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Organic Matter and the Impact of Management on Orchard Soil Health

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Soil is a regenerative living ecosystem; a place where energy and matter are transformed and transported. It is the foundation of healthy orchards. A healthy soil is one that resists degradation and responds to management in predictable manner. This paper is divided into the following three parts: 1) a brief overview of how soil works in regards to the growth and development of orchard trees and their fruit; 2) a summary of three Michigan research projects related to the impact of organic matter and management on soil health; and 3) system science concepts designed to assist the Washington State tree fruit industry in their work to provide leadership in the evolving domain of Soil Health.

Soil is composed of all three states of matter: gases, liquids and solids, with the solid component consisting of both mineral and organic matter. The organic portion contains dead, decomposing and living matter. The living portion consists of plant roots, bacteria, fungi, nematodes, flagellates, ciliates, amoebae, arthropods, earthworms *etc*. To understand the concept of soil health, it is necessary to know basic concepts of chemistry (especially chemical element mineralization and fixation) and how ecosystems function. There are two types of chemistry, organic and inorganic. In organic chemistry, atoms (smallest complete unit of an element) of different elements (fundamental types of chemicals) are bound to chains of carbon atoms to form essential chemical compounds such as proteins and nucleic acids that are essential for fruit tree functions (Figure 1). In most cases, plant roots are not able to takeup and utilize organic chemicals for orchard growth, development and fruit production. For uptake of essential plant growth and development chemicals by roots, the chemicals must be in their inorganic form. These are called ions which have a positive or negative charge. The chemical transformation process of going from an organic compound to an ion is referred to as mineralization. The opposite reaction (bonding a particle of matter to carbon) is fixation.

In soil, chemicals such as nitrogen are immobilized (not directly available to plant roots) in the bodies of decomposer organisms such as bacteria and fungi. In soil food webs, these are fed on by other types of organisms, such as nematodes, flagellates, ciliates and amoebae (Figure 2). Bacteria are rich in nitrogen (low C:N ratio). When an organism with a higher C:N ratio feeds on bacteria, they acquire more nitrogen than what is required for their life processes. This is excreted as NH_4^+ which can be takenup by orchard tree roots and used for growth and development of the tree and its fruit, or biologically converted into NO_3^- which is also readily available for fruit tree use. Many of these transformations take place in the rhizosphere (environment adjacent to the root) or on the rhizoplane (root surface), long before NO_3^- can reach the water table or be further transformed into N_2 gas and subsequently released into the atmosphere.

Figure 1. Process of nutrient mineralization and fixation for orchard trees.

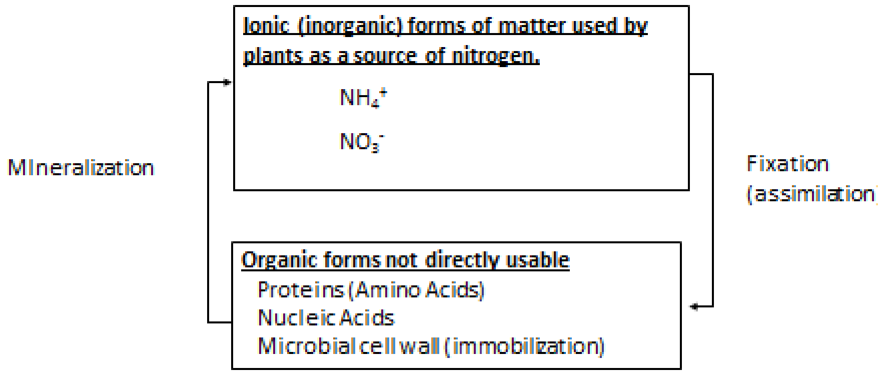
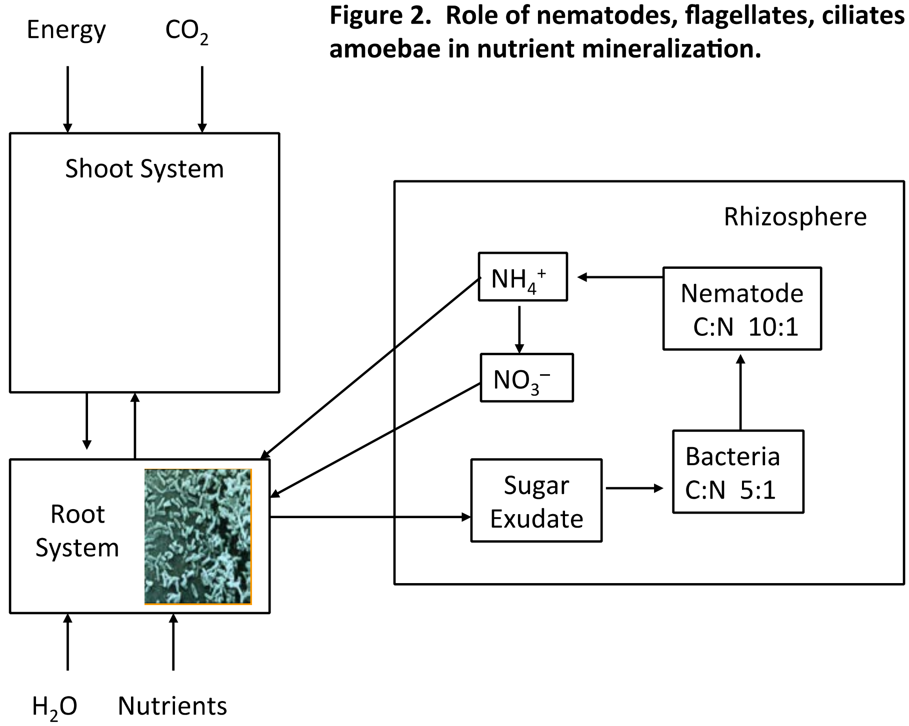


Figure 2. Role of nematodes, flagellates, ciliates and amoebae in nutrient mineralization.



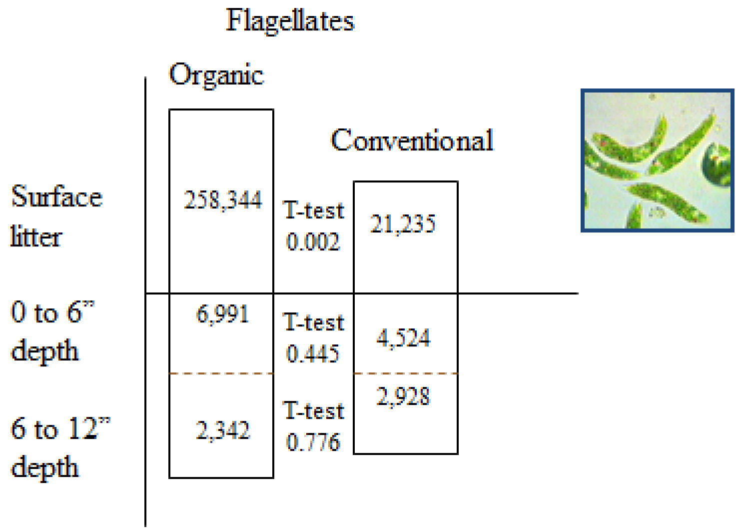
Bird, 2011

A team of Michigan State University scientists and Michigan tree fruit community members conducted a 6-year research project in a mature commercial tart cherry farm adjacent to the Northwest Michigan Horticultural Research Station to determine the impact of cherry orchard floor management systems on soil health and crop productivity (Sanchez *et al*., 2003). While thirteen different systems were evaluated, only four (conventional with herbicides, natural vegetation, mulch and compost) are discussed here. The six-year means for cherry yield (tons/hectare), carbon (mg/kg), nitrogen (mg/kg), carbon mineralization potential (mg/g), nitrogen mineralization potential (mg/g) and a nematode population density ratio (bacteriovores + fungivores/herbivores) were used as the final system evaluation parameters. Tart cherry yields (18.5 tons/ha) were statistically greater ($p=0.05$) for the system using mulch, compared to a mean yield of 15.2 tons/ha for the other systems (Table 1). Carbon, carbon mineralization potential, nitrogen mineralization potential and the nematode ratio were all significantly ($p=0.05$) higher for the mulch system, compared to the current conventional practice. Based on these results, it appears that an orchard floor management system involving mulch should be highly beneficial in tart cherry production in Michigan. The research team hypothesized that these results could be repeated with a different tree fruit crop during a different series of years.

A seven-year research project was then conducted at the Michigan State University Clarksville Research Station to determine the impact of various apple orchard floor management systems on soil health (Zopollo *et al*., 2011). Four systems - mulch, natural vegetation, tillage and flaming - were evaluated in regards to their impacts on soil organic matter (%), carbon (tons/hectare), nitrogen (mg/kg), carbon mineralization potential (mg/kg), nitrogen mineralization potential (mg/kg), nematodes/cm^3 soil, bacterivore/herbivore nematode ratio and root-lesion nematodes/cm^3 soil. The percent organic matter, carbon and nitrogen associated with the much system was significantly ($p=0.05$) greater than that of the other three systems (Table 2). Both carbon and nitrogen mineralization were significantly greater than the flaming system. The total nematode population density and the bacteriovore/herbivore ratio was significantly ($p=0.05$) greater in the mulch system than in the other three systems. After seven years, the root-lesion nematode population density associated with the mulch system was an average of 21.6-fold less in the much system, compared to the natural vegetation, tillage or flaming systems. These results in relation to mulch are basically the same as those obtained for the tart cherry system. The next question asked was about the relationship of the nutrient mineralizers to the orchard management system.

The G.W. Bird Nematology Laboratory at Michigan State University selected eight northern Michigan tart cherry orchards for determination of the population densities and vertical distributions of four types of nutrient mineralizers (Bird and Smith, 2013). Population densities of bacterial-feeding nematodes were greatest ($p=0.001$) in the O-horizon (surface litter) compared to the A-horizon at 0-6 and 6-12 inch soil depths. The same was true for flagellates, amoebae and ciliates ($p=0.001$, 0.001 and 0.007, respectively). A nearest-neighbor design was used in selection of the orchards to obtain four pairs of conventional vs organic orchards. There was an order of magnitude (10-fold) more flagellates in the O-horizon of organic tart cherry orchards, compared to conventional orchards (p=0.002). This is clear evidence of a reason for the greater mineralization potential of organic and mulch-based orchard management systems.

Figure 3. Comparative vertical distribution of flagellates associated with four conventional and four organic commercial tart cherry orchards in Michigan (Bird and Smith, 2013).



During a meeting with Washington State fruit growers, it was mentioned that the author of this paper would recommend a trans-disciplinary systems science approach for research and education programs designed to enhance the understanding of soil health in regards to orchard systems. The concept of trans-disciplinarity is described briefly in an IPM paper included as Appendix A. It is known that soil-borne organisms (most are your friends) and management regulate orchard systems. Crop productivity, orchard quality and soil health are system responses. Evidence indicates that with proper management, a degraded soil can be returned to health in about seven years. There is often a need to be patient. If you remember your soil-borne friends, they will take care of you. The next step is development of a comprehensive conceptual model of soil health for Washington State orchard systems. This needs to be done with key fruit growers and other member of the fruit industry working closely in a trans-disciplinary mode with the new Soil Health faculty position at Washington State University.

References Cited

Bird, G.W. and Smith, J. 2013, Observations on the biology of organic orchard soils. Acta Horticulture 1001:287-294.

Sanchez, J. et al. 2003. Orchard floor and nitrogen management influences soil and water quality and tart cherry yields. J. Amer. Soc. Hort. Sci. 128:277-284.

Zopollo, R. et al. Soil properties under different management systems for organic apple production. Organic Agric. 1:231-246.

Table 1. Impact of cherry orchard floor management on soil and productivity (Sanchez et al., 2003).

Six year means	Straw/Hay Mulch	Vegetation	Compost	Conventional
Carbon (mg/kg)	10,750 a	11,966 a	9,602 ab	8,670 b
Nitrogen (mg/kg)	740 b	1,000 a	725 b	713 b
C mineralization (mg/g)	675 b	775 a	825 a	550 c
N mineralization (mg/g)	45 a	47 a	55 a	35 b
Nematode Ratio (B+F/P)	8 a	4 b	8 a	3 b
Cherry Yields (tons/ha)	18.5 a	14.7 b	15.0 b	15.9 b

Table 2. Impact of apple orchard floor management systems on soil quality parameters in Michigan (Zopollo et al., 2011).

Soil depth (0-30 cm)	Alfalfa Mulch	Vegetation	Tillage	Flaming
Soil organic matter (%)	2.4 a	2.1 b	2.1 b	2.1 b
Carbon (tons/ha)	47 a	45 b	45 b	44 b
Nitrogen (mg/kg)	24 a	4 b	7 b	4 b
C mineralization (mg/kg)	1250 a	1050 ab	1050 ab	950 b
N mineralization (mg/kg)	90 a	75 ab	75 ab	65 b
Nematodes/ cm^3 soil	1246 a	754 b	343 c	471 c
Bactivores/Herbivores	28.3 a	4.7 b	13.5 b	8.4 b
Root Lesion Nema/100 cm^3 soil	1 a	22 b	22 b	21 b

Appendix A.

Interdisciplinary Nature of Pest

G.W. Bird, Michigan State University, Proceedings of the 1977 National Pest Management Workshop, United States Department of Agriculture, Kansas City, MO, December 13-15, 1977, pp. 137-138.

Agricultural systems, by their very nature, are interdisciplinary. They cannot be readily compartmentalized into classical disciplines. Historically, it was because of this and other reasons that the interdisciplinary sciences of horticulture and agronomy evolved. These areas, however, continued their evolutionary development and became disciplinary activities. Pest management is also an interdisciplinary activity. Its interdisciplinary nature is readily visible in analysis of natural ecosystems, grower implemented pest control programs and the pest management activities of private practitioners and field-based extension agents. Unfortunately, the interdisciplinary nature of pest management is not nearly as evident in an evaluation of the activities of university researchers, academic instructors and campus-based extension specialists. The objectives of this presentation will be to demonstrate that pest management is truly an interdisciplinary activity, and that for its continued development and optimum success, it must remain as an interdisciplinary science.

Pest management is the development, coordination, and use of pest control strategies that result in favorable ecologic, economic and sociologic consequences. The majority of individuals engaged in pest management have disciplinary backgrounds such as entomology, plant pathology, nematology and weed science. Coordinated research, extension and academic instruction activities are needed for the successful development and implementation of a pest management program. Such a system must contain an effective and efficient delivery system, a biological monitoring component, an environmental monitoring component and pest crop ecosystem models that provide suitable management recommendations. This cannot be accomplished without a broad interdisciplinary base.

There is little or no literature on interdisciplinary activities in the biological sciences and only a limited literature in the physical sciences. A reasonably extensive

While both disciplinary and multidisciplinary activities are essential for the future development of various components of pest management, they are inadequate for the development of a complete pest management system.

Interdisciplinary aspects of pest management pertain to extension, research and teaching activities in which individuals from different disciplines work as a team, with continual intellectual interaction in conceptual synthesis.

This is not always easy, and is frequently in conflict with many of our existing institutional designs. While true implementation of the interdisciplinary aspects of pest management will provide us with many advances, it should not be considered as an ultimate goal. An example of a further development might be the **transdisciplinary** aspects of pest management.

This pertains to extension, research or teaching activities in which individuals from different disciplines work as a team within a mutually accepted set of systems objectives, and within the general frame work of the principles of system science (the coordinated study of the structure and interactions among related entities).

The need for interdisciplinary activities has been recognized on a larger scale than individual or state pest management programs. The formation of the Intersociety Consortium for Plant Protection is a good example of the recognition of this need. ISCPP is an amalgamation of the American Phytopathological Society, Entomological Society of America, Weed Science Society of America and Society of Nematologists. It represents approximately 14,000 scientists. Its goal is to provide interdisciplinary communications and cooperation among those national scientific societies within the United States which are concerned with the science of plant protection. ISCPP is administered through an executive committee made up of the president, vice-president and immediate past president of each of the four member societies. The interdisciplinary activities literature on interdisciplinary activities exists for the social sciences. In pest management, there is considerable confusion pertaining to the meaning of the word interdisciplinary. It can perhaps, best be explained by showing its relationship to several other types of closely related activities.

> ***The disciplinary aspects of pest management pertain to extension, research or teaching activities done by one or more individuals, and involving a single discipline.***

In contrast, there can be multidisciplinary aspects of management.

> ***These pertain to extension, research or teaching activities in which individuals from different disciplines work together on a common problem, but with limited interaction.***

fo the consortium are implemented by standing committees in pest management, crop loss assessment, survey and detection, pesticides and teaching. ISCPP has already had a definite influence on pest management. It provides a unique mechanism for working with the present and future interdisciplinary problems of pest management.

Most Land Grant institutions are designed and administrated in a disciplinary manner. In many cases this can hinder the development and implementation of interdisciplinary activities. These constraints are not insurmountable. Some individuals believe that interdisciplinary activities such as pest management could have a detrimental influence on the classical disciplines. Nothing could be further from the truth. By the very definition of the word interdisciplinary, the success of such activities depends on the continued strength and growth of the supporting disciplines. Because many disciplines other than entomology, plant pathology, nematology and weed science are essential for the successful development and implementation of pest management programs it is highly probable that the classical pest-oriented disciplines will be greatly enhanced by the development of a strong interdisciplinary philosophy and science of pest management.