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Review

The potential use of cover crops for building soil quality and as trap crops for stinkbugs in sub-tropical fruit orchards: Knowledge gaps and research needs

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There is a renewed interest in cover crops and the role they can play in the pursuit of sustainability in agroecosystems. These versatile crops have not only demonstrated the ability to improve soil but numerous species have also shown the potential to act as trap crops for insect pests. We suggest that cover crops may concurrently serve both these purposes in sub-tropical fruit orchards, depending on the choice and application thereof. We recommend that cover crops should be investigated for this dual purpose and propose a selection of soil health indicators for measuring the resulting changes in the soil. We suggest that cover crops will be more effective if the biodiversity within and adjacent to the main crop can be increased through habitat manipulation to enhance natural enemies of pest insects. A selection of cover crops that have the added potential as trap crops for stink bugs have also been identified for investigation.

Key words: Cover crops, soil quality, soil health indicators, trap crops, sub-tropical fruit orchards, diversification, natural enemies, pentatomid, stink bugs.

INTRODUCTION

Agroecological conversions aim to provide sustainable solutions for agricultural endeavours and food security. Two of the important focus areas in these conversion processes include crop nutrition and crop protection. Sustainable organic solutions for crop nutrition are based on the foundation of high quality soils which may provide healthy growing media for plants. Nicholls and Altieri (2004) postulate that ecosystems become productive when a balance of rich growing conditions prevail that allow crops to become strong and healthy, which in turn render them resilient to stress and adversity. Soil organic matter influences almost all characteristics related to healthy soils. Practices that promote good soil organic matter management are thus the very foundation for high quality, healthy soils and consequentially result in more sustainable and thriving agricultural ecosystems (Magdoff and van Es, 2009).

Sustainable organic solutions for crop protection are based on an array of cultural and biological management strategies. These have to cater for pests, diseases and

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adverse environmental conditions which may affect plant survival and quality. Fruit trees are susceptible to attacks by a wide spectrum of insects at all stages of their growth just like all other annual and perennial crops. Virtually all herbivore insect pests, however, show distinct preferences for certain plant species, cultivars, or certain crop stages (Hokkanen, 1991). Attractive alternative host plants can, therefore, potentially be used to lure pests away from the main crop to the more attractive host plants, commonly called trap crops. Cover crops could serve both the purposes of promoting soil organic improvement and of trap crops for pest insects depending on the choice and application thereof. Schipanski et al. (2013) estimated that cover crops could increase 8 of the 11 ecosystem services they investigated without negatively influencing crop yields.

AGROECOLOGICAL CONVERSIONS

What is a sustainable agroecosystem? It is one that maintains the resource base upon which it depends, relies on a minimum of artificial inputs from outside the farm system, manages pests and diseases through internal regulating mechanisms, and is able to recover from the disturbances caused by cultivation and harvest (Altieri, 1989; Buchs, 2003; Dalsgaard et al., 1994; Edwards et al., 1990; Gliessman, 2007). A number of processes fundamental to the sustainable functioning of ecosystems have been identified. These include the flow of energy, cycling of nutrients, population regulating mechanisms and a state of dynamic environmental equilibrium where succession approaches a condition of stability within a particular ecosystem (Altieri, 1989; Gliessman, 2007; Moonen and Barberi, 2008). It is important to understand these processes in order to apply them successfully in agroecosystems (Malézieux, 2012; Ratnadass et al., 2012). The main strategy of the agroecological approach to achieve sustainability is to apply these ecological processes and components to the design and management of agroecosystems. Pure organic conversions may solve all or most of the problems associated with conventional farming practices, but will not necessarily prevent problems from arising in the first place (Gliessman, 2007). When agroecosystems are redesigned to achieve natural ecosystem-like characteristics by incorporating ecological processes, the most important causes of many of these problems are addressed and ecological sustainability may be achieved. Studies have shown that conversion of agroecosystems improves the overall sustainability of most of these cropping systems (Benayas and Bullock, 2012; Caporali and Campiglia, 2001; Evenari et al., 1961; Fernandez et al., 2008; Gliessman et al., 1996; Letourneau et al., 2011; Pywell et al., 2011; Reeve et al., 2011; Swezey et al., 1994, 1998). Although there is still a long way to go to achieve sustainability, these conversions have increased the components of sustainability. Farmers have also achieved organic certification and promoted awareness of alternative food systems, which have proved not only popular, but also profitable.

SOIL QUALITY

Enhancing soil quality in intensive agricultural systems is important to sustaining productivity and improving environmental quality (Subbian et al., 2000). High quality soils *per se* are therefore worth quantifying because soils and their biota provide valuable ecosystem services like storing and releasing water, decomposing plant and animal matter, transforming and recycling nutrients, sequestering and detoxifying toxicants, and promoting plant health by suppressing plant-pathogenic microbes and phytophagous fauna (Doran and Zeiss, 2000). Soil quality, as such, deals with the integration and optimization of the physical, chemical and biological properties of soil for improved productivity and environmental quality (Karlen et al., 2001). Doran (1994) defines soil quality as ‘the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health. Kremer and Hezel (2012) describes soil quality assessment as the indication of the ability of management systems to optimize soil productivity and to maintain its structural and biological integrity.

SOIL ORGANIC MATTER

Some of the most significant ecological processes in crop production are those occurring within the soil, such as interactions between soil, nutrients and micro-organisms. The functioning of these processes is essential for healthy crop growth and sustainable production. Good soil organic matter management is the foundation for creating a favourable environment for the proper functioning of these ecological processes in the soil. Anything that adds large amounts of organic residues to a soil may increase organic matter (Joseph et al., 2008). One of the oldest practices in agriculture has been to apply manures or other organic residues generated off the field. A typical agricultural soil has 1 to 6 percent organic matter which consists of three distinctly different parts: living organisms, fresh residues like compost and well-decomposed residues called humus (Magdoff and van Es, 2009). The availability of nutrients is influenced either directly or indirectly, by the presence of organic matter. The intimate contact of humus with the other soil components allows many reactions, such as the release of available nutrients into the soil solution, to occur rapidly (Seiter and Horwath, 2004). Most of the nutrients in soil organic matter cannot be used by plants as long as they exist as part of large organic molecules. Soil organisms are positively correlated with organic matter content (Nair and Ngouajio, 2012). As soil organisms decompose organic matter, nutrients are converted into simpler inorganic or mineral forms that plants can easily use. This process, called mineralization, provides much of the nitrogen that plants need. Soil organisms are therefore essential for keeping plants well supplied with nutrients because they make nutrients available by freeing them from organic molecules (Anderson, 2003; Doran and Zeiss, 2000; Hulugalle et al., 1999). For example, proteins are converted to ammonium (NH_4^+) and then to nitrate (NO_3^-). The mineralization of organic matter is also an important mechanism for supplying plants with such nutrients as phosphorus and sulphur, and most of the micronutrients they need (Magdoff and van Es, 2009). The organisms referred to are highly dependent on soil organic matter as source of food.

If soil organisms are absent or inactive, more fertilizers will be needed to supply plant nutrients. Organic matter, as residue on the soil surface or as a binding agent for aggregates near the surface, also plays an important role in decreasing soil erosion. Organic matter is also the single most important soil property that reduces pesticide leaching since it can change the chemical structure of some pesticides, and other potentially toxic chemicals, rendering them harmless. It is therefore clear that the supply of active organic matter must be maintained so that humus can continually accumulate to assist in the eventual mineralization (Magdoff and van Es, 2009).

COVER CROPS

The use of cover crops have the potential not only to act as an aid in maintaining diversity below ground but also to return residues to the soil when they are mulched or green manured. Some cover crops may produce as much as 1900 to 2900 kilograms biomass per hectare (Clark, 2007; Hulugalle et al., 1999; Jokela et al., 2009) and are considered as strategic in sequestering carbon in soils of agro-ecosystems (Lal, 2011). De Lima et al. (2012) found the use of cover crops to affect the support capacity of soil and least limiting water range to crop growth positively. Cover crops also supply nutrients to the follow-up crops, suppress weeds (Mennan and Ngouajio, 2012), and break pest cycles (Sullivan, 2003). McDaniel et al. (2014) consider cover crops to sustain soil quality and productivity by enhancing soil C, N, and microbial biomass, making them a cornerstone for sustainable agroecosystems. Bugg et al. (2009) found understory cover crops in pecan orchards to enhance some arthropods that may aid the biological control of pecan pests. Cover crops are not only important for improving soil quality by adding organic matter to the soil (Nascente et al., 2013), but can also serve a second important purpose in protecting crops against certain pests. They may act as ‘trap crops’ to lure pests away from the main crop or create a favourable environment for more diverse insect populations which may harbour beneficial insects such as pollinators and predators. Silva et al. (2010) found significantly higher numbers of beneficial arthropods in orchards with ground cover vegetation in comparison with bare soil. Cover crops also help maintain high populations of mycorrhizal fungal spores which improve inoculation of the next crop. Their pollen and nectar are also important food sources for predatory mites and parasitic wasps, which are both important for the biological control of insect pests. A cover crop also provides a good habitat for spiders which in turn assist in decreasing pest populations (Magdoff and van Es, 2009; Ramos et al., 2010).

SOIL HEALTH INDICATORS

Many authors have attempted to develop soil health indicators by measuring various soil characteristics (Arshad and Martin, 2002; Doran and Zeiss, 2000; Glover et al., 2000; Gugino et al., 2009; Karlen et al., 2003, 2008; Knoepp et al., 2000; van Antwerpen, 2009; van Bruggen and Semenov, 2000; Werner, 1997). Indicators of soil quality for agroecosystems are described by many different variables that include mainly chemical, physical and biological parameters (Mele and Crowley, 2008). These indicators refer to measurable soil attributes that influence the capacity of soil to perform crop production or environmental functions (Arshad and Martin, 2002). The choice of a standard set of specific properties as indicators of soil quality can be complex and will vary among agroecosystems and management objectives (Schoenholtz et al., 2000. The concept of soil quality seems to be clear, but measuring it still remains difficult (Zornoza et al., 2007).

As modern agriculture is forced towards low input systems where soil biological processes primarily account for soil fertility, nutrient cycling, and disease control, key indicators of soil quality must include biological measures. Biological indicators have consequently become increasingly important in the assessment of quality in soils that are managed mainly to enhance their ecological functioning (Nielsen and Winding, 2002). Soil quality must be inferred from easily measurable soil properties and these soil quality indicators must be comprehensible and useful to land managers, who are the ultimate stewards of soil quality and soil health (Acton and Padbury, 1993; Doran and Zeis, 2000). Magdoff and Weil (2004) point out that researchers have found soil organic matter (SOM) related properties to be important indicators of soil quality and Dumansky (1994) concluded that soil organic matter is emerging as a key indicator for assessing sustainability of land management systems. Soil organic matter (SOM) management is the key for not only converting degraded or low quality soils into high quality ones, but also for maintaining or improving already healthy soils (Magdoff and van Es, 2009).

When confronted with the question of which soil quality indicators are most likely to be affected by the use of cover crops, soil quality indices and indicators should be selected according to the soil functions of interest and the defined management goals for the system (Andrews et al., 2002). Indicators for any study should, therefore, firstly, be selected to best reflect the achievement of the goals identified and secondly to meet the criteria proposed by Doran and Zeiss (2000), that is, sensitivity to variations in management and good correlation with beneficial soil functions; usefulness for elucidating ecosystem processes; comprehensibility and usefulness to land managers and whether easy and inexpensive to measure. Gugino et al. (2009) developed a protocol for assessing the health status of soils. They evaluated 39 potential indicators for their use in rapidly assessing soil health based on:

- Sensitivity to changes in the soil
- Management practices
- Relevance to soil processes and functions
- Consistency and reproducibility
- Ease and cost of sampling
- Cost of analysis

This protocol (also known as the Cornell soil health assessment protocol) emphasizes the integration of soil biological measurements with soil physical and chemical measurements. A total of four physical and four biological indicators with a standard chemical soil test analysis were selected for the protocol. This protocol conforms well to the criteria proposed by Doran and Zeiss (2000) and we therefore propose soil health indicators which are based mainly on the Cornell soil health assessment protocol. The following indicators are proposed for measuring soil quality changes in sub-tropical fruit orchards with cover crops:

1. Soil Physical Properties
- Aggregate stability
- Available water capacity
- Surface and subsurface hardness (penetrability)
- Bulk density

2. Soil Biological Properties
- Organic matter content
- Active carbon content
- Potentially mineralizable nitrogen
- Earthworm abundance and biomass
- Meso-arthropod assessment (*Collembola* count)
- Nematode community profiling

3. Soil Chemical Measurements
- Exchangeable macronutrients
- Micronutrient concentrations
- pH
- Electrical conductivity
- Cation exchange capacity and cation ratios

TRAP CROPS

Habitat and vegetation management can be used effectively as the basis of ecologically-based pest management tactics in sustainable agriculture (Andow, 1991; Altieri and Letourneau, 1984; Bukovinsky and van Lenteren, 2007; Gurr et al., 2003; Hendrickx et al., 2007; Letourneau et al., 2011; Pickett and Bugg, 1998; Proveda et al., 2008; Schoeman, 2007; Schoeman and Mohlala, 2007). The concept of trap cropping fits into the ecological framework of habitat manipulation of an agroecosystem for the purpose of pest management (Altieri and Nicholls, 2004). Phytophagous hemipterans are, in general, polyphagous, but they may show feeding preferences for certain taxa (Panizzi, 2000). Plants that are highly attractive to these insects, therefore, have the potential to be used as trap crops. The potential success of a trap cropping system depends on the interaction of the characteristics and deployment of the trap crop with the ecology and behaviour of the targeted insect pest (Shelton and Badenes-Perez, 2006). In general, the attractiveness of the trap crop and the presentation of trap crops in the field are important factors in attracting the insect and in the success of the trap cropping system (Velasco and Walter, 1992). Various trap crops have been recorded to attract pentatomid stink bugs (Knight and Gurr, 2006; Lockwood and Story, 1986; Mizell et al., 2008; Shelton and Badenes-Perez, 2006; Velasco et al., 1995; Velasco and Walter, 1992; Velasco et al., 1995). Shelton and Badenes-Perez (2006) are of the opinion that the potential of trap cropping significance would be greater if farmers, scientists and extension educators could expand their concepts of trap cropping to include more diverse modalities in their research. These should include modalities based on the trap crop plant *per se*, modalities based on the deployment of the trap crop and others such as biological control-assisted trap cropping and semiochemically assisted trap cropping.

TRAP CROPS AND BIODIVERSITY

Various researchers have demonstrated the potential of increased biodiversity to enhance biological control of insect pests in agroecosystems. Diversified crops exhibit better plant pest suppression, natural enemy enhancement and less crop damage +than monocultures (Altieri and Letourneau, 1984; Andow, 1991, Gurr et al., 2003; Bianchi et al., 2006; Poveda et al., 2008; Letourneau et al., 2011). Landis et al. (2000) however caution that to selectively enhance natural enemies, the important elements of diversity should be identified and provided rather than simply increasing diversity *per se* which can exacerbate some pest problems. This can be achieved by enhancing the natural resources needed by natural enemies by providing suitable habitat with adequate shelter, more suitable microclimates as well as alternative food sources such as pollen and nectar. The challenge is to integrate these resources into the landscape in a way that is spatially and temporally favourable for natural enemies and practical for producers to implement. Habitat manipulation for the inclusion of cover crops may be particularly effective by simultaneously increasing biodiversity within and adjacent to the main crops. Altieri and Nicholls (2004) reviewed the influence of adjacent habitats on insect populations in field crops. They concluded that habitat edges are important for the development and maintenance of natural enemies which may choose to move back and forth from the edge to the crops for feeding etc.

Gurr et al. (2004) view orchards as having high potential for ecological engineering for pest management. They suggest that orchards are usually more diverse because of some type of ground cover and are subject to lower levels of disturbance than annual crops and therefore have more potential for this type of management. Orchard managers should endeavour to manage orchard groundcover and adjacent vegetation toward enhancing opportunity for biological control of orchard pests by natural enemies (Prokopy, 1994). The understory vegetation in an orchard need not be managed uniformly (Bugg and Waddington, 1994). Different zones may be treated differently, called strip management. Various options include sowing cover crops of different floristic composition in different strips or combining it with strips of natural vegetation in or adjacent to the orchards. A complex of stands having differing floristic compositions could remain attractive to arthropods for longer periods of time. Arthropod habitat can be retained through time with the aid of strip management combined with adjacent natural edges.

KNOWLEDGE GAPS AND RESEARCH NEEDS

Gliessman (2007) maintains that there is an urgent need for more research on the sustainability of agroecosystems. Wezel et al. (2014) distinguished fifteen categories of agroecological practices of which only 6 are currently well integrated in practices for sustainable agriculture. One of the gaps in existing knowledge that needs to be addressed relates to the transition of conventional sub-tropical fruit cultivation which depends heavily on agrochemicals, to more sustainable cultivation practices which are based on ecological principles. In conventional fruit production systems, the external input of inorganic fertilizers circumvent the ecological processes of nutrient cycling, capture and release in soils. Conventional crop protection practices in fruit orchards that depend largely on the application of synthetic agrochemicals similarly disrupt natural ecological processes and populations of both target and non-target species. The potential of cover crops to build soil quality have been well documented (Clark, 2007; Magdoff and van Es, 2009; Ramos et al., 2010; Seiter and Horwath, 2004). Various cover crops have also proven to be highly attractive to pentatomid stinkbugs (Knight and Gurr, 2006; Mizell et al., 2008; Rea et al., 2002; Shelton and Badenes-Perez, 2006). The question that arises is whether cover crops can be deployed within sub-tropical fruit orchards in such a way that a dual goal is achieved? Can cover crops be utilized in sub-tropical fruit orchards to restore soil quality or to maintain it at levels where agrochemical inputs may be reduced significantly without compromising yield and simultaneously act as trap crops to reduce insect damage to sub-tropical fruit crops significantly? There is a need to investigate the use of cover crops or combinations thereof which have already proven not only to be good soil builders, but which also have the potential to concurrently act as trap crops for pentatomid pest insects in sub-tropical fruit cropping systems. Mustard (*Brassica* spp.), Sunnhemp (*Crotolaria juncea*) and Cowpea (*Vigna unguiculata*) have all been identified as crops which all have twofold potential in this regard (Bensen and Temple, 2008; Bugg and Waddington, 1994; Fischler et al., 1999; Rea et al., 2002; Shelton and Badenes-Perez, 2006; Yost and Evans, 1988). All three of these cover crops are leguminous and considered to be reputable soil builders (De Baets et al., 2011; Fatokun et al., 2002; Hubbard et al., 2013; Munoz-Carpena et al., 2008; Singh et al., 2010; Snapp et al., *2006;* Wang et al., 2011). A number of studies have also demonstrated their potential as trap crops for various insect pests as well as promoting an increase in natural enemies (Agboka et al., 2013; Bone et al., 2009; Hinds and Hooks, 2013; Hokkanen, 1991). Will cover crops be more effective if the biodiversity within and adjacent to the main crop can be increased through habitat manipulation?

CONCLUSION

The principles on which sustainability can be built are well established, but there is a lack for more detailed knowledge necessary to apply these principles to the design of sustainable systems and the global conversion of agriculture to sustainability. Cover crops may contribute significantly to this cause if their correct combination, application and management can be determined within the existing circumstances of sub-tropical fruit cropping systems. Where the latter occur in developing countries facing resource constraints, the optimal configuration of cover and trap crops have the potential to significantly reduce external farm inputs, prevent disruption of natural ecosystem processes and improve agricultural sustainability. We propose that mustard (*Brassica* spp.), sunnhemp (*Crotolaria juncea*) and cowpea (*Vigna unguiculata*) be investigated in sub-tropical fruit cropping agroecosystems to determine their potential in this regard. The contribution that edge vegetation combined with cover crops can make for the development and maintenance of natural enemy populations should also be investigated. Agroecology aims to create sustainable agroecosystems and conversions which are mediated by the application of supplementary crops serving a dual trap and cover purpose, may achieve the goal of ecosystem conformity in sub-tropical fruit orchards more rapidly than conventional organic conversions.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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