

Project Summary

(i) *Project Type*: Research

(ii) *Summary Statement*: This is a Research project.

The overall goal of this project is to improve crop production through the integration of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth. The specific objectives of the proposed work are (1) to improve crop production through a combination of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth, (2) to better understand the ecological processes occurring as a result of these sustainable practices, to allow their further development, and (3) to evaluate the efficacy, sustainability, and economics of these systems. To accomplish these objectives, the following soil amendments will be used alone or as combinations: A) Organic matter in the form of mature conifer compost which would be a) capable of supporting ample microbial biomass, and b) rich in phenolics to suppress virulence of *Rhizoctonia solani*; B) Biocontrol agents, such as *Bacillus subtilis*, and *Trichoderma* spp., that suppress *Rhizoctonia* and other soilborne diseases; C) A hypovirulent strain of *R. solani*, which provides biocontrol against *Rhizoctonia* disease, and enhances plant growth, and; D) Biofumigation brought about by a *Brassica* cover crop. Effects on soil chemical, physical, and biological properties, soil microbial communities, plant diseases and insect pests, and crop yield and quality will be monitored and evaluated on a potato crop through two consecutive field seasons. A cost/benefit analysis will be conducted to determine the relative economic feasibility of the sustainable treatments included in this study. The proposed work will be conducted on an organic potato farm, owned by Jim and Megan Gerritsen, and on the University of Maine Aroostook Research Farm, to determine the ecological impacts of the above practices on an organic and a conventional agro-ecosystem, respectively. The work proposed here was formulated on the basis of priorities set by stakeholders in Maine, other Northeastern States, and the General IPM Priorities for the Northeast (<http://northeastipm.org/priority/2005/generalpriorities.htm>).

(i) PROBLEM, BACKGROUND, AND JUSTIFICATION

Problem

Agricultural production in the New England Region has seriously declined in recent years. Within the past decade alone, farmland in New England has decreased by 400,000 acres. Sustainable cropping systems and management practices are needed to improve agricultural viability and rural economic vitality in this region. Integrated pest management (IPM) or ecologically based pest management (EBPM) has become an important component in this process, with emphasis on natural inputs, sustainable management practices, and environmental and health concerns. In the Northeast, crop losses and reduced crop quality due to pests and diseases and low overall crop productivity are critical limitations in many crop production systems. Due to relatively high levels of insect pest and pathogen pressure, and high fertility requirements, conventional agricultural production routinely uses high inputs of agricultural chemicals. In contrast, sustainable farming practices involve the principles of improving soil quality, increasing soil biodiversity, and enhancing natural disease suppression and plant resistance. Although sustainable production provides major improvements over conventional agriculture regarding soil conservation and crop management practices, there are still many limitations to sustainability, crop productivity, and farm profitability that need addressing.

Soilborne diseases of potato can be persistent, difficult-to-control problems in potato production, and typically result in substantial losses in tuber yield and quality. Common soilborne diseases in the Northeast include: stem canker and black scurf caused by *Rhizoctonia solani*; common scab, caused by *Streptomyces scabiei*; powdery scab, caused by *Spongospora subterranea*; silver scurf, caused by *Helminthosporium solani*; white mold, caused by *Sclerotinia sclerotiorum*; pink rot, caused by *Phytophthora erythroseptica*; pythium leak, caused by *Pythium* spp; black dot, caused by *Colletotrichum coccodes*; Verticillium wilt, caused by *Verticillium dahliae*; and Fusarium dry rot, caused by *Fusarium sambucinum* and *F. solani*. Many of these pathogens are associated with seed potatoes and, once introduced into soil, they can become established and survive for many years becoming worse with each susceptible crop. Crop rotation may provide some relief from these diseases, but most pathogens of potato that reside in soil are not effectively managed with crop rotation alone.

Rhizoctonia disease occurs wherever potato is grown, but is most severe where soils are moist and cool (16-23 C). These environmental conditions occur frequently in most potato production regions, particularly in the Northeast. The disease is both seed-borne and soil-borne. *R. solani* causes two distinct disease problems on potato, both of which can reduce yield and tuber quality. The first, called stem canker, is the result of lesions on the stem, roots, and stolons of developing potato plants, often resulting in the loss and stunting of potato plants, as well as fewer and smaller tubers. The second aspect of the disease, black scurf, refers to the formation of black survival structures (sclerotia) on the tuber surface, resulting in substantial reduction in tuber quality, unmarketable tubers, and unusable (infested) seed potatoes. Quantitative and qualitative yield losses due to Rhizoctonia disease vary (Anderson, 1982), but can be quite high (Carling et al., 1989). In Maine, Rhizoctonia disease is often the most persistent, and recurrent disease problem facing potato growers, resulting in substantial loss of yield and tuber quality. Chemical seed treatments used by conventional producers to reduce these disease problems are not a desirable long-term option and only provide protection near the developing seed piece. Control methods most commonly used include crop rotations and cultural manipulations to reduce length of contact under favorable disease conditions (late plantings, green sprouting, early harvest), but these are generally not sufficient for adequate disease control and improved disease management options are needed.

Background

Soil-borne diseases, especially those incited by *R. solani*, are a serious problem in both conventional and organic farms in Maine. Many organic potato farmers follow a four-year rotation to minimize the impact of these diseases on their potato crop. Due to the low prices of conventionally grown potatoes, four-year potato rotations are a high financial burden to conventional potato growers. So, more often than not, conventional farmers employ a two-year rotation that exacerbates endemics and epidemics caused by pathogens and insect pests, resulting in more serious disease and insect pest problems. These

intensive two-year rotations require a large input of synthetic pesticides and fertilizers, which are associated with serious environmental and food safety risks as well as other problems related to tolerance development and increasing costs of development.

Organic matter management is a very important component of sustainable agricultural systems which support high levels of plant growth and protect environmental quality and ecological integrity (Robinson et al., 1994). Farmers are frequently advised to build levels of soil organic matter by adding organic amendments, such as composts and animal manure, to soils (Magdoff and van Es, 2000). Total soil carbon and soil microbial biomass have been shown to be clearly related to organic matter inputs to soils (Griffin and Porter, 2004). Potatoes, one of Maine's most important agricultural crops, are particularly notable for intensive soil disturbance, including tillage, planting, cultivation, and harvesting activities. Potato crops tend to return low amount of plant residues to soil (Porter and McBurnie, 1996), and potato soils are often quite low in organic matter, making them subject to compaction and erosion. Research at Aroostook Farm has shown that recovery of organic matter levels and soil aggregation can occur in potato soils with application of compost and manure (Grandy et al., 2002).

In the work proposed here, three primary tools of sustainable crop management, the use of organic matter amendments, biological amendments, and effective crop rotations, will be customized, managed, and combined to provide improved control of soil-borne diseases and increased crop yield in organic and conventional production in the Northeast. The overall objective of this project is to suppress soil-borne, and perhaps foliar, diseases and insect pests and to improve crop production through a combination of sustainable management practices that promote soil regeneration, reduce disease pressure, and enhance plant growth. Our strategy includes addition of 1) organic matter (composts and a rapeseed cover crop), 2) biological control agents, including a plant-growth-promoting, non-disease-causing (hypovirulent) strain of *R. solani*, a bacterium *Bacillus subtilis* or a fungal parasite *Trichoderma sp.*, and 3) crop rotation with selected *Brassica* spp. with biofumigation potential. The benefits of increasing organic matter in soil are numerous, including: 1) Providing a food source for beneficial soil organisms and ultimately nutrients for plants; 2) Improving water infiltration, decreasing evaporation, and increasing water-holding capacity; 3) Reducing crusting, especially in fine-textured soils; 4) Diminishing compaction; 5) Enhancing root development, and 6) Improving soil particle aggregation, thus helping reduce erosion (Brady, 2002; Narayanswami, 2002). In addition, the organic amendments will be designed to optimize a unique biochemical mechanism for inactivating pathogenesis in *R. solani* and possibly other soil-borne pathogens.

Justification

The principles used in this project are applicable to most crops, soils or climates. The ultimate goal is to demonstrate the economic and environmental merits of the proposed sustainable agricultural practices to organic and conventional farmers that can be used in their specific production systems. Although the system described here revolves around a vegetable crop (potato), the practices employed are applicable to ornamentals, turf, nurseries, and landscaping.

The work proposed here was formulated on the basis of priorities set by a number of stakeholders in Maine, and other Northeastern States (see below). In September 2005, the Maine Potato Board and the United States Department of Agriculture published a press release (<http://www.mainepotatoes.com/press-releases/USDA&MPB%20INCENTIVES.doc>) in which they announced that ***“Producers willing to adopt practices that improve soil health and environmental quality will be eligible for incentive payments”***.

The General IPM Priorities for the Northeast (<http://northeastipm.org/priority/2005/generalpriorities.htm>) Include the following:

- Provide research for and outreach on alternative control technology for nursery pests including insects, diseases, weeds, vertebrates and soil pests.
- Respond to pest management needs and priorities identified by stakeholder input to Regional IPM Centers (http://northeastipm.org/regu_regional.cfm).
- Increase efforts to improve and maintain soil health to minimize soil borne disease.

Areas of emphasis identified by NEREAP-IPM (<http://northeastipm.org/nereap/priority/2006.htm>) include:

- Development of IPM packages that improve eligibility for NRCS program funds and satisfy the food industry (e.g. Sysco sustainability program)
- Improvement and expansion of biocontrol in high value crops including greenhouse.
- IPM packages for diversified, high value crop producers

Among the Regional IPM Centers (http://northeastipm.org/regu_regional.cfm): New York State - 2006 Vegetable IPM Priorities include:

Multiple Crop Priorities - Implementation Priorities (H indicates a high priority):

- Demonstrate new biological and biocompatible control measures, including practices for organic systems that look promising in replicated experiments (H).
- Evaluate new biological and biocompatible control measures including practices for organic systems (H).

New York State Potato Industry Priorities: (http://northeastipm.org/priority/potatoesNY_2003.html)

“Optimal cultural practices need to be developed for the most efficient, consistent and profitable production. Potato farming is a very complex system where it is very important to know the interactions between cultural practices, the crop, and the environment to be able to correctly select the most appropriate combination of production practices for an efficient and environmentally sound operation”. Included are:

- IPM and best management strategies – disease, insect & weed control.
- Soil health management – disease, fertility, manure, compaction and erosion.
- Profitable crop rotation studies.

Interest in and support of sustainable farming has been steadily growing in Maine and the Northeast. The Maine Organic Farmers and Gardeners Association (MOFGA), founded in 1971, is the oldest and largest state organic association in the country (<http://www.mofga.org>), and is growing in size, influence, public acceptance and visibility each year. The mission of MOFGA is to “ help farmers and gardeners grow organic food, protect the environment, recycle natural resources, increase local food production, support rural communities, and illuminate for consumers the connection between healthful food and environmentally sound growing practices”.

The proposed work will be conducted on 1) Wood Prairie Farm, a commercial organic potato farm owned by Jim and Megan Gerritsen (<http://www.woodprairie.com>), and 2) Aroostook Research Farm, Maine Agricultural and Forestry Experiment Station located near each other in the potato-growing region of Maine. The two sites have been selected to determine the response of a certified organic and a conventional crop production system to the proposed crop management practices. Jim Gerritsen is an exceptional grower and recognized leader in the sustainable agriculture community, who has attended and has been invited to speak at professional meetings at a national and international level. He has shown considerable interest in our work over the years, and has been successfully using some of the practices described here (commercial biocontrol agents, rapeseed cover crop). *Rhizoctonia solani* is the most important potato pathogen on his farm. He has been able to manage this pathogen to some extent using these practices. We propose to improve these and other successful practices and their combinations, and use scientific methodology to assess their effectiveness (both ecological and financial) and reproducibility. Upon determining the ecological and financial impact of the proposed management practices, Mr. Gerritsen has agreed to serve as a resource person for growers who are interested in learning the complexities of a sustainable agro-ecosystem in Maine and New England. The experiments will be replicated on the Aroostook Research Farm to determine the response of a conventional cropping system to these sustainable practices. This is a commercial-scale implementation project aimed at demonstrating the multiple benefits of the adopted practices to conventional and organic growers. In the second phase of

our mission, we plan to use both the Cooperative Extension and MOFGA forums for outreach, following the first two years of this project as part of a follow-up research/extension project.

Replacing or supplementing conventional practices with IPM or ecologically-based pest management (EBPM), as proposed here, including implementing compost and cover crop amendments, introduction of biocontrol organisms, and biofumigation, has the potential to significantly enhance and protect environmental quality, and reduce health risks and other problems associated with conventional pest management. IPM and EBPM, however, need to be safe, effective, profitable and durable (sustainable) to be embraced by growers. This research includes some of the most promising strategies for a successful EBPM program, and is designed to provide critical information needed to accelerate adoption of sustainable pest management strategies that are safe and profitable. Understanding the ecological processes occurring as a result of these practices and their interacting components (when used in combination) will lead to the development of effective pest management tools.

We strongly believe that this research/implementation project will 1) provide a better understanding of the ecological processes occurring in sustainable crop production in Maine and the Northeast, and 2) encourage growers to use the incentive payments offered by the USDA to help them defray costs involved with adoption of these sustainable approaches to farming. The strategies described in this proposal will improve yields, conserve the environment, enhance the farmers' knowledge of the agro-ecosystem, and help them become stewards of the land on which they live. Mr. Gerritsen has agreed to serve as a resource person to those farmers who are willing to make the transition to a more sustainable or organic crop production. Upon completion of this two-year project, we believe we can recruit several more growers like Mr. Gerritsen to help us establish a network for the sustainable farming community using the Cooperative Extension, MOFGA, and other farmer forums.

(ii) OBJECTIVES AND ANTICIPATED IMPACTS

The **objectives** of the proposed work are: (1) to improve crop production through a combination of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth; (2) to better understand the individual and collective contributions and ecological processes occurring as a result of these sustainable practices; and (3) to evaluate the profitability of these systems.

The **anticipated impacts** are as follows:

1) Soil fertility and quality will be enhanced by the addition of organic matter as compost and cover crop residue, which will bring about an increase in soil biodiversity, improved water infiltration, improved water-holding capacity.

2) Suppression of soil-borne and, perhaps, foliar diseases will be achieved through competition, antibiosis, parasitism/predation, and induced systemic resistance brought about by increased soil biodiversity, introduction of biocontrol organisms, and composts.

3) Rapeseed cover crop-mediated biofumigation is expected to nullify the need for Metam-sodium as it suppresses soil-borne diseases. In addition, biofumigation, increases yields (by contributing biomass as a green manure), enhances soil microbial biomass, increases the bacteria:fungal ratios by enhancing the levels of aerobic bacteria (including *Pseudomonas* sp.), and nitrogen-fixing bacteria.

4) Suppression of the Colorado potato beetle and other insect pests will be through increasing plant resistance to herbivory by optimizing nutrient balance in affected plants, and increased beneficial insect populations, thus diminishing the need for synthetic insecticides.

5) Enhanced crop yields will be brought about by improved soil fertility and quality, and suppression of soil-borne diseases and insect pests, thus reducing the need for synthetic fertilizers.

Thus, we anticipate implementation of these practices will lead to significant improvements in the sustainability of the agro-ecosystem, and safeguarding human health and the environment. It has been well documented that plants grown on soils amended with composts are more resistant to soil-borne, foliar pathogens and insect pests (see Background section). Upon adoption of the above sustainable practices, we expect to realize significant reductions in the use of synthetic pesticides by conventional growers, and significant improvements in organic crop production systems currently used by organic

farmers operating across the Northeast. One of the goals of our next research-implementation project will be to use the data generated by the work proposed here to persuade a large number of growers to adopt the most effective combination (ecologically and economically) of practices as determined by this project.

Economic benefits:

Potential economic benefits include higher marketable yields due to increased productivity and reductions in losses due to disease and pest problems. Additional economic benefits may derive from long-term reductions in pesticide (fungicides and insecticides) and fertilizer usage and expenses. Although initial expenses for implementing some of these sustainable practices (compost amendments, biocontrol agents) might be high, long-term efficacy and sustainability may lower overall costs in the long-term. We plan to conduct an economic analysis of each treatment at the two sites (see section iii) to determine relative costs (of the different sustainable and conventional treatments), which will serve as a starting point for a broader economic analysis.

A full appreciation of the economic benefits brought about by adoption of the crop management strategies proposed here is possible when one considers that: 1) Some pests develop resistance to whereas others cannot be controlled by pesticides (Gould 1991); 2) For some soilborne pathogens, nematodes, and arthropods there are no acceptable synthetic pesticides; 3) Health effects of pesticide residues in foods of humans, livestock animals, and wild life; 4) Broad-spectrum pesticides kill non-target organisms and exacerbate or create new pest problems by eliminating biocontrol organisms that previously held certain pests in check (DeBach & Rosen, 1991); and 5) Synthetic chemical pesticide companies have serious problems with escalating costs and fewer discoveries (Ollinger and Fernandez-Cornejo, 1995).

It is difficult to quantify the issues outlined above, and fit them into a cost/benefit analysis. But it is apparent that we need a paradigm shift from managing components or controlling single pests to maintaining ecological balances that result in sustainable agro-ecosystems and, in turn, enhanced plant health and significantly reduced pathogen or pest pressure. For this new approach to be successful, we shall need an information system to help growers manage their particular agro-ecosystem. Implementation research (such as this project) is the first step. The second step (our next project) is putting together a sustainable agriculture community support system to assist growers interested in the development and implementation of ecologically-sound crop production systems. The third step will occur when enough growers are convinced that the systems approach harbors much less risk (economical or environmental) than the current “band-aid” approach. Then a new knowledge-intensive industry will emerge – private consultants – to help growers maintain a complex crop production system that is safe, sustainable and profitable.

The desirability of sustainable agro-ecosystems producing healthy food should be part of economic feasibility analyses. There exist numerous cases of Community Supported Agriculture (CSA) farms in which “members share the full costs of food production and local, sustainable agriculture. The CSA movement aims to educate consumers that supermarket prices do not reflect the real costs of our industrial agricultural system. These costs include packaging waste disposal, soil erosion and groundwater contamination, pollution caused by long-distance transport, and fair farm labor wages.”

http://www.cias.wisc.edu/archives/2001/01/01/csa_more_for_your_money_than_fresh_vegetables/index.php. These initiatives distribute the costs of sustainably-produced food to the consumer, and protect farmers from shouldering all the risks involved in the function of food production. However, sharing food production costs and risks is not the prevailing consumer attitude at this time. Therefore, relative profit is the major incentive that will induce a grower to consider an alternative farming system (Reichelderfer, 1981).

(iii) APPROACH AND PROCEDURES

Background

One of the reasons plant diseases cause greater problems in commercial agriculture versus natural environments is the dramatic reduction in biomass and biodiversity of soil-inhabiting organisms (bacteria, fungi, flagellates, ciliates, amoebae and protozoa) that antagonize plant pathogens and pests and render

soils disease- or pest-suppressive (Garbeva, 2004; Mazzola, 2004). Soil regeneration can be achieved by the addition of organic matter (compost, cover crops or green manures) and beneficial organisms that allow restoration of microbial diversity (Cook and Baker, 1983; Lugtenberg et al., 2001; Weller et al., 2002). Plants grown on soils amended with manure have been shown to be less favorable hosts for phytophagous insects than plants grown on conventionally managed soils fertilized with synthetic fertilizers (Eigenbrode and Pimentel, 1988, Phelan et al., 1995 and 1996, Morales et al., 2001, Alyokhin et al., 2005). Phelan et al. (1996) and Phelan (1997) suggested that the organic matter and microbial activity associated with manure-amended soils afford a buffering capability to maintain nutrient balance in plants. Moreover, plants grown on compost-amended soils are more resistant to soil-borne and foliar pathogens (Zhang et al., 1998; Pharand et al., 2002; Krause et al., 2003; Vallad et al., 2003). Additions of compost increase levels of soil organic matter, improve soil physical properties, and stimulate the activity of soil microbial communities (Lynch et al., 2005). Compost amendments can suppress plant pathogens by stimulating microorganisms competitive with, or predatory to, pathogenic organisms such as *Pythium*, *Phytophthora*, *Fusarium* spp. and *Rhizoctonia solani* (Hoitink and Boehm, 1999). Composts are colonized by a large variety of microorganisms potentially capable of controlling the severity of plant disease outbreaks by suppressing pathogenic microorganisms or inducing systemic resistance in plants (Krause et al., 2003; Vallad et al., 2003). Different disease suppressive species within the soil microbial community are thought to be differentially affected by the solubility and chemical nature of the organic material in the compost (Hoitink and Boehm, 1999). A few studies have begun to characterize the chemical changes in soil organic matter resulting from compost amendment (Adani, et al., 2006). Linking soil chemical studies with observed effects of soil amendments on plant disease will increase our understanding of these complex ecological processes.

Hypovirulence-mediated biocontrol and composts: In addition to plant pathogens, the genus *Rhizoctonia* includes species and particular strains within certain species that not only are not pathogenic but also are beneficial to plants (see review by Andersen and Rasmussen, 1996). A particular group of nonpathogenic isolates of *R. solani*, called hypovirulent, has shown the ability to reduce disease caused by virulent *R. solani* (Bandy and Tavantzis, 1990). Moreover, in addition to having biocontrol properties, a particular hypovirulent isolate (Rhs 1A1) has been shown to promote plant growth (Fig. 1) and increased potato yields (Bandy and Tavantzis, 1990). It should be noted that this isolate is naturally-occurring, and the biocontrol and growth-promotion properties are not the result of any laboratory or genetic manipulation. The phenotype of this isolate has remained stable for twenty-five years.

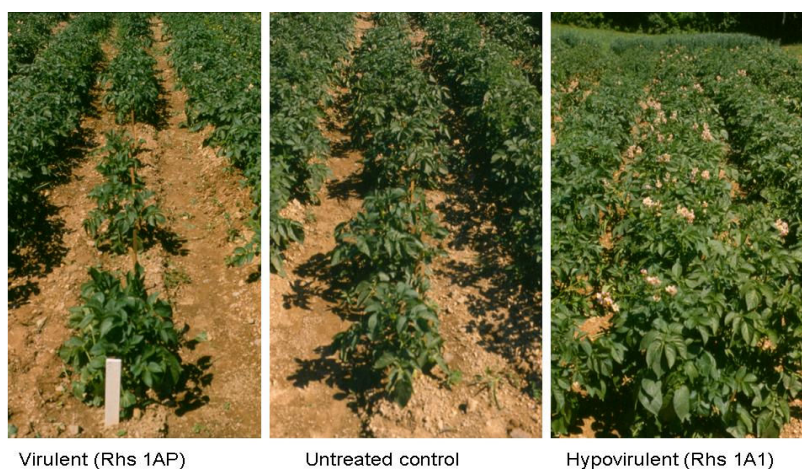


Figure 1. Potato plots (cv. Katahdin) treated with designated *R. solani* isolates.

We have shown that in *R. solani* (AG 3) 1) hypovirulence is associated with upregulation of a carbon utilization pathway called the quinic acid pathway, and 2) quinic acid dramatically reduces virulence in this plant pathogen (Liu et al., 2003a; 2003b). Quinic acid is one of the most prevalent

phenolic compounds in composted leaf or bark litters, and is used as a carbon source by numerous soil-borne bacteria and fungi. It is a constituent of up to 2 to 10% of dry weight in coniferous needles (Dittrich and Kandler, 1971; Leuschner et al., 1995) and in the leaves of woody angiosperms (Boudet, 1973). Composts prepared from lignocellulosic substrates, such as tree barks, suppress *R. solani* more effectively than composts prepared from low lignocellulosic and high sugar substrates (Hoitink and Boehm, 1999). The former group of composts contains higher levels of quininate than the latter group during their *R. solani* suppressive phase.

The degree of compost maturation appears to be an important factor determining the effect this compost will have on plant infection by *R. solani*. Fresh plant amendments generally increase the severity of Rhizoctonia disease (Wall, 1984), whereas cured compost suppresses the pathogen (Chung et al., 1988). It has been reported that colonization of the compost by species of *Trichoderma* is necessary for the suppression of *R. solani* (Chung et al., 1988a). However, fresh hardwood bark did not suppress Rhizoctonia damping-off in spite of the high density of *Trichoderma* sp. (Krause et al. 1997). In contrast, composted bark suppressed the pathogen even though populations of *Trichoderma* were two orders of magnitude lower than that of the fresh bark. It appears that suppressiveness of the composted bark coincided with the breakdown of lignins and the formation of quininate. Furthermore, many composts suppress *Pythium* and *Phytophthora* root rots, but only 20% of the composts tested suppress *Rhizoctonia* damping-off (Krause et al., 1997). In fact, a review of the literature indicates that disease suppression can be attributed, at least in part, to modifications of the abiotic soil environment (including nutrients) affecting the disease-causing activity of *R. solani* (Huber and Sumner, 1996).

We conducted a pilot field experiment using different pine tree byproducts as soil amendments. These included pine needles and pine mulch. A randomized complete-block experimental design was employed with five replications per treatment. Tubers from potato plants treated with pine-derived amendments or the hypovirulent isolate had a dramatically lower amount of black scurf and greater yield than tubers treated with the pathogen alone. In addition, the root systems of plants treated with organic matter were significantly more vigorous than that of control plants (Tavantzis, unpublished data; Fig. 2).



Figure 2. Effect of conifer amendment and *R. solani* inoculum on potato (Katahdin) roots and tubers.

A 3-year field study comparing selected biocontrol treatments and compost amendments (16 ton/acre) was conducted recently. A randomized complete block design was employed with four replicate

blocks (6.1 m x 1.8 m plot size). Treatments included a pine bark-based and a peat-based compost (Coast of Maine Organic Products, Inc), the hypovirulent *R. solani* isolate Rhs 1A1 and a bacterial biocontrol agent (*Bacillus subtilis*). Both pine and peat-based composts, alone and in combination with the hypovirulent Rhs 1A1, reduced stem/stolon canker and black scurf of potato, and also generally increased potato yield relative to an untreated control (Larkin and Tavantzis, unpublished).

We hypothesize that the concentration and availability of quinic acid (quininate) in a compost is an important factor that determines this compost's effect on *Rhizoctonia* disease. Some of the experiments we propose here will address this hypothesis, and will complement the multifaceted study on organic soil amendments and biocontrol agents described in this proposal. Composts have been known to have disease-suppressive properties, and compost-derived seed-dips and plant or soil sprays have been used in sustainable farming for several decades (Koepef, 1992). For consistency of disease-suppressive properties, it is important to use standardized inputs and methods of composting.

Other biocontrol organisms. The use of bacteria (*Bacillus*, *Pseudomonas*, and *Streptomyces*) and fungi (various species of *Trichoderma* sp., *Gliocladium* sp.) for biological control of soil-borne pathogens has resulted in disease reduction and/or increased yield in numerous agricultural crops (Asaka and Shoda, 1996; Cartwright and Benson, 1995; Lewis et al., 1995; 1998; Lewis and Larkin, 1997; Sumner et al., 1992). On potato, the bacterial colonization of their roots resulted in a 17% yield increase (Kloepper et al., 1980). Thus, biological control of *Rhizoctonia* diseases could restore the plant rhizosphere ecosystem and improve crop performance, including yield. In a recent evaluation of a wide variety of potential biocontrol organisms for their efficacy in reducing *Rhizoctonia* disease of potato (Brewer and Larkin, 2005), *B. subtilis* and *T. virens* were among the most effective, reducing stem canker and black scurf by 30 to 50%. The use of *Trichoderma* spp., including *T. virens* and *T. harzianum*, has also reduced *Rhizoctonia* disease of potato under field conditions, including reduction of stem canker when applied as a seed treatment (Beagle-Ristaino and Papavizas, 1985), and reduction of black scurf in organic production when applied as an in-furrow treatment (Tsorer et al., 2001) Larkin (2001;2002;2003a) has shown that in-furrow applications of the biocontrol organisms *B. subtilis* (Kodiak, Gustafson, Inc.) and *T. virens* (SoilGard, CertisUSA, Inc.) reduced *Rhizoctonia* stem canker (by 37-75%), reduced black scurf (by 11-25%), and increased tuber yield (by 11-15%) compared to a pathogen control in field trials conducted over multiple years. These biocontrol organisms may provide even greater control when used in conjunction with the organic amendments proposed here. Addition of biocontrol agents to compost amendments has shown increased capability for disease-suppression (Krause et al, 2003). In a preliminary field experiment, combinations of biocontrol agents with compost provided some of the greatest levels of disease reduction of canker and black scurf observed, as well as the highest overall tuber yields (Larkin and Tavantzis, unpublished), indicating the potential for improved disease control with biocontrol and compost combinations. Several other soil-borne pathogens of potato, including *Streptomyces scabies* (cause of common scab), *Spongospora subterranea* (cause of powdery scab), *Sclerotinia sclerotiorum* (cause of white mold), and *Helminthosporium solani* (cause of silver scurf) may also be reduced by organic and biological amendments.

Brassica crop rotations and biofumigation. The use of *Brassica* spp. and related plants as cover, rotation, or green manure crops has great potential for reducing soil-borne pathogens and diseases by a process known as biofumigation (Sarwar et al., 1998). *Brassica* crops, which include broccoli, cabbage, cauliflower, kale, turnip, radish, canola, rapeseed, and various mustards, produce compounds called glucosinolates that break down to produce sulfur compounds (isothiocyanates) and have been successfully used to reduce soil-borne fungal pathogen populations (Brown and Morra, 1997; Kierkagard et al., 1996; Olivier et al, 1999; Smolinska and Horbowicz, 1999), nematodes (Buskov et al., 2002; Mohtahejdi et al., 1993), and weeds (Boydston and Hang, 1995; Brown and Morra, 1995), and to improve soil characteristics and crop yield (McGuire, 2003). As part of our potato cropping systems research, we have consistently observed that canola and rapeseed crops prior to potato result in substantially lower soilborne diseases such as *Rhizoctonia* and common scab than most other rotations (Larkin and Honeycutt, 2002; 2006). Recent research conducted by Larkin's group in on-farm trials indicated that use of *Brassica* crops, such as rapeseed and mustard, as green manure rotation crops, could reduce powdery

scab (by 15 to 40%), Rhizoctonia disease (by 50-85%), and common scab (by 11-25%) compared to a nonsuppressive oats or ryegrass rotation crop (Larkin and Griffin, 2006).

Soil microbial ecology. Soil microorganisms greatly impact many important soil and plant processes and functions. They are critical determinants of soil nutrient status, crop health, and overall crop productivity. Many factors can affect soil microbial communities, including soil characteristics, environmental conditions, and crop management strategies (Hoitink and Boehm, 1999; Garbeva et al., 2004). One of the most important cultural practices driving changes in soil ecology and microbiology is the particular crop species grown and the amount and type of organic matter (Curl and Truelove, 1986). All of the treatments we propose (organic matter, biological amendments, *Brassica* crop rotations) for improving soil fertility, reducing soil-borne diseases, and increasing crop production, function primarily through their effects on soil microbial communities and soil microbial ecology. Thus, monitoring effects on and changes in the soil microbial communities is critical for understanding the relationships among these factors and their roles in disease management and crop productivity.

In recent years, several techniques, useful for community-level characterization, have been developed that do not solely rely on culture-based assays. These include molecular analyses of DNA and RNA extracted from soil (Dunbar et al., 1999; Liu et al., 1997; Ritchie et al., 2000), and community profiling based on phospholipid fatty acids (PLFA) (Bossio and Scow, 1998; Bossio et al., 1998; Frostegård et al., 1993; Zelles et al., 1992, 1995) and fatty acid methyl esters (FAME) (Cavigelli et al., 1995; Ibekwe and Kennedy, 1999). Another useful community-level approach often used is profiling based on sole carbon source substrate utilization (SU) (Garland and Mills, 1991; Grayston et al., 1998; Zak et al., 1994). These techniques have been used to detect and characterize differences in soil microbial communities based on varying soils and land use (Ibekwe and Kennedy, 1999; Yao et al., 2000), agricultural management practices (Bossio et al., 1998; Lupwayi et al., 1998), and plant species present (Siciliano et al., 1998; Marschner et al., 2001; Miethling et al., 2000; Fang et al., 2001), among other factors. Although no one approach provides a complete depiction of soil microbial characteristics, each of these approaches offers a slightly different perspective (Mazzola, 2004). So, the use of multiple approaches allows a more complete representation of soil microbial characteristics. From this information, specific effects of amendments and management practices on microbial composition, structure, and function can be determined and, in turn, correlated to effects on disease management and productivity.

Recent evaluations of the influence of specific potato cropping systems on soil microbial community characteristics using several different approaches for the detection and determination of community-level characteristics (Larkin, 2003b; Larkin and Honeycutt, 2006), indicated that soil populations of culturable bacteria, actinomycetes, fluorescent pseudomonads and overall microbial activity tended to be highest following barley, canola, and sweet corn rotations, and lowest with continuous potato. Analysis of soil microbial communities based on substrate utilization (SU) and FAME profiles demonstrated distinct differences among the rotation soils regarding the functional and structural microbial attributes, indicating that different crop rotations have distinctive effects on soil microbial communities that are detectable using a variety of techniques. In subsequent research including a rapeseed rotation, microbial effects were comparable to those of canola, and reductions in soil-borne disease were slightly better (Larkin et al., 2006a). In ongoing research projects, these techniques have and are being used to evaluate soil microbial communities affected by manure amendments (Larkin et al., 2006b), cover crops, and biological amendments (Larkin, 2006). In the proposed research, these same techniques will be used to identify specific changes in microbial communities associated with the amendments and treatments imposed and relate these changes to potential effects on disease management, crop health, and crop productivity.

Insect Pests. A number of insect pests create problems for organic and conventional growers. Some of them are limited to a single crop species, while others are polyphagous and damage multiple crops across Mr. Gerritsen's rotation sequence (Table 1). The potato pest complex is the most economically important. There is increasing concern among growers about pests of rapeseed and other crops (Alyokhin, unpublished). Although these pests have not been a persistent problem on Wood Prairie Farm, they will be monitored throughout this project across all treatments. Colorado potato beetle, *Leptinotarsa decemlineata*, is the most important insect defoliator of potatoes (Weber and Ferro, 1994).

Table 1. Major pests affecting crops grown on 2- and 4-year rotation schedules in Maine.

Crop	Pest
Potato	Colorado potato beetle (<i>Leptinotarsa decemlineata</i>), potato flea beetle (<i>Epitrix cucumeris</i>), aphids (<i>Macrosiphum euphorbiae</i> , <i>Aphis nasturtii</i> , and <i>Myzus persicae</i>), wireworm complex (numerous species of soil-dwelling Elateridae larvae), European corn borer (<i>Ostrinia nubilalis</i>)
Rapeseed	Crucifer flea beetle (<i>Phyllotreta cruciferae</i>), black cutworm (<i>Agrotis ipsilon</i>), variegated cutworm (<i>Peridroma saucia</i>), green peach aphid (<i>Myzus persicae</i>)
Cereals	Black cutworm, variegated cutworm, wireworms
Clover	Clover root weevil (<i>Sitona hispidula</i>)
Buckthorn	Tarnished plant bug (<i>Lygus lineolaris</i>), aphids (<i>several unidentified species</i>)

In field studies conducted at Aroostook Research Farm (Presque Isle, Maine) in 1999-2003 (Alyokhin et al., 2005), we investigated effects of soil amendment practices on Colorado potato beetle populations in potato fields. Manure-amended plots used in that study received organic amendments for a total of 13 years. Beetle densities were almost universally lower in plots receiving raw cow manure soil amendments in combination with reduced amounts of synthetic fertilizers compared to plots receiving full rates of synthetic fertilizers but no manure (Alyokhin et al., 2005). Furthermore, tuber yields were higher in manure-amended plots. In accordance with the mineral balance hypothesis (Phelan et al. 1996, Phelan 1997), there was a dramatic dissimilarity in the mineral composition of potato leaves collected from manure-amended and synthetically fertilized plots. Subsequent field-cage and laboratory studies confirmed that the observed reduction in beetle densities was plant-mediated (Alyokhin & Atlihan, 2006).

Little is known about the effects of other organic amendments on the Colorado potato beetle populations or other crop/pest systems. Eigenbrode and Pimentel (1988) recorded significantly lower peak densities of two flea beetle species, *Phyllotreta crucifera* and *P. striolata* on collards grown in manure-amended soil compared to the collards receiving a comparable amount of macronutrients from synthetic fertilizers. Similarly, when given a choice between corn plants grown in manure-amended and synthetically fertilized soils, European corn borer females strongly preferred to oviposit on the latter (Phelan et al. 1995, 1996). Also, Morales et al. (2001) reported that corn plants grown on organically fertilized soils hosted fewer aphids, *Rhopalosiphum maidis*, compared to corn plants grown on synthetically fertilized soils.

In addition to plant-mediated effects, we hypothesize that at least some of the pests may be directly affected by biofumigation. Except for aphids, the European corn borer, and the tarnished plant bug, all other insects listed in Table 1 inhabit soil for at least part of their life cycles. Therefore, increased concentration of isothiocyanates may create an unfavorable environment for their survival and development (Matthiessen and Shackleton 2000, Tsao et al. 2001, Warton et al. 2003).

Weeds are considered to be a major problem in sustainable farming (Bond and Grundy 2001). Gerritsen, however, is quite successful with weed management. They have been using an array of practices and tools, such as flaming at 10% potato emergence and rear mount fingerweeders as they cultivate the potatoes using mid-mount cultivators with calves tongue feet. They cultivate/fingerweed twice about a week apart and then hill twice with mid-mount spades timing the last hilling approximately a week before row closure occurs around July 10. Prior to planting, they do tillage mostly with a disk harrow that tends to push the rocks down and bring fine soil particles up. Similar weed management strategies will be employed at the Aroostook Research Farm site.

Experimental Plan and Procedures

Experimental Plan:

Greenhouse compost evaluations. Using our limited resources, we plan to carry out (January to April 2007) greenhouse evaluations of different types and levels of maturity of composts to determine what type of compost would have the greatest activity in suppressing soil-borne diseases, particularly *Rhizoctonia solani*. We plan to use a variety of conifer-based composts that are high in lignocellulosic

compounds at different stages of maturation. A hardwood-based compost will be used as a low-lignin control. Phenolic compound concentrations will be correlated with the amount of quinic acid found in each of the above composts. Greenhouse screening assays will be carried out using each compost mixed with soil infested with inoculum of *R. solani*, and the effects on pathogen propagule numbers and disease development on emerging potato plants and seed pieces will be evaluated. We also plan to evaluate survival, development, and reproduction of Colorado potato beetles and the three species of potato-colonizing aphids (*Macrosiphum euphorbiae*, *Aphis nasturtii*, and *Myzus persicae*). These experiments will help determine the type and characteristics of compost with the greatest potential for reducing Rhizoctonia and other soilborne diseases and insect pests. One or two composts showing the greatest potential for disease and insect reduction in these greenhouse tests will then be used in the field trials (May/June 2007).

Field Trials. Replicated on-farm field trials, in which the compost treatment will be tested alone and in conjunction with biological treatments and a preceding rapeseed rotation crop at Wood Prairie Farm, Bridgewater ME, and Aroostook Research Farm, Presque Isle, ME. Thus, there will be three factors evaluated: compost (no compost, compost), biocontrol agents (no biocontrol, hypovirulent *R. solani*, *Trichoderma* spp., *Bacillus subtilis*, or combination of biocontrol agents), and crop rotation (standard rotation crop, rapeseed rotation) (2 x 5 x 2 factorial). Each treatment will be tested for two consecutive field seasons (years). After planting, plant emergence and disease and insect problems would be monitored throughout the growing season. Underground plant parts will be sampled for assessment of stem and stolon cankers from *R. solani*, and other root diseases. Foliar symptoms characteristic of late blight or virus diseases will also be monitored. Soil samples will be taken to monitor soil-dwelling insect pests. At harvest, yields will be determined for all crops. Potato tubers will be assessed for symptoms of black scurf, common scab, other soilborne diseases, viruses, and insect pests. This would identify the best combination of treatments and their efficacy against the above pathogens and pests.

To determine the contributions of compost or cover crops to soil quality, we plan to chemically and physically characterize soils by determining a) nutrient content (standard soil test), total carbon, total nitrogen, water stable aggregates, bulk density, and soil moisture before each growing season, b) soil moisture, nitrate content, total soluble carbon content, and total soluble phenolic content during the growing season 4, 6, 8, 10, and 12 weeks after planting, and c) water stable aggregate content 8 and 12 weeks after planting.

Procedures:

Objective 1: Improve crop production through a combination of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth.

Greenhouse compost evaluations. We are working with two well-established companies located in the area. Envirem Technologies Inc. (ETI) (<http://www.envirem.com/>), New Brunswick, Canada, and Coast of Maine Organic Products, Inc. (CMOPI) (<http://www.coastofmaine.com/>) located in Maine. They offer a variety of composts and amendments. ETI and CMOPI are planning to build joined facilities about 90 miles from UMaine. The directors of both companies have agreed to produce custom blends and batches of compost for our specific research needs. ETI has worked with Dr. Harry Hoitink (Ohio State Univ.) in the past. We plan to include compost blends differing in terms of the conifer species or the conifer raw material used (bark, paper mill waste, etc.), and follow the guidelines for disease-suppressive compost production and utilization provided by Hoitink and Changa (2004). Compost maturity will be evaluated using the Solvita Compost Maturity Test Kit, a commercially-available test that assesses CO₂ and NH₃ evolution and based on these tests assigns a compost maturity index from 1 to 8 (Woods End Research Lab, Inc., Mt. Vernon, Maine; <http://www.woodsend.org/index.html>). Phenolic compounds occurring at different compost maturity levels will be quantified by homogenization, organic solvent extraction, and spectrophotometry as determined by Erhart et al (1999). Quinic acid and other phenolic byproducts will be measured by HPLC as described by Pereira et al. (2003). Nutrient analysis will be performed by the UM Soil Testing Laboratory (<http://anlab.umesci.maine.edu/>) on each compost to normalize each compost treatment for equivalent amounts of N, K and P.

A relatively small number (4-6) of compost blends differing in quinic acid content and origin of raw material will be assessed for suppression of *R. solani* and *Streptomyces scabiei* (common scab) under greenhouse conditions. Each compost:soil mix combination (1 part compost: 1part field soil) and control field soil without compost will be planted with three seedpieces of Yukon Gold potatoes per standard 6” pot in a randomized complete block design with 5 replicate pots per treatment. Ten grams of virulent *R. solani* (isolate Rhs 1AP) inoculum (colonized grains) will be placed symmetrically at four points around the pot. The pots will be fertilized and watered as needed. Soil temperatures will be kept between 12° and 16° C. Virulence assessment will be performed as described by Bandy et al. (1984). Plant growth will be monitored to determine as to whether or not a particular compost has significant effects on plant growth as compared to control plants grown in unamended soil.

A design similar to that used for disease assessment experiments will be employed to evaluate plant reaction to insect pests. The study will be conducted separately for Colorado potato beetles and for each of the three species of aphids (*Macrosiphum euphorbiae*, *Aphis nasturtii*, and *Myzus persicae*). Early (no older than 12 hours) first instars will be obtained from laboratory colonies and placed on individually caged potato plants (six beetle larvae or 12 aphid nymphs per plant). Five cages will be used for each treatment. Cages will be checked daily, and the number of individuals dying and molting to the next instar will be recorded. This experiment will be repeated with adult insects. Three beetle pairs (three males + three females) or ten aphids (viviparous parthenogenic generation) will be placed on each plant. Ten cages per treatment will be used for the beetles, and five cages per treatment will be used for the aphids. Cages will be checked daily, and numbers of individuals dying and offspring produced will be recorded. The offspring will be removed from the cages. Plants will be replaced as needed. The experiment will continue until all adults are dead.

Milestones: Compost characterization and standardization. Determination of compost characteristics associated with maximum disease and pest suppression, and selection of compost(s) to be used in subsequent field trials.

Field Trial established at Wood Prairie Farm. Treatments evaluated for effects on soil-borne potato diseases, alone and in combination, will be: compost amendment (no compost, compost added to furrow at planting); biocontrol amendments (none, hypovirulent *R. solani*, *Trichoderma* spp., *Bacillus subtilis*); and rotation (standard 4-yr rotation, preceding fall rapeseed crop). One full set of research plots will be established within the existing four-year rotation previously implemented on this farm (year 1, potato; year 2, spring wheat or oats under-seeded with clover and timothy; year 3, clover; year 4 (2006), plowdown clover, buckwheat planted in June). An adjacent set of plots (paired with first set) will be established within the same four-year rotation sequence, with the addition of a fall (August 2006) planting of ‘Dwarf Essex’ rapeseed following the buckwheat, grown for ~2 months, and incorporated in late fall (November 2006). Rapeseed crops, such as this, grown as a cover or green manure crop preceding potato, have been shown to reduce soilborne disease, particularly Rhizoctonia, in previous field trials (Larkin and Griffin, 2006). Each plot will be 18 by 25 ft, which will include six rows of planted potatoes in the potato year (2007). The two outside rows (1 and 6) will serve (along with outside rows of the neighboring plots) as buffer zones between treatments. The experiment will be established as a randomized complete block design with 4 replicate plots per treatment. All treatments will be conducted on both standard rotation and rapeseed rotation plots. Thus, rotation will be an additional factor, implemented in paired plots. This same experimental set-up would then be repeated in the appropriate rotations for the 2008 potato planting year.

The compost amendment will consist of the compost determined to be most effective in previous greenhouse screening trials. Compost will be added to the furrow at planting at a rate of 15-20 tons/acre. Biocontrol amendments will consist of the hypovirulent *R. solani* (Rhs 1A1), a mix of two different *Trichoderma* isolates and preparations (*T. virens* isolate G1-21, commercially available as SoilGard, Certis, USA, Columbia, MD; *T. harzianum* isolate KRL-22, commercially available as RootShield, Bioworks, Inc, Geneva, NY), and *Bacillus subtilis* (isolate GB-03, commercially available as Kodiak, Gustafson, Inc, Plano, TX). Each of these isolates has shown potential for reducing soil-borne disease due to *R. solani* in separate tests (Bandy and Tavantzis, 1990; Larkin, 2001, 2002, 2003a), but there is little information on their use in combination with each other or with other control measures. Each of these

biocontrol amendments will be added to the furrow at the time of planting at previously established and appropriate rates.

Plots will be planted by hand, with Yukon Gold seed potatoes at 6.7-in within row spacing and 3 ft between row spacing. All seed potatoes will be randomly mixed (for uniform seed-borne inoculum distribution) and green-sprouted prior to planting, as is the standard practice at the Wood Prairie Farm. Green-sprouting results in faster and more uniform emergence, and can also reduce the impacts of some soil-borne pathogens, such as *R. solani*, by reducing the time to emergence (Larkin 2003a). Fertilization and all other management practices for the potato crop will be conducted as the standard production practices for the farm, and all inputs and practices will conform to certified organic requirements. Emergence (counts) will be assessed at 4 wk after planting.

If Colorado potato beetle density in any of the treatments exceeds economic thresholds currently recommended by the UMaine Cooperative Extension by more than 50%, the entire experiment will be sprayed with Spinosad-based insecticides. This will allow preventing beetle re-distribution among the plots following depletion of their food resources.

Field Trial established at Aroostook Farm. Field plots established at Aroostook Farm will follow the same experimental design, set-up, and procedures as at Wood Prairie Farm, except that the cropping history and management practices will reflect conventional crop management practices. Thus, the treatments, plot size, configuration, etc., will be the same. The rotation, however, will be a two-year, small grain (barley) rotation as the standard rotation, and barley with a fall rapeseed cover crop as the rapeseed rotation treatment. Crop management practices consistent with conventional potato production will be used, such as pre-emergence herbicide treatment followed by cultivation and hilling for weed control, synthetic fertilizer applied at planting, and preventative fungicide sprays (alternating between chlorothalonil and mancozeb) for control of late blight as needed. Fertilizer rates will be adjusted for amount of NPK included in compost treatments so that total amount added reaches 200 lb N/ac. Also, potato seed will not be green-sprouted, which is consistent with conventional practices. Minimal applications of pesticides will be made for insect control (and only if necessary), and comparable material as used in organic trial will be used when possible, in order to provide the best assessment of the experimental treatments regarding pest control. One additional treatment (with 4 replicate plots) will also be included in a separate block for comparison; a treatment consisting of standard conventional management, including use of imidacloprid-based insecticides for control of Colorado potato beetle, full synthetic fertilizer rates, and other conventional practices that may not be appropriate within the context of the sustainable management treatments. In this way, a comparison can be made among all of the sustainable management practices with reduced chemical inputs with that of the full conventional treatment containing the standard chemical inputs, and efficacy of disease and pest control can be made in comparison to standard conventional pest management. This treatment would reside in a separate block outside the sustainable management treatments, so as not to physically interfere with their maintenance. All other aspects of the field operation at Aroostook Farm will be comparable to those already described for the trial at Wood Prairie Farm. As at Wood Prairie, the experiment would be conducted in both the 2007 and 2008 field seasons.

Milestones: Establishment of field trials at Wood Prairie and Aroostook Farms, including three treatment factors evaluated alone and in combination with others (compost, biocontrol organism, and rapeseed rotation prior to potato planting) to assess multiple integrated approaches to disease, insect and soil fertility management under both organic and conventional production practices.

Objective 2: *Understand the ecological processes occurring as a result of the sustainable practices described in Objective 1.*

Pathogen, disease, insect, and soil microbial assessments (Summer-Fall 2007 and 2008). Visual assessment of potato plants will be conducted throughout the growing season for any symptoms of soilborne diseases. Rhizoctonia disease assessments, including destructive sampling of 4 plants/plot (taken from the 2nd and 5th rows), will be conducted at 8 and 12 weeks after planting, for determination of plant dry weight and root and crown assessment of stem, root, and stolon canker by previously described

methods (Bandy et al., 1984). At maturity, tubers will be harvested from the middle two rows (3rd and 4th) of each plot, and yield and size distribution determined. In addition, tubers will be assessed for all observed soil-borne tuber diseases (black scurf, common scab, powdery scab, silver scurf, etc.) as described by Bandy and Tavantzis (1990). In other rotation crops, soil-borne diseases such as damping-off, *R. solani*, and white mold will be assessed and monitored, and grain crops will be assessed for take-all and various foliar diseases, as warranted.

In potato, twenty plants will be randomly selected at weekly intervals from each plot and visually examined for the presence of pest insects and their natural enemies. The number of Colorado potato beetles in all life stages and flea beetle adults, as well as the number of European corn borer egg masses and entrance holes will be recorded on a whole-plant basis. The number of potato-colonizing aphids will be recorded for a top, middle, and a bottom leaf of each selected plant (Dwyer et al. 1997, Gallandt et al. 1998, Alyokhin et al. 2002). The number of flea beetle holes will be counted on one terminal leaflet of each selected plant. Eight soil cores (4" dia. X 8") will be taken at weekly intervals at each plot (four samples within the rows and four samples between the rows) and checked for the presence of wireworms, cutworms, and flea beetle larvae.

In other crops at the Wood Prairie Farm, 20 net sweeps will be made at weekly intervals on each plots and checked for the presence of pests listed in Table 1. In rapeseed, the number of flea beetle holes will be counted on cotyledons and first true leaves of 20 plants randomly selected on each plot for the first two weeks after plant emergence from soil (the most vulnerable period in rapeseed life cycle). Eight soil cores (4" dia x 8") will be taken weekly at each plot and checked for the presence of wireworms, cutworms, flea beetle larvae, and root weevils.

Soil samples (8 soil cores, 1" dia. x 6 in, composite sample for each plot) will be collected from each plot 2 wk after planting and again at harvest time to be used to assess pathogen populations and soil microbial characteristics. Quantitative estimation of populations of *R. solani* and the added biocontrol agents will be carried out by real time PCR analysis, as described by Chapon et al. (2003). Primers are commercially available for *Bacillus subtilis* (<http://www.takarabioeurope.com/pdf/hd/BV16.pdf>) and *Trichoderma harzianum* (<http://www.epa.gov/nerlcwww/moldtech.htm>). Soil microbial characteristics in the different treatment plots will be assessed by determination of soil dilution plate counts of total bacteria and fungi, single carbon source substrate utilization (SU) profiles, and fatty acid methyl ester (FAME) profiles, as described by Larkin (2003b). SU and FAME profiles will be analyzed and compared among treatments, and particular substrate guilds, structural classes, and biomarkers used as indicators for particular microorganism groups (Larkin, 2003b). These approaches will provide a comprehensive assessment of both general and specific effects on soil microbial characteristics.

Soil fertility and physical properties: Soils will be chemically and physically characterized prior to treatment at the beginning of each growing season. Ten to 15 soil cores will be taken throughout each plot to a depth of approximately 20 cm, composited, air dried, and sieved through a 2 mm sieve. Nutrient content and pH will be determined by the Maine Soil Testing Service using standard methods (Hoskins, 1997). Total carbon and nitrogen content will be determined by combustion using a Leco CN-2000 Analyzer.

Water stable aggregates will be determined prior to planting, at mid-season, and just prior to harvesting. Samples for aggregate analysis will be collected to a depth of approximately 20 cm using a hand trowel avoiding field edges and compacted areas. Approximately 10 to 15 sub-samples will be gathered, composited, and dried in paper bags at about 26° C. Samples will be sieved through a 6.5 mm sieve and separated into three size classes (2-6.5 mm, large; 1-2 mm, medium; and 0.25-1 mm, small) using a modification of the wet sieving method developed by Yoder (1936). Briefly, a 25 g sample of soil will be placed on the top screen of a nested series of screens, completely immersed in water, and oscillated for 10 min at 35 oscillations min⁻¹. After sieving the sample collected on each screen will be washed into a separate beaker, oven dried and weighed. Sand content will be determined following dispersion in sodium hexametaphosphate (Grandy et al., 2002).

Soil moisture, nitrate and ammonium content, soluble carbon content, and soluble phenolic content will be determined prior to planting and 5 times during the growing season. Ten to 15 soil cores will be taken throughout each plot to a depth of approximately 20 cm. Cores will be mixed together,

sieved moist through a 4 mm sieve, and stored in the refrigerator until analysis. Soil moisture will be determined by weighing 15-20 g of moist soil. Soil:water extracts will be made by adding deionized water to field moist soil (15 g dry weight equivalent) so that the total water in the tubes (added plus soil water) equals 30 g. They will then be shaken at 95 rpm for 1 h and centrifuged for 30 min at 1610Xg (Piper et al., 2006). Aliquots of the filtrate will be analyzed for soluble carbon using a Shimadzu TOC-5000 analyzer. Separate aliquots will be analyzed for total soluble phenolic content using the Folin-Ciocalteau reagent (Conklin et al., 2002). Soluble nitrate and ammonium will be determined by the Maine Agricultural and Forest Experiment Station Analytical Laboratory.

Milestones: Assessment of soil pathogen populations and development of soilborne diseases. Assessment of soil microbial characteristics (including biodiversity) associated with all treatments and comparisons among treatments. Evaluation of the impacts of compost and rotation on insect pests, soil fertility, and, chemical and physical properties of soil.

Objective 3: Evaluate the profitability of the system.

Cost/benefit analysis: We plan to carry out an economic analysis of each replicated treatment at the two field sites, Wood Prairie Farm/Organic and Aroostook Research Farm/Conventional adopting treatments described in this proposal. Standard data processing methods will be used to determine variable costs and inputs of the different treatments using professional assistance (PD's spouse is a professor of accounting and a CPA). The purpose of this analysis will be to determine relative economic feasibilities of the various treatments described here rather than comparing their profitabilities with those of relevant practices currently used by farmers in the area. Operation costs used in the analysis will be obtained from the National Agricultural Statistics Service (<http://www.nass.usda.gov/>) and Jim Gerritsen whereas cost of inputs will be the average prices at the time of use scaled for a 10-acre vegetable farm. Crop values will be either those received by Gerritsen (organic farm) or those received by conventional growers (Aroostook Research Farm) in the particular year. Thus, cost/benefit comparisons of treatments will be performed within each cropping system.

Milestones: Evaluation of the relative economic feasibilities of the different treatments in organic and conventional cropping systems.

Table 2. Timetable for completing research objectives

Date	Task
Jan.-May '07	Compost analysis for quinic acid content; greenhouse compost efficacy trial
May '07	Sample soil in experimental plots for nutrient and physical properties, quinic acid, microbial biomass C+N, and microbial diversity
May-June '07	Incorporate compost and biological control agents into experimental plots, plant potatoes
Three weeks Post-planting	Assess potatoes for emergence, disease and insect pest damage
Summer '07	At regular intervals (see text), collect soil samples to determine microbial diversity, microbial biomass C+N; quantify populations of pathogens and insect pests; assess potatoes for disease and insect damage
September '07	Harvest potatoes, assess incidence and severity of soil-borne diseases; determine yield quantity and quality
October '07	Collect soil samples for microbial diversity analysis and assessment of soil fertility, chemical and physical properties
Nov. '07- Jan. '08	Complete soil analyses; data processing; report data at grower and Coop. Extension meetings
'08 season	Repeat same field operations as listed above for the '07 season; analyze data, report at grower and professional meeting. <i>Fall '08:</i> develop a proposal for phase II; recruit more growers to the study; start developing a sustainable agriculture support network.

(iv) EVALUATION PLANS

One of the novel aspects of this proposal is the hypothesis that quinic acid derived from plant compost decay renders *Rhizoctonia solani* AG 3 (and perhaps other soil-borne pathogens) non-pathogenic on potato. Since conifer tissues contain higher proportions of lignins, they are expected to be more effective in this regard. Previous studies conducted by other research groups have shown that conifer-derived, mature composts are more suppressive on *R. solani* than other composts. *So, one of the major anticipated impacts will be that in treatments involving a conifer compost amendment, plants will exhibit significantly lower incidence and severity of soil-borne diseases.* In addition, plant composts have been associated with 1) induced systemic plant resistance against soil-borne and foliar pathogens, and 2) increased soil biomass and biodiversity which contribute to antagonism and suppression. These well-documented composts properties (which will be closely monitored in this study) are expected to ensure that compost-amended plots will harbor a lower disease levels than other treatments. Moreover, the introduction of three different biocontrol organisms (alone or in combination) into compost-amended soil will further erode or ameliorate pathogen populations as our 3-year unpublished data (Larkin and Tavantzis) shows.

Standard disease assessment, microbial diversity and microbial biomass methods (described in section iii) will be used to determine if the expected impacts of compost and biocontrol organism amendments have been achieved, that is, manage disease levels without (organic) or with limited (conventional) use of synthetic pesticides. Quantitative PCR tests will be used to determine *R. solani* (AG 3) levels and, in turn, whether reduced rhizoctonia disease levels can be attributed to reduction in virulence (compost, hypovirulent isolate Rhs 1A1) or population (biofumigation, antagonism) of *R. solani* in the different treatments.

The impact of compost amendments on insect pest populations and damage caused by them will also be assessed. It is known that plants grown in manure-amended soil and reduced amounts of synthetic fertilizer have less insect pest damage and harbor lower pest populations. Since little is known about the effect of plant composts on insect pests, quantitative data on population levels and damage caused by Colorado potato beetle, aphids and other pests will provide valuable information on the suitability of compost-treated plants as a food source for these pests.

Enhanced quantity and quality of crop yields, brought about by the use of compost and biological soil amendments, are a major anticipated impact of the work proposed here. Crop value, however, is only one aspect of the financial feasibility of a treatment. The *relative* competitiveness of each treatment will be assessed by a cost/benefit analysis. The results of this analysis will determine the value of this project to the growers. In contrast, the long-term sustainability (durability) of the treatments described here cannot be determined in the context (two years) of the proposed project.

REFERENCES

- Adani, F., P. Genevini, F. Tambone, and E. Montoneri. 2006. Compost effect on soil humic acid: A NMR study. *Chemosphere* 65:1414-1418.
- Alyokhin, A. and R. Atlihan. 2005. Reduced fitness of the Colorado potato beetle (Coleoptera: Chrysomelidae) on potato plants grown in manure-amended soil. *Environmental Entomology* 34: 963-968.
- Alyokhin, A. and R. Atlihan. 2006. Reduced fitness of the Colorado potato beetle (Coleoptera: Chrysomelidae) on potato plants grown in manure-amended soil. Accepted by Environ. Entomol.
- Alyokhin, A., G. Porter, E. Groden, and F. Drummond. 2005. Colorado potato beetle response to soil amendments: a case in support of the mineral balance hypothesis? *Agriculture, Ecosystems, and Environment* 109: 234-244.
- Alyokhin, A., G. Sewell, and E. Groden. 2002. Aphid abundance and potato virus Y transmission in imidacloprid-treated potatoes. *Am. J. Potato Res.* 79: 255-262.
- Anderson, N.A. 1982. The genetics and pathology of *Rhizoctonia solani*. *Ann. Rev. Phytopath.* 20:329-347.
- Asaka, O., and Shoda, M. 1996. Biocontrol of *Rhizoctonia solani* damping-off of tomato with *Bacillus subtilis* RB14. *App. Env. Microbiol.* 5:397-404.
- Bandy, B. P., S. S. Leach, and S. M. Tavantzis. 1988. Anastomosis group 3 of *Rhizoctonia solani* is the major cause of Rhizoctonia disease in Maine. *Plant Disease* 72: 596-598.
- Bandy, B. P., and S. M. Tavantzis. 1990. Effect of hypovirulent *Rhizoctonia solani* on Rhizoctonia disease, growth, and development of potato. *Am. Potato J.* 67: 189-199.
- Beagle-Ristaino, J. E., and Papavizas, G. C. 1985. Biological control of Rhizoctonia stem canker and black scurf of potato. *Phytopathology* 75:560-564.
- Bond, W. and A. C. Grundy. 2001. Non-chemical weed management in organic farming systems. *Weed Research* 41: 383-405.
- Bossio, D. A., and Scow, K. M. 1998. Impacts of Carbon and flooding on soil microbial communities: Phospholipid fatty acid profiles and substrate utilization patterns. *Microbial Ecology* 35:265-278.
- Bossio, D. A., Scow, K. M., Gunapala, N., and Graham, K. J. 1998. Determinants of soil microbial communities: Effects of agricultural management, season, and soil type on phospholipid fatty acid profiles. *Microbial Ecology* 36:1-12.
- Boudet, A., Les acides quinique et shikimique chez les angiospermes arborescentes, *Phytochemistry*, 12, 363, 1973
- Boydston, R. A., and A. Hang. 1995. Rapeseed (*Brassica napus*) green manure crop suppresses weeds in potato (*Solanum tuberosum*). *Weed Technology* 9:669-675.

- Brady, N. C. (2002) The nature and properties of soils. Upper Saddle River, NJ : Prentice Hall, 13th ed.
- Brewer, M.T., and R. P. Larkin. 2005. Efficacy of several potential biocontrol organisms against *Rhizoctonia solani* on potato. *Crop Protection* 24:939-950.
- Brown, P. D. and M.J. Morra. 1995. Glucosinolate-containing plant tissues as bioherbicides. *J. Agric. Food Chemistry* 43:3070-3074.
- Brown, P. D. and M.J. Morra. 1997. Control of soil-borne plant pests using glucosinolate-containing plants. *Advances Agron.* 61:167-231.
- Buskov, S., Serra, B., Rosa, E., Sorensen, H., and Sorensen, J.C. 2002. Effects of intact glucosinolates and products produced from glucosinolates in myrosinase-catalyzed hydrolysis on the potato cyst nematode (*Globodera rostochiensis*). *J. Agr. Food Chem.* 50:690-695.
- Carling, D. E., R. H. Leiner, and P. C. Westphale. 1989. Symptoms, signs and yield reduction associated with *Rhizoctonia* disease of potato induced by tuberborne inoculum of *Rhizoctonia solani* AG-3. *Am. Pot. J.* 66:693-701.
- Cartwright, D. K., and Benson, D. M. 1995. Comparison of *Pseudomonas* species and application techniques for *Rhizoctonia* stem rot of poinsettia. *Plant Dis.* 79: 309-313.
- Cavigelli, M. A., Robertson, G. P., and Klug, M. K. 1995. Fatty acid methyl ester (FAME) profiles as measures of soil microbial community structure. *Plant Soil* 170:99-113.
- Chapon, A., Boutin, M., Rime, D., Delalande, L., Guillerm, A., and Sarniguet, A. 2003. Direct and specific assessment of colonization of wheat rhizosphere by *Pseudomonas fluorescens* pf29A. *European Journal of Plant Pathology* 109: 61-70.
- Chung, Y.R. Hoitink, H.A.J. Lipps, P.E., Interactions between organic-matter decomposition level and soilborne disease severity, *Agric. Ecosyst. Environm.*, 24, 183, 1988.
- Chung, Y.R. Hoitink, H.A.J. Dick, W.A. and Herr, L.J., Effects of organic matter decomposition level and cellulose amendment on the inoculum potential of *Rhizoctonia solani* in hardwood bark media, *Phytopathology*, 78, 836, 1988.
- Conklin, A.E., M.S. Erich, M. Liebman, D. Lambert, E.R. Gallandt, and W.A. Halteman. 2002. Effects of red clover (*Trifolium pratense*) green manure and compost soil amendments on wild mustard (*Brassica kaber*) growth and incidence of disease. *Plant and Soil* 238:245-256.
- Cook, R. J. 1986. Interrelationships of plant health and the sustainability of agriculture, with special reference to plant diseases. *Amer. J. Alternative Agric.* 1:19-24.
- Cook, R. J. 2000. Advances in plant health management in the twentieth century. *Annu. Rev. Phytopathol.* 38:95-116.
- Cook, R.J. and Baker, K.F. 1983. The nature and practice of biological control of plant pathogens. The American Phytopathological society, St. Paul, MN, USA.

- Curl, E., and Truelove, B. 1986. *The Rhizosphere*. Springer-Verlag. Berlin, p.288.
- DeBach, P., and D. Rosen. 1991. *Biological Control by Natural Enemies*. Cambridge, U.K. Cambridge University Press.
- Dittrich, D. Kandler. O., Einflu der Jahreszeit auf Bildung und Umsatz von Phenolkörpern in der Fichte (*Picea abies* L. Kast.), *Ber Dtsch Bot Ges*, 84, 465, 1971.
- Doran, J. W., Bezdicek, D. F., Coleman, D. C., and Stewart, B. A. 1994. *Defining Soil Quality for a Sustainable Environment*. SSSA Spec. Pub.#35. Soil Sci. Soc. Amer., Madison, WI.
- Dunbar, J.S., S. Takala, J.A. Barns, and C.R. Kuske. 1999. Levels of bacterial community diversity in four soils compared by cultivation and 16S rRNA gene cloning. *Appl. Environ. Microbiol.* 65:1662-1669.
- Dwyer, J.D., Johnson, S.B., Kleinhenz, M.D., Plissey, E.S., 1997. *Maine Potato Pest Control Guide*. Univ. Maine Coop. Ext. Bull. #2002.
- Edwards, C. A. 1976. *Persistent pesticides in the environment*. CRC Press, Cleveland.
- Eigenbrode, S. D. and D. Pimentel. 1988. Effects of manure and chemical fertilizers on insect pest populations on collards. *Agric. Ecosystems Environ.* 20: 109-125.
- Fang, C., Radosevich, M., and Fuhrman, J. J. 2001. Characterization of rhizosphere microbial community structure in five similar grass species using FAME and BIOLOG analyses. *Soil Biol. Biochem.* 33:679-682.
- Frostegård, A., E. Bååth, and A. Tunlid. 1993. Shifts in the structure of soil microbial communities in limed forests as revealed by phospholipid fatty acid analysis. *Soil Biol. Biochem.* 25:723-730.
- Gallandt, E.R., Mallory, E.B., Alford, A.R., Drummond, F.A., Groden, E., Liebman, M., Marra, M.C., McBurnie, J.C., Porter, G.A., 1998. Comparison of alternative pest and soil management strategies for Maine potato production systems. *Am. J. Altern. Agric.* 13, 146-161.
- Garland, J. L., and Mills, A. L. 1991. Classification and characterization of heterotrophic microbial communities on the basis of patterns of community-level sole-carbon-source utilization. *Applied Environ. Microbiol.* 57:2351-2359.
- Garbeva, P. van Veen, J. A, and van Elsas, J. D. 2004. Microbial diversity in soil: selection of microbial populations by plant and soil type and implications for soil suppressiveness. *Annu. Rev. Phytopathol.* 42: 243-270.
- Gould, F. 1991. The evolutionary potential of crop pests. *Am. Sci.* 79:496–507.
- Griffin, T.S., and G.A. Porter. 2004. Altering soil carbon and nitrogen stocks in intensively tilled two-year rotations. *Biology and Fertility of Soils* 39:366-374.

- Grandy, A. Stuart, Gregory A. Porter, and M. Susan Erich. 2002. Organic amendment and rotation crop effects on the recovery of soil organic matter and aggregation in potato cropping systems. *Soil Science Society of America Journal* 66:1311-1319.
- Grayston, S. J., Wang, S., Campbell, C. D., and Edwards, A. C. 1998. Selecting influence of plant species on microbial diversity in the rhizosphere. *Soil Biol. Biochem.* 30:369-378.
- Handelsman, J., and Stabb, E. V. 1996. Biocontrol of soilborne plant pathogens. *The Plant Cell* 8:1855-1869.
- Hoitink, H.A.J., and Boehm, M.J. 1999. Biocontrol within the context of soil microbial communities: A substrate-dependent phenomenon, *Ann. Rev. Phytopathol.* 37: 427-446.
- Hoitink, H.A.J., and Changa, C.M. 2004. Production and Utilization Guidelines for Disease Suppressive Composts. *Proc. XXVI IHC – Managing Soil-Borne Pathogens. A. Vanachter, Ed. Acta Hort.* 635: 87-92.
- Hoitink, H.A.J. and Keener H.M. eds, *Science and engineering of composting: Design, Environmental, Microbiological and Utilization Aspects*, Worthington, OH: Renaissance Publ. 728, 1993.
- Hoskins, B.R. 1997. *Soil Testing Handbook for Professionals in Agriculture, Horticulture, Nutrient and Residuals Management.* 3rd ed. Maine Agricultural and Forest Experiment Station, Orono, ME.
- Huber, D.M. and Sumner, D.R., *Suppressive soil amendments for the control of Rhizoctonia species*, In "Rhizoctonia Species: Taxonomy, Molecular Biology, Ecology, Pathology and Disease Control" Eds. Sneh, B. Jabaji-Hare, S. Neate, S. and Dijst, G. Kluwer Academic Publishers, The Netherlands, 433, 1996.
- Ibekwe, A. M., and Kennedy, A. C. 1999. Fatty acid methyl ester (FAME) profiles as a tool to investigate community structure of two agricultural soils. *Plant Soil* 206:151-161.
- Jian, J., Lakshman D. K., and Tavantzis, S. M. 1997. Association of distinct double-stranded RNAs with enhanced or diminished virulence in *Rhizoctonia solani* infecting potato. *Molecular Plant-Microbe Interactions* 10:1002-1009.
- Karlen, D. L., Leash, N. S., and Unger, P. W. 1992. Soil and crop management effects on soil quality indicators. *Amer. J. Alternative Agric.* 7:48-55.
- Kirkegaard, J.A., Wong, P.T.W., and Desmarchelier, J.M. 1996. In vitro suppression of fungal root pathogens of cereals by Brassica tissues. *Plant Path.* 45:593-603.
- Kloepper, J.W., M.N. Schroth, T.D. Miller. 1980. Effects of rhizosphere colonization by plant growth-promoting rhizobacteria on potato plant development and yield. *Phytopathology* 70:1078-1082.
- Koepf, H.H. (1992) *Biodynamic Farming: Principles and Practice*. Anthro. Press, NY
- Krause, M.S. Musselman, C.A. Hoitink, H.A.J. 1997. Impact of sphagnum peat decomposition level on biological control of *Rhizoctonia damping-off* of radish induced by

- Flavobacterium balustinum* 299 and *Trichoderma hamatum* 382, *Phytopathology*, 87, S55 (Abstr.)
- Krause, M. S., De Ceuster, T. J. J., Tiquia, S. M., Michel, F. C., Jr., Madden, L. V., and Hoitink, H. A. J. 2003. Isolation and characterization of rhizobacteria from composts that suppress the severity of bacterial leaf spot of radish. *Phytopathology* 93:1292-1300.
- Larkin, R. P. 2001. Control of Rhizoctonia stem canker and black scurf of potato by biological products. *Biological and Cultural Tests for Control of Plant Diseases* 16:PT70.
- Larkin, R. P. 2002. Control of Rhizoctonia canker and black scurf of potato by biological products, 2001. *Biological and Cultural Tests for Control of Plant Diseases* 17: PT05.
- Larkin, R. P. 2003a. Effect of green sprouting and biocontrol products on soilborne diseases of potato, 2002. *Biological and Cultural Tests for Control of Plant Diseases* 18:PT011.
- Larkin, R. P. 2003b. Characterization of soil microbial communities under different potato cropping systems by microbial population dynamics, substrate utilization, and fatty acid profiles. *Soil Biol. Biochem.* 35:1451-1466.
- Larkin, R.P. 2006. Biological amendments and crop rotations for managing soil microbial communities and soilborne diseases of potato. *Proceedings of the 18th World Congress of Soil Science, Philadelphia, PA, July, 2006.*(Abstr.)
- Larkin, R.P., and Griffin, T.S. 2006. Control of soilborne diseases of potato using *Brassica* green manures. *Crop Protection: (In Press)*.
- Larkin, R. P., and Honeycutt, C. W. 2002. Crop rotation effects on Rhizoctonia canker and black scurf of potato in central Maine, 1999 and 2000. *Biological and Cultural Tests* 17:PT06.
- Larkin, R. P., and Honeycutt, C. W. 2006. Effects of different 3-yr cropping systems on soil microbial communities and soilborne disease of potato. *Phytopathology* 96:68-79.
- Larkin, R.P., Griffin, T.S., and Honeycutt, C.W. 2006a. Crop rotation and cover crop effects on soilborne diseases of potato. *Phytopathology* 96:S64 (Abstr.)
- Larkin, R. P., Honeycutt, C. W., and Griffin, T. S. 2006b. Effect of swine and dairy manure amendments on microbial communities in three soils as influenced by environmental conditions. *Biol. Fert. Soils* 43:51-61.
- Leuschner, C. Herrmann, K.M. and Schultz, G., The metabolism of quinate in pea roots, *Plant Physiol.*, 108, 319,1995.
- Lewis, J. A., Fravel, D. R., Lumsden R. D., and Shasha, B. S. 1995. Application of biocontrol fungi in granular formulations of pregelatinized starch-flour to control damping-off diseases caused by *Rhizoctonia solani*. *Biol. Cont.* 5:397-404.
- Lewis, J. A., and Larkin, R. P. 1997. Extruded granular formulation with biomass of biocontrol *Gliocladium virens* and *Trichoderma* spp. to reduce damping-off of eggplant caused by *Rhizoctonia solani* and saprophytic growth of the pathogen in soil-less mix. *Biocont. Sci. and Technol.* 7:49-60.

- Lewis, J. A., Larkin, R. P., and Rogers, D. L. 1998. A formulation of Trichoderma and Gliocladium to reduce damping-off by *Rhizoctonia solani* and saprophytic growth of the pathogen in soilless mix. *Plant Dis.* 82:501-506.
- Liu C, Lakshman DK, Tavantzis SM. 2003a. Quinic acid induces hypovirulence, and expression of a hypovirulence-associated dsRNA in *Rhizoctonia solani*. *Current Genetics* 43:103-111.
- Liu C, Lakshman DK, Tavantzis SM. 2003b. Expression of a hypovirulence-causing double-stranded RNA (dsRNA) is associated with up-regulation of quinic acid pathway, and down-regulation of shikimic acid pathway in *Rhizoctonia solani*. *Current Genetics* 42:284-291.
- Liu, W. T., T. L. Marsh, H. Cheng, and L. J. Forney. 1997. Characterization of microbial diversity by determining terminal restriction fragment length polymorphism of genes encoding 16S rRNA. *Appl. Environ. Microbiol.* 63:4516-4522.
- Lugtenberg, B. J. J., Dekkers, L., and Bloemberg, G. V. (2001) Molecular determinants of rhizosphere colonization by pseudomonas. *Annual Review of Phytopathology*, 39: 461-490.
- Lupwayi, N. Z., Rice, W. A., and Clayton, G. W. 1998. Soil microbial diversity and community structure under wheat as influenced by tillage and crop rotation. *Soil Biol. Biochem.* 30:1733-1741.
- Lynch, D.H., R.P. Voroney, and P.R. Warman. 2005. Soil physical properties and organic matter fractions under forages receiving composts, manure or fertilizer. *Compost Science and Utilization* 13:252-261.
- Magdoff, F. 2000. Concepts, components, and strategies of soil health in agroecosystems. *J. Nematol.* 33:169-172.
- Magdoff, F. and Van Es, H. 2000. *Building Soils for Better Crops*, 2nd Edition. Sustainable Agriculture Network (SAN): Beltsville, MD.
- Mao, W., Lewis, J. A., Lumsden, R. D., and Hebbar, K. P. 1998. Biocontrol of selected soilborne diseases of tomato and pepper plants. *Crop Protection* 17: 535-542.
- Marschner, P., C. H. Yang, R. Lieberei, and D. E. Crowley. 2001. Soil and plant specific effects on bacterial community composition in the rhizosphere. *Soil Biol. Biochem.* 33:1437-1445.
- Matthiessen, J. N. and M.A. Shackleton. 2000. Advantageous attributes of larval whitefringed weevil, *Naupactus leucoloma* (Coleoptera: Curculionidae) for bioassaying soil fumigants, and responses to pure and plant-derived isothiocyanates. *Bull. Entomol. Res.* 90: 349-355.
- Mazzola, M. 2004. Assessment and management of soil microbial community structure for disease suppression. *Annu. Rev. Phytopathol.* 42:35-59

- McGuire, A. N. 2003. Mustard green manures replace fumigant and improve infiltration in potato cropping system. Online. Crop Management doi: 10.1094/CM-2003-0822-01-RS.
- Miethling, R., Wieland, G., Backhaus, H., and Tebbe, C. C. 2000. Variation of microbial rhizosphere communities in response to crop species, soil origin, and inoculation with *Sinorhizobium meliloti* L33. Microbial Ecology 2000 41:43-56.
- Mojtahedi, H., G.S. Santo, J.H. Wilson, and A.N. Hang. 1993. Managing *Meloidogyne chitwoodi* on potato with rapeseed as green manure. Plant Disease 77:42-46.
- Morales, H., Perfecto, I., Ferguson, B., 2001. Traditional fertilization and its effect on corn insect populations in the Guatemalan highlands. Agric. Ecosystems Environ. 84, 145-155.
- Narayanswami, P. (2002) Microbial Plant Pathogens and Crop disease management. Page 182. Science Publisher's Inc. Enfield, New Hampshire.
- Ollinger, M., and J. Fernandez-Cornejo. 1995. Regulation, Innovation, and Market Structure in the U.S. Pesticide Industry. Economic Research Service, Agricultural Economic Report No. 719. Washington, D.C.: U.S. Department of Agriculture.
- Olivier, C., Vaughn, S.F., Mizubuti, E.G., and Loria, R. 1999. Variation in allyl isothiocyanate production within Brassica Species and correlation with fungicidal activity. J. Chem. Ecol. 25:2687-2701.
- Pereira A.S., Pereira, A.F.M., Trugo, L.C., Neto, F.R.A. 2003. Distribution of quinic acid derivatives and other compounds in Brazillian propolis. Z. Naturforsch. 58c:590-593.
- Pharand, B., Carisse, O., and Benhamou, N. 2002. Cytological aspects of compost-mediated induced resistance against fusarium crown and root rot in tomato. Phytopathology 92:424-438.
- Phelan, P. L. 1997. Soil-management history and the role of plant mineral balance as a determinant of maize susceptibility to the European corn borer. Biol. Agric. Hortic. 15: 25-34.
- Phelan, P. L., J. F. Mason, and B. R. Stinner. 1995. Soil-fertility management and host preference by European corn borer, *Ostrinia nubilalis* (Hubner), on *Zea mays* L.: a comparison of organic and conventional chemical farming. Agric. Ecosystems Environ. 56: 1-8.
- Phelan, P. L., K. H. Norris, and J. F. Mason. 1996. Soil management history and host preference by *Ostrinia nubilalis*: evidence for plant mineral balance mediating insect-plant interactions. Environ. Entomol. 25: 1329-1336.
- Piper, A., M.S. Erich, G.A. Porter and T.S. Griffin. 2006. Root growth effects on soluble C and P in manured and non-manured soils. Plant and Soil 283:359-372.
- Porter, G.A., and J.C. McBurnie. 1996. Crop and soil research. p. 8-62. In M.C. Marra (ed.) The ecology, economic, and management of potato cropping systems: A report of the first four years of the Maine Potato Ecosystem Project. Bull. No. 843 MAFES, Orono, ME.

- Reichelderfer, K. H. 1981. Economic feasibility of biological control of pests. Pp. 403–417 in *Biological Control in Crop Production*, G. C. Papavizas et al., eds. New York: Allanheld, Osmun.
- Ritchie, N.J., M.E. Schutter, R.P. Dick, and D.D. Myrold. 2000. Use of length heterogeneity PCR and fatty acid methyl ester profiles to characterize microbial communities in soil. *Appl. Environ. Microbiol.* 66:1668-1675.
- Robinson, C.A., R.M. Cruse, and K.A. Kohler. 1994. Soil management. Chap. 4 In *Sustainable agriculture systems*. Hatfield, J.L. and D.L. Karlen (eds.). Lewis Publisher, Boca Raton, FL.
- Sarwar, M., Kirkegaard, J.A., Wong, P.T.W., Desmarchelier, J.M. 1998. Biofumigation potential of Brassicas. III. In vitro toxicity of isothiocyanates to soil-borne fungal pathogens. *Plant Soil* 210:103-112.
- Schroth, M.N., and J.G. Hancock. 1982. Disease-suppressive soil and root-colonizing bacteria. *Science* 216:1376-1381.
- Siciliano, S. D., Theoret, C. M., de Freitas, J. R., Hucl, P. J., and Germida, J. J. 1998. Differences in the microbial communities associated with the roots of different cultivars of canola and wheat. *Can. J. Microbiol.* 44:844-851.
- Smolinska, U., and Horbowicz, M. 1999. Fungicidal activity of volatiles from selected cruciferous plants against resting propagules of soil-borne fungal pathogens. *J. Phytopathology* 147:119-124.
- Sumner, D. R., Lewis, J. A., and Gitaitis, R. D. 1992. Chemical and biological control of *Rhizoctonia solani* AG-4 in snap bean double-cropped with corn. *Crop Protection* 11:121-126.
- Thrane, C., Nielsen, M. N., Sorensen, J., and Olsson, S. 2001. *Pseudomonas fluorescens* reduces sclerotia formation, biomass development, and disease incidence of *Rhizoctonia solani* causing damping-off in sugar beet. *Microbial Ecology* 42:438-445.
- Tsao, R., C.J. Peterson, and J.R. Coats. 2002. Glucosinolate breakdown products as insect fumigants and their effect on carbon dioxide emission of insects. *BMC Ecology* 2: 1-7.
- Tsorer, L., Barak, R., and Sneh, B. 2001. Biological control of black scurf on potato under organic management. *Crop Protection* 20:145-150.
- Vallad, G. E. Cooperband, L., Goodman, R. M. 2003. Plant foliar disease suppression mediated by composted forms of paper mill residuals exhibits molecular features of induced resistance. *Physiol. Molecular Plant Pathol.* 63: 65-77.
- Wall, R.E., Effects of recently incorporated organic amendments on damping-off of conifer seedlings. *Plant Dis.*, 68, 59, 1984.
- Warton, B., J. N. Matthiessen, and M.A. Shackleton. 2003. Cross-enhancement: Enhanced biodegradation of isothiocyanates in soils previously treated with metham sodium. *Soil Biol. Biochem.* 35: 1123-1127.

- Weller, D. M., Raaijmakers, J. M., McSpadden Gardener, B. B. and Thomashow, L. S. (2002) Microbial Populations responsible for specific soil suppressiveness to plant pathogens. *Annual Review of Phytopathology* September 40: 309-348.
- Yao, H., He, Z., Wilson, M. J., and Campbell, C. D. 2000. Microbial biomass and community structure in a sequence of soils with increasing fertility and changing land use. *Microbial Ecology* 40:223-237.
- Yoder, R.E. 1936. A direct method of aggregate analysis of soils and a study of the physical nature of erosion losses. *Journal of the American Society of Agronomy* 28:3371-351.
- Zak, J. C., Willig, M. R., Moorhead, D. L., and Wildman, H. G. 1994. Functional diversity of microbial communities: a quantitative approach. *Soil Biol. Biochem.* 26:1101-1108.
- Zelles, L., Bai, Q. Y., Beck, T., and Beese, F. 1992. Signature fatty acids in phospholipids and lipopolysaccharides as indicators of microbial biomass and community structure in agricultural soils. *Soil Biol. Biochem.* 24:317-323.
- Zelles, L., Bai, Q. Y., Rackwitz, R., Chadwick, D., and Beese, F. 1995. Determination of phospholipid- and lipopolysaccharide-derived fatty acids as an estimate of microbial biomass and community structures in soils. *Biol. Fertil. Soils* 19:115-123.
- Zhang, W., Han, D.Y., Dick, W.A., Davis, K.R., and Hoitink, H.A.J. 1998. Compost and compost water extract-induced systemic acquires resistance in cucumber and Arabidopsis. *Phytopathology* 88:450-455.

(i) Relevance Statement

Project Directors: Stellos Tavantzis (Department of Biological Sciences, University of Maine), Robert Larkin (Plant Pathologist, USDA, ARS, New England Plant, Soil, and Water Laboratory), Andrei Alyokhin (Department of Biological Sciences, University of Maine), Susan Erich (Department of Plant, Soil and Environmental Sciences, University of Maine).

Project Title: An Integrated Approach for Enhanced Soil Fertility, Improved Plant Health and Suppression of Plant Diseases and Pests

Project Type: Research

Project Summary:

The overall goal of this project is to improve crop production through the integration of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth. The specific objectives of the proposed work are (1) to improve crop production through a combination of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth, (2) to better understand the ecological processes occurring as a result of these sustainable practices, to allow their further development, and (3) to evaluate the efficacy, sustainability, and economics of these systems. To accomplish these objectives, the following soil amendments will be used alone or as combinations: A) Organic matter in the form of mature conifer compost which would be a) capable of supporting ample microbial biomass, and b) rich in phenolics to suppress virulence of *Rhizoctonia solani*; B) Biocontrol agents, such as *Bacillus subtilis*, and *Trichoderma* spp., that suppress *Rhizoctonia* and other soilborne diseases; C) A hypovirulent strain of *R. solani*, which provides biocontrol against *Rhizoctonia* disease, and enhances plant growth, and; D) Biofumigation brought about by a *Brassica* cover crop. Effects on soil chemical, physical, and biological properties, soil microbial communities, plant diseases and insect pests, and crop yield and quality will be monitored and evaluated on a potato crop through two consecutive field seasons. A cost/benefit analysis will be conducted to determine the relative economic feasibility of the sustainable treatments included in this study. The proposed work will be conducted on an organic potato farm, owned by Jim and Megan Gerritsen, and on the University of Maine Aroostook Research Farm, to determine the ecological impacts of the above practices on an organic and a conventional agro-ecosystem, respectively. The work proposed here was formulated on the basis of priorities set by stakeholders in Maine, other Northeastern States, and the General IPM Priorities for the Northeast (<http://northeastipm.org/priority/2005/generalpriorities.htm>).

Description of the Problem, Background, and Justification:Introduction

Agricultural production in the New England Region has seriously declined in recent years. Within the past decade alone, farmland in New England has decreased by approximately 400,000 acres. Integrated cropping systems and management practices are needed to improve agricultural viability and rural economic vitality in this region. Sustainable agriculture has become an important component in this revitalization process, with its emphasis on natural inputs, sustainable management practices, and environmental and health concerns. In the Northeast, crop losses and reduced crop quality due to pests and diseases and low overall crop productivity (yield) are critical limitations in many crop production systems. Due to relatively high levels of plant disease pressure, pest problems, and high fertility requirements, conventional agricultural production routinely uses high inputs of agricultural chemicals. In contrast, sustainable farming practices involve the principles of improving soil quality, increasing soil biodiversity, and enhancing natural disease and pest suppression. Although sustainable production provides major improvements over conventional agriculture regarding soil and crop management practices, there are still many limitations to sustainability, crop productivity, and farm profitability that need addressing. In the work proposed here, three primary tools of sustainable management, the use of organic matter amendments, biological amendments, and effective crop rotations, will be customized,

managed, and combined to provide improved control of soil-borne diseases and increased crop yield in sustainable production systems in the Northeast.

Stakeholder-identified Priorities:

The work proposed here addresses priorities set by a number of stakeholders in Maine, and is in line with policies adopted by other New England (<http://www.uvm.edu/~susagctr/>), Northeastern States (http://northeastipm.org/regu_regional.cfm; <http://northeastipm.org/nereap/priority/2006.htm>) and beyond (<http://www.sustainable-ag.ncsu.edu/>). In September 2005, the Maine Potato Board and the United States Department of Agriculture (USDA) published a press release (<http://www.maine potatoes.com/press-releases/USDA&MPB%20INCENTIVES.doc>) in which they announced that “Producers willing to adopt practices that improve soil health and environmental quality will be eligible for incentive payments”.

Moreover, interest and support of sustainable farming has been steadily growing in Maine and the Northeast. The Maine Organic Farmers and Gardeners Association (MOFGA), founded in 1971, is the oldest and largest state organic association in the country (<http://www.mofga.org>), and has been growing in size, influence, public acceptance and visibility each year. The mission of MOFGA is to “help farmers and gardeners grow organic food, protect the environment, recycle natural resources, increase local food production, support rural communities, and illuminate for consumers the connection between healthful food and environmentally sound growing practices”.

Most importantly, potato growers Jim and Megan Gerritsen, owners of Wood Prairie Farm (<http://www.woodprairie.com>), are interested in having this work conducted on their farm, which is their lives’ investment. The Wood Prairie Farm as well as the Aroostook Research Farm are located in the midst of the potato-growing region of Maine. Jim Gerritsen is an exceptional grower who has shown interest in our work over the years, and has been successfully using some of the treatments described in this proposal. However, this will be the first time that such a wide spectrum of sustainable treatments will be used under commercial conditions, Mr. Gerritsen is an enthusiastic partner and plans to be closely involved with every aspect of the project, and looks forward to adopting the treatments that will significantly reduce disease pressure, enhance plant growth and yields, and increase profits. Upon determining the ecological and financial impact of the proposed treatments, Gerritsen has agreed to serve as a resource person for growers who are interested in learning the complexities of a sustainable agro-ecosystem in Maine and New England

Implementation of Nonpesticidal Tactics

The proposed work will improve organic crop production through a combination of sustainable practices promoting soil regeneration, reduction of disease and pest pressure, and enhancement of plant growth. *None of the treatments employed in this study involves use of pesticides.* More specifically, soil fertility and quality will be enhanced by the addition of organic matter as compost and cover crop residue, which will bring about an increase in soil biodiversity, improved water infiltration, improved water-holding capacity. Suppression of soil-borne and, perhaps, foliar diseases will be achieved through competition, antibiosis, parasitism/predation, and systemic induced resistance brought about by increased soil biodiversity and introduction of biocontrol organisms. In addition, the compost amendments used will be designed optimize a unique biochemical mechanism for suppression of *Rhizoctonia* disease, and potentially other soilborne diseases. Moreover, *Brassica*-mediated biofumigation is expected to nullify the need for Metam-sodium as it suppresses soil-borne diseases. In addition, *Brassica* increases yields (by contributing biomass as a green manure), enhances soil microbial biomass, increases the bacteria:fungal ratios by enhancing the levels of aerobic bacteria (including *Pseudomonas* sp.), and nitrogen-fixing bacteria. Suppression of the Colorado potato beetle and other insect pests will be through increasing plant resistance to herbivory by optimizing nutrient balance in affected plants, and thus diminishing the need for conventional insecticides. Finally, enhanced growth and yield of crops will be brought about by improved soil fertility and quality, and suppression of soil-borne diseases and insect pests.

Potential Multi-state Impacts Resulting from this Project

The principles used in this project (soil regeneration, enhanced plant health, reduction of pathogen and pest populations using biological approaches) are applicable to most crops, soils or climates. One of the strengths of this work is the simultaneous testing of the proposed treatments under

commercial conditions. The model used here is a crop rotation revolving around potato, since it has been the main crop raised by growers in Maine and other locations in the northeast and the Nation, and a major food crop in the world. The project also offers the opportunity to integrate the production of high quality seed and tablestock potatoes. The ultimate goal is to demonstrate the economic and environmental merits of the proposed sustainable agricultural practices to organic and conventional farmers that can be used in their specific production systems.

Environmental Stewardship and Risk Management

Soil-borne diseases, especially those incited by *Rhizoctonia solani*, are a serious problem in both conventional and organic farms in Maine. The Gerritsens, as well as other organic farmers, follow a four-year rotation to minimize the impact of these diseases on their highest cash-producing crop - potatoes. Due to the low prices of conventionally grown potatoes, four-year potato rotations are a high financial burden to conventional potato growers. So, more often than not, conventional farmers employ a two-year rotation that exacerbates endemics and epidemics caused by pathogens and insect pests, resulting in more serious disease and insect pest problems. These intensive two-year rotations require a large input of synthetic pesticides and fertilizers, which are associated with serious environmental and food safety risks as well as other problems related to tolerance development and increasing costs of development.

Replacing or supplementing conventional practices with sustainable practices, as proposed here, including implementing compost and cover crop amendments, introduction of biocontrol organisms, and biofumigation, has the potential to significantly enhance and protect environmental quality, and reduce health risks and other problems associated with conventional pest management. IPM and EBPM, however, need to be safe, effective, profitable and durable (sustainable) to be embraced by growers. This research includes some of the most promising strategies for a successful EBPM program, and is designed to provide critical information needed to accelerate adoption of sustainable pest management strategies that are safe and profitable. Understanding the ecological processes occurring as a result of these practices and their interacting components (when used in combination) will lead to the development of effective sustainable pest management tools. Two of the biological control organisms to be used in the proposed study are commercial products (*Trichoderma harzianum* strain T-22; *Bacillus subtilis*, Kodiak™) that have been tested for several years and are environmentally safe. The third, hypovirulent isolate Rhs 1A1 of *R. solani*, has been genetically stable for 25 years. It is associated with reduction of rhizoctonia disease in potato, and enhanced plant growth and yields. It has been used in field biocontrol experiments for a number of years, and is not expected to pose environmental or financial risks. Finally, *Brassica* cover crops, known for their multiple benefits to agro-ecosystems, are not associated with environmental or financial risks in appropriate crop production systems. The goal of this study is to generate information on the ecological and financial impact of the above treatments (alone or in combination) under the prevailing environmental and socioeconomic conditions prevailing in New England and other northeastern states.

Project objectives and expected outcomes

The **objectives** of the proposed work are (1) to improve crop production through a combination of sustainable practices promoting soil regeneration, reduction of disease pressure, and enhancement of plant growth, (2) to better understand the ecological processes occurring as a result of these sustainable practices, to allow their further development, and (3) to evaluate the efficacy, sustainability, and economics of these systems. The anticipated **outcomes** are as follows:

- 1) Soil fertility and quality will be enhanced by the addition of organic matter as compost and cover crop residue, which will bring about an increase in soil biodiversity, improved water infiltration, improved water-holding capacity.
- 2) Soil-borne, and perhaps foliar, diseases will be suppressed by increased soil biodiversity, use of biocontrol agents, and biofumigation.
- 3) Colorado potato beetle, aphids, and other insect pests will be contained by improved plant resistance brought about by optimization of nutrient balance in affected plants, and the rise in populations of beneficial insects.
- 4) Superior soil fertility and quality, and suppression of soil-borne diseases and insect pests will result in higher crop yields.