SLIDE 1:
My name is Bob Larkin. I'm a research plant pathologist for the USDA, ARS, New England Plant, Soil, and Water Lab in Orono, Maine. Today, I'd like to talk to you about soil health, soil health management practices, and disease-suppressive rotation crops, and our research efforts and incorporating them into productive potato cropping systems.

SLIDE 2:
So first, what do we mean by soil health? It can be defined as the continued capacity of soil to function as a vital living system to sustain biological productivity, maintain environmental quality, and promote plant animal and human health. Some features of this definition are that it considers soil a vital living system, and also it places emphasis on the importance of all the multiple functions of soil, from biomass production and nutrient cycling, filtering, buffering, et cetera. It also encompasses all of the various physical, chemical, and biological attributes of the soil. We know that building and maintaining so health is essential to agriculture sustainability and ecosystem function, yet we also know that intense agricultural production tends to degrade soils. And potato production in particular can be especially hard on soils due to the extensive tillage involved, the lack of residues put back into the soil, and it's relatively short rotations.

SLIDE 3:
I also want to emphasize the importance of soil microbiology to soil health, as this aspect has been generally neglected in the past. But an active, diverse soil microbiology is necessary for decomposition, nutrient cycling and availability, soil structure, and breakdown of toxins and suppression of pathogens and diseases. In essence, the soil microbiology is the primary workhorse of soil and is what is most responsible for most of the things that we expect the soil to do. Thus to a large degree, managing soil health is largely a matter of maintaining a suitable habitat for the organisms that make up the soil biology. And organic matter is the primary food source for these microorganisms, thus a diverse soil microbiology is promoted by a diversity of plants and plant types, releasing different sets of organic compounds and interacting with different assemblages of microorganisms. And an active diverse soil microbiology helps keep pathogen populations in check and interferes with their capability to cause disease.

SLIDE 4:
So then, how is soil health related to disease management? Well, we know that soil-borne diseases tend to be most severe when soil conditions are poor, whether it's due to inadequate drainage, poor soil structure, low organic matter and

fertility, high soil compaction, or low microbial biomass and diversity are all aspects that will tend to make soil borne diseases more severe. Thus, most practices that improve soil health will also reduce soil borne diseases. They improve conditions for crop growth, resulting in less disease, they may stimulate or increase microbial biomass activity and diversity, resulting in a general disease suppression, as well as the increase in populations of antagonists to those pathogens. And also in addition to that, there are other specific disease-suppressive practices and strategies that can be used for further disease reduction.

SLIDE 5:

There are a number of important management practices that are closely associated with improving or maintaining soil health. And these include such things as crop rotations, use of cover crops and green manures, organic amendments, and conservation tillage. Today, I'm mainly going to focus on these first two aspects of using crop rotations and cover crops and green manures, but the other two organic amendments and conservation tillers are also important.

Organic amendments are useful for increasing the amount of organic matter you put into the soil, using such things as compost or manures, or increasing the level of crop residue in mulches. Conservation tillage involves the reduction in tillage operations. And this is something that is somewhat limited and is in availability for potato because of the tillage operations that are inherent in potato production. But there still can be reductions implemented, particularly in the non-potato rotation years, and thus should be considered as much as possible.

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With crop rotations, there are several factors that are important in determining their effects on soil health, the crop type being the first one. It's important to select rotation crops that are not a host to the same pathogens that your main crop is. Also want to select rotation crops that have somewhat different characteristics from your main crop to promote plant diversity and variety in those crops. Their effects on soil health can vary quite a bit though, all the way down to the cultivar level.

Rotation length is important. And generally for soil health benefits, longer rotations tend to be better. However, it's recognized that there are economic constraints that may push for shorter rotations. Rotation sequence becomes a factor in rotations of three or more years where the order of your crops is important. And particularly with potato rotations, the crop that immediately precedes your potato crop is of particular importance. Also then how you use your rotation crop, whether it's used as a full season rotation crop, or as a partial season, or between season cover crop or green manure.

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Now, there are three basic mechanisms by which crop rotations can help manage diseases. The first is simply by serving as a break in the host pathogen cycle. This occurs with any non-host crop in which the pathogen populations decrease in the absence of a host. Some rotation crops though can also result in changes to physical chemical or biological attributes, resulting in the stimulation of microbial activity and diversity or increase in beneficial soil organisms, which also can inhibit pathogens. For example, a forage of grass crops that have extensive root systems and high residue amounts tend to increase microbial activity, increase rhizobacteria, and increase organic matter, which leads to reduction in some soil borne pathogens.

Third mechanism involves the direct inhibition of pathogens by the rotation crop. This occurs when breakdown products of the rotation crops can result in the occurrence of inhibitory compounds. This is what happened with biofumigation, where the breakdown of the brassica species results in the formation of toxic metabolites, which then directly inhibit pathogens and nematodes. It also can occur with stimulation of specific microbial antagonists, such as Trichoderma and non-pathogenic Streptomyces, which interfere or inhibit pathogens.

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Crops that can utilize these second or third mechanisms, that is the more active means of disease suppression, can be considered disease-suppressive crops. The largest group of these are the brassicas and their related species, including the mustards and broccolis, cauliflower, turnips, and so forth, as well as the group of sudangrass or Sorghum/sudangrass hybrids. These groups of plants suppress disease through multiple mechanisms, including biofumigation, which I just mentioned, involves the breakdown of plant products to produce volatile toxic metabolites, producing a fumigation effect, as well as other changes in soil microbial communities that also is active in reducing diseases. Thus, because these types of processes involve the breakdown of the plants themselves, they tend to be most effective when used as green manures. Meaning that they are incorporated while still green and growing.

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Some of the primary soil borne diseases we work with and those that are most prevalent in our soils are things such as diseases caused by Rhizoctonia solani, which causes stem canker on the plant and black scurf on tubers, as well as common scab, which is caused by Streptomyces scabies. These are the two most common diseases. We see that occur pretty much everywhere. A couple others that

are very important are powdery scab caused by Spongospora, and Verticillium wilt. The occurrence of these varies, but where they do occur, they can be major problems.

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We first started looking at brassicas and other disease-suppressive crops many years ago, as a result of some rotation crop trials we were doing, where in some of these initial two year rotation studies, we observed that canola and rapeseed rotations consistently reduced soil borne diseases, reducing black scurf by 20 to 45%, and common scab by 15 to 25% relative to other rotation crops.

But we also observed that the addition of a fall cover crop of winter rye following each rotation crop resulted in further reductions in soil borne diseases of about nine to 20% across all rotation crops. And further, we observed that the use of ryegrass as an under-seeded cover crop with small grains instead of red clover, which is a common cover crop used with grains, we found that that substitution also reduced soil borne diseases by about 10 to 20%.

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So over the last 15 years, we've conducted many field studies assessing different brassica crops and other disease-suppressive crops as green manures for disease suppression and crop productivity. And although results vary from trial to trial and year to year ,overall in most trials we have observed in general, yield increases of about six to 12%, decreases in soil borne diseases, such as large reductions in black scurf, modest reductions in common scab, and reductions in powdery scab and Verticillium and silver scurf in trials where those diseases occurred.

So then, there are a variety of crop that could be considered disease-suppressive in potato rotations. These include many of the brassicas, such as the high glucosinolate mustards, which are specifically bred for biofumigation and provide the most effective suppression of multiple soil borne diseases. But other types of mustards, the white and yellow mustards, as well as turnip, radish and other cole crops, such as broccoli, cauliflower, cabbage, and kale also can be effective rotations for their biofumigation effects. Rapeseed and canola, which tend to have the lower level of biochemical activity, however, still can be quite effective against black scurf, although somewhat less effective against other soil borne diseases.

Some of the non-brassica type crops that still can be considered disease-suppressive include Sorghum-sudangrass group, which has moderate efficacy, somewhat less than mustards in our trials, and such things as ryegrass, which has

shown to reduce black scurf and common scab in some tests comparable to the mustards, buckwheat, which as a green manure also reduced common scab comparable to brassicas in some trials. And as far as grain crops, barley tends to have less disease problems than some of the other grain rotation crops. And as a cover crop, winter rye used as a fall cover crop has also been shown to reduce soil borne diseases.

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So after establishing the efficacy of some of these disease-suppressive crops, we wanted to determine how they best could be utilized in potato rotations here in Maine. We did look at the potential of using them as a fall cover crop, following a regular rotation crop, but under the main conditions here in Aroostook County, that was not very practical as these crops need to be planted by the first week of August, which did just doesn't fit in very well with most other rotations. In warmer climates, this can be effective, but it just didn't work very well as a fall green manure crop here in Maine. So they pretty much need to be grown as a summer crop here in Maine. And when used as a summer crop green manure, that means you're removing a potential cash crops from your rotation.

So, we set up a study to look at different ways to manage these disease-suppressive crops and to determine if the disease-suppressive benefits were still apparent if grown for a harvested crop or how they best could be utilized. So we set up a study looking at five different rotation crops, three that are disease-suppressive, mustard blend, sudangrass, and rapeseed, soybean as our non-suppressive rotation crop, and barley/clover representing the kind of standard rotation crop. And we looked at these under three different management practices as a green manure crop, where everything was incorporated green, used just as a cover crop where they were grown and then just left there and not incorporated, and then two variations on a harvested crop, first harvested for the seed, and then the stubble incorporated or harvested, but stubble not incorporated.

SLIDE 13:

So, first looking at the effect of management practice on yield and disease severity. All crops grown as a green manure produce higher yield, about 12% increase in yield relative to use as a cover crop. But also when they were harvested, but then stubble incorporated, we also got a significant increase in yield of about 6% increase in yield under that criteria. As far as disease, all crops, again, that were grown as green manures reduced disease. In this case, this is black scurf. Substantially, about 28 to 30% reduction in black scurf. But also again, the harvested, but incorporated version of this also reduced disease by about 10 to

15%. This indicates the importance of the incorporation of the organic matter, even when it's not a disease-suppressive crop.

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Okay. Looking at results by rotation crop, again at yield in black scurf disease, we found that the biofumigant mustards were most effective in increasing yield, increasing yield by about 11% relative to a barley crop. Whereas the sudangrass and rapeseed increased yield by about 6%. As far as disease suppression then, again, the mustards, all three of the disease-suppressive crop, the mustard, sudangrass, and rapeseed all reduced black scurf relative to the barley crop.

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So when both of these factors are put together, the effect of rotation crop and management practice on yield, the maximum yield was produced with the mustard crop growing as a green manure, increasing yield by 25%. However, you still observed a 15 to 20% increase in yield when the mustard crop was grown and harvested for seed and then incorporated, as well as 10 to 15% increase in yield with the other disease-suppressive crops.

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Likewise for black scurf, the greatest reduction in disease was observed with the mustard crop grown as a green manure, reducing black scurf severity by 50%, and the other disease-suppressive crops grown as green manures reducing disease by about 30%. But again, when grown has a harvested crop and then incorporated, you still got disease reduction benefits of between 20 and 30%. Thus, the benefits in both disease reduction and yield were observed with the harvested crop when incorporated stubble, even when not grown as green manure, indicating that mustard and other brassicas that are grown for seed can also still provide a benefit. And thus, provide both an economic return on the seed as well as potential benefit for yield and disease reductions in your potato crop.

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We did conduct economic analyses of these studies and they showed that use of green manures did result in a substantial increase in overall economic return in the two year rotation over that of a standard barley/clover rotation. However, the greatest return was for crops that were harvested and then incorporated, due to that additional income received for the harvested crop. The increase in revenue for the green manure crops were due to the increase in potato yields, which more than made up for the cost of production for those green manure crops. This indicates the

importance of incorporation of the organic matter into these systems, but also the incorporation of smaller residue amounts in the harvested and then incorporated crops that were still beneficial overall.

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So lastly, I want to talk about our long-term cropping system trials, which have been in place for over 15 years now, and which focus on incorporating various soil health management practices, including the use of brassica green manures into potato cropping systems. We set up three different three-year cropping systems focused on management goals of soil conservation, soil improvement, and disease suppression, and compared those with a standard two year barley/potato rotation, as well as a non rotation of continuous potato.

In the initial phase of the project, we tried to maximize the potential for changes with these systems. So in our soil conserving system, we had two years of barley, followed by the forage grass, Timothy, using severely limited tillage and adding mulch. The soil improving system, we started with the same system, but it made yearly additions of compost to build up organic matter. And in the disease-suppressive system, we had two years of a disease-suppressive system, the first year having a mustard green manure, then a sudangrass green manure, and followed by covered crops.

So after several years of observation, we then modified the systems to be more practical and feasible as rotations that would fit in to grower practices. So, in the modified rotations then, we added a cash crop of canola to the soil improvement in conservation, reducing the forage grass. And in the disease suppressed, we went to just one year of the green manure before potato and added in a barley rotation crop.

SLIDE 19:

So, this is what the trial looked like. We examined all aspects of these rotations regarding their soil properties, crop growth and development, soil borne diseases, and soil microbiology over a number of years. Today, I'm just going to briefly highlight some of the effects on yield and disease.

SLIDE 20:

So initially, these trials were conducted under both irrigated and non-irrigated conditions. And this graph showing tuber yield. First looking at non-irrigated conditions, the soil improving system had the highest yields with increases of 30% relative to the standard rotation, and over 40% relative to no rotation. The disease-suppressive soil also substantially increased yield relative to

the standard rotations. Under irrigated conditions, all rotations, except the SI, substantially increased yield when irrigated. Average increase of about 25%.

overall, the disease-suppressive soil resulted in the highest yield under irrigated conditions. And if you compare the disease-suppressives under irrigated conditions with the standard rotation under non-irrigated conditions, that's over a 40% increase in yield over 100 [inaudible 00:24:01] weight increase in yield between those two.

SLIDE 21:

Looking at disease severity in black scurf, again with both irrigated and non-irrigated, notably the disease-suppressive system resulted in the lowest level of disease, black scurf disease under both irrigated and non-irrigated conditions. Whereas overall, they had slightly higher disease levels under irrigated conditions than non-irrigated conditions. All rotations reduced disease relative to no rotation, but the disease-suppressive soil did reduce disease quite a bit more than any other system.

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And this was observed also with common scab in similar manner.

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So we've continued to monitor these systems and this slide shows some of the results of these modified rotations over the last five years. And they generally have continued these same trends, where as far as yield, we tend to see the highest yield under the soil improving system due to those higher levels of organic matter. But also higher yields in the disease-suppressive system than in the standard system or compared to no rotation. And the same trends are observed in microbial activity, as well as you can see the differences in soil organic matter here, how the soil improving system has built up soil organic matter over the years.

This disease-suppressive system has also slightly enhanced soil organic matter from the initial levels, which were around 3.8. The standard rotation has maintained those levels at about the same as where they started, whereas the no rotation we've got reduction in soil organic matter over time. And the disease-suppressive system has been able to maintain lowered disease levels for black scurf and common scab throughout many years of these rotations. And after a number of years, the soil improving system now also has reduced levels of disease relative to these other systems.

SLIDE 24:

In conclusion then, disease-suppressive rotation crops can be effectively incorporated into potato cropping systems to provide improved management of soil borne pathogens and other soil health benefits. The brassica green manures can reduce multiple soil borne diseases and improve yield. And brassica crops grown and harvested for seed may provide a greater economic term and still provide some benefits for disease reduction. Rotation crops grown as green manures were more effective than when grown as cover crops for their effects on tuber yield and disease reduction. And the use of disease-suppressive crops and other soil health management practices can substantially reduce soil borne disease problems, but they cannot completely eliminate them. Some cases may take time to develop and should be used in conjunction with other approaches to achieve sustainable disease management.

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Thus, based on our research, the best management of soil borne diseases, soil health, and sustainable production using cropping systems would include use of a three-year rotation or longer if possible, incorporating conservation tillage where possible, and the use of a disease-suppressive rotation crop prior to potato, such as a brassica crop as a green manure or sudangrass as a green manure. If those don't fit into your system, then a more disease-suppressive regular crops, such as ryegrass or small grain that can help reduce some diseases.

Use of cover crops where you can following rotation crops, such as winter rye or ryegrass. Compost or other organic amendments can also be used to improve organic matter and soil property. And usually also will result in increased yield. And that after potato year of the rotation could be used to include some other alternative cash crop or small grain.

SLIDE 25:

And with that, that covers pretty much what I wanted to talk about. And this slide just shows some of the other people that were involved in this research, as well as some of the references of literature or publications that contain some of this information in data. And I'm also available. My email address is here. Also available if anyone wants to contact me and get more information about this research or related research. Thank you.