for integrating and optimizing the physical, chemical and biological properties of soil to enhance soil functions including plant health and productivity in an economic and environmentally sustainable manner. Sustainable management practices for improving soil health include reduced tillage systems, alternative crop rotations, cover crops and organic matter amendments. Research results have demonstrated that all these practices significantly impact soil biology and especially the population of plant pathogens, epidemiology of resultant diseases and crop damage. The effect of soil management practices on the major soilborne vegetable pathogens prevalent in New York and the northeast will be described. The challenge will be to develop sustainable IPM programs for managing soilborne pathogens that are compatible and integrated with long-term sustainable soil management.

Nematode assemblages as indicators for plant health. H. Ferris. Department of Nematology, University of California, Davis. Phytopathology 97:S142.

Soil nematode assemblages include representatives that obtain food from higher and lower plants, bacteria, fungi, or from other soil organisms. Feeding on higher plants may be considered detrimental if the plants have economic or aesthetic value; it may be beneficial if the plants are considered undesirable. Generally, a preponderance of herbivores in the nematode assemblage is an indicator that recent soil management has diminished functional diversity. Together with other soil organisms, nematodes perform important ecosystem services in healthy and productive soils; they enhance mineral cycling, transport bacteria and fungi to untapped resources, enhance microbial turnover, provide resources to other organisms, and regulate opportunistic species. Absent continued input of mineral fertilizers, a healthy and productive soil requires an active soil food web to provide resources for plants and to regulate populations of root herbivores. Nematodes participate in activities at most functional levels in well-structured soil food webs. Consequently, analysis of the nematode fauna indicates the extent to which important ecosystem services are being performed by nematodes and by their functional counterparts in other groups of soil organisms. The management challenge is to enhance the diversity and abundance of beneficial soil organisms so that the ecosystem services are in concordance with the needs of healthy plants.

Manipulation of rhizosphere bacterial communities to induce disease suppressive soils. M. Mazzola. USDA-ARS Tree Fruit Research Lab, Wenatchee, WA. Phytopathology 97:S142.

The biological nature and operative functional groups have been described for several disease suppressive soils. Transforming this knowledge into effective field-level disease management requires strategies that selectively promote the operative microbial population. Plant cultivation is a viable means to manipulate the composition and function of rhizosphere bacteria for disease suppression. Several examples exist of suppressive soils developing in response to crop monoculture, and in several cases disease control corresponds with specific transformations in composition of the rhizosphere bacterial community. Efficacy of soil amendments in disease control is commonly attributed to a general increase in microbial activity or, in the case of brassicaceae plant residues, generation of biologically active chemistries. However, suppression of root rot incited by *Rhizoctonia solani* in response to several different brassicaceae seed meal amendments required an active soil microbial community. Disease suppression is associated with elevated *Streptomyces* rhizosphere populations, and individual strains from seed meal amended soils provided disease control to an equivalent level and in similar manner. These and additional studies demonstrate that management of resident microbial resources holds promise as a means to achieve the biological suppression of soil-borne diseases.

Linking arbuscular mycorrhizal fungi with plant health: Mechanisms and challenges. S. Hu (1) and T. Rufty (2). (1) Department of Plant Pathology and (2) Department of Crop Science, North Carolina State University, Raleigh, NC 27695. Phytopathology 97:S142.

Arbuscular mycorrhizal (AM) fungi colonize roots of terrestrial plants and contribute to plant health through enhancing plant resistance to abiotic and biotic stresses. In low fertility, acid soils, which exist in many parts of the world, AM fungi can enhance plant uptake of nutrients and alleviate aluminium and manganese toxicities. Recent evidence indicates that mycorrhizae also facilitate nutrient acquisition from decomposing organic residues and large-scale transfer of nutrients between plants. Results from controlled environment studies show that AM fungi often induce plant defense responses and suppress plant pests and pathogens. The relationships are difficult to assess in field, so complexities of mycorrhizal fungi and pathogen interactions and their regulation remain unresolved at this time. Enhancement of mycorrhizal fungal populations can provide the greatest benefit to plant hosts in highly degraded soils, where the number and species diversity of native AM fungi are low. And, a recent area of emphasis is manipulation of mycorrhizal populations to assist land sustainability projects attempting to increase crop productivity in alternative agroecosystems or restore areas to native vegetation. An understanding of the relationship between mycorrhizal diversity and function, and mycorrhizal interactions with other beneficial microbes and soil-borne pathogens in the rhizosphere seems prerequisite for development of management practices that optimize the potential benefits of mycorrhizae.

Soil health indicators and the challenge of understanding how organic mulches affect root health of berry crops in the field. T. A. Forge, D. O'Gorman, C. Koch, X. Wu, and A. Muehlchen. Agriculture and Agri-Food Canada, Pacific Agri-Food Research Centre. Phytopathology 97:S142.

Root growth of perennial fruit crops is enhanced by organic mulches. This enhanced root growth is the result of interrelated changes in soil physico-chemical properties and several biological processes, including pathogen suppression and enhanced nutrient cycling. We studied the effects of a variety of organic mulches on root growth, soil health indicators (nematode community structure, physico-chemical properties), nutrient fluxes, oomycete community structure, and abundance of root-lesion nematodes, *Pratylenchus penetrans*, in the root zone of red raspberry. Compost and manure treatments with the lowest *P. penetrans* abundance also produced the greatest root biomass. Nematode indicators of enhanced nutrient cycling were positively correlated with fine root biomass. While actual nutrient fluxes and other nematode indicators of soil food web structure were affected by mulch treatments, the changes were not related to changes in root biomass. Hybridization arrays, PCR and greenhouse bioassays indicated the presence of several *Pythium* species that could also be contributing to the observed differences in root growth. Changes in *P. penetrans* abundance explained changes in root growth better than any other biotic or abiotic variable assessed. The relationships of *Pythium* spp. and enrichment opportunist nematodes with root growth deserve additional study.

The Ecological Complexities of Biological Control: Trophic Cascades, Spatial Heterogeneity, and Behavioral Ecology

Spatial variation in top-down control, multiple enemy interactions, and the probability for trophic cascades. R. F. Denno. University of Maryland Entomology Department, University Park, MD. Phytopathology 97:S142.

A key question in biological control is how multiple natural enemies interact to collectively suppress populations of pest herbivores. Interactions among natural enemies can be antagonistic, synergistic, or simply additive, which can alter the strength of top-down control, herbivore suppression, and the probability for trophic cascades. Moreover, spatial subsidies of predators and local habitat structure can moderate or intensify multiple enemy effects and mediate the strength of top-down forces. Thus, from a biocontrol perspective, it becomes essential to critically assess the nature of interactions among natural enemies, how such interactions affect herbivore populations, and how habitat and landscape structure might alter top-down control and its cascading effects to plant resources. We conducted manipulative experiments in an arthropod-dominated grassland to assess the effects of predator diversity on food-web dynamics. We found a significant negative relationship between predator diversity and the ability of the predator complex to suppress herbivores, a relationship that resulted from extensive intraguild predation. However, increasing habitat complexity reduced intraguild predation by providing spatial refuges for intraguild prey. Associated with dampened intraguild predation was increased top-down control of herbivores and the occurrence of a trophic cascade. Across the landscape, spatial variation in habitat structure results in gradients in the strength of top-down control. The consequences of food-web complexity are compared between arthropod- and nematode-dominated systems.

Constraining complexity to achieve effective biological control of *Diaprepes abbreviatus* in Florida citrus orchards. L. Duncan, R. Stuart, and J. Graham. Citrus Research and Education Center. Phytopathology 97:S142.

The Diaprepes root weevil, *Diaprepes abbreviatus*, is an exotic pest of citrus, ornamentals, other crops and native plants in Florida, Texas and California.

Observations in Florida indicate that weevil population levels and damage to citrus trees is greater in orchards growing on shallow poorly-drained fine-textured sandy soils in the "flatwoods" than in orchards growing on the deep well-drained coarse sandy soils of the "central ridge". Caged sentinel weevil larvae buried beneath citrus trees on the central ridge are killed by endemic entomopathogenic nematodes (EPNs) at rates as high as 70% per week during certain periods of the year whereas mortality rates in flatwoods orchards rarely exceed 10% per week. Significant spatial and temporal relationships between EPNs and nematophagous fungi (NF) on the central ridge are consistent with the hypothesis that steinernematid EPN populations are directly regulated by NF and that heterorhabditid EPNs are indirectly regulated by the influence of NF on steinernematid competitors. Current laboratory and field studies are assessing these kinds of food web interactions for a variety of sites and soil types in an effort to enhance the effectiveness of weevil biological control programs through habitat manipulation and both augmentation and conservation of EPNs.

Spacial ecology of food webs with entomopathogenic nematodes. D. Strong. Section of Evolution and Ecology, UC Davis. Phytopathology 97:S143.

During last decade a combination of conceptual and technical tools has greatly accelerated science in the rhizosphere. Molecular biology, ecology, and evolution have combined to provide extraordinary insights of the rhizosphere as an environment more viscous and finely heterogeneous than the more familiar aboveground aerial or purely aquatic milieus We have learned that living roots and foodwebs of soil organisms is an environment in which ecological neighborhoods are smaller, grain is finer, dispersal more restricted, and abiotic factors (gravity, moisture, temperature, and nutrients) vary over shorter distances than the aerial and aquatic realms that we have known quite well for a century or more. Powerful and subtle synergies are coming to light. Rhizosphere mutualisms with mycorrhizae and rhizobia, which provide water and nutrients to plants, have recently been shown to be delicate states, subject to a web of interactions with other microbes and readily ranging into parasitism and pathogenesis. By grazing upon these bacteria and fungi, larger eukaryotes (nematodes, mites, enchytraeid worms, collembola, and detritus shredding insects) are probably also important actors in these foodwebs, either promoting plant growth by releasing mineral nutrients or the opposite by short circuiting nutrient flow. Finally, root pathogens and herbivores have can have hugely harmful effects upon plants, which natural enemies of these harmful organisms can reverse. The key notion of foodweb ecology applies in spades to the interspecific interactions of the rhizosphere, indirect interactions originating several trophic steps away from the root have large influences upon plant fitness. These interactions are ancient, as bacteria, fungi, and other eukaryotes have evolved together for the 400 MY since the origins of roots and their progenitor organs. No longer is the biology of the rhizosphere "out of sight, and out of mind".

Applications of spatial and temporal ecology to management of plant parasitic nematodes. B. Westerdahl. Department of Nematology, UC Davis. Phytopathology 97:S143.

The spatial and temporal ecology of plant parasitic nematodes has been examined on a number of crops by various researchers. Examples are (1) root-knot nematode on annual crops including potatoes, carrots, sugarbeets, and tomatoes; (2) ring nematode on perennial crops such as peaches, almonds, prunes and walnuts; (3) lesion nematode on walnuts and Easter lilies; (4) citrus, root-knot and dagger nematode on grapes; and (5) spiral, ring, root-knot and *Anguina pacificae* on turfgrass. The results of these studies will be discussed in the context of their contribution to the integrated pest management of plant parasitic nematodes.

From trophic cascades to biological control: Does it all come down to how individual parasites make infection decisions? E. Lewis and G. Stevens. Dept. of Nematology, UC Davis, Davis, CA. Phytopathology 97:S143.

Entomopathogenic nematodes (EPNs) are common in soil around the world and they sometimes reduce host insect populations in natural conditions. But natural EPN populations are usually distributed in ways that limit their large-scale impact on hosts. Thus, these natural populations require augmentation to render acceptable levels of pest reduction. How does EPN behavior interact with environmental characteristics to determine their distribution in soil? Our data suggest that infection decisions made by EPN infective stage juveniles (IJs) are part of a multi-component feedback loop that reinforces EPN patchy distributions in soil. When given a choice between an infected host and a healthy uninfected host, IJs of *Steinernema glaseri* will invade the infected one. Given the same choice, *S. carpocapsae* will usually invade the uninfected one. When natural populations of these EPN species are sampled, *S. glaseri* is more highly aggregated than is *S. carpocapsae*. We suggest that infection decisions of individuals relate to population distributions for EPNs in a species-specific manner and that EPN behavior may limit the potential to manipulate their population structure in agricultural systems.

A realistic appraisal of attractants involved in nematode orientation to roots. R. Perry. Rothamstead Research. Phytopathology 97:S143.

The response of plant-parasitic nematodes to various stimuli has been the subject of much research, principally in the context of root location. Such stimuli can be divided broadly into three distance-based classes. 'Long distance attractants' enable nematodes to migrate to the root area. Movement to individual roots (using 'short distance attractants') and movement of juveniles of endoparasitic nematodes to preferred invasion sites (using 'local attractants') depend on gradients set up from the root surface into the soil medium. Such gradients are likely to include volatile and non-volatile chemicals and electrical signals. The techniques used to assess nematode responses have been mainly agar plate or electrophysiological assays and there are only a few studies using three-dimensional methods. However, it is not always possible to translate the results of *in vitro* behavioural bioassays to the reality of the soil environment without knowledge of plant and soil biology. This talk will examine some of the putative attractants in the context of information on plant physiology and the root environment, especially in terms of the temporal and spatial attributes of root-induced gradients.

Trophic phylogeography: A research program for examining ecosystem assembly and functioning within a historical coevolutionary framework. B. Adams and D. Wall. BYU, Dept. of Microbiology and Molecular Biology; Department of Biology and Natural Resource Ecology Laboratory, Colorado State University, Fort Collins, CO. Phytopathology 97:S143.

A pressing issue facing ecosystem ecologists today is the ability to predict how biodiversity will respond to global changes (land use, climate change). Additionally, little is known of the roles biotic and abiotic factors play in ecosystem assembly over space and time. We suggest that understanding how biodiversity responded to change in the past offers a logical framework for examining the range of potential changes that can be expected to occur in the future. Research programs in historical ecology, evolutionary biology, and molecular systematics have developed analytical tools that can inform the universe of possible future evolutionary responses. We propose a novel method for investigating soil food webs and distribution ecology that treats the players in soil food webs as co-evolving entities in time and space, with additional consideration for geophysical constraints. We suggest that our approach can reveal patterns of soil community assembly over time and space, and serve as a framework to test hypotheses of biotic and geophysical drivers of trophic relationships.

Molecular/Cellular Plant–Microbe Interactions

Advances in Bioengineered Resistance to Nematodes

Transfer and enhancement of natural R genes for nematode resistance. I. Kaloshian. University of California, Riverside, CA. Phytopathology 97:S143.

Plant wild germplasms have been a rich source of disease resistance (R) genes. Several nematode resistance genes were first identified in wild relatives of crops and then introduced to cultivated species. However, the introgression process was often slow because of linkage drag of undesirable traits frequently associated with wild plant species. An example is the tomato R gene *Mi-1* that confers resistance to three species of root-knot nematodes, potato aphids, and whiteflies. *Mi-1* was identified in *Solanum peruvianum* in the1940s but it took over two decades to introgress *Mi-1* into tomato, *Solanum lycopersicum*. Another limitation in this process has been identifying the nature of the R gene. For example, more than a decade was required to clone *Mi-1*. Using virus-induced gene silencing, it is now possible to identify R genes and devise efficient cloning strategies. Once a gene is cloned, it can be quickly transferred into desirable cultivars using stable plant transformation. Such an approach was used to identify *Mi-9*, a heat stable root-knot nematode R gene in *Solanum arcanum*. Approaches used in *Mi-9* discovery will be presented as an example for identification and transfer of R genes into cultivated crops.