to diagnose the exact issue.

14 <https://www.earthdata.nasa.gov/topics/land-surface/normalized-difference-vegetation-index-ndvi>

Phenological event	Stage number	Description	Sucking bugs (adults & nymphs)
Flower development	Stage 1	Swollen bud	
	Stage 2	Cauliflower stage	X
	Stage 3A	Flower with flush = indeterminate	X
	Stage 3B	Flower without flush = determinate	X
	Stage 4	Open flower (pollination)	X
	Stage 5	Fruit set	X
Fruit development	Stage 1	Cell division & expansion	X
	Stage 2	Oil accumulation and maturity	
Tree development	Stage 1	Foliar flush (after vegetative bud development)	
	Stage 2	Root flush(usually after foliar flush)	

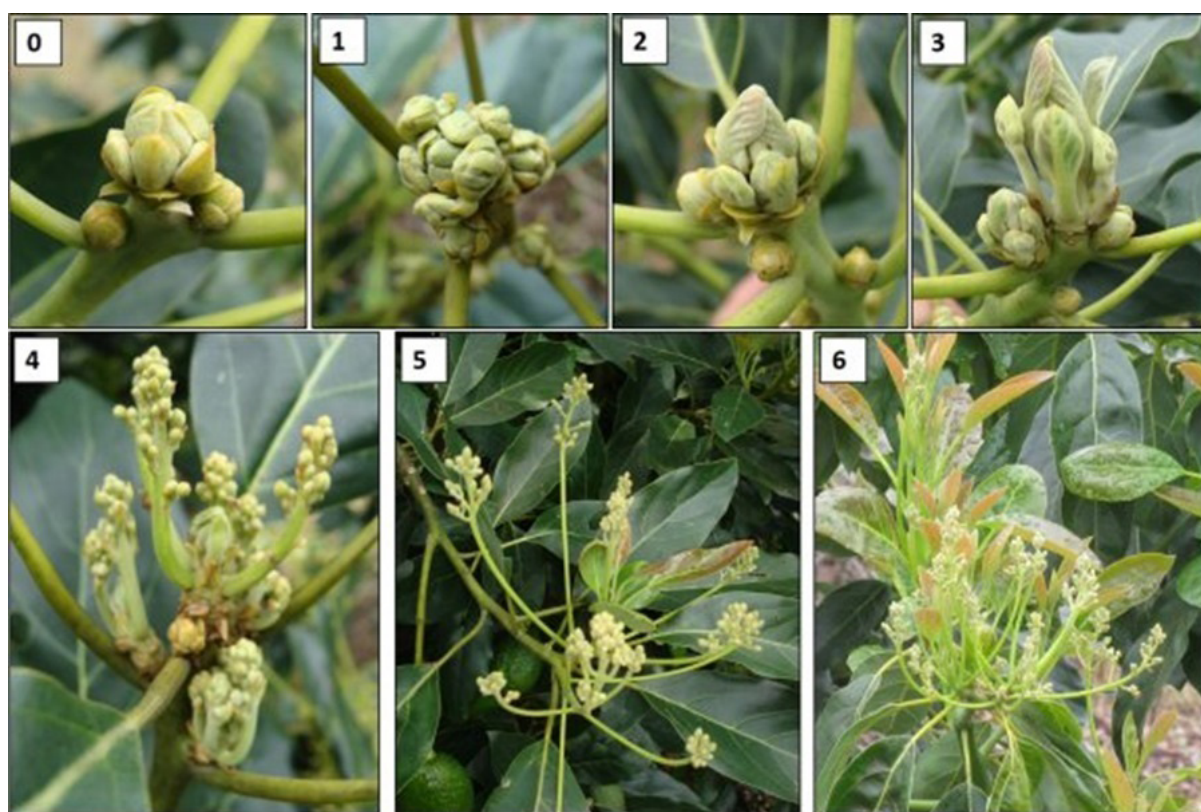


Figure 24: Avocado flower developmental stages.

0 = bud swell;

1 = cauliflower stage;

2 = slight elongation of inflorescence axes and vegetative flush;

3 = elongation of inflorescence axes;

4 = elongated inflorescence axes with individual flower axes starting to elongate;

5 = fully extended inflorescence axes with first open flowers and vegetative flush 2–4 cm long;

6 = full flower with extended vegetative flushes and fruit set.

Macadamia phenology and scouting

Stage & Visual Reference	Phenological Phase	Timeline (Southern Hemisphere / East Africa)	Scout Target & Action
Stage 1	Flower Initiation & Bud Elongation	May – July	Thrips & Aphids: Inspect developing green racemes before they open. Look for distortion or silvering on flower buds.
Stage 2	Full Bloom / Anthesis	July – September	Blossom Blight: Check open florets for brown discoloration. Avoid chemical spraying to preserve active pollinators.
Stage 3	Initial Nut Set (“Matchhead”)	September – November	Stink Bugs: Shake branches early in the morning over white drop sheets to track adult populations before nut piercing begins.
Stage 4	Rapid Nut Growth & Development	October – December	Nut Borer & Stink Bugs: Look for tiny pin-sized entry holes, frass, or wet translucent spots on green hulls.
Stage 5	Shell Hardening & Oil Accumulation	December – February	Internal Damage: Cut open 10 dropped nuts per data tree. Check inside the green shell for borer larvae or kernel staining.
Stage 6	Nut Maturity & Natural Drop	February – May	Orchard Sanitation: Monitor ground drop. Collect mature nuts quickly to disrupt the lifecycles of overwintering pests.

Figure 25: Scouting major insect pests in macadamia in East and Southern Africa, based on phenology

Simple scouting sheet for small macadamia orchards.

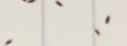
Scout _____		Year _____												Farm & Area _____											
		Jan	Feb	March	April	May	June	July	August	Sept	Oct	Nov	Dec												
Flower Initiation																									
Early Flower																									
Full Flower																									
Nut Set, pin head																									
Peaberry																									
Nuts develop to maturity																									
Mature Nut Drop																									
Thrips																									
Stink Bugs																									
MNB/FCM																									

Figure 26: A simple monthly scouting sheet developed for macadamia farmers to enable farmers to plan which months to use sticky traps and lures.

Weather monitoring

Linking weather data (temperature, humidity and rainfall) with scouting results helps fine-tune monitoring and control timing, and can improve outbreak prediction. Growers need access to localised historical weather data from a weather station.

In temperate climates, stink bugs and mirids are strongly seasonal: they emerge in spring, reproduce in summer, and seek shelter to overwinter in autumn. Temperature drives development and activity, while heavy rain can reduce populations.

Temperature

Insects' body temperature is generally determined by the ambient temperature of their surroundings; they are ectotherms. Higher temperatures speed up insect metabolism, growth and reproduction, reducing egg-to-adult development time and allowing more generations per year. Temperature also influences insects' geographical range, body size – they are often smaller in warmer temperatures – and pest outbreak potential.

Each species has an optimal temperature range. Below the lower threshold, insects become sluggish or hibernate. Above the upper threshold, high temperatures decrease survival, egg-hatching rates, longevity and egg production, affecting pest dynamics.

Degree-day model

Degree-day models for insects predict developmental stages such as egg hatch, adult flight, or pest emergence by calculating accumulated heat units between specific lower and upper threshold temperatures.¹⁵ This method tracks growth and life stages to support precise timing of monitoring and pest management, such as applying insecticides when the pest is most vulnerable. Growing degree days (GDD) and thresholds at different life stages have been calculated for some insects, and US GDD libraries are available for a range of regional pests.^{16 17}

Lower threshold /base temperature

($T_{\min}$ or T_{base}): the minimum temperature below which the insect stops developing.

Upper threshold ($T_{\max}$): the maximum temperature above which insect development stops or the insect dies.

Biofix: a biological event used as the starting date for accumulating degree-days (such as the first adult caught in trap).

Heat accumulation: insects are ectothermic and develop faster in warmer weather. They require a certain amount of heat to complete each life stage, for example larva to adult).

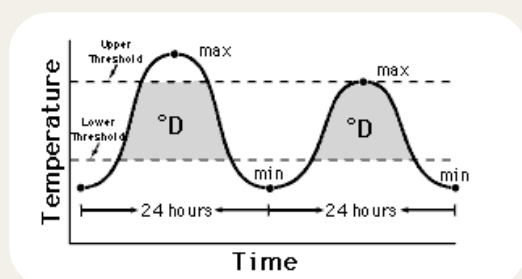


Figure 27: Thresholds and accumulated growing degree days.

Daily heat accumulation in degree-days can be roughly calculated as the average temperature minus the lower threshold/base temperature

$$\text{Daily degree-days} = \frac{\text{daily max temperature} + \text{daily minimum temperature}}{2} - \text{lower threshold}$$

15 <https://ipm.ucanr.edu/weather/ddconcepts.html>

16 <https://uspest.org/wea/wealib.html>

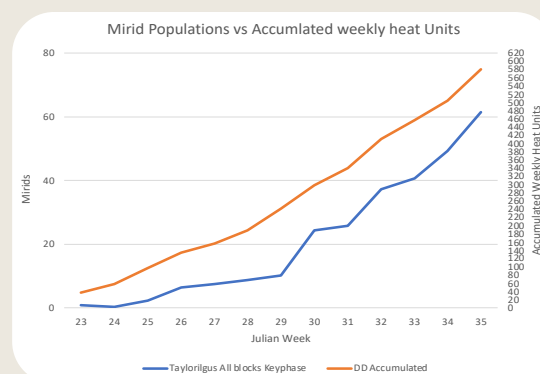
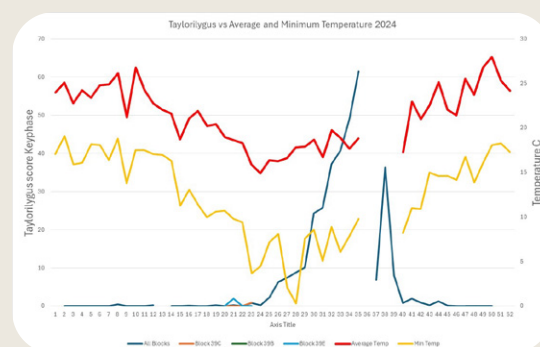
17 <https://vegento.russell.wisc.edu/ipm/degree-day-modeling/>

Case Study: *Taylorilygus* in avocados in South Africa

SAAGA has released an excellent paper to help estimate degree-days in sucking bugs.¹⁸ In this paper, the base temperature for mirids is 12.2 °C.

Mirids in Strawberries	Heat Accumulation (DD) °C
Eggs	140
Nymphs	206
Total Generation Time (egg to adult)	346
Pre-egg laying Adults	97.8
Total Generation Time (egg to egg)	443.8

Figure 28: Heat accumulation units for mirids.



In this graph, low numbers of avo bugs enter the Hass avocados in week 22 as pre-egg-laying adults, before the flower shoots open. There are four generations, each becoming larger, during flowering and before fruit formation and expansion, when they have an unlimited food source. Spraying in week 38 at 95%-flowering resulted in a quick knockdown; however, populations had already reached levels where measurable fruit drop and damage occurred. Targeting the incoming adults and eggs much earlier in the crop cycle with softer chemicals, predators or traps would reduce the need for strong chemicals and reduce yield loss due to insect damage.

18 https://www.avocadosource.com/Journals/SAAGA/SAAGA_2011/SAAGA_2011_34_PG_42.pdf

Climate change impact

Rising global temperatures can alter insect life cycles, increasing pest pressure in some areas while causing insect declines in other areas due to heat stress.

Humidity

Humidity influences insect development and survival. It can also be managed indirectly through practices such as irrigation. Many natural enemies also have preferred humidity ranges (e.g., some parasitoids perform best at around 60–80% RH). Understanding humidity can help explain pest surges and improve the performance of biological control agents such as parasitoids and entomopathogenic fungi.

Humidity affects insect water balance. Low humidity can cause desiccation, especially in larvae, while optimal humidity supports egg hatch, growth, fecundity and longevity. Very high humidity can promote fungal and bacterial pathogens that harm insects.

Humidity also affects the efficacy of entomopathogenic fungi (EMFs): higher relative humidity generally improves spore germination and infection, increasing kill rates.

Humidity affects how quickly sprays dry on the crop. Many products perform better with longer leaf wetness, which increases contact time and can improve efficacy. Always follow label guidance.

Rain

Rainfall can physically wash away or kill insects, causing significant mortality, especially in sucking bugs. Rainfall also increases humidity, encouraging fungal infections in insect populations. Rain promotes fresh growth in weeds, cover crops and orchard crops, which can attract, feed, and promote insects.

Rain can affect spray efficacy: it can wash products off leaves, while spraying onto wet leaves can dilute products and reduce efficacy. In wet weather, spray equipment can become a limiting factor in pest control due to reduced orchard access or higher spray demand.

Rain events can affect insect lifecycles and trigger egg laying, egg hatching or the emergence of adults from dormant pupae.

Lunar cycles

Moth activity and population counts are heavily influenced by the moon, with many species showing increased activity during the new moon, when conditions are darker, and reduced activity during the full moon, when conditions are brighter. Increased activity allows them to navigate better but makes them more vulnerable to predators. Insect catches in light traps are lower during the full moon and higher during the new moon.

Packhouse quality control reports

Packhouse quality control (QC) reports are a useful monitoring tool for yield, quality and reject rates. Breaking rejects down by cause, such as climate, nutrition, handling, pests and diseases, helps prioritise agronomic improvements and supports the development of economic thresholds. QC data is also valuable for evaluating the effectiveness of IPM interventions over time.

Farm	Block	Planting Date	Harvesting Date	Variety	Area (ha)	No of Trees	Tree Age (years)	Budgetted Production (tons/ha)	Budgetted Yield (kg)	Total Pick (kg)	Grade 1 (kg)	Grade 2 (kg)	Grade 3 (kg)	Small Fruit (kg)	QC Reject (kg)	Quality Control Reject Analysis											
																Sucking Pests (kg)	FCM (kg)	Scale (kg)	Thrips (kg)	Caterpillar (kg)	Fungal Disease (kg)	Rodent (kg)	Sunburn (kg)	Windburn (kg)	Mechanical Damage (kg)	Ground fruit (kg)	Deformed Fruit (kg)
	1			Hass																							
	2			Pinkerton																							
	3			Carmen																							
	4			Castle																							

Table 4: Packhouse QC Report for avocados. [Download it here](#)

Figure 29: A simple avocado QC report allows farms to calculate the percentage of damage in harvested fruit.

Macadamia packhouse quality control sheet

A packhouse quality control sheet is essential for identifying and categorising defects to ensure that only premium kernels reach the market. The following design focuses on critical insect-damage categories: **stink Bug** (early and late season) and **macadamia nut borer (MNB)**

Batch Information

Grower name/ID: _____ **Date:** _____

Variety: _____ **Batch number:** _____

Sample Size (e.g., 100 nuts): _____

Damage category	Visual identification guide	Reject count	% of total
Stink bug: early season	External: small, dark, sunken spots or “pinpoint” marks on the shell. Internal: heavily shrivelled, deformed, or “empty” kernels.		
Stink bug: late season	External: often “blind stings”, with no visible marks on the hard shell. Internal: discoloured brown pits or water-soaked lesions on the kernel surface.		
Macadamia Nut borer (MNB)	External: tiny entry holes in the husk/shell, often with protruding frass (larval faeces). Internal: Tunnels eaten into the kernel or feeding marks just under the shell.		
Other insect damage	General chewing marks, webbing, or presence of live larvae (e.g., false codling moth).		
Secondary damage	Mould or fungal growth entering via insect puncture wounds.		

Key identification criteria

- **Stink bug (early vs late):** Early damage typically occurs before shell hardening, leading to severe kernel shrivelling or premature drop. Late damage happens after the shell has hardened; the bug uses enzymes to penetrate the shell, leaving “blind stings” that only reveal kernel pitting when the nut is opened.
- **Nut borer (MNB):** Look for characteristic entry holes with brown, sawdust-like frass. If the shell was soft when attacked, the larva will be inside the kernel; if the shell was hard, damage may be restricted to the husk but can still lead to immature, low-oil kernels.
- **Grading action:** Batches with insect damage exceeding the customer’s agreed limit (typically 2-4%) are usually downgraded or rejected entirely.

Inspector signature: _____ **Total reject %:** _____

Decision-making based on monitoring and thresholds

Monitoring, forecasting, warning systems and pest thresholds form the decision-making backbone of IPM. Regular scouting tracks pests, natural enemies and early damage. These observations can be combined with forecasting tools (e.g., weather-based models, pheromone trap counts and seasonal development charts) to anticipate when pests may reach damaging levels. Warning systems, whether farm-based or regional, flag sudden risk increases and support timely, targeted responses. Thresholds define the pest density or damage level at which economic losses are

likely to exceed control costs. Acting only when thresholds are reached reduces unnecessary pesticide use, protects beneficial insects and lowers costs while maintaining long-term control.

Economic injury level

The economic injury level (EIL) is the theoretical point at which financial loss due to insect damage is equal to control costs. This threshold guides growers in deciding when to implement control measures to prevent economic losses. For some pests, tables or charts are available that outline thresholds for different life stages, helping prioritise monitoring and management. The **EIL** can be calculated using the following formula.

Steps to calculate an EIL

- Determine the treatment cost per hectare for pest control.

Product Name	Product \$/litre	Application Rate (ml/100 litre water)	Spray Volume (litre/ha)	Tractor Costs \$/1000 l (fuel and maintenance)	Labour cost \$/1000 lt	Cost of Product \$/ha	Cost of Application \$/ha	Spray Cost \$ per ha
Bulldock	20	6	2000	12	10	2.4	44	56.4

- Estimate the per-hectare market value of the crop. For example, for avocados at 23 ton/ha and \$4 per kg:
Market value of crop = projected yield x projected value
(*Market value = 23 x 1000 x 4 = \$92,000/ha*)
- Estimate the proportion of yield lost for the level of pest observed. Data can be taken from packhouse QC reports or scouting reports. For example, 20 sucking bugs/ha at fruit set causes 90% fruit drop. (*Yield Loss = 90%*)
- Consider how effective the chosen management strategy is at reducing pest numbers or damage. For example, scouting reports may show a 90% drop in populations after spraying. (*Efficacy of treatment = 0.9*)
- Calculate the EIL by applying the formula to find the pest population or damage level at which treatment becomes economically justified

$$\text{EIL} = \frac{\text{cost of treatment}}{\text{market value of crop} \times \% \text{yield loss} \times \text{efficacy of treatment}} - \text{lower threshold}$$

Scenario	Cost Of Treatment (ZAR/ha)	Market Value (ZAR/ha)	Yield Loss (%)	% efficacy of spray	Losses	Economic Injury Level
Bulldock for Sucking Bugs	842	5 332 000	3	90	143 964	0,005848684

Table 5: Calculating Economic Injury Level. [Download it here](#)

- Calculating the economic injury level (EIL) for *Taylorilygus* (the avocado bug) involves integrating both the cost of management and the biological impact the bug has on yield. In South African avocado production, where this mirid complex is a primary concern, the EIL is typically determined using a standard bio-economic formula.



The EIL formula

The standard formula to calculate the EIL is:

$$EIL = \frac{C}{V \times I \times D \times K}$$

Where:

- **\(C\)** – **Cost of management**: The total cost of control per unit area, for example the cost of insecticide plus labour/ application costs per hectare.
- **\(V\)** – **Market value**: The expected market value per unit of avocado, for example price per kg or per carton. This is highly variable based on export versus local market rates.
- **\(I\)** – **Injury per pest**: The amount of injury, for example the number of fruit lesions or “vosknoppe” caused by a single *Taylorilygus* bug.
- **\(D\)** – **Damage per unit injury**: The reduction in yield or quality, for example the percentage of fruit downgraded from export to local grade, caused by each unit of injury.
- **\(K\)** – **Efficiency of control**: The proportional reduction in the pest population expected from the treatment, for example 0.8 for 80% control.

1 2 3 4

Simplified practical thresholds

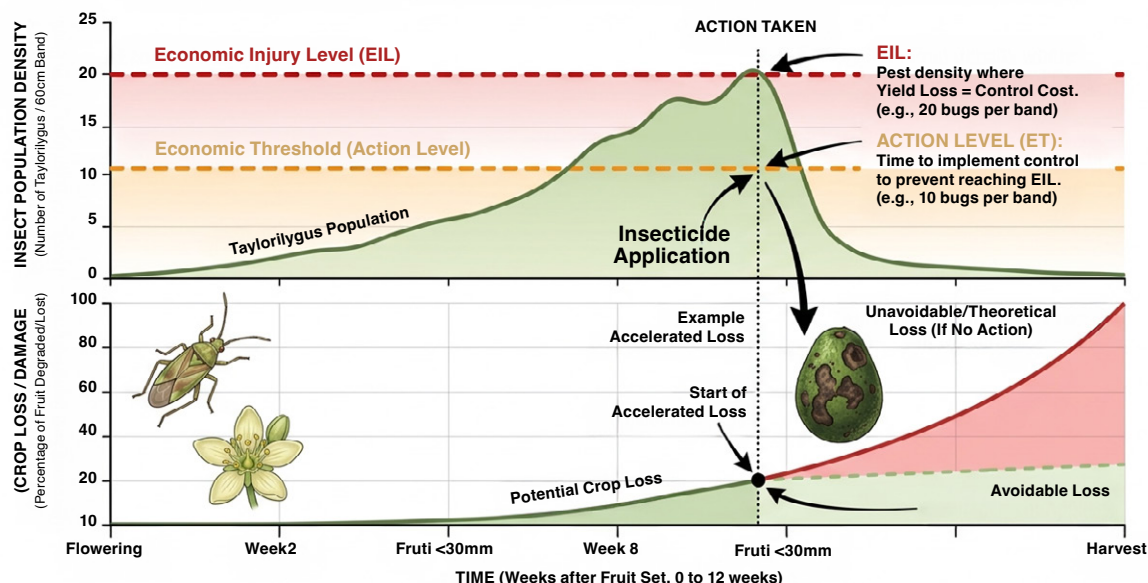
While the EIL is a theoretical calculation, researchers have established simplified **economic thresholds (ET)** for field use to trigger action *before* the EIL is reached:

1 2 3

- **Flower infestation**: During an “on” year, when yield is high, action is often taken at **20% flower infestation**.
- **Off-year sensitivity**: During an “off” year, the threshold drops to **10% flower infestation**, as each fruit lost represents a higher percentage of the total potential income.
- **Fruit-size window**: Monitoring is most critical when fruit are **less than 30 mm in diameter**, as this is when *Taylorilygus* feeding causes the most severe permanent skin lesions.

1 2

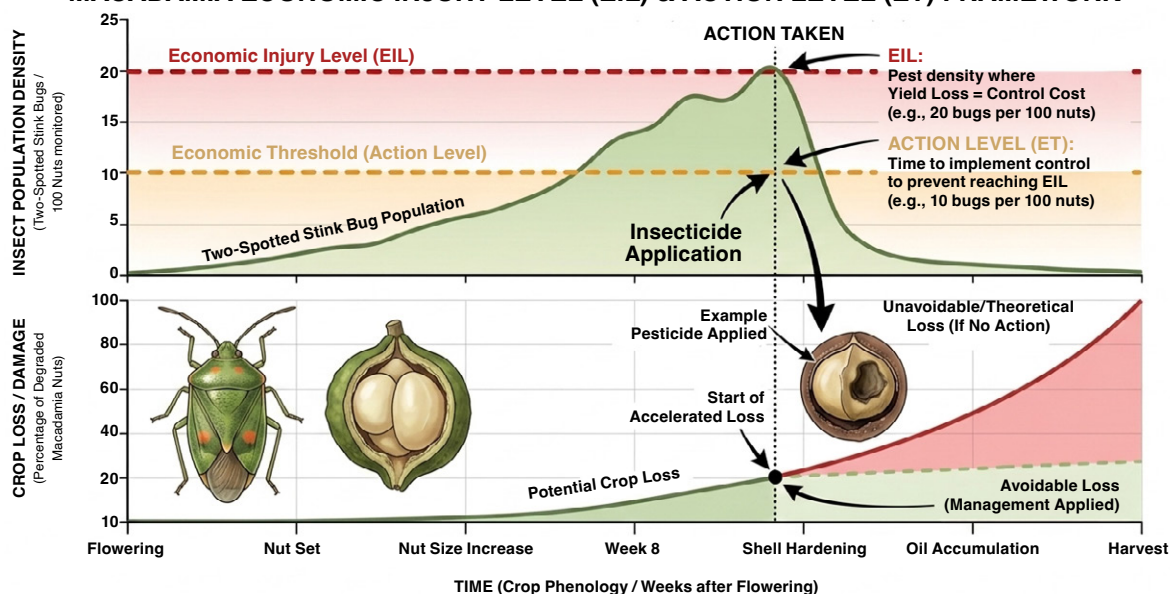
TAYLORILYGUS ECONOMIC INJURY LEVEL (EIL) & ACTION LEVEL (ET) FRAMEWORK



This graph illustrates the critical relationship between pest density and management timing:

- **Economic injury level (EIL):** The point at which the cost of crop damage equals the cost of control. If the pest population stays above this line, the value lost through reduced fruit quality or yield is greater than the cost of treatment.
- **Action level / economic threshold:** This is the “trigger point” for intervention. It is set safely below the EIL to allow time to organise labour, equipment and treatment before the pest population reaches economic injury level.
- **The goal:** By intervening at the **action level**, the pest population is reduced (as shown by the post-treatment curve) before it ever reaches the point of causing economic loss.

Two-Spotted Stink Bug (*Bathycoelia distincta*) MACADAMIA ECONOMIC INJURY LEVEL (EIL) & ACTION LEVEL (ET) FRAMEWORK



This diagram is specifically tailored for **two-spotted stink bug** (*Bathycoelia distincta*) in macadamias and highlights the extremely low tolerance for this pest due to its direct damage to the nut kernel.

Section three:

Control

Mechanical control

Mechanical pest control uses physical actions to remove pests, kill them, or block access to the crop. Methods include handpicking, trapping using sticky, light or baited traps, tillage, screens or nets, flaming, high-pressure water sprays, and heat or cold treatments. Used within IPM, these approaches reduce reliance on chemicals by making the crop environment less accessible or less suitable for pests.

Common mechanical methods:

- Handpicking: Manually remove pests (e.g., caterpillars and beetles); best for low infestations.
- Trapping and pheromones: Using sticky, light or baited traps to monitor and reduce pests (e.g., yellow sticky traps for aphids).
- Barriers and screens: Installing fences, nets or screens to block pest entry.
- Soil tillage/cultivation: Ploughing or turning soil to expose and kill soil pests and eggs.
- Mowing/weeding: Removing vegetation that harbours pests.
- Water sprays: Using high-pressure water to dislodge pests (e.g., spider mites and mealybugs), especially from leaf undersides.
- Temperature control: Using heat, such as steam, or cold to kill pests in soil or stored-product systems.

Mechanical control can be labour- and/or equipment-intensive, and results depend on pest pressure and how consistently methods are implemented.

Physical control

Physical control relies on barriers and structures that prevent pests from reaching the crop. Nets, screens, tree bands and similar measures reduce pest access and pressure, protect plant health and can support early detection by limiting pest movement within the orchard.



Figure 30: Shade netting and insect netting create a physical barrier that protects this apple crop from bright sun, hail and large flying insects. A top and side cover is only economically viable on very high-value crops, however insect netting around the edges of orchards can reduce sucking bug insect fly-ins.

Using traps and pheromones for insect control

Once appropriate attractants or pheromones have been identified for specific pests, they can be used for monitoring pest populations and adapted to control the pest populations. These methods integrate well into an IPM system and complement other sustainable methods such as monitoring and biological control. They are environmentally friendly, avoid or substantially reduce toxic chemical use, and reduce risks to farmers, beneficial insects and the environment.

Mass trapping

Insect trapping methods use visual cues like colours, for example yellow or blue for aphids, thrips and whitefly, bright lights or UV lights for nocturnal insects, or chemical attractants¹⁹ such as pheromones or food baits, including sugars, fruit or proteins, to attract insects. An appropriate capture mechanism, such as glue, soapy water pans or funnel/bucket traps, is then used to catch the insects.

¹⁹ <https://insectscience.co.za/mass-trapping>

Case study: Mass trapping for FCM

False codling moth (FCM, *Thaumatotibia leucotreta*) is a highly destructive quarantine pest native to Africa. The EU enforces strict zero-tolerance for FCM in avocados imported into Europe, leading to increased inspections and rejections, and costly system-based management strategies by exporting nations to maintain market access. Delta traps, with FCM pheromones and sticky papers, are hung at chest height or higher in the trees, at a rate of 4-20 traps per hectare, to catch male FCM. Pheromones should be replaced every 5-6 weeks, or every four weeks in very hot weather. It is useful to set a reminder for when the pheromones need changing. The sticky papers²⁰ are replaced when full. Extra traps should be deployed around orchard perimeters and on the windward side of the farm.

FCM can travel great distances, and the traps catch only males, so incoming fertilised females can be a problem at certain times of the year. FCM trapping is most effective for area-wide management, so growers are encouraged to coordinate with neighbours. Mass trapping can be combined with field hygiene (removing fallen fruit) and biological control like granuloviruses.²¹ Mass trapping of FCM should be in place all year round, and well before fruit development, to maintain consistently low populations. Extra traps should be placed around main roads, packhouses and reject-handling areas, and during peak pressure.

²⁰ <https://www.dudutech.com/problem/false-coddling-moth/>

²¹ <https://www.elephant-vert.com/en/crops/arboriculture/>



Figure 31: Mass trapping of mirids in young avocados using Black Sticky Tuta Rolls and Lygus lures.

Mating disruption (MD)

Mating disruption saturates orchards with species-specific sex pheromones, which confuse male insects, so that they cannot find females to mate. This leads to fewer offspring and lower pest populations. Mating disruption is suitable for large, isolated areas such as avocado and macadamia orchards. In smaller units and around orchard perimeters, mated females may fly in from untreated areas. This method is effective for controlling lower insect populations. When populations are high, farms may require an initial insecticide to bring populations down, and can then use mating disruption to keep populations low.^{22 23}

Mating disruption is most successful for moths (Lepidoptera), like the macadamia nut borer and the false codling moth, but is being developed for other insects.

Bait stations

Bait stations combine baits (sugars/proteins and fruit extracts) with pesticides that attract and kill specific fly pests. This lowers pest populations without applying chemicals to the crop, reducing risk to people and the environment.²⁴

²² <https://treefruit.wsu.edu/crop-protection/opm/mating-disruption/>

²³ <https://insectscience.co.za/mating-disruption>

²⁴ <https://insectscience.co.za/bait-stations>

Many fruit fly genera are designated as EU quarantine pests, and exporting infested fruit into Europe is a phytosanitary risk. In addition, some genera can cause significant damage in fruit like avocado. Successful control can be achieved by mass baiting fruit flies, for example:

- M3a: A protein bait station that attracts and kills female *Anastrepha*, *Dacus* and *Ceratitis* fruit flies. By eliminating females, it reduces egg-laying and lowers fruit fly populations before harvest.

The pest pressure, crop surface to be protected and strategy employed (mass trapping, perimeter strategy, etc.) determine the number of fly traps needed per hectare. Between 70 and 120 traps per hectare are used for mass trapping to provide adequate pest control at peak pest pressure.

Attract and kill

Attract-and-kill solutions combine the precision of pheromones or species-specific baits with the effectiveness of insecticides to attract and kill adult pests. They are suspended in grease droplets (Last Call™²⁵, for FCM, fruit fly and macadamia nut borer) or in blocks in Lynfield traps (*Ceratitis* Block).

²⁵ <https://insectscience.co.za/attract-and-kill>

Cultural control

Mulching

Avocado trees have shallow, fragile root systems that lack root hairs, with most feeder roots concentrated in the top 20 cm of soil, primarily within the tree drip zone. The root system is highly sensitive to waterlogging and soil-borne diseases such as *Phytophthora* root rot. Due to their shallow nature and sensitivity, avocado roots require well-aerated soils and are easily damaged by fluctuations in moisture and temperature, or by compaction.

Mulching improves root and soil health while reducing several pest and disease pressures. A well-maintained mulch layer suppresses weeds that can harbour insects or compete with trees for nutrients and water, making the crop less stressed and less susceptible to pests. Organic mulches support beneficial soil organisms that break down organic matter and help suppress soil-borne pathogens through natural microbial competition.

In orchard crops, mulching improves drainage and reduces soil splash, lowering the risk of *Phytophthora* root rot and preventing spores from reaching the trunk or low branches. A stable mulch layer also helps maintain consistent soil moisture and soil temperature, improving tree vigour, one of the strongest natural defences against pests.

Figure 32: a) Un-mulched soil is exposed to the elements and can become compacted, support algal growth and develop many weeds. b) A young avocado tree mulched with grass clippings to reduce weeds and reduce fluctuations in soil moisture and temperature. c) As trees grow, they become self-mulching through fallen leaves.





Figure 33: Skirting of a young avocado tree to remove low-lying branches that touch the ground. Note: the prunings were removed from the crop after the photo was taken.

Additionally, mulching creates the habitat for natural predators such as ground beetles, *Hypoaspis* mites,²⁶ lizards and spiders, strengthening biological control within the orchard. Overall, mulching contributes to a healthier, more resilient orchard ecosystem that requires fewer chemical interventions.

Pruning and skirting trees

Pruning and skirting are essential cultural practices in IPM because they directly reduce pest habitats, improve spray penetration and enhance orchard sanitation.

Pruning opens the tree canopy, increasing light and airflow, which creates an environment that is less favourable for pests such as mites, scale insects and fungal pathogens. Better airflow also helps foliage dry faster after rain or dew, reducing disease pressure. An open canopy allows more effective coverage when applying targeted pesticides or biological agents, improving their efficiency and reducing the need for repeated treatments.

Skirting, the removal of low-hanging branches near the ground, prevents fruit and foliage from touching soil where pests like rats, beetles, ground-dwelling insects and *Phytophthora* spores can easily access the tree. Skirting also improves the ability to monitor pests and place traps under the canopy, while reducing humidity pockets that favour pests and disease. Together, pruning and skirting strengthen the orchard's natural resilience and make other IPM measures, such as monitoring, biological control and chemical intervention, more effective and sustainable.

Cover crops and inter-row vegetation

Cover crops and inter-row vegetation play an important role in soil fertility and weed control, as well as providing shelter for beneficial insects. Planting grasses, legumes or other suitable species between orchard rows helps protect soil structure, increase organic matter, fix atmospheric nitrogen and support a wide range of soil organisms. These plants reduce erosion, improve water infiltration and moderate soil temperature, all of which contribute to healthier, more resilient trees. Cover crops also suppress weeds and harbour beneficial insects that prey on pests or compete with them for resources, thereby reducing pest pressure without relying heavily on chemical inputs.

²⁶ <https://www.koppert.co.ke/crop-protection/biological-pest-control/predatory-mites/stratiolaelaps-scutum-hypoaspis-miles/>



Figure 34: (a) Weeds compete with young avocado trees for nutrients, damage fragile roots and can act as a food source for insects. (b) Flowering weeds are a reservoir for insects. (c) Weeds treated with herbicide. Mechanical weeding can damage the avocado root system.

In avocado and macadamia orchards, flowering cover crops and flowering weeds that provide a year-round source of nectar and pollen, but do not provide a highly attractive plant sap, can help reduce mirids in avocados and secondary pests like thrips and mealybugs in avocados and macadamia.

Weed control

Weeds can provide alternative food sources for pests and encourage pest population explosions. Weeds can also compete with orchard trees for soil nutrients, and their roots can damage fragile avocado roots. Weeds can be controlled by manually weeding, spraying with selective herbicides or mowing. Mulching young trees, or growing cover crops under the trees, will reduce weed pressure. As macadamia and avocado trees age, they drop their leaves and can become self-mulching. In mature orchards with tall, dense trees, very little light gets to the soil, discouraging weed and cover crop growth.

Flowering weeds like blackjack can be advantageous to orchards, as they provide a good source of pollen. On the other hand, weeds that produce a lot of sap can build up sucking-bug populations. Good IPM practice involves identifying the weeds in your orchard and including them in observations and scouting protocol to understand insect-weed dynamics and harness their potential.

A weed is only a plant in the wrong place – some weeds can be very beneficial to your orchards

Section four:

Biological control

Biological control uses living organisms and naturally derived products to suppress pests in a targeted, sustainable way. It includes botanical extracts that repel, disrupt feeding or development, or reduce reproduction, as well as biological agents such as entomopathogenic fungi, bacteria, nematodes and viruses, and beneficial insects that prey on or parasitise pests.

Biological control works best within a holistic IPM programme alongside monitoring, cultural practices and habitat management. Before introducing new biological agents, confirm that they are approved for your region to avoid unintended impacts. Always use registered products, follow label instructions and wear appropriate PPE—even for biological products.

By strengthening natural ecological processes, biological control reduces reliance on synthetic pesticides, supports long-term resilience and helps slow pesticide resistance. The goal is usually to keep pests below damaging levels, not eradicate them, supporting a more stable, balanced orchard ecology.

Botanical Pest Control

Botanical control uses plant-derived compounds (phytochemicals) to repel pests, reduce feeding, disrupt growth and reproduction, or interfere with behaviour (e.g., mating or egg laying). Botanicals are often biodegradable and generally less persistent than many synthetics, but they still require careful, label-guided use.

- Apply carefully to avoid non-target effects (some can harm beneficials, bees or fish); always read the label.
- Many botanicals have multiple modes of action, which can reduce resistance risk.
- The botanical pest-control field is expanding quickly, with new products released regularly.
- Because botanicals can degrade quickly, they may require more frequent applications.

Combining botanical products with microbial pest-control products can greatly enhance the efficacy of insect control. Some examples of botanical products and their modes of action include:

Neem oil, containing the active ingredient azadirachtin, is a powerful insecticide that acts in several ways: **growth disruption** by blocking metamorphosis (moulting from larvae to pupa to adult); **antifeedant** action by repelling insects or triggering a swallowing block; **repellent** action that stops insects landing on or laying eggs in crops; and **reproductive interference** affecting egg laying and hatching. Its action is slow, affecting insect life cycles, and requires repeated application.²⁷

Example: In the AgDevCo TAF funded IPM trial on sucking bugs, combining neem oil with *Beauveria bassiana* gave an 80% knockdown of *Taylorilygus* populations after 7–10 days in avocado. The neem dissolves the waxy cuticle and weakens the insects, improving the ability of the fungi to penetrate the insect's exoskeleton.

Orange oil is derived by cold-pressing orange peel, which is a waste product. It is rich in d-limonene, which **dissolves insects' waxy exoskeletons** and dehydrates them. It is effective against soft-bodied insects like termites, mites and sucking-bug nymphs. It is also a **pheromone disruptor** for ants and termites, dissolving their scent trails. Orange oil has a fungicidal effect by disrupting fungal cell structure, so it should not be mixed with fungal insecticides.²⁸

Natural pyrethrin is a mixture of up to six insecticidal compounds extracted from pyrethrum (*chrysanthemum*) flowers. It is a broad-spectrum contact poison that targets the insect's nervous system, causing rapid paralysis and death.

²⁷ <https://npic.orst.edu/factsheets/neemgen.html>

²⁸ <https://biocontrolcoalition.eu/orange-oil-fights-pests-and-fungi-in-fruits-and-vegetables/>

It is toxic to fish, bees and beneficial insects but has low mammalian toxicity. It breaks down quickly in sunlight, so it only works for a quick period and has no residual effect, a low post-harvest interval and no pesticide residues. It is better sprayed in the evening.²⁹

Canola oil, derived from low-erucic acid rapeseed, is used as a cooking oil, but is also widely used alone as an insecticide or as a carrier for biological pesticides, like *Beauveria bassiana*, where it works as a UV-blocking agent. The oil blocks the breathing pores (spiracles) of soft-bodied insects, and it can create a repellent film on leaves to deter pests.

Essential oils derived from aromatic plants are widely used as natural pesticides. They may contain terpenes with insecticidal and fungicidal properties, phenols that disrupt fungal development, aldehydes that repel insects and ketones that stimulate plants' natural defences.

Diatomite (diatomaceous earth) consists of fossilised diatoms and physically kills insects by abrading their exoskeletons, causing fatal dehydration over time. It is applied as a fine, dry dust in areas where insects are likely to crawl. It is often used to augment the effects of biological pesticides by providing UV protection and damaging insects' skin to allow biological agents to penetrate.

29 <https://npic.orst.edu/factsheets/pyrethrins.html>

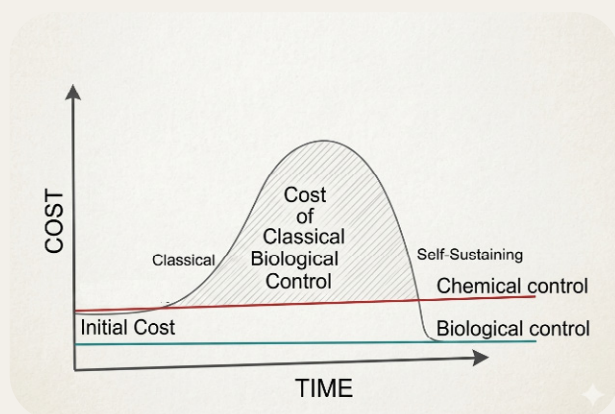


Figure 35: A theoretical diagram of the cost and efficacy of biological control over time during the transition from long-lasting broad-spectrum insecticides (chemical control), to augmentation control with low efficacy due to residual pesticides, to a combination of conservation and augmentation control.

Biological control through predators, parasites and pathogens

Biological control uses living organisms like predators, parasites and pathogens (bacteria, fungi and viruses). There are four main approaches to biological control.

Conservation: Conserving and promoting existing natural enemies in the area by providing habitat and/or food, and by using broad-spectrum insecticides carefully to avoid destroying natural enemies. This is ultimately the cheapest system. Natural predators may have to be reintroduced, and it can take time for the effect of long-lasting broad-spectrum insecticides to disappear. This should be factored into the IPM programme.

Augmentation: Releasing large numbers of beneficial organisms periodically to suppress pests. This can be expensive initially, as residual fungicides may reduce the efficacy of microbial control, and residual pesticides may reduce the efficacy of macrobial control (insects). As existing pesticide residues decay from the crop, the efficacy of the biological control improves.

Conservation and augmentation: A combination of the two approaches above is the most stable and economical system. This involves conserving available natural enemies, supported by augmentation releases when scouting indicates that pest populations have risen.

Classical: Introducing a new natural enemy from one region to another to control a pest. In most countries, biological control agents are registered and controlled through government legislation. Moving natural enemies from one region to another is recommended only after stringent research by the relevant authorities.

Microbial control with beneficial microbes

Beneficial microbes are microorganisms that have positive effects in their environment, including in various biological systems and organisms. Beneficial microorganisms for pest control include fungi, bacteria and viruses that occur naturally in environments such as soil, water and air. These microorganisms can be harnessed for pest control by introducing them to target pests, providing an eco-friendly alternative to chemical pesticides.

Entomopathogenic fungi (EMFs), like *Beauveria bassiana* and *Metarhizium*, work when their spores attach to the insect cuticle, germinate and penetrate the cuticle, colonising the insect's body and causing internal damage and death. The fungus continues to grow and eventually produces more spores that can be released into the environment to infect more insects.

EMFs tend to be insect specific, minimising harm to beneficial insects and pollinators. Indeed, *Beauveria* has great potential to kill the varroa mite that threatens honeybee colonies³⁰.

Their efficacy depends on specific environmental conditions, and moderate temperature and high humidity are required for them to germinate and infect insects (research the specific fungus and read the label). Through scouting and keen observation, you might pick up insects on your farm that have been infected by EMFs. These will be strains that are more suitable for your farm conditions (climate, crop or insect). It can help to collect these samples and give them to your biopesticide suppliers for further research and strain identification.



Figure 36: (a) A stink bug infected with an EMF was collected and taken to the lab for identification and possible development as a stink bug-specific EMF. (b) During an IPM TAF project on smallholder macadamia farmers, it was seen that Beauveria bassiana continued to infect insects in the field six months after it was sprayed in the trees.

Insect-killing viruses: Baculoviruses used for biocontrol are naturally occurring viruses that can infect insects. They are sprayed on the crop and, once ingested by suitable insects, reproduce within the gut cells of the insect, causing it to become ill and die. They have a narrow spectrum of activity and are often able to infect only the species of insect from which they were originally isolated. They are commonly used for the control of Lepidoptera, including moths and caterpillars.³¹



Figure 37: Two years after spraying Cryptex® (a granulovirus against false codling moth [FCM]) in avocados, dead caterpillars were still seen in the orchard; however, this beneficial effect was not present the following year.

Control with beneficial insects

Biological pest control with insects (macrobial control) uses natural enemies to reduce insect pest numbers. These work by predation or parasitism.

Predatory insects are beneficial insects that actively hunt, kill and consume other insects. They are key agents in ecological balance. They are generally larger than the insects they eat and kill them quickly. They are active, highly mobile hunters, enabling them to catch their prey. They have chewing mouthparts to devour prey, or piercing-sucking mouthparts to drain fluids.

Common examples include spiders, dragonflies, praying mantids, ladybirds, assassin bugs, hoverflies and lacewings.

Parasitoid insects are specialised parasites, primarily wasps or flies. They are highly species-selective and often target only specific life stages of a particular host species (egg, larva or pupa). Adults are usually free-living and feed on nectar, pollen or honeydew. Adult females lay their eggs in or on the host insect. The hatching larvae feed on the host's body, developing until they pupate and emerge as adults. Unlike parasites, parasitoids always kill the host insect; however, the host often does not die immediately. The use of broad-spectrum insecticides depletes naturally occurring insect parasitoids in orchards.

30 [https://www.researchgate.net/publication/varroa_mites Beauveria](https://www.researchgate.net/publication/varroa_mites_Beauveria)

31 <https://andermattuk.com/blogs/crop/baculoviruses>

Example: Conservation control of stink bugs with tachinid flies

Tachinid flies are beneficial parasitoids of stink bugs; they look like hairy house flies.³² The adults feed on nectar and lay their eggs directly onto stink bug adults or nymphs. The larvae bore into the stink bugs and feed on them, killing them after several days. They can be very effective biological control agents, with high rates of parasitism.

The impact of tachinids on stink bugs in Africa is not well researched or understood, but broad-spectrum insecticides are probably highly toxic to these beneficial insects. Nectar-rich plants are required as a food source for the adults (e.g., dill, coriander, lavender and milkweed).

Stopping the use of broad-spectrum persistent pesticides and moving to targeted sprays using softer chemicals, together with encouraging flowering weeds and planting flower banks, has reduced the need for chemical sprays for stink bugs on one avocado farm.

32 <https://doi.org/10.1093/jisesa/ieaf046>



Figure 38: Tachinid flies caught on black sticky traps with stink bug lures, and on blue sticky traps close to the black traps with the lures. The farm had a history of stink bug infestation and damage to avocados, (food source for larvae). It had not sprayed persistent broad-spectrum insecticides for several years (conservation of beneficial insects), and there were nectar-rich weeds in the inter-rows and tree gaps for the adult tachinids (food source for adults). This triple combination allows the tachinids to complete their life cycle and continue to parasitise the stink bugs.



Figure 39: (a) An unsprayed and inaccessible wildflower area along the perimeter of an avocado orchard, suspected to be a source of adult stink bugs causing damage to the avocado fruit. (b) Augmentative releases of registered and commercially available flying adult *Trissolcus* wasps were done every few weeks along this boundary. They are supplied as parasitised stink bug eggs from which the adults emerge.

Example 2: Augmentative control of stink bugs with parasitic wasps

Stink bugs are seen intermittently in an avocado orchard in South Africa and have accounted for lost income due to insect damage in harvested fruit. A commercially available wasp, *Trissolcus basalis*,³³ was released every 2-4 weeks (augmentative releases) at the edge of the orchard, close to an area of unsprayed wildflowers (nectar source). Stink bug eggs were not seen inside the orchard, so the effect of these augmentative releases will hopefully be seen in the quality control reports through reduced stink bug damage.

33 <https://www.koppert.co.za/greenshield/>

Conservation of bats, lizards and other animals

Providing habitats that attract and protect animals can help create a balanced ecosystem that suppresses insect pests.

Bats have a voracious appetite, and a single bat can eat hundreds of insects a night. Installing bat houses in orchards can attract bats and support insect control. A recent study has shown that bats have the potential to help control stink bugs in macadamia orchards.

Lizards, geckos and chameleons are also voracious feeders of insects and should be encouraged. Creating log and rock piles helps protect and encourage them.

Baboons and small antelope scavenge and eat fallen fruit and nuts, helping with orchard sanitation.

Section five:

Chemical control

Chemical control is one part of IPM and should be used only as a last resort, when monitoring shows that other options will not prevent unacceptable damage. When chemical intervention is necessary, careful pesticide selection is essential. Choose selective, targeted products that affect specific pests and minimise harm to natural enemies, pollinators, workers and the environment. Prefer lower-toxicity products with shorter environmental persistence to help maintain ecological balance and long-term sustainability.

Minimising pesticide use is a core IPM goal. Prioritise cultural, mechanical, biological and ecological controls, and spray only when pests are correctly identified and action thresholds have been exceeded. Avoid routine or “preventative” spraying. Good practice, calibrated equipment, spot or border treatments where appropriate, and spraying at times that avoid peak pollinator activity reduces costs and off-target impacts.

Resistance management is essential. Repeated use of the same active ingredient or mode of action selects for resistant pests and shortens the useful life of products. Rotate modes of action, use full label rates with good coverage, and keep chemical pressure low by integrating non-chemical strategies. This protects efficacy while supporting a resilient, sustainable production system.

Chemical selection

Chemical pesticides should be a targeted rescue remedy of last resort rather than the primary control method, applied only when scouting shows that action thresholds have been exceeded. Used this way, they protect beneficial organisms while still addressing pest outbreaks when necessary. For this reason, it is important to maintain an appropriate stock of chemicals so they can be applied efficiently as a rescue remedy, avoiding further pest damage caused by delay in the procurement process.

The following factors should be considered when selecting chemicals and determining the appropriate stock to hold:

- Select sprays that are registered and approved for use by local authorities, market off-takers, certification bodies and investors.
- Use the softest effective option to manage the pest while conserving beneficial insects.
- Pick products with short half-lives and low re-entry intervals to allow beneficial insects to be reintroduced or recover quickly after the chemical has dissipated.
- Prefer selective products that target the pest (e.g., for sucking bugs, consider products with systemic activity in sap where appropriate).
- Use buffers or adjuvants only when needed to improve coverage or efficacy, and follow label guidance on compatible products and rates.

Spray considerations

Spray protocols should ensure that products (chemical or biological) reach the target pest at the correct dose and with adequate coverage. Good spray practice improves efficacy, reduces off-target impacts and helps slow resistance development.

Always follow the label: dose (per ha or per 100 L), mixing instructions, re-entry interval, post-harvest interval (PHI), and any restrictions on temperature, humidity and wind speed. Check environmental cautions (e.g., buffers near water; risks to pollinators and beneficial insects).

Product compatibility

Physical compatibility: Before tank-mixing, confirm products mix properly. Incompatible mixes can sludge, separate, settle out or foam excessively, reducing performance and blocking equipment. If compatibility is unknown, do a simple jar test before mixing a full tank.



Figure 40: A mist blower spraying a young avocado orchard.

Functional compatibility: Some products reduce the effectiveness of others. Always read labels and supplier guidance, and avoid these mixes:

- Fungicides with entomopathogenic fungi
- Copper with microbial control agents
- Metallic fungicides with foliar feeds containing chelates or metallic ions
- Nematicides with beneficial nematodes

Spray timing and environmental factors

For best timing, apply insecticides early in the morning (before 9 am) or late in the evening (after 5 pm) to avoid peak bee activity and reduce evaporation. Cooler conditions extend “wet contact” time and can improve uptake and efficacy. Always follow label limits for temperature, humidity and wind.

Aim to spray at wind speeds of 6-19 km/h (Beaufort 2 to 3). In very calm conditions (often evenings) temperature inversions can carry fine droplets off target. Above 19 km/h, drift risk increases. Spray with a steady wind away from sensitive areas and use larger droplets where drift is a concern. The Beaufort scale relates wind speed to observable conditions.³⁴

Avoid spraying above 28-30 °C, especially in low humidity. Heat and dryness increase evaporation, shrinking droplets and increasing drift; they can also increase volatility and off-target vapour movement. Heat-stressed plants may absorb products poorly and can be more prone to phytotoxicity.

In wet seasons, spray onto dry leaves and only when no rain is forecast for at least 4 hours (check rain fastness on the label). Rain can wash products off, and leaf wetness can dilute spray deposits and reduce adhesion.

Spray coverage

Good spray coverage requires targeted application, correct set-up and uniform delivery across the canopy.

Ensure coverage of the target surfaces, including leaf undersides, the inner canopy and the tops of tall trees (where pests may shelter).

Use scouting data to decide whether the inter-row or orchard floor also needs treatment. Some pests (e.g., mirids) can shelter in grasses and weeds during the day.

³⁴ <https://www.health.vic.gov.au/environmental-health/beaufort-wind-scale-for-pesticide-spraying>

Use the correct spray volume to achieve full coverage; labels may provide guidance. Small trees require less volume than large, dense canopies, so base volume on tree size rather than age. Tree row volume (TRV) calculations can help set appropriate volumes.^{35 36}

Calibrate sprayers at least once a year (often twice a year as canopy density changes). One simple check is to use flagging tape to confirm ground speed and identify the fastest speed that still delivers spray through the tops of the tallest trees.^{37 38}

Insecticide resistance management

Insecticide resistance management (IRM) reduces the risk of resistance developing in on-farm pest populations.

Pesticide resistance is the inherited ability to survive doses that previously controlled a pest. It develops through natural selection: repeated use of the same product or mode of action kills susceptible individuals and leaves resistant ones to reproduce. As fewer active ingredients remain available, protecting the efficacy of existing tools becomes increasingly important.

Key IRM strategies

- Reduce reliance on insecticides by strengthening IPM (cultural, physical and biological control).
- Rotate products with different modes of action (MoA). Use IRAC group numbers on labels or the IRAC database.³⁹
- Spray based on scouting and thresholds, not at first sighting. Use spot or border sprays where feasible to contain spread.
- Use best application practice: correct rate, correct timing (pest present and vulnerable), good coverage and calibrated equipment. Sub-lethal doses accelerate resistance.
- Maintain unsprayed refuges (e.g., hedgerows) to preserve susceptible pests and beneficial insects and dilute resistance genes.
- Maintain crop hygiene (remove crop debris and dropped fruit/nuts that provide food and overwintering sites).
- Avoid persistent products where possible and use longer-lasting products judiciously.

39 <https://irac-online.org/mode-of-action/classification-online/>

35 <https://www.fgv.com.au/fgv-news/grower-news/409-tree-row-volume-concept-calculations-and-application>

36 <https://www.syngenta.com.au/news/fruit/best-practices-spray-application>

37 <https://www.almonds.org/almond-industry/industry-news/proper-spray-calibration-application-delicate-balance>

38 <https://fieldreport.caes.uga.edu/publications/B979/orchard-sprayers/>

Section six: Evaluation

Evaluation is essential to a successful IPM programme. Using scouting records and packhouse quality control (QC) data, farms can track pest pressure and damage over time and assess whether interventions are delivering the expected results. Because pest dynamics, weather and available IPM tools change continually, evaluation helps keep programmes effective and sustainable.

Adopt a structured, ongoing process to review what worked, what did not, and what to change next season. Use results to refine tactics, timing and resource allocation.

Pest control evaluation combines monitoring and analysis to understand what influenced outcomes. Key activities include:

- Scout regularly and record pest and beneficial insect life stages.
- Compare outcomes against thresholds, targets and objectives.
- Review packhouse QC results to quantify pest damage and overall quality.
- Assess timing and performance of cultural, biological and chemical actions.
- Account for weather and other environmental drivers of pest pressure and efficacy.
- Prioritise effective, low-risk options that align with IPM principles.

Consistent evaluation supports adaptive management: it improves timing and targeting, reduces unnecessary inputs and costs, and protects quality and market access. Over time, it helps ensure IPM remains economically viable and aligned with long-term sustainability goals.

Key aspects of pest control evaluation

Measuring effectiveness

Measure effectiveness by recording what changed after an intervention: pest numbers and life stages, damage levels, speed of impact, how long effects lasted, and the conditions during application. This shows what works best under specific orchard and weather conditions and informs future decisions.

Adaptive management

Adaptive management uses evaluation results to adjust tactics, timing and intensity. It helps managers scale back ineffective or unnecessary actions and focus resources where they deliver the greatest benefit.

Risk assessment

Risk assessment considers potential health, environmental and economic impacts of products and practices before and after use. It supports the selection of approaches that manage pests effectively while minimising risks to people, beneficial insects and ecosystems.

Efficacy trials

Efficacy trials provide objective evidence of how well a new product or approach works and under what conditions. Trials often follow standard protocols for registration and help managers make evidence-based adoption decisions.

Reporting

Good reporting documents observations, actions and outcomes in a consistent format. Clear records improve internal decision-making, support compliance and enable continuous improvement across seasons.

Benefits of evaluation

Evaluation improves IPM efficiency by showing which strategies deliver results, when they work best and where they are needed. This enables better targeting, reduces wasted effort and lowers costs by avoiding ineffective or unnecessary treatments.

By highlighting effective, low-risk options, evaluation reduces reliance on broad-spectrum pesticides and helps protect workers, consumers, beneficial insects and surrounding ecosystems.

Evaluation also supports compliance and product approval by generating the evidence needed to justify use and demonstrate safety and effectiveness. Overall, it strengthens profitability, stewardship and long-term resilience.

Annex 1

Insect classification

Insect classification supports accurate identification and helps explain behaviour and life cycles, which are core foundations of IPM. Insects belong to kingdom **Animalia**, phylum **Arthropoda** and class **Insecta**.

Classification groups organisms from **species** to **genus**, **family** and **order**. Insects are placed into about 30 orders, mainly based on wing structure, mouthparts and metamorphosis. For practical identification, seven orders are most useful.

Order	Description
Hemiptera (true bugs)	These have sucking mouthparts and wings that are often held flat over the body.
Coleoptera (beetles)	The largest order; adults are characterised by hardened forewings that meet in a straight line down the back.
Lepidoptera (butterflies and moths)	Adults have wings covered in microscopic scales and a proboscis for siphoning nectar.
Hymenoptera (ants, bees and wasps)	Adults have narrow waists and membranous wings. Many species are social.
Diptera (true flies)	Adults have only one pair of flight wings and a pair of balancing organs called halteres.
Orthoptera (grasshoppers, crickets and locusts)	These have large hind legs adapted for jumping.
Odonata (dragonflies and damselflies)	Nymphs are aquatic; adults are aerial predators with two pairs of membranous wings.

Hemiptera ("true bugs") are the main focus of this toolkit. They have piercing-sucking mouthparts (a beak/rostrum) used to feed on plant sap or other animals. Their development is incomplete: juveniles pass through several nymph stages (instars) that gradually become adult-like, without larval and pupal stages. Hemiptera are commonly grouped into three suborders:

- **Heteroptera** includes stink bugs, mirids, mosquito bugs, coconut bugs and allied families. These have a thickened and opaque basal part to their forewings, with a transparent outer part.
- **Auchenorrhyncha** includes leafhoppers, planthoppers, cicadas and allies. Many have enlarged back legs and can jump.
- **Sternorrhyncha** includes macadamia felted coccid, aphids, psyllids and allies.

Annex 2

Avo bugs (mirid bugs), e.g., *Taylorilygus apiculus*

Avo bugs (mirids) are Hemiptera (“true bugs”) in the family **Miridae**. They are major avocado pests that can damage shoots, flowers and fruit, causing high crop losses. Some mirid species are phytophagous, some predatory, and some both, so correct identification matters. Species can look similar and are often scouted as seasonal sucking-bug complexes that vary by region, climate, altitude and host plants.

In many crops worldwide, mirids have shifted from minor or secondary pests to major pests, with high infestations causing economically important feeding damage.



Figure 41: Avo bugs caught on a black sticky trap above a light trap at the perimeter of an avocado orchard next to swampy grassland. A high trap count was detected **when the grass was mown** and the bugs were disturbed from their natural habitat.

Pre-egg-laying adult mirids arrive in avocado orchards as the flower shoots form. Eggs are inserted singly beneath the surface of young leaves and flowers; they hatch in about five days. Nymphs pass through five instars before emerging as winged adults that can move to later-flowering cultivars. The life cycle is about 33 days; adults live for about 45 days. Adults are very mobile, and populations increase rapidly through both immigration and local egg laying.

Mirids are very small, and the average number of days per life-cycle stage is temperature-dependent. SAAGA has released an excellent paper to help estimate degree-days in sucking bugs.⁴⁰ In this paper, the base temperature for mirids is 12.2 °C.

Mirids in Strawberries	Heat Accumulation (DD) °C
Eggs	140
Nymphs	206
Total Generation Time (egg to adult)	346
Pre-egg laying Adults	97.8
Total Generation Time (egg to egg)	443.8

Figure 42: Heat accumulation units for mirids.

40 https://www.avocadosource.com/Journals/SAAGA/SAAGA_2011/SAAGA_2011_34_PG_42.pdf

		Week Number															
		20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Taylorilgus		0.00	0.23	0.10	0.82	0.29	2.3	6.39	7.51	8.77	10.2	24.3	25.8	37.3	40.7	49.3	61.5
Temp Average C		19.0	18.6	18.3	15.9	14.9	16.4	16.3	16.6	17.8	17.9	18.7	16.7	19.7	18.9	17.7	18.8
T _{base} Mirids C		12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2
Daily Average DD C		7	6	6	4	3	4	4	4	6	6	6	5	8	7	5	7
	Heat Accumulation Units C	Average Days per Life Cycle Stage															
Eggs	140	21	22	23	38	51	33	34	32	25	24	22	31	19	21	26	21
Nymphs	206	30	32	34	56	75	49	51	46	37	36	32	46	27	31	38	31
Pre-egg laying adult	98	14	15	16	27	36	23	24	22	17	17	15	22	13	15	18	15
Egg to Egg	444	65	69	73	120	162	106	109	100	79	77	69	99	59	66	81	67

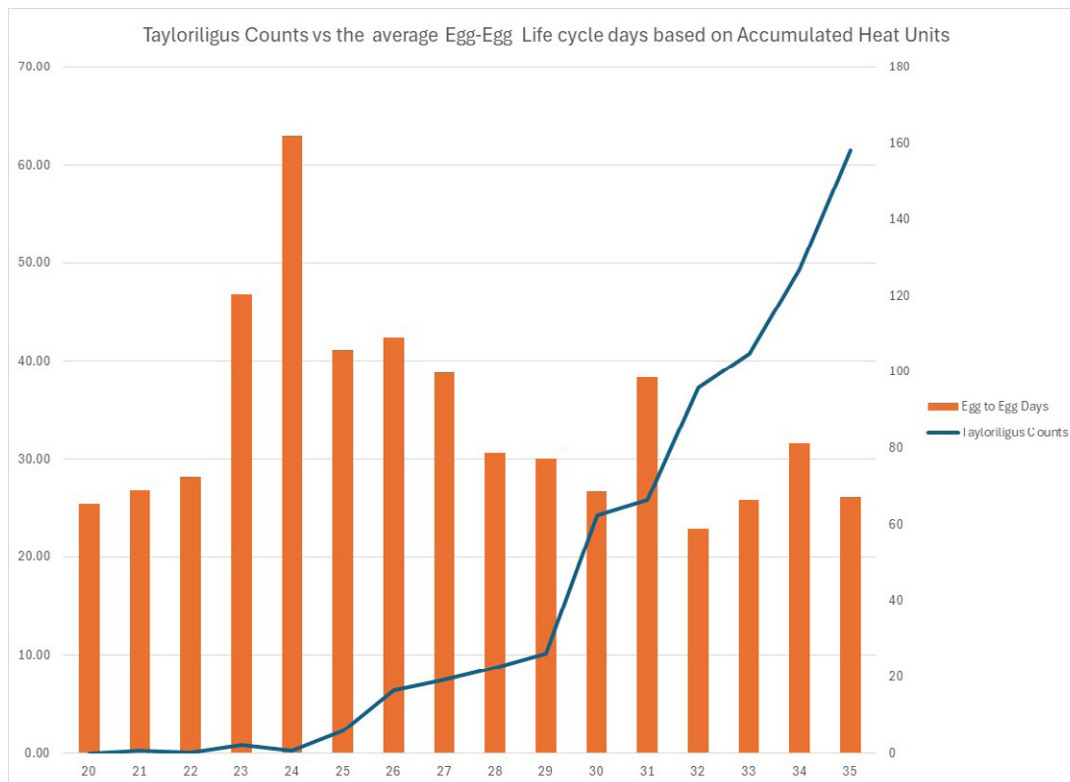


Figure 43: Scouting and weather data from a Tzaneen avocado orchard, showing that as the weather warms, the number of days required to complete a full life cycle decreases and the population growth rate increases, as shown by the slope of the blue line.



Figure 44: (a) First-instar mirid bug nymphs are very small and difficult to identify. (b) A third-instar mirid bug feeding on young leaves. (c) An adult mirid bug feeding on flower shoots early in the morning while the dew is still present in the crop.

Overwintering egg survival is strongly affected by climatic conditions. Rainfall can act as a trigger for egg development, hatching and nymphal emergence. In addition to rainfall, elevated spring temperatures lead to higher egg hatches, while cold spells delay the initial onset and size of mirid bug spring populations.

Damage caused by mirid bugs

Mirid bug feeding damage occurs in young shoots, soft stems, flowers and fruits. Feeding wounds serve as points of entry for secondary disease and decay organisms.

Attacks mainly affect flowers and young fruit. If excessive flower drop occurs alongside high mirid numbers, chemical intervention may be warranted (spray at night to protect bees and beneficials).



Figure 45: (a) Feeding damage in small fruit (<5 mm) causes fruit drop. (b) Feeding causes white sap to form, which later washes off.

Damage to avocado fruit is caused within the first few weeks after fruit set. If scouting indicates that large populations of mirid bugs are present shortly after fruit set, chemical control should be considered. Feeding damage on avocado fruit <5mm will cause the fruit to drop; in some instances, 100% fruit drop has been seen.

Fruit damage is first seen as white exudates, which wash off, and pimply elevated lesions (vosknoppie) develop about a month after feeding. When avocado fruit is >30 mm, there is less risk of feeding damage

from mirid bugs. This varies between cultivars, according to the thickness and palatability of the skin of the young fruit.

Scouting hints

Mirid activity is temperature- and dew-dependent: they forage in the canopy early in the morning and evening, then move under leaves, into bracts or disperse to shaded habitats as leaves dry and temperatures rise.

- Scout very early in the morning while dew is still present.
- Scout 10 trees per block and 10 flowering panicles per tree.
- Focus on the cool side of the tree at 80-100% flower.

Natural enemies

Spiders, ants, predatory bugs, predatory wasps, lacewings, ladybirds and predatory mites have been observed attacking mirid bugs in the field. Naturally occurring pathogenic fungi (e.g., *Beauveria*) may also infect and kill mirids, but are rarely observed in the field, as infection requires very high humidity.

IPM considerations

Keep the grass and weeds in and around the orchard as short as possible to reduce habitats for mirid bugs. Mirid bugs are often found in environments with diverse vegetation containing flowering plants (willows, *Salix*, Asteraceae, chamomile, fennel etc.).

LIFE CYCLE OF A MIRID BUG

(Hemiptera: Miridae)

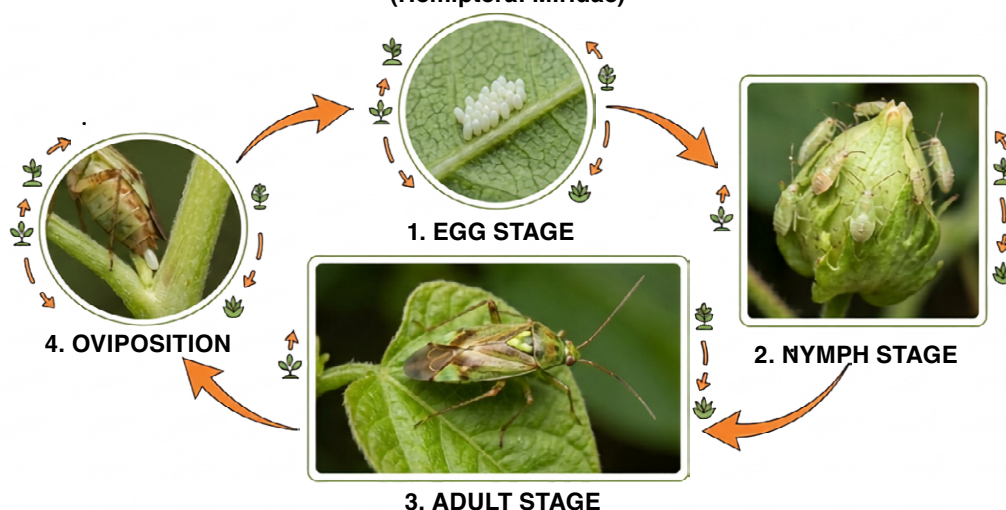


Figure 46: Generalised life cycle of mirid bugs.

Shortening a crop's flowering period reduces the length of time the crop is at risk of mirid bug damage. Damage on early-flowering cultivars is usually lower than on later-flowering cultivars, except where flowering is prolonged on early cultivars.

Mixing different cultivars or different fruit crops that flower at different times in one orchard extends the effective flowering season and allows populations to build up to high levels.

In southern regions, the row orientation of the trees is important. East – west orientated rows show large flowering variations between the warm side and cold side, extending the in-crop flowering season.

Maintaining low populations of mirid bugs by growing year-round flowering strips, hedgerows or areas of natural biodiversity will encourage and sustain mirid predators and parasitoids.

Case study: Avocados

This case study is based on a farm in South Africa with a cool, dry winter. One orchard boundary consists of a wetland area full of natural flowering plants that provide habitat for both pests and predators. In spring, this area dries up and the flowers die back at the same time as the avocado trees are irrigated to induce a spring flush and flowering, resulting in a rapid movement of sucking bugs into the commercial crop.

Another boundary is a grassy, marshy area. The grasses can harbour sucking bugs, especially if they are allowed to grow tall. When the grass is cut, the insects are disturbed and move into the avocados. Managing grass height through mowing, and timing the mowing appropriately, can reduce insect pressure in the avocados.

Two fields are orientated east-west and are the only blocks with distinct warm and cold sides. This extends the flowering season by six to eight weeks. The prolonged availability of flowers and small fruit attracts and maintains higher insect populations. This microclimatic effect influences spray efficacy, as insects continue to move back into the orchard after pest-control applications, drawn by the ongoing flowering within the crop.

In addition, an adjacent orchard of Carmen, which flowers out of sync with the Hass crop, creates an early build-up of sucking insects that move into the Hass crop.



Figure 47: Blocks with warm and cool side, which have been shown to extend the flowering and fruiting period by six to eight weeks.

Wind speed and direction can also have a major impact on the speed and direction of adult mirid bug movement. On this farm, the prevailing wind moves from a wild area full of plants that flower in winter towards the flowering avocado crop.

Annex 3

Avocado mosquito bug (*Helopeltis schoutedeni*)

Mosquito bugs are true bugs (Hemiptera), family **Miridae**. They are an emerging pest of avocados and other soft fruit in sub-Saharan Africa.

Adults are attracted to soft, sap-rich flushes. Eggs are laid singly near shoot tips and leaf petioles (two filaments protrude). Nymphs pass through five stages, feeding on young shoots and developing fruit; egg-to-adult development takes about 24 days under favourable conditions (about 24.9–33°C and 72–88% RH). Nymphs cannot fly, so they can concentrate and cause heavy local damage. They are agile and often found under young leaves or flower buds.

Adult females lay eggs continuously for about 45 days. Adults are slender and long (7–10 mm), with long legs and very long segmented antennae (nearly twice body length). Females are red; males are brown. They have a distinctive odour when crushed.

Scouting: Look at flower panicles, the upper and lower surfaces of leaves, and fruit **early in the morning**. Mosquito bugs leave the trees early in the day. Yellow sticky traps may be effective for flying adults.

Damage: Mosquito bugs infest leaves, flowers and fruit at all stages of development, including fruit set and mature fruit. Brown, water-soaked lesions on young tissue and fruit indicate fresh damage and the presence of live pests. Affected leaves often curl and become deformed, and dieback of young shoots is common. Water-soaked lesions develop into corky patches and bark splits.

Alternative host plants and potential trap crops: guava, coffee, kei apple, cotton, castor bean, fig trees, cashew nuts and other fruit and nut trees.

Control: Early and accurate detection is pivotal for IPM and allows for targeted interventions such as biological control, judicious use of insecticides or cultural practices like pruning infested shoots.

- Promote beneficial predators (ladybird beetles, spiders) in the ecosystem.
- Remove and destroy infested plant parts to limit spread.
- Apply insecticides only when threshold levels are reached and after correct identification.

Several other true bugs and mirids can be confused with mosquito bugs, especially at nymphal stages.

- *Helopeltis* vs. other mirid bugs: mosquito bugs have more distinct colouration, longer antennae and a characteristic scent when crushed.
- *Helopeltis* vs. aphids: aphids are soft-bodied, pear-shaped and much smaller, often forming dense colonies. They lack the jumping and rapid movement of *Helopeltis* nymphs.
- *Helopeltis* vs. leafhoppers: leafhoppers are wedge-shaped and move sideways; *Helopeltis* is more elongated and moves forward or jumps.

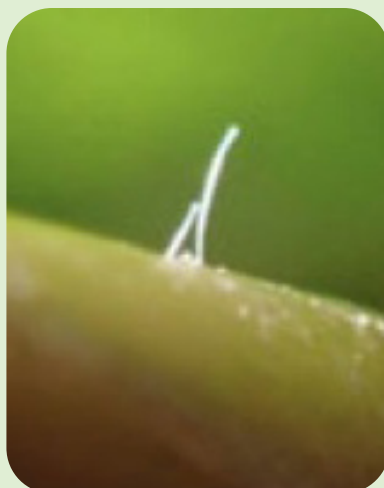


Figure 48: (a) Recent fruit damage showing indented, brown, water-soaked lesions emitting sap. (b) Adult female mosquito bugs feeding on a soft avocado shoot, with sap droplets emitted from the plant tissue. (c) Eggs laid singly at the tips of fresh shoots, with two filaments protruding outside the plant tissue.

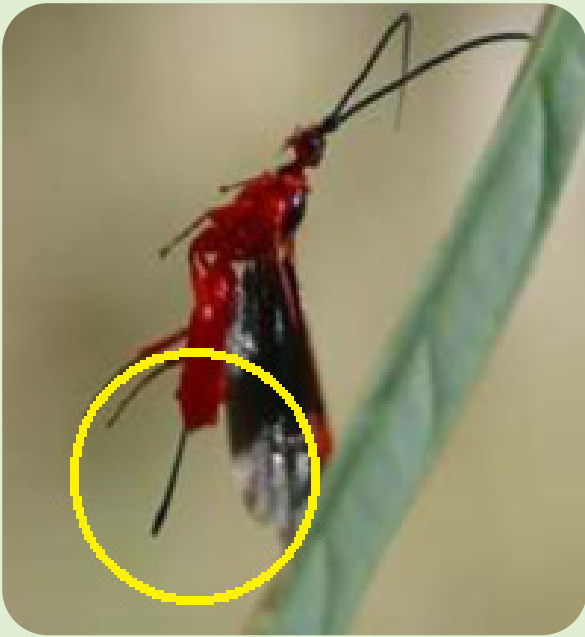


Figure 49: Braconid wasps, common parasitoids in avocado orchards, are often confused with mosquito bugs.

Mosquito bugs are easily confused with beneficial braconid wasps. Braconid wasps have an ovipositor; mosquito bugs do not. Mosquito bugs have five-segmented antennae; braconids do not.

Annex 4

Stink bugs (*Pentatomidae*)

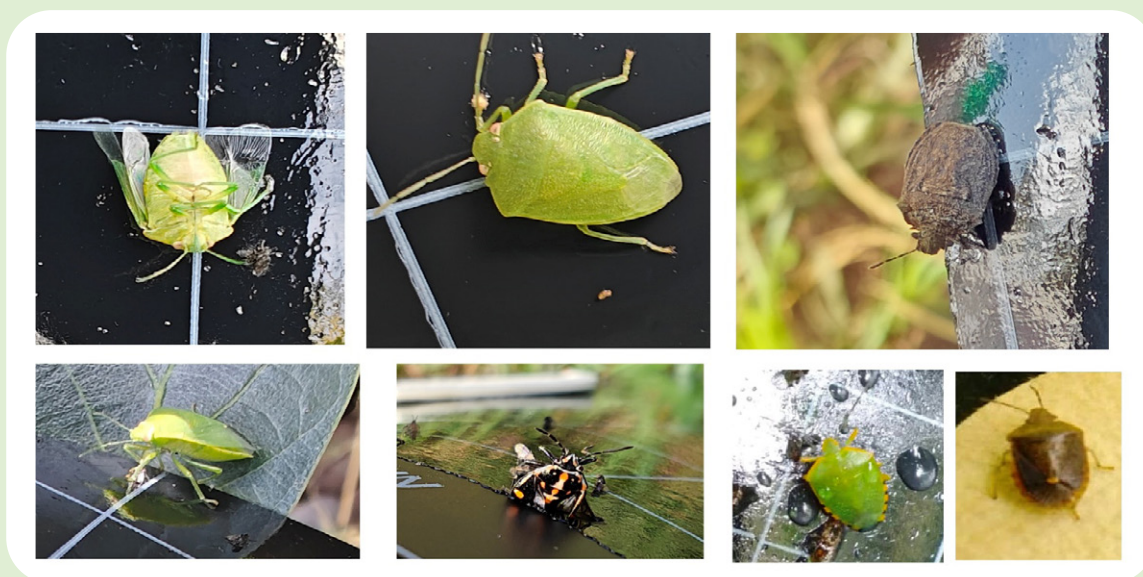


Figure 50: Different species and life-cycle stages of stink bugs trapped using brown marmorated stink bug (BMSB) pheromones and black sticky traps under the AgDevCo TAF IPM project.

Stink bugs are Hemiptera (true bugs), family **Pentatomidae**. They have broad, shield-shaped bodies, five-segmented antennae, a triangular scutellum, scent glands and piercing-sucking mouthparts. They range from about 2–20 mm, and the family includes thousands of species. Many are polyphagous and feed on fruit, nuts, pods and foliage of numerous crops and wild hosts.

In temperate zones, adults leave overwintering sites in spring as temperatures rise and lay egg rafts, often 10 to 100 eggs, on leaves or bark. Nymphs hatch and pass through five instars; because nymphs are wingless, orchard hotspots often develop near egg sites. In autumn, shortening day length and cooler temperatures trigger diapause (dormancy) and movement back to shelter.

Stink bugs are most active early in the morning and evening, often hide high in the canopy or in dense foliage, and may drop when disturbed. They are therefore difficult to scout visually; branch shaking and knockdown scouting are commonly used.

Stink bugs are a major pest in macadamia, causing early and late kernel damage. There are eight main species that have been detected in high numbers in macadamia, and an identification guide is available.⁴¹

Stink bugs feed on avocado fruit throughout the season, causing major losses due to fruit drop in early fruit, and hard, dark lesions and fruit deformities in older fruit.

Pheromones in conjunction with synergists and light traps were found to be effective for trapping most stink bug species, and are therefore suitable for scouting. However, the two-spotted stink bug (*Bathycoelia distincta*), the major macadamia stink bug pest, comprising about 80% of stink bugs in macadamia in South Africa, was not caught in the traps, despite being found in the trees. Pheromone trapping was very effective in avocado orchards. Pheromone trapping is an area that shows great potential but needs more work.

Life cycle of *Bathycoelia distincta* (two-spotted bug) in macadamia

The life cycle of the bugs is synchronised with the phenology of the macadamia nuts; no egg laying and therefore no immature stages, are normally encountered during the first nine weeks after flowering. Nuts are most susceptible to damage after premature nut drop and before the shells have fully hardened about six weeks later. Although shell hardening limits damage,

B. distincta can still penetrate the shell and damage the kernel up to harvest.

41 <https://www.malawivaluechains.com/resources/macadamia/stink-bug-identification>

Eggs are usually deposited in clusters of 14 on the nuts, leaves, branches and main stems of the trees. The eggs hatch after about seven days, and the first-instar nymphs tend to cluster together on the empty eggshells. From the second instar, the stylets are long enough to penetrate the combined thickness of the hulls and shells of most macadamia cultivars.

Hotspots develop in orchards because the ability of the flightless nymphs to disperse is limited. Adults are low-density feeders and, in peak season when adults are most numerous, up to three insects per tree may be encountered in badly managed orchards.

The entire life cycle lasts between 49–70 days, depending on temperature.

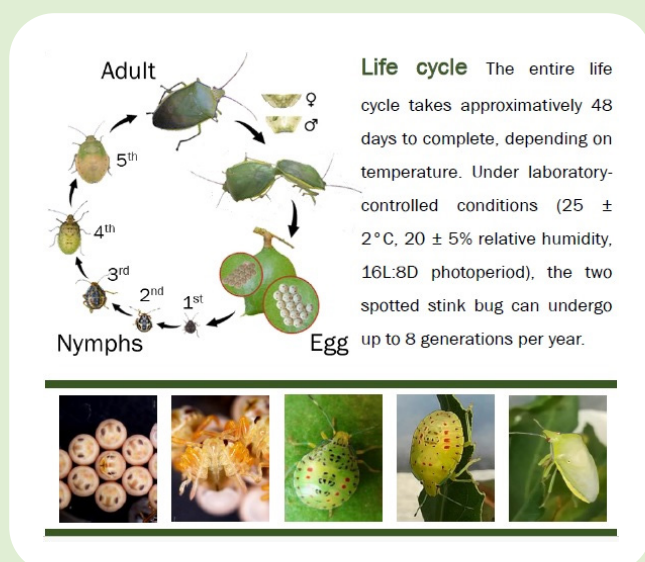


Figure 51: Life cycle of the two-spotted stink bug (*Bathycorlea distincta*).⁴²

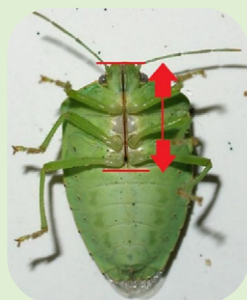


Figure 52: A primary factor in determining whether a stink bug species is a pest in macadamia is the length of its stylet.

A primary factor in determining whether a stink bug species is a pest in macadamias is the length of its stylet-like mouth. Some stink bug species have very short stylets and are unable to pierce the husk. It is good practice to turn stink bugs over to measure the length of the stylet.

⁴² https://www.fabinet.up.ac.za/images/groups/MPP/Fact_sheets/Two-spotted_EP.pdf

Natural enemies of stink bugs

Tachinid flies (e.g., *Trichopoda*) are parasitoids that control stink bug populations by laying eggs on adults or nymphs. The larvae hatch, burrow into the host and consume it internally, eventually killing the stink bug. To attract these beneficial flies, plant or maintain nectar-rich flowers like dill, fennel, yarrow and aster.

Female *Trissolcus sp.* wasps lay their eggs in stink bug eggs. The wasp larvae mature inside the host egg, consuming the contents and preventing the stink bug from hatching. Parasitised stink bug eggs turn dark, whereas unparasitised eggs remain pale. Access to carbohydrates from flowers significantly extends the lifespan of adult females and improves their fecundity (number of eggs laid), increasing parasitism rates of host eggs. *Trissolcus basalis* is available commercially⁴³ and is very effective at controlling certain stink bug species, for example *Nezara viridula*.

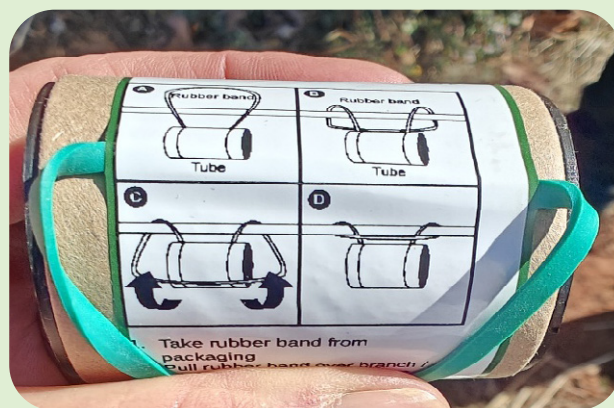


Figure 53: Commercially available *Trissolcus* wasps arrive as parasitised stink bug eggs, transported with their food source, and hatch out as adults for a slow-release effect in the orchard.

⁴³ <https://www.koppert.com/welcome-nezapar-so-long-stink-bug/>

Annex 5

Macadamia felted coccid (MFC)



Figure 54: (a) Close up of the scales – the adult males (yellow circle) are smaller than the females; females (red circle) are larger and can be identified by the circular opening. (b) MFC infest the nuts. (c) MFC infests all above-ground parts, including the leaves and stem. Photos courtesy of Schalk Schoeman.

Macadamia felted coccid (MFC), *Acanthococcus ironsidei*, is a Hemiptera (true bug) in the family **Eriococcidae** (felt scale).

MFC was first recognised in South Africa in 2017 and is a serious quarantine pest that can kill trees quickly. It is spreading in sub-Saharan Africa. Feeding causes leaf distortion and discoloration, premature flower and nut drop, branch dieback and major yield loss; heavy infestations can kill large parts of trees.

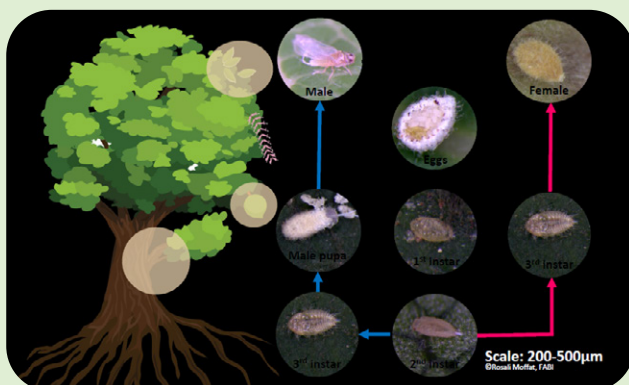


Figure 55: Life cycle of the macadamia felted coccid.

Use strict biosecurity: control movement of vehicles, people and plants, source planting material carefully, and quarantine young plants for several weeks before planting out.

Biological EMFs like *Beauveria bassiana* and *Lecanicillium lecanii*,⁴⁴ mixed with biological oils, are effective at reducing populations, especially in cooler months.

Ladybirds like *Rhyzobius*, and their larvae, are voracious eaters of both armoured and soft scale insects, attacking all life stages, including eggs, nymphs (crawlers) and adults. They are available commercially as Rhyzobug from Koppert.⁴⁵

Attracting and retaining ladybirds in your orchards involves creating a habitat rich in prey – scale insects and aphids – while providing pollen-rich flowers and avoiding pesticides. If you have a minor infestation of scale or aphids, resist the urge to spray immediately. A small, managed infestation will attract ladybirds and keep them there. They feed on pollen-rich plants when there is no prey, including umbellifers (flat-topped plants that are easy to land on) like dill, fennel and coriander, as well as marigolds, sunflowers and cosmos.

44 <https://www.dudutech.com/products/lecatech-wp/>

45 <https://www.koppert.com/rhyzobug/>

Annex 6

Coconut bug (*Pseudotheraptus wayi*)

Pseudotheraptus wayi (coconut bug) is a Hemiptera true bug in the family **Coreidae** (leaf-footed bugs). It is an important avocado and macadamia pest in East and Southern Africa and is highly polyphagous, feeding on many crops and wild hosts.

Adults are about 15 mm long, live for 2-6 months and are strong fliers. Females lay 2-3 eggs per day (70-170 eggs in a lifetime), singly on flowers, fruit, young nuts and twigs. Eggs turn reddish-brown before hatching. Nymphs pass through five instars; egg-to-adult development is about 31-43 days.

Young nymphs feed on flowers, causing flower drop, while adults and older nymphs feed on developing fruit and nuts, causing premature fruit and nut drop, damage and deformities. They feed by piercing host tissue with a specialised, needle-like mouthpart (called a rostrum) and injecting saliva containing toxins, before sucking out the

sap or dissolved juices. In avocados, they cause necrotic, sunken, bruise-like depressions.

They are highly active during the night (scotophase), between 6 pm and midnight, with mating at mid-scotophase.

The coconut bug thrives in warm, tropical temperatures. Although it has short mouthparts (rostrum), it can inflict significant damage and is one of the only bug species that can damage the hard shell of mature macadamia nuts.

The coconut bug has a wide host range. The following hosts are listed: coconut palm, macadamia, mango, guava, avocado, loquat, cacao, cinnamon, *Combretum collinum*, ebony/*Diospyros*, pecan and litchi. This bug is particularly active in South African macadamia during late summer and autumn.



Figure 56:
(a) Eggs are deposited singly. (b) First-instar nymph. (c) Second-instar nymph.
(d) Third-instar nymph. (e) Fourth-instar nymph. (f) Adult.
Photos courtesy of Schalk Schoeman.



Figure 57: (a) Damage inside husk in macadamia. (b) Early-season damage. (c) Late-season damage. Photos courtesy of Schalk Schoeman.

Control includes preserving or encouraging weaver ants, which are natural predators of the bug, or intercropping with plants like citrus and mango that attract the ants. It is possible that planting trap crops between source areas (e.g., *Combretum*

forests) and commercial crops may entice coconut bugs away from the crop. Softer chemicals and biological EMFs would be the next option. Commercial predators are not yet available, and coconut bugs are not attracted to sticky traps.

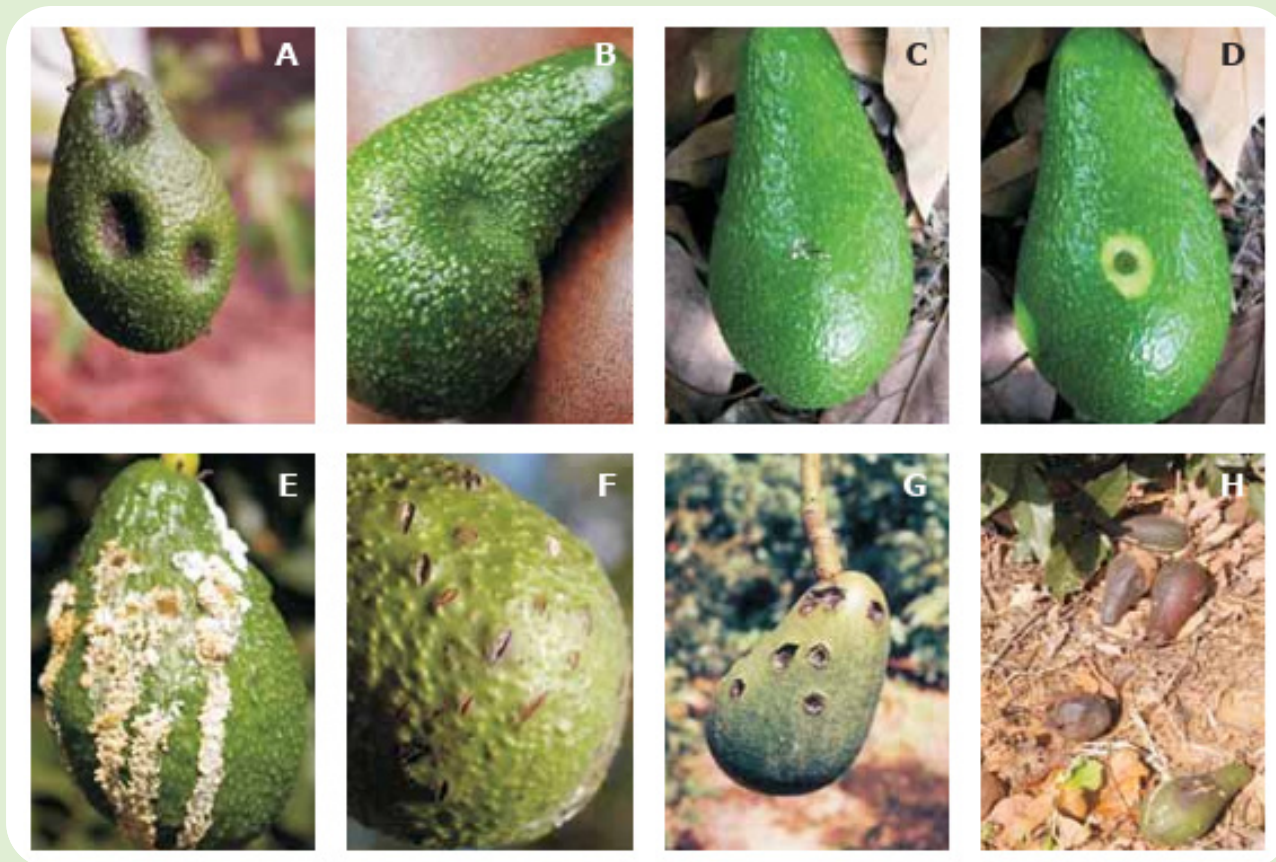


Figure 58: Damage patterns in avocado fruit vary according to the stage at which the coconut bug feeds on the fruit. Photos courtesy of Schalk Schoeman.