SLIDE 1:

SLIDE 2:
So here's my logic path for this presentation. If we want to close the gap between what we produce now and what is possible, one way is to manage disease because that limits production. And I think you said that, Chad, as well. Pathogens are introduced into field by planting infected seed potatoes, and once introduced into the soil, they can be difficult to manage. So a good way to manage disease is exclusion, preventing introduction of pathogens. And pathogens are not introduced into fields if the seed is free of pathogens, duh. If you don't have pathogens in the seed, they're not going to get in the soil. So improving the health of seed potatoes to improve the health of commercial potatoes will ultimately improve productivity, profitability, and sustainability. And those are the three targets, I think, for health management with potatoes. So, planting clean seed can help close the gap of soil pathogens, seed pathogens, and those pathogens that are seed and soil born. So that's where I'm going with this presentation.

SLIDE 3:
First time I'll to talk some basic pathology to make you smarter so you can amaze your friends and mystify your enemies. It's important to do that. Plant pathology is the study of plant diseases, defined as harmful alteration that interferes with normal structure, function or economic value over time. As opposed to injury, which is sudden. An example is lightening. And this photo that I have in this slide is lightening injury. And you can see this light-like appearance. So this is a nice little thing to tuck away for trivial pursuit that this is the symptom that is lightning and it's sudden. And injury is sudden, but disease goes over time. So the two categories of disease that we should keep in mind, non-infectious, weather, nutrient excess, deficiency, chemicals. Those kinds of non-infectious are called disorders and they're not transmissible. Okay. So I like to call them disorders. And probably Mike and Andy will probably talk about some of those. And then we have infectious diseases. These are ones that are transmissible and caused by a living organism. And those organisms, fungi, bacteria viruses, nematodes, okay. Those are the pathogens that cause problems.

SLIDE 4:
Remember that disease is the interaction of three factors, susceptible host, virulent pathogen, a favorable environment. This is the Holy Grail of plant pathology, the disease triangle. And if you had time to that, you have the disease pyramid and

epidemics are this favorable disease triangle over time. So when we have disease, we have the triangle. If that happens over time, we can have an epidemic.

SLIDE 5:
Symptoms change in the plant due to disease. This is how the plant reacts to the disease, stunting, yellowing, twisting, whatever the plant reacts, however it reacts. Signs, which is the presence of the pathogen itself, fungal growth, bacterial ooze, sclerotia, the pathogen itself.

And in agriculture, remember a single plant is not very important, a single potato plant, a single corn plant. Okay? It's the whole field that becomes a problem. We don't care about those single plants but there are examples where it is important trees with Dutch elm, citrus trees, orchards, landscape plants. So sometimes they're important, but most of the time we don't care about those single plants. So only when many plants become diseased over time do we have an epidemic, and that's what we're trying to stop with those epidemics really or widespread disease in the field. Plant pathology tries to prevent disease, as opposed to human medicine that concentrates on curing. Okay. So plant pathology and most of my talk is how can we prevent diseases from happening rather than trying to cure the disease. We don't have much curative activity in plant pathology, we have more prevention. So let's go back to the gap a little bit and see how we can build on this now.

SLIDE 6:
So I want to talk about soil-borne pathogens. So these are soil inhabitors and these are always in the soil. The soil inoculum is the source of infection. Seed inoculum is not important at all. So this category is there strictly soil pathogen. Seed is not important at all. It's immaterial. The examples are pink rot, upper photo on the right. You can see why it's called pink rot. Leak is the middle one on the right hand side and early blight is the lower photo in this collage of photos. So pink rot and early blight are not seed-borne. The inoculum is in the soil and they're managed by fungicides after the fact, right?

So we don't have to worry about them being seed-borne diseases. These are strictly soil-borne pathogens. the same with early blight... I'm sorry, with leak. Leak is always in the soil. We don't have fungicides for that but we manage by harvest conditions, harvest temperatures below 68 degrees and avoiding injury because this critter needs an injury to infect the potatoes. And the other member of this group is white mold. White mold is also a soil-borne disease. sclerotia in the soil where it survives... It's also managed with fungicide. So seed management is really not

important for these guys. If we're going to manage these diseases, we can only improve the health of this disease by treating the soil. So we can't improve the seed health of these diseases to close the gap. So we can't improve seed quality to manage these diseases to help close the gap. So that for many here, but they're important and we have to remember that the seed health doesn't make any difference for these diseases.

SLIDE 7:
Here's a group where managing seed health will really help close the gap because I'm going to talk now about the seed-borne pathogens. And these are invaders. They only persist in field soils for a short period of time, at the most one to two years. So crop rotation can deal with these pathogens pretty easily. In this group of pathogens, the seed inoculum is the most important source of inoculum, and often the only source of inoculum. Soil inoculum is not important. So these are not good targets for treating the soil. These are good targets for improving the health of the seed. So these diseases can be managed by producing seed potatoes with the low incidence of disease and by crop rotation to help close the gap. So what I've done here is show some examples and management consideration for some of these diseases that are seed-borne so we can improve the health of the seed potatoes that are used to produce our commercial crop. That will help close the gap. So we talk about soft rot bacteria Dickeya and Pectobacterium. It used to be called Erwinia for those of you that have been around the industry a long time. They've been renamed. Dickeya just started in 2014 in the U.S. Pectobacterium's been around for a long time. Basically, all seed potatoes are infected with Petcobacterium. They cause seed decay and blackleg, which you can see in this photo, in this slide. They survive in surface waters. They do not survive in soil. They are not good soil competitors. Management is done by preventing injury to seed that are sites of infection because they need an injury to infect. And water management is the key because these are facultative anaerobes that will cause decay when you cut off the source of oxygen. The potato can't wound heal, the bacteria can grow. So if you have wet conditions that cut off the oxygen, you'll end up with decay. So these are seed-borne. So seed management is the key to closing the gap for these soft rot bacteria. Dickeya, it's a little bit different. We have now developed a system for screen seed lots and getting rid of seed lots that have high percentages of Dickeya. All the seed lots have Pecto but we can do seed lot testing for Dickeya. So we can begin to eliminate any seed lots that have Dickeya.

SLIDE 8:

Those seed-borne pathogens continued, late blight. Late blight is probably the most... Some people say, the most important disease in the world. Seed is the most important source of infection. Soil inoculum is not important in the U.S. because the [inaudible 00:09:52] that survive in the soil are not found in North America but they are important in Europe. So soil is not important. Seed is the source of late blight. When late blight seed is planted in a field, that's the source of late blight. So clean seed happens by field inspection and fungicide applications to provide clean seed that's planted for commercial potatoes. So simply managing the disease by clean seed and fungicides closes the gap for late blight.

Ring rot bacteria caused by Cms... And most of you don't care what Cms is, so I'm not going to say but it's a bacteria that persists in the seed and seed inoculum is the most important. It does not survive in the soil. It's a very poor competitor and it... Because it's in the seed, it spreads by cutting, and it's managed again by Cms-free seed. And you can get Cms-free seed by seed lot testing. There's a PCR test that works really, really well for screening samples from seed lots. And what's coming in the future, we want to look down the road. Don't cut seed. Because it's spread by the cutting operation. I think we're the only country in the world that still cuts seed. And most of the other countries in the world don't cut seed because of this particular disease. So in the future, I think one of the ways to close the gap, don't cut seed.

SLIDE 9:
Here's some other ones, silver scurf. Silver scurf causes a blemish like you can see in this upper right-hand corner. And you can see why it's called silver scurf. Silver scurf, this organism, Helminthosporium solani, is only on the seed. We've never been able to find it in the soil, including soil in Chile that's 25% organic matter. So you would think that it might survive there but we can't find it there. So it's strictly a seed-borne disease. So keeping the seed free of silver scurf prevents introduction into the soil where it can infect the new potatoes, the progeny tubers developing from that seed. So obviously, clean seed free of the pathogen is the way to manage this disease. You can do that with seed treatment and you... It's important to consider separate storages for early generation seed potatoes because these spores spread in storage. And if you have all your potatoes from all the generations in a single storage, they all get infected. So separate storages for early generation plus a seed treatment can manage this disease. Soil is not important.

Viruses, especially PVY causes this mosaic card. At least some strains of it cause mosaic. Some of them don't cause symptoms. It seed-borne only. Viruses do not

survive in soil. So trying to manage this by soil treatment doesn't make any difference. These are seed-borne diseases. So planting clean seed that's been ELISA-tested to show that it's free of viruses, field inspection, seed certification, are all important to ensuring that a crop free of viruses is planted in the field.

SLIDE 10:
You can prevent introduction of these pathogens by planting clean seed. But if you plant infected seed, you're introducing those pathogens into the field soil. So you can manage these best by preventing them from even getting into the soil. And most of these pathogens, once they're introduced, increase with subsequent potato plantings. So every time you plant a potato crop, you get an increase in the soil pathogens. Then pretty soon, like Chad alluded to earlier, the field can be full of pathogens and you've got old soil that's a tired old soil, partly because it's full of pathogens because there've been so many potato crops. Because everybody wants to plant in the good ground.

Most of these pathogens that are seed and soil borne infect the underground plant parts. And they have long persistence in field soils, years. So they can persist in the soil for years. And they have special structures that are usually thick-walled and dark in color that allow them to survive, things like sclerotia and oospores. There are big resting spores in sclerotia that can survive adverse conditions like we have in North Dakota for long periods of time. And they are very difficult to manage in the soil. Crop rotation doesn't work because they don't go away with crop rotation. Bio-remediation, green manure, cover crops are a really good idea to do but we need to figure out how we can do that best. And the soil health project I think that's currently ongoing is looking at this as well. And these are the ones that are the soil fumigation targets because they persist a long time. They're in the soil. They can't be managed once they're in the soil except by things like bioremediation and soil fumigation. So these are the ones, the stickers. These are the hard ones. These are really good targets to close the gap. So if you can pick some diseases to close the gap, this group is probably the best ones to look at. Examples, Verticillium, Fusarium, Rhizoctonia, common scab, powdery scab and black dot. All of those guys stay in the soil a long period of time, great targets to manage if we can.

SLIDE 11:
So I'm going to look at these generation two seed, no silver scurf at all and you put it in a bin that's got a common air handling system with generation seven seed that's full of silver scurf. And it's sporulates in storage. Those spores get released

into the air handling system and contaminate and infect those generation one potatoes in storage.

So you've already got it in the seed, going into the soil. So one of these tricky diseases is Rhizoctonia, survives as black scurf. I can see in this lower photo, a sclerotia on the tubers and it also survives in the soil. So it survives on the seed and in the soil. The sclerotia survive because they're dark masses of fungal growth. They do not produce any spores at all. So, the way this works is the infected seed infests the soil... And you can't infect soil, you can only infest it, right? And it persists for years in the soil, almost everything gets Rhizoctonia. So if we want to close the gap for this particular critter, remember, we can't use crop rotation, there's lots of seed treatment fungicides that can be used to suppress Rhizoctonia or plant seed with low levels of Rhizoctonia. And we say less than 5% coverage with Rhizoctonia.

And I'm going to go back to seed treatment fungicides, there's a bunch of them. And they are so effective in reducing Rhizoctonia that we can hardly find an infected seed lot to use as a control to use for as a seed lot with inoculum in our Rhizoctonia trials because over the years we've got all these fungicides. So this disease is waning, if you will.

SLIDE 12:
Fusarium, infected seed like you see in the upper photo here, that's an infected seed piece. It decays in the field, contaminates the soil with Fusarium propagules. And then those propagules in the soil infect the root and the stem. And they can persist in the field debris and field soil for years and years. And then the Fusarium in the soil infects tubers at harvest through wounds. And for this disease, wounds are mandatory for infection. So one of the ways of closing the gap is to avoid harvest injury. Then you don't get infection. If you do get an injury, like you can see in this middle photo on the edge, the fungus gets in and grows slowly or ramifies throughout the internal part of the potato. And it's difficult to see, especially in seed potatoes because they're not washed and all the decay's inside. So when you plant infected seed or when you handle a seed with dry rot, whether you cut or don't cut, the dry rot spores spread during handling and cutting, and you end up with decay like you see in this lower photo. S,o one of the ways of closing the gap for Fusarium... Do I say that again?

SLIDE 13:

Oh, yeah, management, one of the ways to close the gap, plant seed free of dry rot, avoid harvest injuries. It can't enter without an injury and provide wound healing and storage after harvest to stop those injuries. The wound healing stops Fusarium decay. So wound healing in harvest, for the first month, is wonderful to do. Seed treatments are effective against Fusarium. Organic amendments to the soil, we hope that green manure will work but we need to do some more testing for this. And I also am saying here that chloropicrin suppresses, manages soil Fusarium in several other crops like spinach and strawberries and peas. I wish it would work in potatoes. And I hope it works in potatoes but we don't know for sure. So I think we need to evaluate this to help close the gap but in order to do that, we need a really good soil, I'll say, to a numerate the amount of Fusarium in the soil to see if it's working or not.

SLIDE 14:
So another one I want to talk about is black dot, widely distributed, common in most potato fields, infects above and below ground parts, causes black dots on the stem, causes foliar disease. It causes late season stem rot, and it causes a tumor blemish that can resemble silver scurf. So it's involved in the whole lifecycle of potatoes. Soil inoculum is important. It's also on the seed. We do not know the role of seed inoculum. So we've been trying to look at this but it's so difficult to find out what the seed inoculum is doing. And we don't really know that but we know that the soil inoculum is important for the field aspect of potato infection. Management is difficult. The only thing you can do is avoid infected seed. You can't avoid infected fields. You can use foliar fungicide but that doesn't really help with the tubers. In my opinion, there's not much we can do to close the gap for black dot. It's a real strong pathogen that really is resistant to management. It's pretty important... I don't know what we can do to close the gap here. We need some room here.

SLIDE 15:
The other one that's difficult is our friend powdery scab, seed and soil borne vectors. The virus persists in the soil up to 14 years, favored by cool, wet conditions. It's managed by resistant cultivars. That's about the only thing you can really do for consistent management. It causes scab-like lesions and calls on the tubers. There are some mixed chloropicrin fumigation results. We've done some work showing that we don't get... We can reduce powdery scab in the soil with chloropicrin results but we get more disease after a fumigation, as opposed to studies in Israel where they get good control of or good suppression of powdery scab with chloropicrin. So really the best way to manage this disease is to plant

clean seed into clean soil. It's a little late for that now because it's in so many fields. It's almost impossible to find a seed lot that's clean and a clean field. So it's going to be hard to close the gap for this one too. So black dot and powdery scab are the ones that are going to be the sticklers in this whole close the gap.

SLIDE 16:
Now I'm going to talk about early dying. And I know that was the first part of my presentation was going to be Verticillium and seed-borne disease. I turned them around and I'm going to tuck that early dying now. How much time do I have? I got enough time here? So early dying is probably the most serious problem for commercial potato production everywhere. And that's early dying is a complex with many causes, most important contributor is our friend Verticillium dahliae. That's the most important component but there's some other actors in this saga as well, lesion nematodes, Fusarium, black dot, stress, nitrogen, water stress. All of these accentuate and exacerbate early dying. It causes a lot of symptoms, wilting and browning of the foliage, general plant decline, brown vascular discoloration in the tubers and in the stem as you can see in the lower right and early death of the potato plants and often the entire field.

SLIDE 17:
The disease cycle is important because soils become infested. When you plant Verticillium infected seed that introduces the Verticillium into the field. And every time you grow a potato crop, you get an increase in the Verticillium population. So this cartoon, if you will, shows first crop, and then you have crop one, and then you rotate and then crop two, it increases. Crop three, it increases if you rotate. It keeps increasing over time. You can see the Vert increases over time. So this is the problem. The first two or three years, you don't see much early dying but then after a while, the population gets high enough. So the Verticillium colonizes the stems. Remember this brown discoloration and the vascular hill. It colonizes the stem for thousands of micro sclerotia. And they are only the size of pepper flakes. Then they remain in the soil after vine killing before harvest. So when you kill the vines, you're just spreading those micro sclerotia all over the field. And they survive for years in the field. And so these populations become economically important after as few as three to five potato crops. And they reduce yield because the plants die early. Duh, that's why they call it early dying. The number of soil propagules, the sclerotia can be used to predict the disease threshold and the need to fumigate. 5 to 15 grams of micro sclerotia per gram of soil depending on the location. So you can manage this and there are places that you can send soil samples to get Verticillium threshold counts in the soil.

SLIDE 18:
There's a nematode synergism that's really important. The lesion nematode Pratylenchus penetrans makes early dying worse. There's a synergistic effect between Verticillium and feeding by Pratylenchus penetrans. There's three other Pratylenchus nematodes. They're not important. It's only penetrans that's important. And even at one nematode per cubic centimeter of soil, it causes this synergism. It probably makes a wound to allow the Verticillium to enter. Penetrans has a huge host range, 164 plant species. So managing this nematode, it's also an important part of the early dying complex. And you can see this arrow shows the stylet that it uses to feed. Management of Verticillium, tolerant varieties. We don't have really good resistant varieties but we have tolerant varieties that can be used in fields with lots of Verticillium. There's a lot of research being conducted, including at NDSU by Gudmestad and Judy Pasche. Gudmestad used to be here. Pasche took his place, that they're trying to find tolerant varieties with Susie Thompson and her breeding program. And those tolerant varieties produce fewer sclerotia in the stems so they put fewer sclerotia back in the field. So that's one of the mechanisms of resistance is fewer sclerotia production. Crop rotation, not effective. Soil fumigation, Vapam and chloropicrin. Vapam being targeted and phased out. So here's a business opportunity for the chloropicrin people to use, green manure crops. We hope that works. Sudan grass, Brassica crops. We hope they're going to work. Managing nematodes. Biologicals don't work for nematodes or for Verticillium. We've done a bunch of testing for that. And I think one of the future places to close the gap is trap crops. For an example, this is a field in Germany and it's a sugar beet field and it's got the sugar beet cyst nematode there. And they plant this white radish as a rotational crop and this prevents the females from feeding. So after a few treatments with white radish, there's only males left in the population. The males don't feed. So you get rid of the damage. So I think a future use may be, or a future direction might be trap crops like this with some of these Brassica species.

SLIDE 19:
And you can also, to help close the gap, good general agricultural practices like I have here. Good soil, no hardpan, food and water, no bruises, no field heat. You can see these good general agricultural practices make for stress-free plants. That will help close the gap as well. And my final points to consider, pathogens can be seed-borne or soil-borne or both. It's possible to close the gap for seed-borne diseases by planning certified clean seed potatoes, not possible to close the gap for most of the soil-borne diseases.

There are possibilities to close the gap for diseases that are both seed and soil borne to prevent introduction of pathogens that are inhibitors but it's probably too late for most potato fields because they're already infested. The good fields are already probably junked up as they say. So the other thing to consider is the terms control, manage, suppress, reduce, eliminate are used interchangeably but may have different meanings to different people. So be careful when you talk about these terms. They may have some legal implications. And I'm going to end by saying like our North Dakota Seed Potato Agency says, good seed doesn't cost, it pays. So that's my last slide. I'm done.