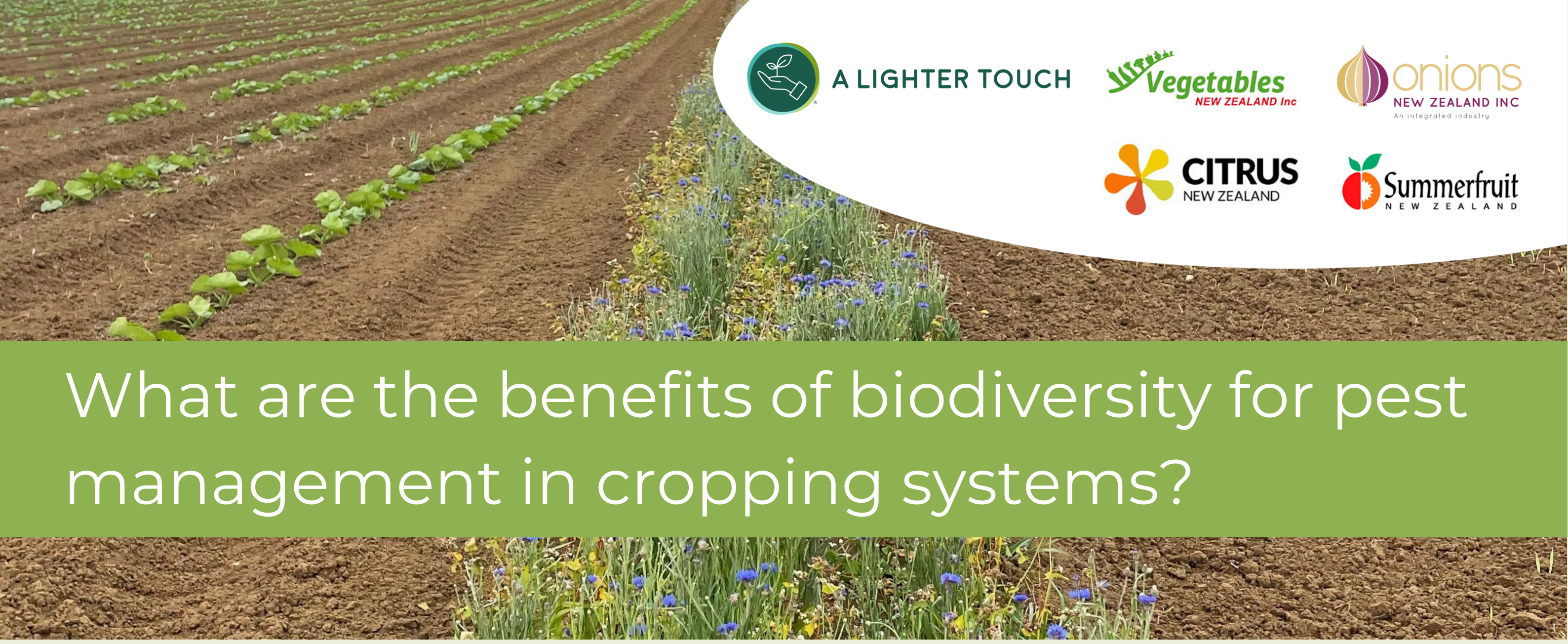


A LIGHTER TOUCH
Vegetables NEW ZEALAND Inc
onions NEW ZEALAND INC An integrated industry
CITRUS NEW ZEALAND
Summerfruit NEW ZEALAND

What are the benefits of biodiversity for pest management in cropping systems?

1.0. Introduction

This report explains what biodiversity is, how it supports pest management on farm, orchard and vineyard, and how it links to concepts such as IPM (Integrated Pest Management), biological control and agroecology.

Horticultural pest management is increasingly facing both opportunities and challenges. The challenges are that agrichemical based control is becoming less effective due to evolved resistance, loss of chemicals due to legislation and market requirements, with very little new chemistry (active ingredients) to replace those being lost. The opportunities are that non-chemical approaches such as IPM and biological control have been around for many decades and are now a mature science and successful on the ground practices. Many of these practices are immune to evolved pest resistance, as the control species are themselves evolving, thus keeping up with pest evolution. They are also viewed positively by customers as creating healthier produce and being better for the environment. They can also be highly effective and manage pests without the need for field work such as spraying, potentially achieving pest management at lower cost than agrichemicals.

Biodiversity is the foundation for non-chemical pest management. It provides the ecological environment that promotes beneficial organisms that control pests, as well as other advantages such as supporting pollinators and making the production environment a nicer place to work.

2.0. What is biodiversity and how does it relate to pest management?

2.1. Key points:

- Biodiversity is the diversity of all living things in an ecosystem, the number of species, their populations, genetic and functional diversity.
- Aotearoa-New Zealand's entire farming system is exotic to our native ecosystem which has significant implications for biodiversity and biocontrol.
- All biodiversity is important for pest management on farm, orchard and vineyard, including soil biodiversity.
- Ecology is the science of how organisms interact with each other and the non-living environment. Biodiversity is a key foundation of healthy ecosystems, and interactions within ecosystems are the foundation of biocontrol.
- Ecosystem services are the services provided to humans by ecosystems, such as breathable air. Pest and disease regulation is a key ecosystem service to horticultural production.
- Agroecology is the practice of farming and growing informed by ecological science, and involves the redesign of the vineyard / orchard / farm system to promote biodiversity to support ecosystem services such as pest management.

The term biodiversity is a contraction of ‘biological diversity’. At a basic level it is the number of different species, and the population size of those species in an ecosystem, such as a farm, orchard and vineyard. At the scientific level, biodiversity is viewed through a more fine-grained lens. Biodiversity is assessed at many scales, from the biosphere as a whole down to tiny individual ecosystems such as a pond. All organisms are included, from the most miniscule virus, through bacteria, fungi, insects and plants to vertebrates including humans. Genetic diversity is a key scientific measure of biodiversity, both among and within individual species. As is functional diversity, where species have different ‘jobs’ or functions in an ecosystem, for example plants are primary producers that capture the energy of sunlight, consumers such as insects and vertebrates eat the plants and each other, and decomposers break down dead organisms, completing the cycle of life. All these different aspects combine together to produce the overall biodiversity of an ecosystem.

2.2. New Zealand’s exotic crop production systems

Aotearoa-New Zealand, along with Australia, are unique globally in that our production systems; all the crop plants, livestock, pests, diseases and weeds, bar a handful of insects, are exotic to NZ’s pre-human ecosystem. Our farm and crop systems have been transplanted mostly from Northern Europe, with additional crops, livestock and pests from the Americas and Asia. This has significant implications for biodiversity and pest management in NZ production systems. There are also some key terms to describe these relationships described in Box 1.

Before humans (both Māori and Pakeha) arrived in NZ, it had some of the highest levels of endemic species (around 80,000) meaning its biodiversity and ecosystems are globally unique. The most obvious aspect of that was the absence of mammals (except for a few bat species) and that birds were the dominant vertebrates. Into this unique ecosystem, humans, particularly Europeans, have introduced entirely exotic farming and growing systems. This means there is limited interaction of native species with our exotic production systems. The exceptions are few insect pests such as grass grub and lemon tree borer, and pollinators, both native and exotic (e.g., honey and bumble bees) which will visit the flowers of most species, native and exotic. This means that crop pests, such as aphids and caterpillars, rarely live on native plants, and pests of native species rarely attack our exotic farmed plants.

In New Zealand, biodiversity is often thought of as meaning native biodiversity, particularly our birds and forests. From an ecological, and pest management perspective, all species, native and both wanted and unwanted exotic species are considered part of biodiversity.

Box 1. Key biodiversity terms

- Endemic means a species only occurs in a given place, such as NZ.
- Indigenous or native means a species naturally occurs (i.e., was not introduced by humans) in a given location, such as NZ, and also in other locations, e.g., Australia.
- Exotic / introduced / non-indigenous means species that did not naturally occur in a given place, rather they have been introduced by humans, both deliberately or accidentally.
- Valued introduced species, means exotic species that are considered useful or beneficial, such as our crops and livestock, as opposed to introduced pest species, like possums and Californian thistle.
- Cosmopolitan, is the opposite of endemic, it means a species that occurs across most of the world, for example humans and pigeons.

One of the most overlooked areas of biodiversity is soil. Soil is the most diverse ecosystem on the planet with some 60% of all species, including those in the oceans, living in or on soil. Soil is also vital to the provision of nearly all ecosystem services (see section 2.4). Soil biodiversity, and overall health is driven by having a continual cover of plants, that are allowed to produce as much foliage as possible, to capture as much energy from sunlight, which then flows into the soil ecosystem via root exudates. All of the energy to ‘power’ the soil ecosystem thus comes from plants, and mostly living plants via exudates. To maximise soil health and biodiversity therefore requires a diversity of living plants, with lots of foliage to capture sunlight to feed the soil ecosystem.

2.3. Biodiversity and Ecology

Ecology is the science of how organisms interact with each other and their non-living environment, e.g., climate. Ecology studies these interactions at the individual, population, community, ecosystem, and biosphere levels. On this simple concept a huge and complex science has been built. Biodiversity is a key concept within ecological science as the number of species and their populations have big impacts on how ecosystems function.

Ecosystem, shorthand for 'ecological system', is all the organisms living in a defined area. Often the boundary of the defined area is a physical boundary that limits the movement of some of the organisms, e.g., the surface of the soil or a river, is a barrier to worms and fish. Ecosystem boundaries can also be human defined, e.g., delineated by a type of cropping system such as an apple orchard.

2.4. Ecosystem Services

Another key concept is ecosystem services. Also called nature's contributions to people (NCPs), these are the services that ecosystems provide to us as individuals, businesses and societies. Indeed, it would be impossible for humans to exist without ecosystem services, as they are effectively all the services provided by the biosphere - i.e., the entirety of the earth's ecosystems. They include services such as provision of food and raw materials, air to breathe, regulation of our climate, atmosphere, pests, diseases and pollination, as well as supporting soil formation, nutrient cycling and photosynthesis, plus cultural services such as mental and physical health (Figure 1).

ECOSYSTEM SERVICES

Provisioning services are the products obtained from ecosystems.
Regulating services are the benefits obtained from the regulation of ecosystem processes.
Cultural services are the nonmaterial benefits people obtain from ecosystems.
Supporting services are those services that are necessary for the production of all other ecosystem services.

Source *WWF Living Planet Report 2016, adapted from the Millennium Ecosystem Assessment 2005.*

Figure 1. Ecosystem services: Provisioning, regulating, supporting and cultural. *Credit: WWF.*

> **“It would be impossible for humans to exist without ecosystem services, as they are effectively all the services provided by the biosphere.”**

As biodiversity is key to healthy ecosystems, biodiversity is therefore also vital for ecosystem services. Diminished biodiversity thus reduces ecosystem services, like pest regulation, while increased biodiversity boosts them. As vineyards, orchards and farms are all ecosystems, even if highly modified, they also provide ecosystem services. Some of the ecosystem services provided by production systems are external and supporting wider society, e.g., climate regulation while others are internal such as supporting pest regulation. Therefore, boosting biodiversity better supports ecosystem services, benefiting both your business and wider society.

The challenge is that most NZ horticultural businesses are only paid for one ecosystem service - the provision of food and drink. The rest are provided for free. Globally there is increasing work being done to work out how to pay producers for more of the ecosystem services they provide, with the aim of encouraging them to produce more services. Our international markets are increasingly requiring that NZ primary producers at least mitigate our negative impact on ecosystem services, or better improve ecosystem services, for example climate regulation (i.e., addressing climate change).

2.5. What is agroecology?

Another key concept in relation to biodiversity and horticultural pest management is agroecology. The term is a contraction of agriculture and ecology (agriculture here includes horticulture). Agroecology is the science and practice of farming and growing informed by ecological science. There is also a broader definition which encompasses the whole food system, including the people involved. Here we are focused on the narrower 'on-farm' definition. Agroecology is based on redesigning the farm, orchard and vineyard based on ecological science to achieve multiple beneficial outcomes such as pest, weed and disease management, increased soil health, biological nitrogen fixation, crop performance, robustness, resilience and profit. These are often described as ecosystem services. Examples of agroecology in NZ are given at the end of this report.

2.6. On orchard / vineyard / farm biodiversity

The following are examples of different levels of biodiversity on orchards, vineyards and vegetable farms.

2.6.1. Perennial crops - orchards and vineyards

The lowest level of biodiversity in perennial cropping systems, such as grapes, pip fruit, summer fruit, cane fruit, etc., are bare earth systems with the crop as the only plant species (Figure 2). This has the least amount of biodiversity, just a single plant species, the crop monoculture, and much reduced soil biodiversity.

Figure 2. Example of vineyard with full bare earth floor and therefore very low biodiversity.

Figure 3. Example of an apple orchard with a mown pasture alleyway / interrow and herbicide strip under the trees, with still limited levels of biodiversity.

NZ perennial crops more commonly have mown pasture alleyways / interrows with a herbicide strip underneath the crop (Figure 3). This is an improvement on full bare earth, but, the pasture strip has limited plant diversity, e.g., just grass and clover. Also, its ability to capture the sun's energy to feed soil biodiversity and enhance biocontrol is constrained by frequent mowing reducing the foliage and preventing flowering. The bare soil under the herbicide strip has much reduced biodiversity.

> **“Agroecology is based on redesigning the farm, orchard and vineyard based on ecological science to achieve multiple beneficial outcomes.”**

An alternative to the mown pasture strip is to sow conservation biocontrol plants, such as buckwheat (Figure 4), in the alleyway to provide nectar and pollen to beneficial insects that will help manage crop pests.


Figure 4. Buckwheat (*Fagopyrum esculentum*) planted in the alleyway in an orchard to provide nectar and pollen for beneficial insects to enhance pest management.


Figure 5. Fully vegetated understory in citrus left to grow longer, from the A Lighter Touch project "Agroecological approaches to insect pest control in perennial crop systems".

A fully vegetated orchard understory is shown in Figure 5. Around twenty species of pasture plants including grasses, legumes and forbs have been strategically planted under the trees and in the alleyway and left unmown as much as possible so they can flower, maximise photosynthesis to enhance soil health, fix nitrogen and provide habitat, nectar and pollen for beneficial insects.

> **"Intercropping is the practice of growing two or more cultivars, or more typically species of plants together, both crop and non-crop, so is the opposite of monoculture."**

Taking diversity to the next step in perennial crops is intercropping. Intercropping is the practice of growing two or more cultivars, or more typically species of plants together, both crop and non-crop, so is the opposite of monoculture. At the simple end is the mixing of cultivars of the same species, e.g., having rows, or blocks of a few rows, of different cultivars of the same crop species. But, to gain the biggest effect, different species, ideally quite different species, e.g., pip and stone fruit, need to be planted together.


Figure 6. Concentric layout of highly diversified tree crops, and living mulch service crops for biocontrol of pests and diseases as part of the INRAE ALTO (Fruit tree production systems and agroecological transition) project. *Credit: Roussel.*

This is the perennial equivalent of strip cropping in annuals, as described in section 2.6.2. This has been taken to the next level in the ALTO project by INRAE France where mixtures of apples, apricots, peaches, plums, figs, soft fruits, hazelnuts and almond trees have been planted in concentric circles to maximise the benefits of biodiversity, including pest regulation (Figure 6).

2.6.2. Annual field crops

In annual field crops, such as vegetables and arable crops, the lowest biodiversity is where whole paddocks are planted in the same crop species, i.e., monoculture, and the field margins and ditches have herbicide applied to create bare earth (Figure 7). The same as the bare earth vineyard (Figure 2) the only plants are the crop, and soil biodiversity is much reduced. There are few ecological resources to support beneficial organisms to control pests.

Figure 7. Monoculture vegetable field with sprayed off headlands, field margins and ditches.

Figure 8. A diversified field margin at the Pukekohe demonstration farm, with native perennial and groundcover vegetation bordering a monoculture crop. *Credit: Olivia Prouse*.

An improvement is monoculture field crops with diversified field margins, planted with a range of woody and herbaceous species that provide resources for beneficial organisms (Figure 8).

To better enhance biodiversity, particularly within larger fields which beneficial insects will struggle to reach the centre of from diversified margins, are flowering strips and beetle banks (Figure 9). Flowering strips can be, short term, e.g., a few months, to permanent, and provide nectar, pollen and other resources to support beneficial insects. Beetle banks are longer term strips of slightly raised ground with tussocky grasses that provide overwintering sites for predators such as carabid beetles that then move into the crop in spring and summer.

Figure 9. A beneficial insect strip with a diverse range of flowering plants (left) and a grass beetle bank (right) across cropping fields. *Credit: Olivia Prouse (left) and Farm Wildlife (right).*

To move away from whole-field monocultures, researchers at Wageningen University in the Netherlands have been studying strip cropping to better understand system performance and which crops play together nicely i.e., perform better as neighbours than monocultures, and which crops make bad neighbours (Figure 10). The strip cropping allows existing field-scale machinery to be used, with the strips varying from a single bed / bout width up to 24 metres after which the edge effects where the two crops meet start to be lost. Significantly better pest management from strip cropping has been achieved, as well as multiple other benefits.

Figure 10. Field scale strip cropping of a diversity of arable and vegetable crops at Wageningen University in the Netherlands. *Credit: ERF B.V.*

> **“Significantly better pest management from strip cropping has been achieved, as well as multiple other benefits.”**

An alternative approach to growing different crops in adjacent strips is to mix cultivars and/or species at the individual plant level by sowing seed mixes. This is common in service / cover crops, but it’s use is increasing in cash crops as well. For example, The Foundation for Arable Research (FAR) are working on three-way wheat cultivar mixtures for disease management. They have found that mixtures dilute pathogen loads resulting in lower, even much lower, disease severity, meaning less fungicide applications are required, thus protecting fungicide chemistry. The mixtures also boost yield over susceptible and intermediate cultivars, particularly in high disease pressure years and also stabilise yield. In Europe cereal cultivar mixtures have gone from being only used by organic farmers a decade ago to some countries having nearly half the crops sown as mixtures, such are the benefits.

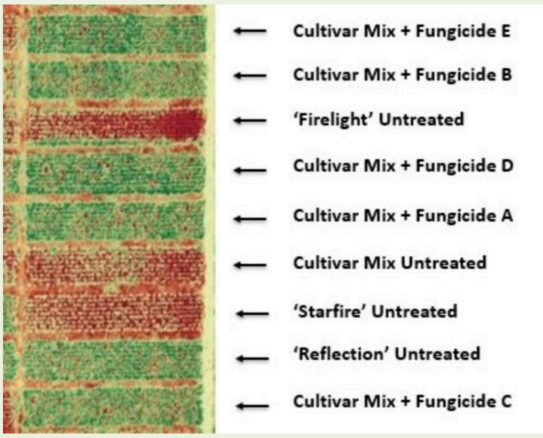


Figure 11. NDVI view of untreated feed wheat cultivars Firelight, Reflection and Starfire grown as monocultures and as an untreated mixture. This trial also includes understanding how cultivar mixtures respond to five different fungicide programmes.
NDVI stands for Normalised Difference Vegetation Index, a measure of quantifying plant health and the density of vegetation. In this image red indicates diseased plant material, green healthy living tissue and yellow indicates vegetation in between these two states.
Credit: Foundation for Arable Research.

Beyond cultivar mixtures, species mixtures, typically a cereal and a bean / legume, e.g., wheat and peas, are becoming more common, with even bigger benefits for pest, pathogen and weed suppression than cultivar mixtures. They also clearly present some challenges, such as ensuring both species ripen at the same time and the resulting mixed harvest can be separated or has a market as a mixture. However, the benefits are such, that like cultivar mixtures, they are becoming increasingly common.

The benefits of mixing crop and non-crop species at the individual plant level for vegetable production are also being studied, and are being called ‘pixel cropping’ or ‘pixel farming’. This is taking the concept of intercropping and crop biodiversity to its logical limit. While considerable benefits have been shown, such as reduced pests, there are clearly practical challenges which limit its adoption at present. The use of multipurpose field robots is one solution being tested.

2.6.3. Conclusions

The path from low to high biodiversity is similar for both annual and perennial cropping systems. The lowest biodiversity are crop monocultures in bare soil and the highest are intercrops of multiple crop species with service crops that support ecosystem services such as nitrogen fixation, improving soil health and pest management.

3.0. What is biocontrol?

3.1. Key points:

- Biocontrol is the management of pests by biology rather than agri-chemical pesticides.
- A range of terms are used to describe biocontrol organisms in part depending on context, including natural enemies, beneficial insects and biocontrol agents. The term beneficials is used as the most general description.
- Biocontrol organisms differ in how they attack and control pests, including generalists that attack a wide range of pests, specialists that attack only one or a few species of pests, predators that eat pests and parasitoids where the larvae hatch and grow inside the pest.
- There are three main types of biocontrol:
    1. **Importation** also called classical, where a biocontrol agent is imported into NZ.
    2. **Augmentation**, where the biocontrol agent is already in NZ, but its population is boosted.
    3. **Conservation**, where the ecosystem is manipulated, mostly by increasing plant biodiversity, to boost existing beneficials.
- IPM (Integrated Pest Management) is the integration of physical, chemical, biological and ecological pest management. Ideally it uses preventative techniques such as conservation biocontrol rather than curative techniques such as agrichemicals.
- Biodiversity supports IPM as a whole and the biological and ecological components of IPM in particular.
- Biodiversity is a key component of an agroecological production system.

Biocontrol, is a contraction of ‘biological control’. Biocontrol manipulates ecological interactions to manage pests, diseases and weeds. In this report we will focus on arthropod pests, but, everything equally applies to diseases (pathogens) and weeds.

There are a number of specialised terms used in relation to biocontrol, described in Box 2 on page 9.

3.2. The five biocontrol ecological interactions

There are five forms of ecological interaction within biocontrol:

- **Predation**, i.e., a predator where the beneficial organism eats the pest.
- **Parasitism**, i.e., a parasite where the beneficial organism parasitizes the pest. This can be both the juvenile and adults of both beneficial and pest, it can be internal and external. It may be lethal for the pest or just reduce the pest’s health / fitness.
- **Disease**, as per the common meaning, as caused by a pathogen, e.g., viruses and bacteria.
- **Herbivory**, i.e., herbivore where the beneficial organism eats pest plants.
- **Competition**, where the beneficial organism competes with the pest for resources such as food, for example, a cover crop outcompeting weeds.

Biocontrol as a name is therefore something of a misnomer, as how organisms interact falls under the science of ecology, so it is really ecological management. However, the term biocontrol has been used for so long it has become the standard term, despite being technically incorrect.

For arthropod pest biocontrol, the main ecological interactions are predation, parasitism and disease.

3.3. Top-down and bottom-up population regulation

The five ecological interactions are also grouped into being 'top-down' or 'bottom-up' population regulation. Bottom-up is where the food supply limits an organism's population; using the classic example, the amount of pasture on the savannah limits the population of zebra. Top-down is where an organism's population is limited by organisms that feed on it. For example, lions feeding on zebra limit their populations, and zebra feeding on pasture, limit the pasture's population. The size of the zebra population also limits the size of the lion population through bottom-up regulation. This gives rise to the concept of food chains, a linear network of organisms one feeding on the other, i.e., the pasture is the base of the food chain, then the zebra and then the lion. However, true food chains are rare, mostly they are food webs, where there are multiple connections between the different organisms.

Top-down and bottom-up population regulation is a key concept in biocontrol and pest management in production systems.

3.4. The three types of biocontrol

Biocontrol is also divided into three main types or approaches, based on how humans are manipulating the biocontrol organisms.

- Importation (classical) biocontrol
- Augmentation biocontrol
- Conservation biocontrol

Box 2. Key biocontrol terms

- Natural enemies, beneficial insects and biocontrol agents are fundamentally the same thing, organisms that attack pests and thus limit their populations, reducing or eliminating the harm they cause. The differences among the names is mostly due to the control and level of human intervention.
    - Natural enemies are naturally occurring, i.e., they have not been purposely promoted by people.
    - Beneficial insects are naturally occurring, but their populations have been boosted by human actions, e.g., planting flowers.
    - Biocontrol agents (BCA) have generally been added by people to the crop environment, e.g., *Aphidius* in glasshouses to control aphids.
    - Beneficial organism, or just beneficial is used in this report as the most general term encompassing natural enemy, beneficial insect, and BCA.
- These definitions are not formally defined, but this is how they are most commonly used.
- Generalist predators / beneficials, are organisms that attack a wide range of prey species, such as lacewings, ladybirds and hoverflies.
- Specialist predators / beneficials, are organisms that attack just one or a few pest species, such as parasitic wasps (parasitoids).

Most of the time pests and beneficials are described as 'insects', however, scientifically insects are defined as having six legs, so excludes spiders and mites with eight legs and others such as centipedes with many more. The term 'arthropod' is therefore used to include all these species.

3.4.1. Importation (classical) biocontrol

Where an exotic organism (i.e., introduced to a new ecosystem) has become a pest it is often because the pest's natural enemies were not introduced with it (either accidentally or deliberately), thus the pest is released from top-down population regulation. This is particularly a problem in New Zealand where the native ecosystem is highly endemic, so there are no or few native organisms that will attack exotic pests, meaning they are completely released from top-down regulation. Importation biocontrol (also called classical biocontrol) identifies one or more natural enemies of the pest in its native ecosystem, then imports them to New Zealand (after very extensive research to confirm effectiveness and that they will not become a pest themselves) to reestablish top-down regulation of the pest. The natural enemy is often then renamed as a biocontrol agent. New Zealand is a world leader in importation biocontrol, due to the large number of exotic organisms that have been introduced. An example is the recent importation of the parasitoid *Tamarixia triozae* to manage tomato potato psyllid (TPP). Due to many examples in the past where the imported biocontrol organism has become a pest itself (e.g., ferrets and stoats, imported to control rabbits, which have decimated native birds), importation biocontrol is now strictly controlled by the government. It is not something that individual growers can implement, though they can clearly benefit from it (e.g., *Tamarixia*), and can boost some beneficial organisms by the other forms of biocontrol such as augmentation and conservation.

3.4.2. Augmentation biocontrol

Augmentation biocontrol is where the beneficial organism is already present, but its population is too small to manage the pest to the required levels. It has two sub forms:
- Inundative.
- Inoculative.

Inundative augmentation biocontrol is where large, often very large, numbers of the biocontrol agent are released to control the pest. Biopesticides are the main example of inoculation biocontrol. Biopesticides are pesticides made of living organisms, mainly microorganisms (microbes) or extracts from living organisms. One of the longest produced biopesticides is *Bacillus thuringiensis* (Bt) (e.g., DiPel®). It is an example of a biopesticide that is a living organism. Neem is an example of a non-living biopesticide (it is extracted from the seeds of the *Azadirachta indica* tree). Typically, a biopesticide is applied using a sprayer, the same as for chemical based pesticides.

Inoculative augmentation biocontrol is where small numbers of the biocontrol agent are released with the aim that they will reproduce and increase their populations. Inoculative biocontrol is most common in protected cropping, particularly glasshouse production. Small numbers of BCAs are purchased from commercial suppliers, released into the glasshouse where they feed on or parasitise the pest, controlling it while increasing the BCA's populations, to control more pests in the future.

3.4.3. Conservation biocontrol

Conservation biocontrol is based on manipulating the production ecosystem (orchard, vineyard, farm) to boost beneficial organisms that are already present, but their populations are too small to achieve effective pest management. The ecosystem manipulations typically involve adding a range of plant species to the production system to provide a range of resources for the beneficial organisms to boost their populations so they can successfully bring pest populations below economic thresholds.

The ecosystem manipulations that boost beneficials are often defined as:
- **S**helter
- **N**ectar
- **A**lternative prey / food
- **P**ollen

Which has the catchy acronym 'SNAP' promoted by the late Distinguished Professor Steve Wratten.

Shelter includes habitats for beneficials to rest, avoid their predators and bad weather and hibernate. Nectar along with pollen, is a key food source for a range of beneficial insects, particularly the adults of generalist predators such as hoverflies and lacewings where it is the juvenile / larval stage that mostly attacks the pest. While grasses don't produce nectar as they are wind pollinated, they do produce copious amounts of very small pollen grains, because they are wind blown. They are therefore important food for small beneficials such as predatory mites. Alternative prey / food is prey or food other than the target pest. For example, lucerne hosts the pea aphid which is alternative prey and food for beneficial insects that attack cereal aphids. Planting strips of lucerne around and through cereal fields thus provides alternative prey / food for cereal aphid beneficial insects.

3.5. Biocontrol and IPM (Integrated Pest Management)

Biocontrol is one component of IPM (Integrated Pest Management). IPM has a broader and narrower definition. In the broader view IPM integrates different pest management techniques, commonly referred to as tool boxes (Figure 12).

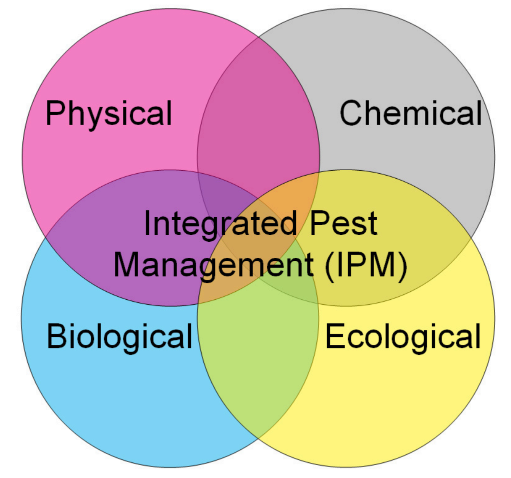


Figure 12. The four IPM (Integrated Pest Management) techniques or toolboxes.

> **"The broader definition of IPM views preventative approaches such as conservation biocontrol as the primary basis for pest management, and interventions such as chemical pesticides as options of last resort."**

In this broader version the toolboxes are physical techniques such as physical barriers, the chemical pesticides, biological as in biocontrol, and ecological techniques. The broader definition views preventative approaches such as conservation biocontrol as the primary basis for pest management, and interventions such as chemical pesticides as options of last resort.

The narrower definition is focused on implementation based on a five step process based on economic thresholds:

1. Set economic action thresholds for each pest species.
2. Monitor pests at the species level: below the threshold take no action, above the threshold take action.
3. If curative action is required, use the most benign / least harmful pest management method / toolbox first.
4. Monitor results of treatment to confirm efficacy.
5. Repeat steps 2 to 4 on a regular basis, e.g., weekly, during the period that pests are a risk to crops.

In the narrower definition of IPM preventative measures are not part of the process, rather they sit outside it. Only curative measures, such as biopesticides or chemical pesticides, are options, with the least harmful, e.g., a biopesticide being the first choice, and chemical pesticides the last choice.

3.6. How Agroecology, biodiversity and IPM relate to each other

The relationship among agroecology, biodiversity, IPM and the four pest management toolboxes can be confusing. Figure 13 (next page) shows how they are related.

Agroecology is the over-arching farm management system (Figure 13). Biodiversity is a key component of an agroecological farm system and supports pest management, so is a large circle within the agroecology circle (Figure 13). The physical, biological and ecological toolboxes / circles overlap the IPM circle as they can be used as part of IPM, in both the broad meaning as preventative measures and narrow meaning as curative, but they can also be used outside of IPM, hence their circles sit partly outside of IPM (Figure 13). Chemical pest management should mostly be used as part of the narrow form of IPM, i.e., when monitoring has shown that a pest species has breached the economic action threshold, and only if all alternative curative methods, e.g., biopesticides, have failed. Exceptions to this are preventative use of agrichemicals where future pest pressure is anticipated but not yet present. For example, the use of seed dressings with targeted modes of action. This approach is part of wider IPM utilising all the toolboxes. Thus, the chemical toolbox / circle sits within the IPM circle (Figure 13).

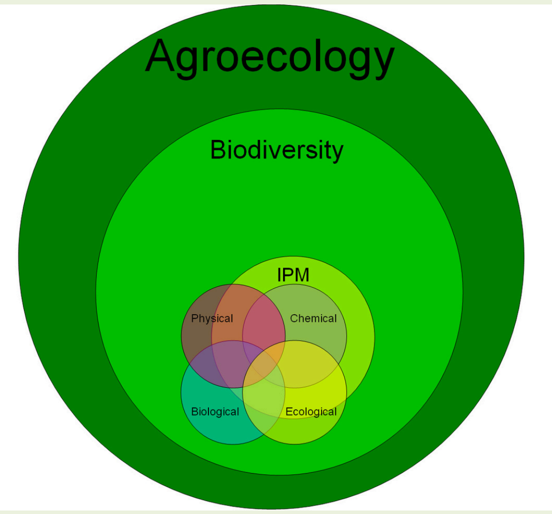


Figure 13. The relationships between agroecology, biodiversity and IPM.

Much of pest management to date, including diseases and weeds has tried to completely eliminate the pest, or at least suppress them to very low levels. However, controlling pests below economic thresholds wastes money, i.e., it is uneconomic, as the cost of control is higher than the returns from reduced pest damage. Overuse of pesticides is also a key driver of pesticide resistance. Therefore, pests must only be controlled with agrichemical pesticides when they exceed IPM economic action thresholds.

3.7. How does biodiversity support pest management?

As Figure 13 indicates, biodiversity underpins / supports all pest management. At the most basic, biodiversity is the opposite of monocultures, as highlighted in section 2.6. Monocultures, and simplified production systems are inherently unstable. From a pest's perspective they are a huge banquet with nothing inedible in the way. Similarly for a pathogen (disease) monocultures are a huge concentration of hosts for them to infect, and for weeds, monocultures have lots of vacant ecological niches they can occupy. In effect there is little bottom-up ecological regulation as there is a huge supply of food and hosts, and much reduced ecological competition by the crop against weeds.

At the same time monocultures are often ecological deserts for beneficial organisms that could limit pest populations by top-down regulation. For example, many of the adults of generalist predators need to feed on nectar and pollen, but in monoculture these are often completely lacking. If the adult beneficials are unable to feed, they cannot lay eggs in the crop to control pests, so without top-down regulation pest numbers can increase exponentially. Monocultures therefore lack both bottom-up and top-down pest regulation. Indeed, if you had to design a farm system to maximise pests, diseases and weeds, it would be a monoculture. Biodiversity in all its forms is therefore the antidote to monoculture for pest, pathogen and weed management.

As section 2.6 highlights, there are different levels of creating / reintroducing biodiversity into the farm, orchard and vineyard. At the lowest levels simply stopping activities such as herbiciding alleyways and non-crop areas and mowing pasture strips. Then deliberately introducing biodiversity around paddock margins and in strips through the crop to provide conservation biocontrol. Finally, there is the more agroecological approach of intercropping by mixing different crop cultivars and species.

3.8. The double edged sword of agrichemical pesticides

While agrichemical pesticides are one of the IPM toolboxes, they can have large negative effects on natural and managed biological and ecological pest management. This is because they can kill non-target beneficial organisms. This is particularly true of broad-spectrum insecticides, but narrower spectrum / biorational insecticides can still kill some beneficial organisms. Some fungicides and herbicides are also toxic to beneficial insects, so although they are not classed as insecticides they still kill insects.

When a chemical pesticide kills beneficial organisms they reduce or remove the top-down ecological regulation of pests. Without top-down regulation, and particularly in monocultures where bottom-up regulation is weak, pest populations can grow very quickly. Chemical pesticides are therefore a double edged sword: they can be highly effective at killing pests, but, when they also kill beneficial insects, they allow the pest populations to bounce back even stronger, requiring more frequent pesticide applications, resulting in a vicious cycle.

There are many examples of pesticides making pest problems worse. For example, Dr Paul Horne, an IPM expert in Australia, describes the case of a potato grower who had not needed to use insecticides for many years due to a successful IPM programme. The grower still needed to use fungicides to control blight. One season there was a mix up between the broad spectrum pyrethroid insecticide Axe® and the SDHI fungicide Ace, with the Axe being applied instead of Ace, the letters x and c being next to each other on the keyboard. The mistake was detected part way through spraying the crop, at which point it was halted. Later on, the part of the crop that had been sprayed with the Axe insecticide was full of aphids, while the unsprayed part had very few. This was due to the broad spectrum Axe killing off the natural enemies and beneficial insects, allowing the aphids to proliferate in the absence of top-down ecological regulation.

4.0. Examples of beneficial insects / arthropods

There are a large number of beneficial arthropods that provide natural pest management, are boosted by conservation biocontrol and mass produced for inoculation augmentative biocontrol. These can be broadly grouped into generalists, that attack a wide range of prey, versus specialists that only attack a small range of pest species. Generalists include ladybirds, lacewings, hoverflies, tachinid flies, mites, carabid and staphylinid (rove) beetles, harvestmen, spiders, and true bugs (Hemiptera). Specialists include parasitoids (parasitic wasps), mites and thrips.

Beneficials are also divided up into predators that eat their prey and parasitoids where the juvenile stages grow inside their hosts and kill them. The following section groups the beneficials that are similar in terms of being generalists or specialists and predators and parasitoids.

4.1. Juvenile stage generalists

For ladybirds, lacewings and hoverflies it is the juvenile larval stage that is the main predator of a wide range of insect pests, at all life stages from eggs to adults.

Figure 14:

Ladybird larvae. *Credit: Oz Animals.*

Hoverfly larvae

Lacewing larvae eating an aphid. *Credit: Mr. Smart.*

Adult ladybirds also eat quite a lot of pests, lacewings less so, and hoverflies none. The adults also consume nectar and pollen, and for hoverflies this is their main food source. Conservation biocontrol through adding flowering plants, including grasses, to the production environment are important for supporting the adults, so they can produce more young. The adults of all three are good flyers, hoverflies in particular spend a lot of time flying, and can move hundreds of metres, even kilometres in their lifetimes. The larvae can only crawl so cannot move far, e.g., on the same plant or among nearby plants that are touching.

4.2. All life stage generalists

Carabid and staphylinid (rove) beetles, true bugs, harvestmen, spiders and mites are mostly generalist predators where both adults and juveniles attack the pest, and that mostly move by walking.

Figure 15:

Carabid beetle. *Credit: Buglife.*

Staphylinid (rove) beetle. *Credit: Landcare Research.*

Predatory mite. *Credit: Plant Natural.*

The beetles can fly, but very rarely do, harvestmen, mites and spiders being arachnids cannot fly, true bugs vary in how much they fly vs walking depending on species. These beneficials mostly only eat pest arthropods, though the larger carabids will also attack things as big as earthworms and slugs, and also eat weed seeds.

Harvestman. *Credit: Charles Merfield.*

Pirate bug.

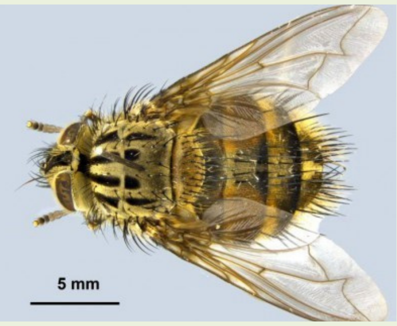
Conservation biocontrol tends to focus on the shelter and alternative prey parts of SNAP for these species, such as beetle banks, section 2.6.2, though nectar and pollen can still be important for them.

4.3. Parasitoids

Tachinid flies and parasitic wasps parasitise mostly other arthropods, laying their eggs in or on their host, with the larvae then feeding on the host from the inside before finally killing it.

Figure 16:

Caterpillar parasitoid. *Credit: Landcare Research.*



Tachinid fly. *Credit: Landcare Research.*

The adults eat a range of food, with nectar and pollen (the N and P in SNAP) often being a key food source. The adults fly, but as the parasitic wasps are often small, e.g., a few millimetres to less than a millimetre, they cannot fly large distances. Many tachinid flies are similar in size to house flies so can fly considerable distances. As parasites, they are often highly specific in their host species, often only attacking a single host species, or a small group of closely related hosts, e.g., aphids.

However, as there are many thousands of individual species of parasitic wasps and tachinid flies, overall they attack a large number of pest species, from as small as aphids to as large as caterpillars.

Thus they can control as many, if not more, pest species than the generalist predators. Beneficials that attack one or a small number of pests are often better at finding their hosts when their numbers are low, generalists tend to focus on areas where prey is abundant.

See the further resources section at the end for publications which have detailed information on individual beneficials.

5.0. Examples of conservation biocontrol in New Zealand

As part of A Lighter Touch, two projects have focused on conservation biocontrol, one in perennial crops and one in field vegetables.

5.1. Perennial crops

In perennial crops a project called “Agroecological approaches to insect pest control in perennial crop systems” was undertaken in Gisborne citrus orchards, hence it is often referred to as ‘the citrus project’ [1]. While the main focus of the project was on conservation biocontrol of crop pests, the project aimed to undertake an agroecological redesign of the production system to achieve multiple benefits within the confines of the existing production system, i.e., working with the orchard as it was. Eight pests were identified by industry as the most problematic and included thrips, aphids, mites, a moth, and a beetle. A desk study [2] was undertaken to determine each pest’s ecology including lifecycle, and natural enemies that have been identified as attacking the pests in published research. The natural enemies identified included a large proportion of well-known beneficial arthropods including ladybirds, predatory mites, hoverflies, pirate bugs, lacewings and parasitoids. SNAP plants that supported each beneficial were then identified from the literature to create an initial list. This list was then filtered, to exclude plants that could be problematic, e.g., become weedy, where seed was not easily and cheaply available etc. Some additional plants that were considered valuable were also added. To minimise the potential for competition with the trees, grasses were excluded from the under tree area (the herbicide strip) resulting in mostly clovers being planted. In the alleyway a diverse pasture mix of grasses, legumes and forbs was planted. Some twenty species of herbaceous plants were established across the orchard floor, not only providing SNAP for pest management but also considerably increasing plant biodiversity which followed through to overall biodiversity (Figure 17).

Figure 17. Before and after photos of the agroecological transformation of a citrus orchard for conservation biocontrol of crop pests.

A number of guides have been produced as part of the project including establishment, management and monitoring toolkits [1]. This work has been built on by Summerfruit NZ and is being trialled in a range of summerfruit orchards [3]. This has found that the most of the species in the seed mixture established well under the trees, with higher abundance of beneficial insects in the understory plantings. Pests were very low in the single sampling season to date so difference in pest numbers between the treatments is yet to be established. Growers also undertook less mowing and herbicide application in the understory blocks compared to standard practice which was a cost saving.

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[1] https://a-lighter-touch.co.nz/our-projects/biodiverse-planting-in-perennial/

[2] https://a-lighter-touch.co.nz/wp-content/uploads/2025/03/Agroecological-pest-management-in-citrus-2021-merfield-shields-paper.pdf

[3] https://a-lighter-touch.co.nz/resource/summerfruit-understory-plant-species-guides/

5.2. Annual field vegetables

A second, later project "Biodiverse planting on vegetable farms" [4], is using a range of conservation biocontrol approaches for pest management and general biodiversity improvements, with a focus on native species, on the Pukekohe vegetable demonstration farm. This has included planting non-cropping areas, such as the sides of track ways and drains with perennial native species. The species were partly selected from work undertaken by Plant and Food Research for the Foundation for Arable Research identifying native woody species that support pollinators [5] (Figure 18).

Planting annual flowering strips through paddocks is designed to attract beneficial insects (Figure 19). A major innovation of the project are the moveable pods, planted with perennial native species that can be moved between crops (Figure 20).

Figure 18. Woody native planting in non-cropped areas/field margins at the Pukekohe vegetable demonstration farm

Figure 19. Annual flower strips in January 2023 (left) and January 2024 (right). *Credits: Olivia Prouse.*

Figure 20. Mobile insectaries of native plants have attracted strong interest from site visitors. *Credits: Alex Dickson and Olivia Prouse.*

Overwinter cover crops of flowering annual species have also proved highly successful in providing SNAP to support beneficial insects as part of the IPM programme, as well as protecting soil over winter from rain, and boosting soil biodiversity (Figure 21).

Figure 21. Winter cover crop at the Pukekohe demonstration farm. *Credit Olivia Prouse.*

> **"A major innovation of the project are the moveable pods, planted with perennial native species that can be moved between crops."**

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[4] https://a-lighter-touch.co.nz/our-projects/biodiverse-planting/
[5] https://www.far.org.nz/resources/far-focus-13-biodiversity

5.3. Conclusions

With the ongoing challenges facing agrichemical based pest control, increasing natural pest management, by boosting on farm / vineyard and orchard biodiversity and implementing IPM is essential. Fortunately increasing biodiversity and implementing IPM are not complex nor prohibitively expensive, indeed they can save costs and increase profit. This will take a change of mindset, away from the old idea that the only good plant in a paddock is the crop, to embracing biodiversity. This can start with simply stopping practices such as herbiciding non-crop areas, through to deliberately planting them, particularly with natives, that will support beneficial organisms that attack crop pests and also pollinators. Within crop diversity can then be enhanced in annuals through the use of beetle banks, flower strips and moveable biodiversity pods, and in perennial crops through eliminating of the herbicide strip, planting a diverse understory and allowing it to go to flower.

Acknowledgements:

This paper was written by Dr Charles Merfield, HND Comm. Hort., M.Appl.Sci. Hons, PhD, MRSNZ.

Charles, better known as Merf, has a diverse background in organic horticulture and agriculture both managing farms and undertaking research and extension in a range of countries. He therefore has a deep knowledge of real-world farming and science which means he is able to effectively bridge these two arenas to ensure that research will be applicable and implementable on-farm and that farmers understand the problems and limits of what research can achieve.

5.4. Further resources

There is a growing range of conservation biocontrol and agroecology resources aimed at growers and farmers, particularly from North America and Europe. Some key ones include:

- Habitat manipulation – as a pest management tool in vegetable and fruit cropping systems, with the focus on insects and mites 2016 https://orgprints.org/id/eprint/30032/
- Habitat planning for beneficial insects. Guidelines for conservation biological control 2016 https://xerces.org/publications/guidelines/habitat-planning-for-beneficial-insects
- Manage insects on your farm. A guide to ecological strategies 2005 https://www.sare.org/resources/manage-insects-on-your-farm/
- Perennial flower strips – a tool for improving pest control in fruit orchards 2018 https://organic-farmknowledge.org/tool/44502
- Protecting crops through plant diversity 2024 https://www.inrae.fr/en/news/protecting-crops-through-plant-diversity

Merfield, C.N. (2025) What are the benefits of biodiversity for pest management in cropping systems? https://a-lighter-touch.co.nz/wp-content/uploads/2025/03/Biodiversity-benefits-for-pest-management-report-1.pdf