Pest and Disease Control Strategies for Sustainable Pacific Agroecosystems

By Hector Valenzuela
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Version history: August 2014

Series editor: Craig R. Elevitch

Publisher: Permanent Agriculture Resources (PAR), PO Box 428, Hōlualoa, Hawai‘i 96725, USA; Tel: 808-324-4427; Email: par@agroforestry.org; Web: http://www.agroforestry.org. This institution is an equal opportunity provider.

Acknowledgments: Thank you to Garien Behling, Heidi Johansen, Andrea Kawabata, Chris Kobayashi, Christopher McCollough, and Gerry Ross for critical review of the manuscript and contributions.

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Sponsors: This publication was produced by Hawai‘i Homegrown Food Network. Publication was made possible by generous support of the United States Department of Agriculture Western Region Sustainable Agriculture Research and Education (USDA-WSARE) Program. This material is based upon work supported by the Cooperative State Research, Education, and Extension Service, U.S. Department of Agriculture, and Agricultural Experiment Station, Utah State University, under Cooperative Agreement 2011-47001-30398.
Food-Producing Agroforestry Landscapes of the Pacific (Series)

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INTRODUCTION
The goal of an ecologically-based pest management program is to establish a resilient production system based on well-tested production practices. Resilient systems are better able to resist stressful environmental growing conditions, pest attack, and even market fluctuations. These systems can also recover faster from many negative impacts on the system. In practice, such systems are created by following key agroecological concepts. Local indigenous knowledge often holds important, time tested clues to establishing production systems that are adapted to the local growing conditions (Lin 2011).

Key strategies for creating a healthy agroecosystem to minimize pest outbreaks

1. Grow healthy crops that will be better able to withstand, outgrow, or repel pest attack;
2. Design a production system in time and space that attracts beneficial organisms; and
3. Design a habitat within and around the farm that will delay, suppress, or repel pest invasions.

A central approach is to improve the quality, fertility, and life of the soil. A healthy soil rich in organic matter will sustain healthier crop growth and host a diverse microbial and arthropod food web, which assists in preventing pest outbreaks. Another key approach to maintaining soil health is to prevent or minimize the erosion typical of many conventional tropical farming systems.

Alternative pest management programs fit well within the scope of agroforestry systems, many of which are indigenous to the tropics and are typically highly diversified, often including crops, animals, and homegardens integrated synergistically with trees (Udwatta and Godsey 2010).

This chapter covers recommended production practices that may be used in agroforestry systems of the Pacific and tropical regions to create resilient production systems and enhance and protect the natural resources on the farm. It should also help the farmer identify pests and understand their life cycles, and develop alternative management practices that can be used to manage pest, disease, and weed infestations in the farm.

FOSTERING RESILIENT PRODUCTION SYSTEMS

Agroforestry
Well designed agroforestry systems may withstand environmental or economic perturbations to the system better than simplified agroecosystems, such as monocultures. This was observed in agroforestry systems of Central America, with their recovery from the effects of Hurricane Mitch in late 1998, as compared to other more simplified production systems (Laurent et al. 2003). Agroforestry systems were also used to successfully reestablish resiliency by rehabilitating degraded lands in the Central Plateau of Burkina Faso, and in the agricultural plains of southern Niger, Africa (Reij et al. 2010).

Agroforestry systems can help maintain or improve long-term soil quality, and to counter the yield and fertility declines often observed under monoculture. Research indicates that agroforestry systems may also remediate soils in which fertility has been degraded due to contin-
uous conventionally managed monocultures (Ilany et al. 2010). In Brazil, where cacao-based agroforestry systems are interplanted either with native forest trees or with introduced *Erythrina* (a nitrogen-fixing legume), the agroforestry species contribute about 10 MT/ha of leaf litter, which enhances the internal nitrogen (N) and phosphorous (P) nutrient cycles. The topsoil layers in the cacao agroforestry systems were found to have high levels of total nitrogen, total phosphorus, microbial activity, microbial biomass carbon, microbial biomass nitrogen, as well as mineralizable levels of nitrogen, all of which contribute to improve soil quality and fertility (Zaia et al. 2012).

Similarly, in Sri Lanka, interplanting coconut palms (*Cocos nucifera*) with either the *Acacia auriculiformis* or *Gliricidia sepium* (both nitrogen-fixing legumes) helped to improve soil quality, and nutrient availability for the companion cash crop. The leguminous intercrops improve the soil's physical condition by increasing soil organic matter, resulting in lower soil bulk density, improved

**Figure 1:** Sustainable pest and disease control strategies are based on a healthy growing environment and healthy plants. Prevention is the central strategy, followed by management. Treatments are applied only when necessary.

Key tactics that are used to create resilient agroecosystems

1. Variety selection, to grow crop or tree varieties that are more tolerant or resistant to pest attack.
2. Crop diversification to maximize the population of beneficial organisms and to minimize the incidence of pest outbreaks.
3. Landscape-level approaches to maintain green corridors or buffer zones that maximize the population of beneficial organisms, and better protect the farm from environmental disturbances.
aeration, and increased water retention. As a result of the improved soil quality under the agroforestry systems, the coconut palms had greater root growth and biomass under the *Acacia* and *Gliricidia* intercrops compared to other treatments (Vidhana and Liyanage 1998). A healthy and expansive root system that reaches deeper layers of the soil profile is well recognized as a key strategy for plants to better tolerate, withstand, or outgrow soil-borne pest attacks, or environmental stress.

The inclusion of nitrogen fixing trees in agroforestry systems imparts the benefit of nitrogen contributions to the cash crop. Nitrogen contributions may occur from falling leaf litter, as well as through direct transfer,
Building healthy soil for better pest management

A healthy soil is considered to be the foundation of a resilient agroecosystem that will allow crops to withstand, overcome, and/or prevent pest outbreaks. Key approaches to obtain and maintain healthy soils include the following.

**Addition of organic matter**

Organic matter provides several benefits to the soil including improved microbial activity, internal nutrient cycles, nutrient availability to plants, soil structure, and soil water retention.

**Soil cover**

Protection of the soil from water and wind erosion is best achieved by minimizing the exposure of bare soil to the elements. This may be done by maintaining the ground cover through intercropping, sequential plantings, rotations, cover crops or living mulches, and application of organic mulches.

**Minimizing soil disturbance by following minimum-till, strip-till, or no-till conservation practices**

Less soil disturbance will help sustain a healthy biological soil food web including enhancing the population of earthworms, which are considered to be key “ecosystem drivers” due to their beneficial effects on soil texture, water drainage, water holding capacity, nutrient cycles, and soil microbial activity (Valenzuela 2010).

**Crop diversification**

By planting a diversity of crops, the soil will host a wider diversity of organisms in the rhizosphere (soil zone affected by plant root systems). Crops with root systems that occupy different layers of the soil profile will both mine and enrich the soil with exudates, resulting in improved nutrient cycles and nutrient use efficiency, a more expansive biological food web, an improved population of beneficial organisms, and a reduced incidence of pest outbreaks.

via the root system of both crops, as has been observed with *Gliricidia* (Kurppa et al. 2010). Nitrogen transfer studies conducted under field conditions between a leguminous tree and a companion grass species found that 62% of the nitrogen in the grass plants was transferred from the companion leguminous species, and that 33% of the total N amount transferred to the grass species originated from the N fixation activity of the leguminous tree (Sierra and Daudin 2010).

Other than the use of leguminous trees as a source of atmospheric fixed nitrogen, nitrogen-fixing cover crops can also be used to contribute nitrogen to a companion or subsequent cash crop. The cover crop can provide ground cover protection and smother the growth of weeds, and subsequently contribute N for the cash crop. Turning in the cover crop has to be timed properly so as to synchronize the release of N by the legume with uptake needs of the companion crop (Parr et al. 2011).

A survey of commercial farming systems in southern Italy found that fruit tree orchards that followed low-input and sustainable farming practices had improved soil quality as compared with farms following intensive, pesticide-based production systems. Soils from the low-input
orchard systems had a greater organic matter content, soil microbial enzyme activity, microbial biomass, fungal mycelia, microbial functional diversity, and bacterial species richness. A standard growth bioassay showed a 17% improved lettuce growth under the low-input management soils, compared to the growth observed on intensively managed soils (Bonanomi et al. 2011).

Research in temperate areas has shown that incorporating agroforestry buffers in grazing areas resulted in greater organic matter content in the nearby soil, perhaps due to the leaf litter provided by the agroforestry species. Overall soil quality parameters, including the number of

Figure 4. A new field planted simultaneously with annual crops of sweetpotato and tomato together with medium-term perennial hot pepper and long term perennials ti and coconut in Dededo, Guam.
water-stable aggregates, microbial enzyme activity, soil carbon, and soil nitrogen were all found to be greater in nearby production forage fields that were undisturbed compared to fields that were cultivated annually (Paudel et al. 2011).

The risk of soil erosion is especially critical in upland or hilly production areas. For instance, considerable erosion is often experienced in upland and intensively managed citrus orchards of Spain. Production practices that may reduce erosion on slopes include planting of cover crops, or the application of organic mulches. Research conducted in hilly production areas of Spain in fields with an 8% slope showed that planting with a common vetch (Vicia sativa) cover crop or applying a straw mulch reduced runoff sedimentation and erosion to negligible levels, as compared to the use of herbicides, or to conventional plow soil cultivation. The researchers cautioned that erosion mitigation practices are necessary to slow down the increased desertification of degraded and eroded agricultural lands in the Mediterranean region (Cerda et al. 2007).

**Disease suppressive soils**

An attractive but elusive strategy for the management of soil-borne diseases and nematodes is the establishment of disease suppressive soils. Suppressive soils host a complex of microbial communities that together act to inhibit the development of certain soil diseases or nematodes that attack the crops grown in that particular soil. Soils have been found that suppress the activity of diseases such as *Fusarium, Phytophthora, Rhizoctonia*, as well as plant-parasitic nematodes. Biocontrol organisms that may be effective in suppressing plant-parasitic nematode populations

![Figure 5. Poor field drainage, or excessive fertilizer applications may result in salt damage on seedlings, as observed here at the cotyledonary section of a tomato seedling. These types of injuries may stunt growth, and predispose plants to pythium or other pests and diseases.](image-url)
may include antagonistic rhizobacteria, nematode-trapping fungi, and pathogenic fungi (Kerry 2000). While little is understood about establishing suppressive soils either naturally or induced by cultural practices, it is important to continually promote soil health and microbial activity with the goal of establishing antagonistic microbial communities that withstand or suppress outbreaks of soil-borne diseases (Peters et al. 2003; Kinkel et al. 2011).

Along these lines, the use of organic amendments and soil conservation practices to improve soil quality have been proposed to promote weed-antagonistic microbial populations, and weed suppressive soils. Researchers have found higher numbers of weed-inhibiting bacteria, as well as greater soil enzyme activity, in fields managed with low-input or sustainable practices. The amount of microbially derived enzymes in the soil is important, because greater enzymatic activity has been correlated with both disease- as well as weed-suppressive soils (Kremer and Li 2003).

Building plant defenses and immune responses (systemic induced resistance)

The previous section discussed the importance of improving soil quality to promote healthy plant growth. To complement a healthy soil, another key pest management strategy is to select the best adapted crops and varieties and to provide an environment that will enhance plants’ tolerance or resistance to attack.

Figure 6. An intricate beans-corn-tomato intercropping system is used by a commercial vegetable farmer in the Zambezia province of Mozambique. Corn is grown on the top of the bed to maximize light interception, tomatoes on the northern side of the bed to maximize heat-units intake, and the beans contribute nutrients to the system via a plant-bacterial symbiotic system of nitrogen fixation.
Research over the past 20 years has begun to elucidate the inherent ability of many plants to resist plant attack in what is termed “systemic induced resistance” or “acquired immune responses” (Buxdorf et al. 2013). Systemic induced responses in plants may be triggered to resist attack against a variety of pests such as viruses, bacteria, fungi, and arthropod (insects and mites) pests.

While we still do not have full understanding of how to promote systemic induced resistance or how to trigger this mechanism at specific times prior to the onset of pest outbreaks, we can continue to search for adapted crop varieties with better ability to resist pest attack. We can also provide growing conditions that are more likely to promote or induce plant immunity responses. Plant defense hormones that are believed to be involved in the systemic induced response include salicylic acid, jasmonic acid, and ethylene. As part of the systemic induced response, plants first recognize when specific pathogens attack, say by landing on the leaves, and then resistant genes are induced in response to the attack by that specific pathogen (Robert-Seilaniantz et al. 2011).

The knowledge that plants may be induced to resist pest attack through inherent immune mechanisms opens up a host of possible management practices in the farm. The key management goals remain to select varieties that are locally adapted and that show better tolerance or resistance to pest attack. It is also important to maintain healthy growing conditions by improving soil quality, and establishing field biodiversity to promote synergistic biological interactions that result in improved crop growth. This may in turn trigger inherent resistance control mechanisms.

Figure 7. Intercropping systems, such as this corn-eggplant field in an organic farm on American Samoa provide increased year-round ground cover to protect the soil from erosion, and maximize efficiency of resource utilization. The weeds in this field may protect the soil from erosion, increase vegetational diversity within the farm, and help to recycle nutrients within the system.
Non-pathogenic microbial organisms, such as non-pathogenic *Pseudomonas* and *Fusarium* species, have been shown to be able to elicit a systemic induced response in plants. Mycorrhizal fungi that have a symbiotic interaction with host plants have also been shown to induce systemic induced resistance, for instance in tomato, in resisting attack by *Phytophthora* (Cordier et al. 1998).

There is also some evidence that systemic induced responses may be triggered under polyculture or agroforestry systems. For instance, fungal isolates obtained from the rhizosphere of zoysia grass (*Zoysia tenuifolia*) were found to elicit a systemic induced response in cucumber against attacks by anthracnose (Meera et al. 1994).

Several products have been shown to induce systemic induced resistance in plants. For example, foliar fertilizers such as phosphate salts induced immune resistance in cucumber against powdery mildew (Reuveni et al. 1993). Other products that have induced immune responses in plants include potassium silicate sprays (against fungal attacks), composts, compost teas, neem extracts, chitin and chitosan soil amendments (Bell et al. 1998).

**Breeding and plant variety selection**

The breeding and selection of crop varieties that are adapted to local microclimates and that have tolerance or resistance to key pests is one of the most cost-effective ways to promote a healthy agroecosystem (Andres et al. 1979). For example, in Hawai‘i, growers may choose to grow banana varieties that have tolerance to bunchy top virus, such as “Dwarf Apple” instead of growing susceptible types such as Cavendish varieties.

**Figure 8.** Vegetable varieties may be selected for their higher value in the market place, and for their local adaptation and resistance to pest attack. A great level of diversity is often observed with vegetable crops, as seen here in bitter melon (*Momordica charantia*). **Figure 9.** Growers also have a range of varieties to chose from in selecting for specific vegetable fruit characteristics. For instance, if searching for long-type eggplants, a range of varieties exist with respect to color, shape, taste, and other growth characteristics.
Traits of improved and adapted varieties

- Tolerance to pest attack
- Increased competitiveness against weeds
- Compatibility with intercrops and in agroforestry systems
- Good germination, vigor, and establishment in tropical climates
- Improved nutrient use efficiency
- Shade tolerance when grown as an understory crop
- Vigorous root system to mine the soil
- Adapted to organic or low-input growing conditions
- Attracts or is compatible with natural enemies (predators or parasitoids) of pests (Bottrell et al. 1998)
- Open-pollinated, therefore carrying a wider genetic background. These are more amenable to on-farm selection, allowing farmers to save seed, and to continue to improve the variety.
- Possess horizontal gene resistance against pests. Horizontal resistance is conferred by multiple genes, rather than a single gene. Horizontal gene resistance is thus more stable and durable than single-gene based resistant varieties (Robinson 1996).

Figure 10. Trials may be required to identify varieties with tolerance or resistance to specific pests or diseases. A trial conducted at the University of Hawai‘i Experiment Station in Waialua, O‘ahu identified a kai choy or mustard cabbage (*Brassica campestris*) variety with resistance to white rust (*Albugo candida*). The resistant variety, now sold by the UH Seed Program, was an original selection made by a gardener on the island of Moloka‘i, Hawai‘i.
Growing healthy seedlings and transplants

Planting material sanitation
Sanitation is important when dealing with asexually or sexually propagated planting materials. Regardless of the choice of planting material, it is important to use “seed” or planting material that is free of contamination from diseases, insects or weeds. When there is a possibility of contamination, it is often recommended to treat seed with hot water or with chemicals. With asexually propagated plants, superficial treatments are unlikely to eliminate systemic diseases or nematodes that may be present in internal tissues. In this case it may be necessary to grow asexual propagating material in an isolated nursery, to ensure that disease symptoms do not appear during the initial growth stages. If the planting material is deemed to be free of diseases, it can then be used for propagation and planting in the field.

Similarly, crops should not be planted in soils that are already contaminated with specific soil-born diseases or arthropod pests. For instance, sweet potato should not be planted in fields infested with the sweetpotato weevil (*Cylas formicarius*), and ginger should not be planted in fields infested with *Fusarium* or bacterial wilt.

Microbial inoculation of seedlings
In some instances it may be possible to inoculate seeds, seedlings, or cuttings with beneficial microbes to improve field establishment and crop growth. For instance in mango, mycorrhizal inoculations with *Glomus fasciculatum* and *G. mosseae* that were propagated in a millet growing medium improved nutrient uptake and crop growth, even 8 years after inoculation (Mohandas 2012).

Landscape-level management and green corridors
To establish more long-lasting and resilient pest management programs, the Integrated Pest Management (IPM) approach calls for area-wide or landscape level strategies, rather than focusing on a particular field plot or an individual farm. Area wide controls allow farmers to coordinate activities to prevent the movement of pests between farms, to control populations of weeds that may harbor pests or viral diseases during the off-season, and to promote the activity of beneficial organisms such as bees, predators, and parasites.

Landscape-level management strategies are especially effective in promoting biodiversity within
Area-wide management strategies may include:

- Planting of specific species to improve nutrient cycles and to attract beneficial organisms.
- Removing alternate hosts of important virus diseases such as Tomato Spotted Wilt Virus that affect a range of crops such as lettuce and tomato, or the cucurbit mosaic viruses. Similarly in areas where kava (*Piper methysticum*) is grown, growers may need to remove alternate weedy hosts of kava dieback caused by cucumber mosaic virus, such as honohono grass (*Commelina diffusa*).
- Area-wide traps or monitoring to manage important pests such as fruit flies.
- Crop-free periods during parts of the year, to reduce virus inoculum levels.

an agricultural community. By their nature agroforestry systems host a diversity of trees and annual crops within the farm. Surveys conducted in tropical areas such as in Bangladesh show that the area-wide management of agroforestry systems can indeed help promote biodiversity and conserve native species (Bardhan et al. 2012). Agroecosystems that support a greater biodiversity are more likely to experience fewer pest outbreaks, and host greater populations of beneficial organisms (Bishop et al. 1979).

Area-wide management programs based on agroforestry systems help to maintain green corridors of biodiversity that provide improved tolerance to environmental stresses such as droughts, germplasm conservation of sensitive species, conservation of beneficial insects, reduced soil erosion, and improved water and nutrient cycles (Jose 2012). In turn, many of the plant species found in agroforestry systems provide several services to

![Figure 12. Agroecologists increasingly promote landscape-level approaches to managing pests and the improved management of natural resources such as soil, water and nutrients, within the farm and at the watershed level. A mosaic planting of orchards, vegetables, tobacco and grain crops display a substantial vegetational diversity and year-round ground cover in agricultural fields of Montecalvo, southern Italy.](image)
the farming community. For instance, in the Tehuacan Valley of Mexico traditional agroforestry systems support 122 different plant species that provide useful products which can be used for 14 different purposes, with 90% of these plants being native to the region (Moreno-Calles et al. 2012).

RESOURCES MANAGEMENT

The proper management of natural resources on the farm, such as the optimal use of water, nutrient, sunlight, and energy is important to establish a balanced production system that is better able to resist or prevent pest outbreaks. The proper use of internal and external resources will increase soil quality, improve crop growth, and will improve economic returns to the farming operation. Operations in which resources are used improperly may lead to outbreaks of opportunistic pest species. Unbalanced crop growth can lead to nutritional deficiencies and lower product quality after harvest.

Water

Crop growth is optimized when plants have access to adequate amounts of moisture during the different growth stages. Sub-optimal amounts of water may reduce growth, and may weaken the plants, making them more susceptible to pest attack and to weed infestations. Excessive amounts of water may leach soil nutrients and promote soil-borne diseases. Proper water management is important, given the close interaction between high humidity and disease incidence in plants (Beattie 2011).

Strategies that can be followed to optimize water use on the farm

- Increase soil organic matter content to improve water holding capacity and drainage.
- Use mulches to conserve water and to lower soil temperatures.
- Practice intercropping, incorporating crops that have compatible water uptake requirements. For instance research conducted in Zambia showed that pigeon pea (Cajanus cajan), a deep-rooted agroforestry species, could take up water from the lower soil layers, and that water could be used by shallower-rooted crops, when grown in an intercropping system (Sekiya and Yano 2004).
- Introduce trees into open fields to reduce runoff and to improve water infiltration, as recently shown in Costa Rican pastures (Benegas et al. 2014).
- Improve soil fertility, soil pH and nutrient balances, to improve crop water use efficiency (WUE) (Gaiser et al. 2004).
Nutrients
Crops that experience nutrient imbalances due to overly acidic or alkaline soil pH or from under- or over-fertilization may experience greater weed competition and pest and disease outbreaks. An optimal nutrient balance is important to match the fertility of the soil with the crop nutrition needed to reach the desired yield objectives. As indicated earlier, a healthy soil (Section 2.1), crop selection and proper habitat design in time and space will result in optimal crop growth and minimize the incidence of pest outbreaks.

In agroforestry systems, soil microorganisms are a key driving force for the supply of nutrients to the plant. For example, microbial populations were found to enhance phosphorus and nitrogen nutrient cycles in Brazilian cacao agroforestry systems by utilizing plant litter deposited by the trees (Zaia et al. 2012). The proper design of an agroforestry system and the selection of compatible intercropping species is important because species vary in their ability to promote soil microbial activity and rhizosphere nutrient cycles, both of which determine the availability of key nutrients such as phosphorus and nitrogen (Zhao et al. 2010).

Enhancing the availability of key nutrients may improve disease tolerance in plants. For instance, calcium has been shown to enhance tolerance or resistance against disease attack, as observed in a recent study with respect to *Phytophthora* infestations on oak-based agroforestry livestock systems in Spain (Serrano et al. 2012). Similarly in cash crops like tomato, calcium improved resistance against bacterial wilt (*Pseudomonas solanacearum*) (Yamazaki and Hoshina 1995), and in potato against *Erwinia* (Nunez and Davis 2003).

Silicon is another nutrient that has long been shown to confer resistance against both insect and disease attack (Marshner 1995). Silicon has also been shown to increase tolerance to drought, salinity, and high temperatures, all of which may better allow plants to resist or overcome pest and disease attack (Lee et al. 2010). Growers may be able to make silicon amendments by applying residues from crops high in silicon, such as sugarcane (Savant et al. 1999).

Figure 13. Prior to the beginning of a farming operation it is important to properly characterize the soil, based on soil classification maps, if available, and based on nutrient laboratory analysis. This picture shows a profile of the University of Hawaiʻi long term organic research plots, taken during the first year before the first field experiments were initiated.
Management of sunlight and wind

Another central component in the design of intercropping and agroforestry systems is the management of sunlight interception and of wind movement on the farm. Both wind and sunlight can have positive or negative impacts on potential pest and weed outbreaks. The goal of managing light interception and wind movement on the farm is to minimize plant stress and to prevent environmental conditions that will allow for the reproduction and dissemination of weeds, pests, and diseases.

Figure 14 (left). A windbreak of pigeon pea protects crops from wind and increases vegetational diversity in an intercropping system with daikon, corn, and carrots at the University of Hawai‘i organic research plots. Figure 15 (right): Sudex, or Sudan-sorghum hybrid varieties, make an effective windbreak in areas that experience strong trade winds. Even though the seeds produced by Sudex are sterile, the plant’s flowers may be effective in attracting beneficial organisms. A Sudex windbreak will regrow after periodic mowing over several years, providing a valuable source of organic residues for use as mulch or for composting.

Figure 16 (left). Row covers placed on mini-tunnels as observed in this organic nature farm in Saitama prefecture, Japan may serve as a physical barrier to protect leafy crops from pests such as whiteflies or aphids. Figure 17 (right): An integrated and diversified production program maximizes labor and resource use efficiency, minimizes production risks, and manages pest problems. Here, mini-tunnels with a clear plastic cover are used as rain shelters and plastic mulches are used to minimize weed pressure and disease incidence on watermelon production beds. Straw mulches are used for the production of onions as part of this intercropping system used at organic nature farming experimental fields in Ohito, Japan.
Agroforestry and polyculture systems are ideally suited to maximizing light utilization because they consist of multistory plantings of several species that intercept incoming sunlight based on plant height, canopy structure, and seasonal growth patterns. By maximizing vegetative ground cover, the soil is protected from erosion and the canopy of the intercrops helps to suppress weed growth. The litter and crop residues provided by the intercrop species help to improve nutrient cycling and promote a diverse fauna both below and above ground. Intercropping promotes the activity of beneficial organisms in the farm.

It is also important to consider the balance between dense vegetation and humidity levels in the farm. Excessive humidity below the canopy may promote an outbreak of moisture-loving pests. In areas where soil-borne diseases, fungal, or bacterial diseases are a problem, growers should allow for adequate air circulation.

PEST IDENTIFICATION, BIOLOGY AND LIFE CYCLES

Pests that attack plants include arthropods (insects and mites), fungi, bacteria, viruses, animals and rodents. To design a pest management program, it is necessary to prepare a list of the top pest species affecting crops in the farm. When symptoms of pest damage are first observed in the farm, the first step is to diagnose and identify the species affecting that crop. Crop damage may also be caused by physiological factors such as environmental or nutritional stress. It is important to properly characterize and identify the source of the problem. Because several diseases or nutritional disorders show similar symptoms, it is often necessary to obtain professional help to make a final determination or identification of the pest attacking a particular crop. Farmers should maintain a list of pests that have been identified in this manner as a historical record of pests that have been found on the farm.
Disruption of insects that spend part of their life in the soil

Many insect species spend part of their life cycle in the soil. This presents the option of soil management that will suppress insect activity. Perhaps a cover crop, organic mulches, or organic amendments may assist to increase biological control activity in the soil. This may help reduce pest numbers when they reside in the soil. Key stages where the life cycle of plant pests may be disrupted include during dispersal (liberation, flight, landing), inoculation, reproduction, and penetration of the host species.

Insects that spend part of their life cycle in the soil include

- Leafminers
- Thrips
- Tomato pinworm
- Chinese rose beetle
- Mediterranean fruit fly
- Cutworms
- Taro root aphid

It is also helpful for farmers to learn to identify beneficial organisms present on their farms in order to make an assessment of natural pest controls. If natural controls are not providing adequate effect, additional action may be necessary to further suppress a particular pest.

Once a pest has been properly identified, the next step is to learn about its life cycle. An understanding of the life cycle and the different hosts that it visits will help to identify specific times when action may be taken to suppress its population with the least effort and minimal collateral damage to non-target organisms. For example, if the life cycle reveals that an insect pest relies on a particular weed as an alternate host, it may be possible to control the weed to break the pest life cycle.

**ALTERNATIVE TECHNIQUES FOR PEST MANAGEMENT**

**Ecological pest control and Integrated Pest Management**

Ecology consists of the study of the interactions between organisms and their physical and biological environment. Ecological pest control uses knowledge of these interactions to devise strategies to suppress pest populations, and attract beneficial organisms to the farm. Organic farmers follow agroecological or ecological pest control strategies to manage pests on their farms (Shennan 2008).

Integrated Pest Management (IPM) considers all methods of pest control to design an optimal control program while minimizing negative disruptions of natural pest control mechanisms. The concept of IPM
was developed during the 1960s and 1970s after it was realized that pest control programs based solely on use of synthetic pesticide applications were disrupting populations of beneficial organisms, causing pest outbreaks (Bishop et al. 1979) and other negative side-effects on human health and the environment. The IPM approach relies on the application of synthetic pesticides only after all other alternative methods of pest control have been considered and exhausted.

Experience over the past 40 years shows that area-wide IPM programs can be effective to control important pests while significantly reducing pesticide consumption. For instance, in California, Oregon, and Washington, the adoption of biologically-based IPM programs for the production of pears and apples resulted in an 80% reduction in the use of synthetic pesticides, lowering pest management costs and improving product quality. These and other IPM programs have been found to be more effective in providing long-term pest control based on more stable and environmentally compatible control strategies rather than the reliance on the use of pesticides alone (GAO 2001).

Figure 18 (left). Pheromone traps, such as this one for the sweetpotato weevil (Cylas formicarius), may be used to mass-trap insect pests in order to keep losses below economic injury levels through mating disruption, and monitoring populations. Figure 19 (right): Pheromone traps, such as this one for the tea leaf roller (Caloptilia theivora), may be used to monitor pest populations or for mating disruption, before a pest reaches economic injury levels. The leaf roller can become a pest when excessive pesticide application decimates natural enemy populations. When pheromone traps identify the incoming populations, the grower may manually remove eggs found in the young stems or larvae present in the young leaves as an early and effective control strategy (Hazarika et al. 2009).
Internationally, the IPM program in Nepal has the goal of improving biodiversity, minimizing the misuse and over application of pesticides, protecting the health of farm workers, and producing healthier food. The IPM program in Nepal has reached over 10,000 farmers, with educational programs based on farmer IPM field schools (Esser et al. 2012). Farmer field schools were also used in India to establish IPM programs in the cotton producing areas of Karnataka State, replacing the conventional practice of calendar-based pesticide applications (Mancini et al. 2007).

Key IPM strategies include prevention, avoidance, monitoring, and suppression (GAO 2001). These strategies are followed based on an intimate knowledge of the pests, and their interaction with the production system. Key IPM strategies include

- Pest identification and understanding of life cycles
- Management of field margins and green corridors between farms
- Prevention strategies to limit pest infestations
- Traditional biocontrol or the inherent activity of biological control that exists on the farm, be it from beneficial insects or microorganisms.
- Classical biological control or the importation of particular beneficial species from other regions to control specific target pests.

Some cultural practices used in IPM

- Crop rotations
- Timing of planting and harvesting
- Trap crops
- Strip harvesting (sequential harvesting to preserve habitat for beneficial organisms)
- Crop diversification (includes multiple varieties, intercropping, and agroforestry)
- Elimination of pest and disease hosts
- Tillage and soil-preparation (conservation tillage)
- Destruction of crop residues, or field sanitation
- Irrigation schedules and volumes
- Harvest methods
- Crop-free periods
- Establishment of insectary plants for beneficials
- Physical and mechanical controls
- Multifaceted approach—combination of multiple cultural practices. Research has shown that each additional control technique that is adopted results in further reductions in pest levels (Bishop et al. 1979).
Biocontrol agents may also be applied through commercial formulations, for example, application of *Beauveria bassiana* for the control of the coffee berry borer (*Hypothenemus hampei*)

- The use of pheromones and chemical attractants or repellents
- Use of resistant varieties
- Sampling and monitoring to make decisions about timely pest controls
- Cultural practices to manage pests on the farm

**Using crop growth stages as part of an IPM program**

The growth stages of crops are often utilized to help diagnose levels of pest damage to estimate potential yield losses from pest attack and to determine the need to take action to manage specific weeds, pests, or diseases. For example, most weeds need to be controlled during the early plant growth stages.

Pest management diagnosis and control strategies are determined based on infestation levels and particular crop growth stage. Key crop growth stages include:

1. **Initial growth**—Between planting or when vegetative growth begins and when the canopy reaches approximately 10% cover.
2. **Crop development**—Between 10% and 70–80% cover.
3. **Mid season**—From 70–80% ground cover to beginning of maturity.
4. **Late**—From beginning of maturity to harvest.

![Figure 20](image)

Figure 20. Green corridors, as observed here in the Amhara region of Ethiopia, help to maintain biodiversity, serve as a source of vegetational resources such as medicinal plants, and serve as a corridor for the conservation of beneficial organisms, which aid in on-farm pest management.
Control strategies

Prevention and suppression control strategies keep a pest from infesting a production field. Preventive tactics include choosing varieties with resistance to pests and diseases, removing and disposing of crop residues and culls from a field that was recently harvested, sanitizing farm implements and equipment prior to entering a new field, and tilling soil to manage pest populations. Other prevention practices include...
using pest-free planting materials, preventing weeds from going to seed, removing alternate hosts of insects and diseases, and preventing the development of diseases with proper irrigation or water management practices (GAO 2001). Prevention also includes standard cultural practices such as crop rotation, proper soil and nutrient management, and following cultural practices that result in optimal crop growth. Physical barriers such as fences or nets are typically used to prevent pigs, cattle, deer, birds, insects or other animals from entering production fields.

Suppression strategies, on the other hand, are taken when a pest has already infested a field, and when sampling of the field, based on the particular crop growth stage, has determined that the pest is causing unacceptable economic damage. Suppression control tactics include the application of biological or organic pesticides, the release of beneficial organisms that may reduce pest numbers, and the use of pheromones to disrupt the activity and reproduction of pests. Cultural practices that may assist in suppressing pests include narrow or wider plant spacings, conservation or zero-tillage, the planting of cover crops or the use of organic mulches, mowing weeds, and using traps for insects or animals (GAO 2001). An example of a suppression tactic is the use of organic amendments to control nematode populations in production fields (Oka 2010).

### Botanicals or plant extracts for pest control

Organic and traditional farmers in the tropics often rely on the use of plant or botanical extracts to manage weeds or pests on the farm. In
general botanicals are only used sporadically, and farmers may use them once or twice during a crop cycle in cases when a pest reaches economic threshold levels. The effectiveness of botanicals is likely to be location and crop specific, so it is recommended that all products be used only on a trial basis. Usually, it is most effective to use locally available resources as sources of botanical extracts. Indigenous knowledge and the experience of local practitioners is important to help identify local botanical species for potential use as allelochemicals or for pest control.

**Organic mulches**

Organic mulches assist with pest management programs by providing a barrier against weed growth, and by preventing soil particles or microbial diseases within the soil from contacting the above-ground crop parts. Because several pests spend part of their life cycle in the soil (such as thrips or aphids).
Botanical extract species examples

The following examples illustrate some of the many botanicals used by farmers for pest control. All commercial products need to be evaluated for their effectiveness under local environmental conditions, as products that are shown to be effective in one region may not be effective in other environmental conditions.

**Disease control**

- Garlic extract for control of *Phytophthora infestans* (Keqiang and van Bruggen 2001).
- Plant extracts from *Inga marginata*, *Miconia argyrophylla*, and *Myrcia fallax* were effective for control of anthracnose (*Colletotrichum lindemuthianum*) (Andrade Pinto et al. 2010).
- Olive mill wastewater for *Verticillium dahlia* control (Yangui et al. 2010).
- Moringa (*Moringa oleifera*) leaf extracts in combination with *Trichoderma* inoculations were effective for control of damping-off and stem rot caused by *Sclerotium rolfsii* (Adandonon et al. 2006).

**Insect or arthropod control**

- *Humulus lupulus* for control of Colorado potato beetle (Gökçe et al. 2006).
- Commercial products made from plant-derived essential oils such as cottonseed, clove, garlic oil, citric acid, canola, coriander, and neem were effective against some pests such as spider mites (Cloyd et al. 2009).
- Quinones derived from *Caesalpinia sappan* heartwoods, *Diospyros kaki* roots, *Cassia obtusifolia* seeds and *Origanum vulgare* leaves showed potential for caterpillar (cabbage looper, *Trichoplusia ni*) control in cabbage (Akhtar et al. 2012).
- Extracts from *Chenopodium ficifolium* were effective for control of melon aphids (*Aphis gossypii*) in cucumber (Dang et al. 2010).

**Weed control**

- The medicinal plant *Pituranthos tortuosus*, showed allelopathic potential for the control of weeds, as well as disease (*Fusarium graminearum*) and insect (*Cryptolestes ferrugineus* and *Culex pipiens*) control (Krifa and Haouala 2011).

**Nematode control**

- Plant extracts of *Brassica* seed meal, poinsettia shoots, and spurge shoots showed potential for sting nematode (*Belonolaimus longicaudatus* Rau) control (Cox et al. 2006).
- Extracts from the desert soap bark tree (*Quillaja saponaria*), marketed in commercial formulations may be effective for the control of root knot nematodes.
as leafminers and thrips) it is possible that mulches may prevent some pests from completing their full life cycle, and in so doing, reducing their populations.

Organic mulches may also help to moderate soil temperatures, which may increase the activity of beneficial organisms. For instance, cooler soil temperatures may improve the activity of ground dwelling predators, such as spiders and ground beetles. Lower soil temperatures in warm areas also promote the activity of soil fauna decomposers such as earthworms, ants, and millipedes resulting in possible improved biocontrol and suppression of specific pest populations (Tian et al. 1993; Blanco-Canqui and Lal 2009). Organic mulches have also been shown to increase microbial activity including that of bacteria, actinomycetes, and soil fungal populations. Mulches may also alter the reflection of light as compared to bare-ground soils, making it more difficult for pests, such as aphids or leafhoppers, to find their target host.

An example of organic mulches for pest control is the use of rice-straw mulch for the control of bean flies in soybeans in Indonesia (Hirano et al. 1993). Organic mulches have also been effective for the control of the Colorado potato beetle in potato (Stoner 1993) and in preventing the spread by rain of soil-borne diseases in strawberry (Ellis et al. 1998). In the Pacific islands, mulching has long been a traditional practice, especially in atoll agriculture, for weed control and to build up the soil. In some Pacific islands, intricate mulching systems include the use of over 20 coastal plant species, such as the leaves of *Guettarda speciosa*,

Figure 25. Trellis systems, as observed here in an organic bean farm from Kamisato Branch, in Saitama Prefecture, Japan, help to maintain crop quality and improve ventilation along the rows, which reduces humidity within the field, resulting in lower disease incidence. Notice the white strips, which are pheromone traps, laid along the length of the row, and about 30 cm above the soil level, to attract, monitor and disrupt caterpillar pest populations.
Tournefortia argentea and Sida fallax, for the production of crops such as giant swamp taro (Cyrtosperma merkusii), pandanus (Pandanus spp. or screw pine), and breadfruit (Artocarpus altilis). In Pacific islands, coconut palm, and banana leaves are also commonly used along with local grasses, ferns, and other leaves, for use as mulches, or worked into the soil to improve fertility (Thaman 1992).
Cover crops and crop diversification

Crop diversification, as opposed to monoculture plantings, consists of having two or more plant species growing in a plot of land. Diversification may occur through intercropping, crop rotations, agroforestry systems, and the use of cover crops. Crop diversification assists with weed and pest management, through the introduction of plant species that are more effective in smothering weed growth, or to help prevent pests from reaching their target host. In many cases plant species also assist in attracting beneficial organisms that help to manage pest, weed, or disease populations.

The use of vegetative ground covers or cover crops is an effective way to improve plant diversification and to help manage weeds and pests. Cover crops can improve soil quality, protect the soil from erosion, smother weed growth, facilitate traffic and transportation within the farm, and may also provide habitat for beneficial organisms both below and above ground.

Growers need to be careful about species selection because cover crops may host undesirable pest populations such as nematodes, or above-ground pests. The cover crops may become weedy themselves if their growth is left unchecked or if they are allowed to seed.

Examples of cover crops that may be used in papaya plantings in Hawai‘i include perennial peanut, carpet grass (*Axonopus* spp.), and St. Augustine grass (*Stenotaphrum secundatum*). However, perennial peanut and carpet grass may host populations of reniform nematodes, while perennial peanut and St. Augustine grass may host high populations of root knot nematodes. On the other hand all three species also host large

Figure 30. Year-round full ground cover is desirable in tropical agroecosystems to improve soil quality and minimize erosion, as observed in this organic farm in Maui, Hawai‘i, where pineapple is grown in an open field between orchard trees.
populations of beneficial nematodes, which may assist in suppressing soil-borne pests (DeFrank 2008). Because of its shade tolerance, carpet grass is often planted in Hawai‘i coffee orchards. In these orchards ‘Tropic Lalo’ paspalum (*Paspalum hieronymii*) is often grown on access roads and equipment-bearing areas, due to its hardiness. In other tropical areas carpet grasses are also often grown and grazed under oil palm, rubber, and coconut plantings (Smith and Valenzuela 2002a).

St. Augustine, or buffalograss, is another shade tolerant grass that can be grown in the understory of orchards. While St. Augustine grass is often grown as a pasture or turf, it is also grown as a cover crop in orchards such as macadamia, guava, and banana. St. Augustine grass performs well in mature orchards under a full canopy (Smith and Valenzuela 2002b).

In degraded tropical soils where phosphorus (P) is often deficient, cover crops may be able to assist by increasing the availability of P. Cover crops may be able to increase P availability by mining P from the lower soil profiles, by conversion of fixed inorganic P into an available form in organic matter. Cover crops may also improve the cycling of available P through root exudation.

Legume cover crops may be used effectively, as intercrops, or as part of a rotation program to help reduce nematode populations in the soil. Research conducted in Kenya showed that the cover crops tree marigold or Mexican sunflower (*Tithonia diversifolia*), silver leaf desmodium (*Desmodium uncinatum*), marigold (*Tagetes minuta*), leucaena (*Leucaena leucocephala*) and sunn hemp (*Crotalaria juncea*) were effective in reducing populations of root knot nematode by up to 80%, when planted in a rotation with beans (Kimenju et al. 2008).

Hedgerows, alley cropping, and windbreaks are other ways that farmers can increase diversity in the farm. Examples of leguminous species that may be used as windbreaks include glicicidia or madre de cacao (*Gliricidia sepium*), pigeon pea, and leucaena. The use of nitrogen fixing trees as fence posts in “live fences” in Colombia was found to have increased field biodiversity. This could result in the provision of additional ecological services to nearby production fields such as improved nutrient cycling and increased activity of beneficial organisms that would help to prevent the outbreak of pests and diseases (Pulido-Santacruz and Renjifo 2011). In general, alley cropping systems have been found to provide several ecosystem services including the improvement of soil fertility, water conservation, control of soil erosion, and provision of food, feed, or fuelwood (Tsonkova et al. 2012).

**Crop rotations**

The use of crop rotations is a key strategy to maintain crop productivity and soil fertility as well as to break weed, arthropod, and disease pest cycles. Both rotational and intercropping planting programs can effectively reduce weed populations, based on improved competition for resources, space, or other factors (Liebmann and Dyck 1993). In agroforestry or
orchard systems, within-field rotations can be used for the annual cash crops that may be intercropped as part of the agroforestry system.

Crops and varieties used in rotation programs should be compatible with respect to nutrient and water use in the farm. Crops in the rotation are selected to match nutrient uptake from the soil and to exploit different sections of the soil profile. For instance, combining non-legume crops with leguminous species has long been practiced as part of rotations or intercropping systems. This has been shown to increase soil quality, soil microbial activity, soil nitrogen levels, and yields of the non-legume crop. Research showed that rotating corn with either soybean or cowpea increased corn yields by 68% and 49%, respectively, compared to continuous maize plantings (Yusuf et al. 2009).
Crop rotations may effectively reduce nematode pest populations. By growing crops that are resistant to or non-hosts of specific nematode species, it may be possible to lower nematode counts in the soil to allow for the production of a subsequent susceptible crop. For example, populations of the soybean cyst nematode may be lowered by rotating soybeans with non-host crops such as sorghum or corn.

With respect to disease control, it is important to note that some viruses and bacteria are more difficult to control with soil rotations because they may have a broad host range or because they are long-lived in the soil. Examples of diseases that are more difficult to control with crop rotations include bacterial wilt, white mold \((Sclerotinia sclerotiorum)\), \(Rhizoctonia\), \(Pythium\) spp., \(Phytophthora\), and \(Fusarium\). For some diseases that tend to persist in the soil, such as \(Fusarium\), rotations of 5–12 years are recommended for susceptible crops such as watermelon.

When planning rotation programs, it is important to avoid following crops with other species from the same botanical family, as crops from the same family are likely to host the same pests and diseases. For example, solanaceous crops such as tomato, pepper, eggplant, and potato should not be planted one after the other.

**Soil biocontrol: enhancement of soil microbial activity as a strategy for pest and nematode control**

In the same way that biodiversity is promoted above ground, a biodiverse microbial population is also desirable in the soil. A rich soil fauna helps to recycle nutrients, assist with the decomposition of plant residues, and may also assist with the biological control of weeds, arthropod pests, and soil diseases. Research indicates that the multiple and complex interactions that occur when a diversity of microbial organisms interact in the root zone are more effective for pest and disease suppression than the activity of any single microbial species that may be applied or relied upon for the control of specific pests (Whipps 2001; Mendes et al. 2011).
Research conducted on vegetable farms of West Java, Indonesia showed that soil microbial activity, as measured by enzymatic activities in the soil, were greater overall in organically managed fields than in conventional fields receiving synthetic fertilizer and pesticide applications. Similar results have been observed in temperate regions (Moeskops et al. 2010).

Arbuscular mycorrhizal populations have been shown to improve nutrient access to crops, allowing them to tolerate periods of temporary drought or low nutrient conditions, and may also assist to increase tolerance to disease attack, as shown in coffee (Andrade et al. 2009). In Thailand, mycorrhizal inoculation of tangerine trees resulted in improved plant growth and reduced disease severity from infection by *Phytophthora parasitica* (Youpensuk et al. 2012). Similarly, in India apple plants that were inoculated with mycorrhizal populations showed improved survival, growth and tolerance to attack by stem brown canker (*Botryosphaeria ribis*). This destructive disease affects up to 90% of the apple orchards in India, usually first attacking stressed or weakened trees (Krishna et al. 2010). Mycorrhizal inoculations have also improved tolerance to attack by diseases and nematodes in coffee, banana, peach, and almonds. As a result, researchers in Brazil recommend that coffee seedlings be inoculated at the nursery stage, to improve their tolerance to environmental stress, nematodes, and diseases (Andrade et al. 2009).

Soil mycorrhizal populations are typically found in traditional crop or agroforestry systems. A survey of coffee orchards in Mexico found a total of 33 different mycorrhizal morphospecies, with *Glomus clarum* being among the dominant ones. Compared to the levels observed in the unshaded coffee monocultures, especially during the dry season, the activity and diversity of mycorrhizal populations in the coffee orchards were similar to those observed in nearby forested areas, and the greatest

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**Examples of diseases that may be controlled with crop rotations**

**Beans.** Common blight (*Xanthosoma campestris pv. phaseoli*); Halo blight, (*Pseudomonas syringae pv. phaseolicola*) (2–3 years); rhizoctonia (4 yrs); rust (*Uromyces phaseoli*); and anthracnose.

**Brassicas or cole crops.** Alternaria leaf spot; black rot (*Xanthomonas campestris*); bacterial leaf spot (*Pseudomonas cichorii*); downy mildew (*Peronospora parasitica*); rhizoctonia; and white rust (*Albugo*).

**Cucurbits.** Alternaria leaf spot; anthracnose; gummy stem blight (*Phylllosticta citrullina*); scab; angular leaf spot (*Pseudomonas syringae*); and fruit rots.

**Sweet corn.** Northern and southern leaf blights (*Helminthosporium* spp.); Brown Leaf Spot (*Physoderma maydis*); and anthracnose.

**Tomato.** Early blight (*Alternaria solani*); Septoria leaf spot; anthracnose; bacterial speck (*Pseudomonas syringae* pv. *tomato*); late blight (*Phytophthora infestans*); Southern blight (*Sclerotium rolfsii*); *Sclerotinia*; and *Verticillium* wilt.
activity occurred under the traditional forest-shaded systems, (Arias et al. 2012).

Beneficial nematodes are another important component of the soil fauna that can play an important role in soil biological control. Beneficial nematodes are often effective in the control of important insect pests. In California, for instance, beneficial nematodes may be effective for the control of the citrus root weevil (*Diaprepes abbreviatus*), which is a major pest of citrus orchards. A survey of citrus orchards in California determined that soil quality including soil texture and organic matter content may impact the activity and population of beneficial nematodes (Kaspi et al. 2010).

As an example of the huge microbial biodiversity in soils, a survey of *Rhizoctonia* suppressive soils in the Netherlands found over 33,000 different bacterial and archaea (members of an ancient family of microbes) species. Among these, a few distinct bacterial groups or phyla appeared to be associated with the suppressive activity observed in those soils (Mendes et al. 2011).

Proper stewardship of the soil to promote adequate soil tilth, texture, and organic matter levels, is more likely to host a richer soil fauna, which in turn may enhance internal soil microbial biocontrol mechanisms on the farm. Along with rich microbial activity, well managed agricultural soils also host a rich macrofauna population. As with microbial activity, management techniques that increase the soil macrofauna population include a continuous soil cover with mulch or vegetation and vegetational diversity in time and space. Surveys conducted in Honduras showed that well managed indigenous agroforestry systems host rich macrofauna populations of up to over 1,900 organisms per square meter (Pauli et al. 2011). A rich soil macrofauna has a positive impact on the soil’s physical, chemical, and biological properties and is more likely to have a positive impact on soil microbial activity.

**Using organic amendments for pest control**

The use of organic amendments is considered to be a viable alternative to meeting the nutrient needs of crops. Organic amendments may help to improve biological diversity within the farm by promoting the activity of beneficial arthropods as well as microbial activity in the soil. Organic amendments such as composts have been shown to be an efficient medium to support a complex of beneficial microorganisms for the control of plant diseases (Hoitink and Boehm 1999).

The use of organic amendments “fortified” with beneficial microorganisms consisting of antagonistic *Aspergillus* and *Penicillium* fungi was shown to be effective for the control of *Fusarium*, an important soil-borne disease in cucurbits (Zhao et al., 2011). The combined application of organic amendments or fertilizers with beneficial disease antagonists was also observed in India for the control of fungal diseases in the bio-energy crop jatropha (*Jatropha curcas*) (Latha et al. 2011).
Crop or cover crop residues may also be used as amendments to alter microbial populations in the soil. The effective use of rapeseed (*Brassica napus*) amendments as a biofumigant has been observed for the control of soil diseases, weeds, and nematodes (Hu et al. 2011; Rahman et al. 2011; Valdes et al. 2012). Organic amendments, in the form of sugarcane plant residues, bagasse or sugarcane refinery sludge were also found to be effective in reducing nematode pest populations in banana (Tabarant et al. 2011). Compost amendments as well as the application of wet or dry molasses have also been observed to reduce nematode populations in Hawai‘i (Valenzuela and Hamasaki, 1995; Schenck, 2001). While wet molasses may be mechanically injected into the soil, dry molasses may be easier to handle and apply for small-scale operations.

Recommendations for the use and application of organic amendments for the control of specific disease, weed, or nematode species are difficult to make because disease response to amendments is often site specific. The composition of organic amendments is also likely to vary from site to site and interact in varied ways with the existing complex of biofauna in the particular microclimate. Nevertheless, general observations and recommendations can be made with respect to the use of organic amendments. Local research, observations, and experience of local practitioners can further refine recommendations for specific locations, cropping systems, and seasons.

**Insectary plants**

Crop diversification such as the use of rotations, intercropping, and hedge or border rows are strategies that may be used to attract and conserve beneficial arthropod species on the farm. Specific plant species called insectary plants may also be introduced into the farming system with the goal of attracting beneficial arthropods to the farm. These plants may help attract beneficial arthropods by providing alternative sources

Figure 33 (left). Yellow mustard, rapeseed, or non-GMO canola cover crops provide a good ground cover, and also act as a biofumigant for soil disease and weed control. In this organic farm on Maui, Hawai‘i yellow mustard is grown as a rotational cover crop. The flowering field may also act as an insectary by attracting bees and beneficial insects to the farm. Figure 34 (right): Composts may be prepared in solid or in liquid form for field application, as observed in this organic nature farming experiment station in Ohito, Japan.
of nectar, shade, moisture, and by hosting their prey. If flowering plants are used, insectary plants may also attract bee populations. Attracting bees is of particular benefit in areas that have experienced declines in domestic bee populations. The use of insectary plants has also been referred as the “banking” method for the enhancement of biological control on the farm (Huang et al. 2011), referring to the build-up and conservation of beneficial species on the farm.

The research literature has documented several plant species and cover crops that attract beneficial arthropods (Valenzuela 1994). This information may be used as a general guideline. The attraction to particular beneficial insects may vary from location to location and may vary depending on the particular complex of crops and wild species present. Some species that are typically used as insectary plants include buckwheat, sunflower, and rape or flowering mustard, as well as cover crops or border rows of alfalfa, and sorghum.

Growers should become familiar with the key beneficial arthropod species on their farm, such as lady beetles, spiders, lacewings, or syrphid flies (Radovich 2010). Specific insectary plant species may then be selected to attract greater numbers of particular beneficial species into the farm. The success of the insectary system may be determined by monitoring counts or activity of the beneficial arthropods prior to and after introduction of the insectary species into the farm. Insectary plants may be planted as border or windbreak rows, interplanted in rows together with cash crops, or planted strategically as insectary “patches” or corridors around the farm.

In Florida, bell pepper growers have used sunflower or weeds such as Spanish needle (Bidens spp.), as insectary species to attract beneficial populations of the pirate bug (Orius insidiosus) to control outbreaks of thrips (Funderburk and Weiss 2009). In England the use of insectary plants as hedges or as part of short rotations with cash crops increased the population of aphid parasitoids (Langer 2001).

Weed species may also be used selectively for their value as insectary plants. Weedy species often host high populations of beneficial organisms, as observed in a survey of Florida vegetable farms (Schuster et al. 1991). This means that selective weeding may allow for the increase population of some beneficial species (Genung et al. 1978). Field surveys have indeed shown that in many instances the populations of beneficial arthropods is greater in weedy than in weed-free fields (Alston et al. 1991). For instance, in Germany, weedy species were found to attract beneficial spider populations (Lemke and Phoeling 2002).

In tropical regions, it is important to rely on the knowledge of local practitioners to help identify specific weedy and indigenous species that may be used to attract beneficial organisms, as shown with the consultation of Mayan practitioners in southern Mexico (Chemas and Rico-Gray 1991). As with several other organic or agroecological techniques, many of the recommendations that are developed will be location specific.
SUMMARY

The agroecological approach to pest management is based on concepts that support the creation of a healthy growing environment and healthy plants. The premise behind this approach is that well designed and healthy landscapes, a healthy soil, and healthy plants are more likely to host populations of beneficial organisms that provide several ecological services such as improved energy, nutrient, and water cycles. This in turn helps make plants more resilient to environmental stress and pest attacks. A healthy agroecosystem, based on crop diversification is more likely to attract or host populations of beneficial organisms and at the same time repel or prevent the incidence of pest outbreaks.

In order to continue to improve and refine the agroecological approach to pest management, it is important to continue research and develop a better understanding of the many ecological interactions that occur at the farm and landscape level. It is important to understand how these interactions may affect soil quality and fertility, beneficial insect and pest levels, and the growth of cash crops and wild species. As we develop a greater understanding of the underlying mechanisms that have an impact on the function of agroecosystems, we will be better able to fine-tune strategies to manage pest infestations on the farm.

Key recommendations for the management of pests on the farm

1. Synchronize soil moisture levels with water uptake by plants.
2. Apply organic amendments to improve soil organic matter and soil quality.
3. Consider making and applying composts. Composts provide an ideal medium for biological activity, and plant growth, serve as a source for the slow-release of nutrients, and assist with the management of raw plant residues on the farm.
4. Have as much ground cover protection of the soil as is feasible. This may be in the form of organic mulches, intercropping, and crop rotations. Ground cover protection prevents erosion, minimizes the spread of diseases, and maintains soil fertility.
5. Promote vegetational diversity. This may be accomplished with rotations, intercropping, cover crops, borders and hedgerows, crop diversification, and by growing several cultivars or varieties from the same crop.
6. Use crop varieties that are adapted to the particular microclimate.
7. Select crop varieties that are more efficient for water and nutrient uptake, that are more competitive against weeds, and that have tolerance or resistance to pests.
8. Use open-pollinated varieties to select and develop varieties adapted to the particular microclimate. Coordinate with farmers in the area to develop a community seed-bank of adapted varieties.
9. Practice rotations to improve soil fertility and to break pest, disease, and weed reproductive cycles.

10. Use cover crops to improve vegetational diversity and to help break pest, disease, and weed reproductive cycles.

11. Learn to identify key pests in the farm and to identify weak links in their life cycles.

12. Select cover crops, non-crops, and cash crops and varieties that are compatible with each other. Compatibility between species helps to prevent pest outbreaks, and helps to optimize the use of water, nutrients, sunlight, and space on the farm.

13. Periodically scout and monitor pest and weed infestation levels on the farm. Use crop-growth stages to better diagnose potential losses, and to identify proper control measures based on the level of pest damage and stage of crop growth.

14. Develop a strategy to attract and conserve beneficial arthropod species on the farm. This may be in the form of vegetational diversification, or by establishing insectary border rows or patches on the farm.

15. Protect pollinators on the farm. Establish habitats that attract pollinators (such as buckwheat) and coordinate with neighboring farmers to prevent untimely pesticide applications.

16. Develop a landscape-level pest management approach. Coordinate with fellow farmers in the community to establish area-wide management programs. This may involve the planting of green corridors to promote the movement and activity of beneficial species, establishing “crop-free” periods during the year to minimize viral infestations, and coordinated educational activities to stay updated with the latest management strategies.

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