Sustainable management of soil-dwelling pests

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Sustainable agriculture is undoubtedly one of the most important concerns nowadays, considering both human population demography and evidence depicting that crop productivity which relies on chemical control is plateauing. Since conventional agriculture poses increasing environmental and health risks, ecological research is providing promising solutions for crop protection against herbivore pests. Whereas most research has concentrated on above-ground systems, several major crop pests feed exclusively on roots (Kergunteuil et al., 2016). Many of the insects spend at least a small part of their life cycle in contact with the soil whereas, true soil-dwelling pests spend most of their developmental time in this medium. Soil-borne pests are often difficult to monitor and control due to the logistical chore of sampling their populations or the use of control tactics on them. Widespread use of soil insecticides is inevitable despite their non-targeted effects and environmental impact. This results from a lack of information about the actual impact of the target pests on crops and a lack of practical and cost-effective methods for identifying infested fields. A commonly used tactic to control soil pests namely, insecticide application to soil can be very disruptive and negatively impact the functional diversity of soil communities. As a result, a comprehensive approach is required to keep these often-invisible pest populations under control and below economic thresholds. Agricultural land accounts for 25% of the earth's terrestrial surface and is a major contributor to global ecosystem health (Landis, et al., 2000). Annually, around 2 million tonnes of pesticides are being used worldwide, with China being the largest consumer, followed by the United States and Argentina, which is rapidly increasing. However, global pesticide use is expected to increase up to 3.5 million tonnes by 2020 (Sharma et al., 2019). Annual crop losses resulting from insect damage could exceed 15%. Root pests have always caused extensive crop damage and are still responsible for a large portion of global yield loss. The grape phylloxera, the root-feeding aphid Daktulosphaira vitifoliae, had nearly wiped out the entire European grape production. Wireworms (Coleoptera: Elateridae) feed a variety of crops, including cereals, potatoes, carrots, sugar beets, and fruit orchards. The annual cost of the damage caused by the western corn rootworm (*Diabrotica virgifera virgifera*) in Europe and the United States could be much higher than $1 billion. Damage caused by cane grubs (*Dermolepida albohirtum*) cost sugarcane producers by more than $10 million in the southern hemisphere. In comparison to above-ground herbivores, developing sustainable solutions to reduce below-ground herbivores is scarce. One of the main reasons is undoubtedly their ambiguous life cycle, which leads to the "out of sight, out of mind" paradigm (Hunter, 2001). The two pillars of agroecosystem health optimization are habitat manipulation and soil fertility enhancement. These two include several strategies for dealing with soil arthropods and are discussed below.

Cultural methods

1. Reduce and/or disrupt pest habitat in and around crop
2. Field sanitation, which includes burning previous crop debris and destroying non-crop pest habitat, reduces insect pests that overwinter on plants growing near field edges. Tillage can disrupt

the life cycle of insect pests, and expose them to predators, which overwinter in the soil as eggs, pupae, or adults. Excessive tillage can hasten the decomposition of organic matter in the soil and deplete the food source. Subterranean and foliar insect pests are both affected by tillage practices. In natural systems, infrequent disturbance of soils preserves food webs as well as the diversity of organisms and habitats. Regular disturbance of agricultural soils disrupts ecological linkages, allowing adapted pest species to proliferate without being dampened by natural controls.

3. Crop planting can be adjusted in both space and time to limit the growth of large pest populations.
4. Divert pest populations away from crops.
5. Reduce yield loss due to insect damage: Planting genetically resistant and tolerant crop varieties can improve host tolerance to damage.
6. Resistant cultivars: Breeding cultivars and rootstocks resistant to specific pests and diseases have long been used to control below-ground pests. Rather than directly breeding for disease resistance, another strategy is to breed crops for root exudate characteristics that suppress pests, either by producing bioactive compounds or by recruiting disease-suppressive microbes.
7. Planting practices: In the case of potatoes, planting depth is important because the potato tuber moth is unable to lay eggs through soil cracks and thus prevents infestation.
8. Mulches: Farmers use organic, synthetic or plastic and natural materials for mulching. Straw mulch can reduce Colorado potato beetle activity in the early season by creating a micro-environment that increases the number of predators such as ground beetles, lady beetles, and lacewings. Mulching helps to keep weeds at bay.
9. Habitat diversification: Many pests prefer to feed on particular host plant species. This preference can be used to reduce pest pressure on the crop. Crop rotation, intercropping, trap cropping, and strip cropping can significantly reduce pest load. Cover crops are typically planted to sequester soil nutrients while also adding organic matter, preventing erosion, and adding nutrients. Beneficial insects can find food and shelter in cover crops. Trap crops draw pest species away from the main crop into a defined site where they can be destroyed.
10. Water management: Irrigation can suppress soil-inhabiting pests by suffocating them or exposing them to bird predation on the soil surface. When high-humidity microenvironments are created, several naturally occurring insect pathogens, particularly insect-pathogenic fungi, provide effective pest suppression. Irrigating potato crops during tuber formation can help to reduce potato scabs. Furrow irrigation, rather than sprinkler irrigation, can control anthracnose of beans, early blight, and charcoal rot of potatoes.
11. Soil organic matter: The ability of host plants to resist or tolerate insect pests and diseases is linked to optimal physical, chemical, and, most importantly, biological soil properties. Soils with a high organic matter content and active biological activity have good soil fertility, as well as complex food webs and beneficial organisms that prevent infection. Several studies have also found that farming practices that cause nutritional imbalances can reduce pest resistance (Magdoff and van Es, 2000).

Ecologically-based pest management (EBPM) strategy

The goal of EBPM is to create soil and above-ground conditions that encourage healthy plant growth, suppress pests and promote beneficial organisms. Fertility practices replenish and maintain a high level of soil organic matter while also increasing the number and diversity of soil macro and microbiota (McGuiness, 1993).

Pest suppressive mechanisms

1. Competition: High levels and diversity of soil microbes reduce soil-borne pathogen populations or infectivity. Microbiota-rich soil reduces the risk of

epidemic outbreaks caused by soil-borne pathogens (Campbell, 1994).

2. Induced resistance: Plants can develop resistance to a wide range of soil-borne and airborne pathogens when treated with compost, compost extracts, or certain microbes (both pathogenic and non-pathogenic) (Kuc, 2001).

3. Natural enemies: Feeding the soil encourages the growth of soil mesofauna, which can serve as alternate prey for natural enemies like carabid beetles and spiders, allowing them to build large populations that can respond quickly to pest outbreaks (Purvis & Curry, 1984).

4. Nutrient supply buffering: Humus and microbial biomass provide a more gradual and balanced release of nutrients than synthetic fertilizers. Crops are more resistant to pests and diseases when their mineral nutrition is more balanced.

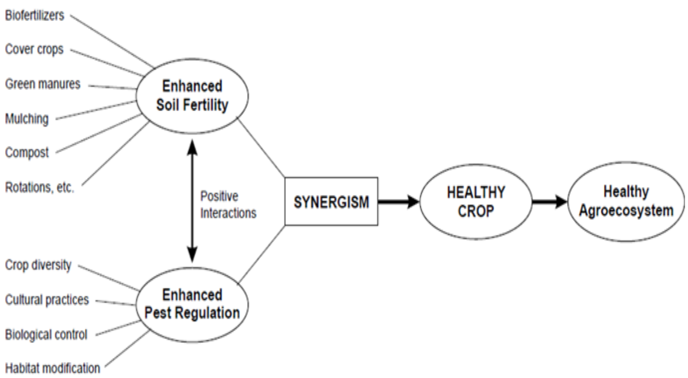

Fig.1 The potential synergism between soil fertility management and IPM

5. Reduced stress: Soils with high humus and biodiversity have a greater capacity to absorb and store water, reducing water stress. Probably due to regulated C and N metabolite release from hairy vetch decomposition. Cover-cropped tomato plants displayed distinct expression of selected genes, resulting in more efficient utilization and mobilization of C and N, improved disease resistance, and increased crop longevity.

6. Soil solarization: Natural solarization or Ultraviolet-protected plastic is recommended in some crops. Certain types of organic matter can be also added. Residues from brassica crops such as broccoli and mustard in the solarization process release plenty of volatile compounds that are toxic to many pests. Soil solarization can provide good pest control up to 8 to 10 inches deep.

7. Pheromone traps: Mainly used for monitoring, mass trapping and mating disruption.

8. Bio fumigation: The process of growing, macerating, or incorporating specific Brassica or related species into the soil, resulting in the release of isothiocyanate compounds (ITCs) from the hydrolysis of glucosinolate (GSL) compounds found in plant tissues (Kirkegaard et al., 1997). To control soil-borne pests and diseases, use biologically active plants as green manures, cover crops, or rotation crops. Glucosinolates are organic compounds found in broccoli, cauliflower, mustard, rapeseed, and horseradish. ITCs are general biocides that behave similarly to commercial pesticides at high concentrations. Mustard and sorghum are two common bio-fumigant crops. The fumigation effect is caused by glucosinolates (GSLs) or cyanogenic glucosides, which are found in Brassicas and specialized sorghums. When the biofumigant crop is macerated, the enzyme myrosinase breaks down GSLs and produces isothiocyanates (ITCs) immediately. Many soil-borne pests, diseases, and weed seedlings are highly susceptible to the toxicity of ITCs. To keep ITCs in the soil, the biofumigant crop must be finely macerated, directly incorporated, and the soil surface sealed with irrigation, rain, or rolling. Potential benefits include soil erosion prevention, nutrient recycling, improved soil structure, and soil organic matter preservation. Mustard can also be used to repel many insects (wireworms) and pests.

9. Biological control: Because the distribution of root herbivores in soils is relatively limited, they are more persistent locally than above-ground pests, favoring

constant and localized applications of bio-control agents in the field. Biological pest control is based on two primary forces:

a) Bottom-up (i.e., the effect of plants on herbivores)

b) Top-down pest control (the effect of predators and parasites on herbivores) (Hairston et al.,., 1985; Price et al.,., 1980)

The inability of microbes to persist in habitats exposed to ultraviolet radiation or desiccation is a key constraint of microbial control, but soil, which affords a conducive habitat for microbes and a reservoir for entomopathogens, should be a better environment for microbial control Hochberg and Holt (1997). Approach used to optimize the isothiocyanate-related biofumigation potential of incorporated Brassica green manures. (Matthiessen and Kirkegaard, 2004).

10. Botanical pesticides

Azadirachtin-treated soil was repellent to wireworms for up to 17 days after application (Cherry and Nuessly, 2010). Commercially available botanical pesticides are derived from plants such as pyrethrum (*Tanacetum cinerariifolium*), neem (*Azadirachta indica*), sabadilla (*Schoenocaulon Officinale*), tobacco (*Nicotiana tabacum*), and ryania (*Ryania speciosa*). Garlic (*Allium sativum*), turmeric (*Curcumalonga*), rosemary (*Rosmarinus officinalis*), ginger (*Zingiber officinale*), and thyme (*Thymus vulgaris*) are other plants with pesticidal properties (Arnason et al., 2012).

Conclusion and future directions

More research comparing soil arthropod pests on plants treated with synthetic versus organic pesticides and fertilizers along with several environmentally friendly integrative control options is specifically required. Understanding the underlying effects of extensive agriculture on plant health may result in the development of new and improved integrated pest management and integrated soil fertility management programme designs. If achieved with a clear-cut knowledge about the relationships between soil fertility and insect pest attack, we will be better

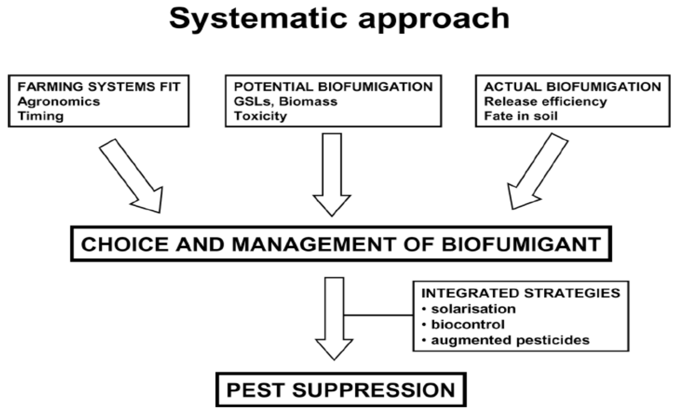

Fig. 2. Diagrammatic depiction of the systematic

positioned to convert conventional crop production systems to those that incorporate agro-ecological strategies to optimize soil organic fertilization, crop diversity management, and more natural pest control systems without incurring yield penalties.

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