The Soil Food Web and Pest Management

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Many agricultural production practices affect insect populations. Crop susceptibility to pest damage may be influenced by differences in plant health mediated by soil management. In general, soil management that replenishes and conserves organic matter and enhances the abundance and biodiversity of beneficial organisms creates an environment that promotes plant health. Crop rotation and preservation of beneficial insects through the reduction of insecticide use can reduce pest pressure. Increasingly, research has demonstrated that the ability of a crop plant to resist or tolerate pests is tied to the physical, chemical, and biological properties of soil (Phelan et al., 1995, 1996; Altieri and Nicholls, 2003; Zehnder et al., 2007). Soils with high organic matter and active soil biology generally have both good soil fertility and complex food webs. Soil organisms are involved in many beneficial processes, e.g., decomposition and nutrient cycling, carbon sequestration, maintenance of plant diversity, bioremediation, and biological control. In this paper, I will focus on how two key functions of the soil food web, decomposition/nutrient cycling and biological control, affect pest management in agricultural systems.

The Soil Food Web

All of life can be thought to operate in a food web based trophic groups. Trophic groups are defined by what an organism eats. Food webs are composed of many food chains - depicted as a linear sequence starting from a species that eats no other species, e.g., decomposers and producers (plants), and ends at a species that is eaten by no other species in the chain, e.g., predators. The "structure" of a food web is the composition and relative numbers of organisms in each trophic group. Food web complexity is a characteristic of both the number of species and the number of different species in the soil. The foundation of the soil food web is organic matter. The lower the level of trophic group, the more heavily it relies on its nutrition from soil organic matter. Management practices can alter the diversity and complexity for interactions in the soil through effects on organic matter. For example, crop type, tillage practices, residue management, pesticide use, and irrigation can alter the structure and complexity of the food web.

Bottom-Up Control: Plant Quality from an Insect's Point of View

From the plant-feeding insect's point of view – the insect is at the center of the food chain – below it are the food it feeds on - plants - and above it, animals that feed on the insect, – natural enemies. What regulates insect populations to determine whether a plant-feeding insect will reach damaging levels? Characteristics of an insect's food are considered "bottom-up" factors. Characteristics that influence the natural enemies of insects are considered "top-down" factors because of the position of these factors in relation to the plant-feeding insect in the plant-insect-natural enemy food chain.

Many kinds of insects feed on plants, although not all plant-feeding insects are pests. Even when a known insect pest is present in the environment with a crop, there are many factors that influence whether or not an insect will choose to eat, and potentially damage a plant. Insects use chemical smell and taste cues to help them recognize host plants, and can differentiate plants based on their odors and tastes. The chemistry of the plant determines its appeal to an insect.

Chemical cues from plants that insects use to determine the suitability of the plant as a resource fall into two broad categories: primary and secondary metabolites. Primary metabolites are compounds synthesized by plants for essential functions, such as growth and development. Examples of primary metabolites include carbohydrates, lipids, proteins, and nucleic acids. A key component of proteins and nucleic acids is nitrogen. Secondary metabolites are compounds produced in metabolic pathways other than those directly involved in growth and development and are not considered essential to the plant. Many thousands of secondary metabolites have been isolated from plants, and often contribute to their distinctive colors and flavors. Some secondary metabolites are toxins for insects, and are called plant defense compounds because they can interfere with an insect's metabolism, often by blocking specific biochemical reactions. The higher the concentration of these chemicals in the insect's diet, the less nutrition the insect can gain from eating plant tissues. These defensive chemicals are usually most effective against non-adapted specialists on other plant species and generalist insects that feed across plant types. Plant defensive chemicals include alkaloids, cyanogenic glycosides and glucosinolates, terpenoids, and phenolics.

These defensive chemicals often render a particular plant species unsuitable as a food plant for particular insect species. However, in some cases, insect species have evolved mechanisms to overcome the defensive function of particular secondary metabolites and are be able to exploit them as a food resource.

The Effects of Fertility Source on Plant Quality

Soil organisms play a key role in decomposition and release of plant-available nutrients from soil organic matter, a process called mineralization. As organisms decompose complex materials, or consume other organisms, nutrients are converted from one form to another, and are made available to plants and to other soil organisms.

The way that soil fertility is managed affects insect-plant interactions by altering plant quality as a resource for plant-feeding insects. Soil fertility in agricultural systems is mainly accomplished through applications of synthetic fertilizers, crop rotation, cover cropping, and the application of plant and animal materials. Healthy, vigorous plants that grow quickly are better able to withstand pest damage. However, over-fertilizing crops can increase pest problems through changes in nutrient and chemical composition of crop plants. Specifically, increasing soluble nitrogen levels in plants can decrease their resistance to pests, resulting in higher pest density and crop damage. For example, increased nitrogen fertilizer rates have been associated with increased soluble N in plant tissue and large increases in numbers of mites, aphids, thrips, and other plant feeding insects.

Practices that promote an increase of soil organic matter and a gradual release of plant nutrients through decomposition and mineralization do not generally lead to excessive N levels in plant tissues. Therefore, in theory, do not promote increases in insect pest populations. In general, organic fertilizers such as animal and green manures contain nitrogen sources that are released over a longer time scale than the pulsed and readily-available nitrogen in synthetic fertilizers.

Bottom-Up Control of Insects: Soil fertility and *Brassica* pests

Plants in the *Brassica* (cole crop) family are rich in sulfur containing compounds called glucosinolates. These compounds play a defensive role in *Brassica* – insect relationships and have a negative effect on generalist plant-feeding insects, although some insect species are able to tolerate or detoxify some glucosinolates. Staley et al. (2010) applied organic and synthetic fertilizer treatments at two nitrogen concentrations each to cabbage (*Brassica oleracea* var. *capitata* cv. Derby Day), and measured their effects on the abundance of plant-feeding insects and plant chemistry. The organic treatments included a green manure (white clover, *Trifolium repens* var. Milvus) for the low-nitrogen treatment (approx. 100 kg nitrogen per hectare), while the high- nitrogen treatment included both green and animal manures (organic chicken manure to provide approx. 200 kg nitrogen per hectare in total). The two synthetic fertilizer treatments included a conventional high fertilizer treatment (ammonium nitrate at 200 kg nitrogen per hectare) and a conventional low fertilizer treatment (ammonium nitrate at 100 kg nitro- gen per hectare).

The most common plant-feeding insects found were the cabbage aphid, *Brevicoryne brassicae* (a cole crop specialist), the green peach aphid, *Myzus persicae* (a generalist plant-feeder), and the diamondback moth, *Plutella xylostella* (a cole crop specialist). The cabbage aphid was more abundant on organically fertilized plants, while the green peach aphid had higher populations on synthetically fertilized plants. The diamondback moth was more abundant on synthetically fertilized plants and preferred to oviposit on these plants. Nitrogen concentration was greater for conventionally fertilized than organically fertilized cabbage. Glucosinolate concentrations were up to three times greater on cabbage plants grown in the organic treatments, while foliar nitrogen was maximized on plants under the higher of the synthetic fertilizer treatments. The varying response of insect species to these strong differences in plant chemistry demonstrates that the response of plant-feeding insects to level and source of fertility is complex.

Top-Down Control of Insects: The Soil Food Web and Biological Control

Complex food webs foster populations of beneficial organisms that can help keep pest organisms in check. The exploitation of the predators and parasites, or natural enemies, to control pest insects is called biological control. Natural enemies include predators, such as birds, lady beetles and lacewings, that consume a large number of prey during their whole lifetime; parasitoids whose immature develops on or within a single insect host, ultimately killing it; and pathogens - disease-causing organisms including bacteria, fungi, and viruses that kill their insect host. Many natural enemies can be purchased, but it may be more economical to use a conservation approach – i.e., create conditions through management that attract and retain these beneficial organisms. Some common biological control organisms associated with the soil include ground and rove beetles, spiders and harvestmen, insect-parasitic fungi, and insect-parasitic nematodes.
Biological control of pest insects may be enhanced by reducing disturbance, such as reducing tillage and pesticide use, by creating refuges from these disturbances, and

providing alternate food resources for the natural enemies (e.g., nectar and pollen from flowering plants). Crop residue may provide habitat and/or food resources for beneficial arthropods, and diversity and abundance of arthropod predators are greater under no-till in comparison to conventional tillage. Organic cropping practices, and cover cropping, in particular, may conserve and increase the activity of natural enemies.

Managing for Diversity and a Functional Soil Food Web

To exploit the benefits and services of soil organisms, such as bottom-up and top-down control of insect pests, some goals of soil management should be to improve the physical, chemical and biological properties of soil. This is mainly achieved through additions and conservation of soil organic matter, as the base resource for the soil food web

Adding plant diversity to a production system in space and time can help break pest cycles. Plants in the same family tend to have similar pests. Crop rotation, planting a series crops from different plant families in the same space in sequential seasons, helps deter the build up of pests that can occur when one crop species is planted continuously. Crop rotations that include sod, cover crops, and green manure crop provide benefits in addition to providing pest management in annual and perennial crops, including: maintenance or improvement of soil organic matter content; management of plant nutrients; and erosion control. Spatial crop diversity can be achieved through crop rotation and various forms of polyculture, e.g., strip cropping, multiple cropping, or interplanting of plant species or varieties. A general effect of polyculture is a spatial mixing of crops, which can slow the build-up and spread of pests during the growing season.

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Additional Resources

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