Extension
UNIVERSITY OF WISCONSIN-MADISON

Fundamentals of Plant Diseases

Transcript

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Slide 1

Hello, everyone. My name is Brian Hudelson. I'm the Director of the Plant Disease Diagnostics Clinic at the University of Wisconsin-Madison, and I'm going to be leading this discussion on plant diseases today. Now, I know for a lot of you, the topic of plant diseases can be rather intimidating. But I have to say that I am a plant pathologist. I think this topic is REALLY, REALLY pretty cool, and I'm hoping by the end of the presentation, you'll be a little less nervous about thinking about plant diseases and how to manage them, and I'm hoping also that maybe you'll find some of the diseases that we discuss really pretty cool, the way that I do.

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Well, if we're going to start talking about plant diseases, the first thing that we really need to do is define what we mean by a plant disease. And the way that I like to do that is in the context of what I call the disease triangle. This is basically a conceptualization that was developed by plant pathologists to describe the three important components that you need to have a plant disease.

The first is what's called a "susceptible host". Basically, you need some sort of plant that can come down with the disease. And by the time that we're done with this talk, you're going to realize that basically any plant can get a disease of one kind or another.

The other thing that you need as part of the disease triangle is something called a "pathogen", and what we're basically talking about here are microorganisms that can cause disease. And we're going to be spending a lot of time during this presentation talking about the different types of pathogens and the diseases that they cause.

Finally, the third important component in the disease triangle is something called a "favorable environment". Basically, you need weather conditions that are favorable to allow the interaction between the pathogen and the susceptible host to occur. And oftentimes, what we're really talking about in terms of favorable environment is a lot of moisture, because many of the disease-causing organisms tend to like wet conditions.

So, it's really this interaction between these three components, the susceptible host, the pathogen and the favorable environment, which leads to what we call disease,

and what we're really looking at when we see disease is some sort of abnormality in the plant. And we're going to talk a lot about what we call symptoms, and these are basically abnormalities that can be caused by different types of diseases.

Now, while I think this triangle is very useful for thinking about what a disease is, the other thing that I think the triangle is very useful for is thinking about disease control. A lot of the techniques that we use for managing disease basically are designed to eliminate or at least reduce the importance of one or more of the corners on this triangle.

So, let's look at susceptible host. What might we do in order to reduce the importance of this particular corner of the disease triangle? Think about that for a second. Well, one of things that we can do is use what are called resistant varieties, and you've probably heard of these before, particularly if you're something like a vegetable or a fruit grower. You can buy varieties of your favorite vegetable or your favorite fruit tree that have been bred for resistance. They're less likely to get severe levels of disease than other types of varieties. And what scientists have found is if they look across the populations of all individuals of a particular type of plant, they see variability. Plants are just as variable as we are as people, and you can find some variants of plants that are less likely to get disease than others, and they take these, they interbreed them, and then they come up with a named variety that they can sell as having disease resistance. Now, that's one technique to use to make that susceptible host corner less important in the triangle.

The other thing sometimes that we have to recommend is simply not to grow a particular plant, because again in certain situations, it's just a losing battle, and you're better off growing some other plant rather than the one that you'd really rather grow but is really prone to disease.

OK, let's move over on to the pathogen corner of the triangle, and let's think about that for a second. How can you get rid of pathogens? Now, I know by the end of the talk, you're going to think that pathogens are EVERYWHERE. You're never going to get away from them. But, there are methods that you can use to make this corner less important in terms of disease. And think about that for a second.

Well, one of the things that you can do is something that you so every fall, or you should be doing every fall, and that's good fall cleanup, removing leaf debris, cutting back old plants that have died back, removing that material from your yard. All of that is really impacting the level of pathogens in your landscape, because pathogens oftentimes survive in old plant debris. And so, one way to get rid of them is to get rid of that debris, and that's a very critical management tool for managing a lot of different types of diseases that you're likely to see.

Finally, in terms of favorable environment, think about that. We've got Mother Nature kind of doing what she wants to do. How can we possibly modify that corner of the triangle? Think about that for a second. Well, with a favorable environment, one of the things we do have a lot of control over is how much we water in a garden. We have to be very careful not to overwater, because that tends to provide a very moist environment that's very favorable for all kinds of disease-causing organisms.

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The other environmental factor that we tend to have a lot of control over is relative humidity, and that's really a function of plant spacing. So, if we have a lot of plants packed tightly in a garden (the way that I do in my garden at home), then we tend to trap a lot of humid air around plants. And you have to keep in mind, plants are natural humidity generators. They do something called transpiration, so they naturally lose moisture through their leaves. That creates a little humid envelope around the leaf surface. So, anything you can do to space plants farther apart, to allow better airflow, that tends to remove that humid air. And that's a function of either, if you've got an existing garden, thinning plants, or, if you are establishing a new garden, making sure your plants are spaced far apart, to get that good airflow.

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As I mentioned, we're going to spend a fair amount of this presentation talking about the different types of organisms that can cause plant diseases. We're going to talk about the fungi and fungi-like organisms, which are the most important of the disease-causing organisms in plants. We will also discuss bacteria, viruses and a couple of organisms you may not have heard of before, the nematodes and the phytoplasmas. In addition to these microorganisms, we'll also talk about abiotic factors. These are nonbiological sorts of things that can adversely affect plant health and growth.

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The largest group of plant pathogens are the fungi and fungi-like organisms. The fungi-like organisms were originally classified as fungi, but have subsequently been broken out into their own group, and we usually refer to these, kind of informally, as water molds. Again, this is the largest group of plant pathogens. There are more than roughly 8,000 different organisms in this particular group that can cause disease. And, keep in mind that there are lots of additional fungi that are out in the environment that do not cause plant diseases, but there's a large group of the fungi and fungi-like organisms that do.

What I like about the fungi is that they are relatively large compared to the other types of disease-causing organisms that we're going to be discussing today, and they can oftentimes be seen with the naked eye. If you've ever been in the grocery store and walked by those mushrooms in the vegetable section, those are fungi, and so, as you can tell, again, those are relatively large. A lot of the ones though that I tend to look at when I'm looking at disease-causing organisms tend to be microscopic, and I do need to use a microscope to see at least some of the structures that I need to see in order to identify them.

Fungi can grow in a couple of different ways. Usually in their day-to-day growth, we call this vegetative growth, and they do this through production typically of structures called hyphae (singular is hypha without the "e"), and these are basically long, threadlike structures that form the main body of the fungus. Typically, these structures are multicellular, so you'll actually be able to see many cells within a given thread, and these can be quite extensive and grow over a large area.

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Fungi can then go into a reproductive mode, and they can reproduce in a couple of different ways. In both methods, they produce what are called spores. These are seed-like structures, which are basically a propagative unit for the fungus. And these can be produced either asexually or sexually. In asexual reproduction, you can think of this as being similar to a cloning sort of process. If you take one of the spores that's produced by this method and grow up a fungus, the fungus that you get is genetically identical to that mother fungus that produced the spore.

In sexual reproduction, it's kind of like humans having kids. Basically, you need two individuals of the fungus that find each other in the environment. They merge. They exchange genetic material, and then there's a spore production process after that, and the spores that are produced here, if you grow up a fungus from sexual reproduction, the fungus that you get from that spore is genetically distinct from either of the two parents. So, it's kind of, again, like us having kids. Your kids have the characteristics partly of mom and partly of dad.

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As I mentioned, when fungi grow vegetatively, they produce what are called hyphae, and this is a photo of the hyphae of a fungus called *Rhizoctonia*, which is a very common root rot organism. You can see how long and tube-like these structures are. They're kind of like threads. Also, if you take a look at where the black arrow is pointing, you're going to see tiny little lines and those are what are called cross-walls. That's what divides that long tube into individual cells, and you can find these in certain types of fungi. Oftentimes in the fungi-like organisms, these particular structures are missing, and so, that's one of the things that I tend to look for when I'm examining fungi under the microscope. I'll definitely look for cross-walls, because if I don't see them, I get a little bit excited, because that can indicate I'm dealing with a water mold, and the water molds oftentimes are some of the more destructive of the root rot organisms that I deal with.

Rhizoctonia itself is also a destructive root rot organism. That's what's shown here. What is distinctive about this particular organism is that it doesn't produce spores, and really, the only way you can identify it is based on its hyphae. What I do to identify this particular organism is I look at places where the hyphae branch. And, again where the black arrow is pointing here, you can see a branch point. And, then I look to see where that cross-wall at the branch point is produced. If it's flush with the original hypha from which the branch has been produced, then it's not *Rhizoctonia.* But, if that cross-wall is offset just a little bit forming kind of a T-shaped cell at that intersection, then I know I'm dealing with this organism called *Rhizoctonia,* and I know I have a problem with a potential root rot organism.

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When fungi go into reproductive mode and start producing spores, they oftentimes produce the spores in what we generically call fruiting bodies. I mentioned mushrooms before. That's actually a type of reproductive structure and thus a fruiting body of a fungus. In this particular case, we have a fungus called *Septoria.* It's causing a fruit spot on a cucumber fruit, and the little black blobs that you can see in this photo are the fruiting bodies of that particular fungus. And, I have one

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right next to a black arrow in this particular slide. And, if you pluck those off. . . And this is what I spend a lot of my time doing in the lab, is plucking these off, putting them on a microscope slide in a drop of water and then squishing them open, and that will release the spores.

This particular structure that you see here is kind of a spherical sort of structure. There is technically a pore at the top, and when you break it open, out pop these little tiny spores, actually not that tiny. They're actually quite elongated and they look kind of like cooked spaghetti.

So, again, fungi produce these sorts of structures quite commonly. In this particular case, the fruiting body is one that's producing asexual spores. So, again, if you grow up a fungus from these particular spores, it's going to look genetically identical to the fungus that's causing the infection in this particular situation.

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Fungi can also produce fruiting bodies when they reproduce sexually, and in this particular case, I'm showing you a picture of the sexual fruiting bodies of one of my favorite fungi. This is a powdery mildew fungus that you're seeing here. And, what's interesting about this particular fruiting body is that the center portion is just an enclosed sphere. This one kind of looks like a Pac-Man, because I've crushed it open under the microscope. And, what I'm trying to do when I crush it open is release bags of spores that will be inside this center sphere. You can actually see one of those bags next to the red arrow. If you take a look at the, kind of the mouth of the Pac-Man on that spherical structure, you can also see the edge of another one that's popping out. Inside of these bags, you'll find these kind of brownish, very oval-looking spores, which are very characteristic of the sexual spores of powdery mildew fungi.

On the center sphere, which is technically called a chasmothecium, you can also see these, kind of radiating arms on that fruiting body. These are modified hyphae called appendages, and what's really cool about these particular structures is they are very, very ornate. And, in this particular case, you can see the green arrow. The end of that appendage kind of looks like an antler. And quite frankly, depending upon which powdery mildew you're dealing with, those appendages will have a different sort of look. In this particular case, they look like antlers. There are other types of powdery mildews where those arms will come out and form perfect spirals. There's another type of powdery mildew where they actually look like spikes that come out from that center sphere, and in that particular case, when it gets relatively humid, those arms, those spikes, will actually bend down and lift that sphere up off the surface of the leaf, and that helps when the spores are released, getting those spores in wind currents, so that they can be moved away from the leaf surface.

Quite interestingly, if you know what those appendages look like, you know how many bags of spores that are inside that center sphere, you can actually identify, at least to genus, the particular powdery mildew that you're dealing with. In this particular case, you've got more than one bag of spores, you've got these radiating appendages that look like antlers, so that tells me that this particular organism is what's called *Microsphaera*, and that's a powdery mildew that commonly occurs on *Viburnum.*

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Fungal spores can come in all different shapes and sizes. I talked about the spores of *Septoria* being long and spaghetti-like. I showed you the picture of powdery mildew spores, which are rather oval. Some types of fungal spores, like the ones in this picture, are kind of canoe-shaped or banana-shaped, and are multi-cellular. These happen to be spores of a fungus called *Fusarium.* Certain species of this fungus can be quite aggressive plant pathogens, and cause root rots. And, *Fusarium* species tend to be quite prolific spore producers. They produce lots and lots of spores. What's interesting about these is they are multi-cellular, so if you see all of those little lines inside the spore, these are cross-walls, like we talked about when we were discussing hyphae, and they divide that big spore into individual cells. And, each one of those cells can potentially germinate, form a fungal thread or a hypha, and infect a plant. So a lot of potential for infection in this particular case. You may notice that these spores look kind of greenish. That's not their natural color. They tend to be colorless. The reason they're green here is because this particular photo was taken with a green filter.

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While a lot of fungal spores are colorless, there are fungal spores that do have dark pigments, and these are typically produced by fungi that at least during part of their life cycle come into contact with adverse environments, particularly soil, where there are a lot of microorganisms that can potentially use the spores as a food source. These pigments are melanins, and these are actually anti-microbial agents, so they keep the spores from being parasitized by other microorganisms in the environment.

This particular spore is one of a fungus called *Thielaviopsis*. I affectionately call this the "Tootsie Roll" fungus, because this particular fungus has spores that look like Tootsie Rolls. They're long. They're brown. You'll notice in that center spore, it's divided up into individual cells. So, it's multi-cellular, and those cells actually break off like the section of a Tootsie Roll. And, each one of those sections can potentially infect a plant. These particular spores are actually embedded in root tissue. That's all of that kind of gold material that you see in the background. You can also see hyphae of this particular fungus growing through that root tissue as well.

This particular fungus, again called *Thielaviopsis,* is a root rot organism that we commonly see in greenhouse settings. It causes a disease called black root rot, and we typically it on greenhouse-grown plants like geraniums and petunias.

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The spores that we've talked about up to this point are primarily designed for both reproduction and also dissemination, that is movement of the fungus from point A to point B in the environment. Certainly, those dark-colored spores of *Thielaviopsis,* that Tootsie Roll fungus, also have a function for survival. And, in this particular slide, another example of a spore where the primary function of the spore is to help the organism survive in really adverse environmental conditions. There's a black arrow in this particular slide pointing to this kind of circular structure. This is what's called an oospore. This is a resting spore that's produced by those fungi-like water molds that I talked about earlier. And, you can see how many of these spores are embedded in this tissue. This is actually root tissue.

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What you'll notice about these spores is that they have a very, very thick wall, and that's what helps them be very, very stable, particularly when they get into a soil environment. There are certain oospores of certain types of water molds (in particular, there have been some reports of oospores of the organism *Phytophthora,* again a common root rot organism) that can survive for up to 40 years in soil. And, think about that in the context of how you're going to manage an organism that can survive for that long.

Now, you may have noticed that I've been using a lot of food analogies. I never really had a good food analogy for this particular spore, until one of my students came up one time and said, "You know. Those look like Cheerios." So, we're going to dub this the "Cheerios fungus". Hopefully, that'll help you remember that these are oospores and that these help with the survival of this particular organism.

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Now that I've discussed the general characteristics of fungi, what I'd like to do is introduce you to a couple of fungal diseases that I think you should be able to identify by eye. The first of these diseases is powdery mildew, and this particular disease is shown here on somewhat of an unusual plant and an unusual plant part. This is on African violet, and you notice all of this kind of white material that's growing on the flowers, in this particular situation. Now, most of the time, when you see powdery mildews, you're going to see them on leaves. For example, if you're out in your yard and you look at a lilac shrub, oftentimes we see powdery mildews, this white powdery material, that grows on the surface of the leaves. But on this particular host, African violet, we tend to see the symptoms on the flowers. What's characteristic about powdery mildews is that they tend to produce a lot of growth along the surface of whatever plant part they're infecting, and a lot of that white material that you're seeing is actually asexually-produced spores.

Now, you may have noticed that I talked about powdery mildews in the plural. That's because there are lots and lots of different fungi that potentially can cause powdery mildew. And, these particular fungi are relatively specific in terms of their host range. So, we have one powdery mildew that can cause the disease on African violet. There's another powdery mildew fungus that causes the disease on lilacs, another powdery mildew that can potentially cause the disease on cucumbers and squashes and those sorts of plants. So, again, we're talking about a large group of closely related organisms.

They are all characterized by having this kind of whitish growth that occurs, again primarily on the surface of the plant. They do penetrate into the epidermal layer of the tissue. So, that's that outer layer of tissue of a leaf or, in this particular case, a flower. And, they produce kind of an octopus-like structure called a haustorium, and it has these fingers on it that help absorb nutrients out of the plant.

Most of the time, powdery mildews are relatively cosmetic diseases, but on occasion on certain hosts, they can cause some leaf loss and cause leaves to dry up. In particular, I see a lot of problems on phlox. Also, on bee balms or monardas, I see a lot of problems. Also, if you ever get powdery mildews on cucurbits, so squashes, pumpkins, cucumbers, that sort of thing, we can also see a lot of leaf drying due to powdery mildews as well. Part of what they do is as they're growing across the leaf

surface or the flower surface, when they produce those haustoria, that opens up a small hole in the leaf surface that allows moisture to escape, and if you get enough of these infected areas on the leaf, that will cause a lot of dehydration, a lot of moisture loss, and that's what leads to the leaves drying up.

In terms of management of powdery mildews, one of the best things that you can do, if you've had a chronic problem in your yard, is try to make sure that you do good fall cleanup, because powdery mildews oftentimes overwinter in old plant debris. And so, making sure you collect up all of the infested material that's died back in the wintertime and getting that out of your yard can reduce the amount of fungal spores that are likely to be produced the following year. Unfortunately, that does not totally take care of the problem, because many powdery mildew fungi will also overwinter not only in this plant debris, but they can also overwinter in overwintering buds on perennials. So, they kind of hang out there, wait for the environmental conditions to be appropriate, and then they can reinfect a plant as it begins to sprout the following year.

Now, in terms of environmental conditions, really, the driving factor that will really get powdery mildews going is relative humidity. They are a little bit unusual compared to other types of fungal pathogens that will infect leaves and flowers, in that most of these other fungi really like wet leaf surfaces. They require what's called a leaf wetness period. So, that's a length of time where there's actually a thin film of water on the leaves. But, that's not what powdery mildews like. They like a dry leaf surface but really, really high humidity around the leaf. And again, keep in mind that plants are their own mini-humidity generators. They transpire. They naturally lose water through the leaves. And, that creates a little humid cloud along the leaf surface. So, one of the things that you need to do in order to manage powdery mildews is try to remove that humid air, and that's really a function of how much air flow is occurring around plants. So, anything you can do to thin out plants, allow better air flow, will really help you in terms of clearing out that humid air and making a less favorable environment for powdery mildews to occur. So, thinning is important, or if you're establishing a new garden, make sure that you plant plants far apart, so that you end up getting good airflow between the plants.

Other things you can consider for control include use of resistant varieties. Certainly, in phlox and rose, which can be hit pretty hard with powdery mildews as well, there are resistant varieties that are sold. And, unfortunately, while you may get good disease control, these particular varieties may not have other horticultural characteristics that you're really interested in, in terms of flower color and that sort of thing. Also, if you're growing cucurbits, oftentimes they have been bred for resistance to powdery mildew, but again, the fruits you get off these plants may not have the flavor that you want. But, it's certainly an option.

Other sorts of things that you can consider. . . There are fungicide treatments, and many of them, for controlling powdery mildews. As with most fungicide treatments though, these applications need to made before you see any symptoms. Or in this particular case, it's what we call signs, where you see the actual fungus on the leaf or on the flower. You need to make these applications before you see any evidence of the disease in order for them to be effective. These fungicide treatments are really preventative treatments, not curative treatments. And, while there are lots of commercial products that are available for powdery mildew control, what I normally

recommend for most homeowners as a start is kind of a home remedy that's based off of some research that was done at Cornell University. What you do is you take a tablespoon and a half of baking soda and three tablespoons of a light-weight horticultural oil (we'll come back to that in just a second), you mix that in a gallon of water, and again, you apply this as a preventative treatment. With any of these fungicide treatments, whether it's this baking soda concoction or the commercial products, you need to get good coverage. Cover the upper surface of the leaves, the lower surface of the leaves, the stems. Any part of the plant that potentially can become infected needs to be covered.

Now, getting back to this baking soda concoction, I mentioned light-weight horticultural oil. There are many types of horticultural oil that are on the market. Most of them are overly heavy in terms of their weight for use for this particular application. Definitely, you do not want to use something like dormant oil. There's a reason it's called dormant oil. That particular oil is designed for use when plants are dormant. If you apply it to leaves, it will burn them. People have also tried to use, ahem, motor oil, which is a great way to kill plants. Definitely, that's not a useful oil in this particular context. When we're talking about light-weight horticultural oil, we're really talking about a paraffin-based oil.

In terms of when you apply these particular materials, what I normally do is, if you've gardened for a long time and have a good sense of when powdery mildews typically show up in your yard, then what I would suggest would be to go back about three weeks before that time point and start applications. Again, you want to apply these products preventatively. In my own garden, I usually start to see powdery mildews about the first of July, but again that can vary from location to location. The other thing that you can do is make applications based on the relative humidity that you can monitor through your favorite weather site. When you start to see humidities that are roughly 60 to 70 percent that are being reported, that would be a point where the humidity along the leaf surface is probably getting pretty close to 100 percent, and that would be a great time to start applications.

But again, with any sort of fungicide application, you really have to weigh the pros and cons of whether you want to do this. It does take a lot of time. It takes a lot of effort. It can be somewhat expensive on occasion. And, sometimes it's really better to forgo the fungicide treatments and replace the plant with something else that's less prone to powdery mildews. And if you decide to go with a resistant variety, do keep in mind that resistance is not perfect. Even though you have a resistant variety, it will still come down with some powdery mildew. And, the level of powdery mildew can really depend upon environmental conditions. I usually have a conversation at least once during a growing season with someone who comes in, usually bearing a powdery mildew-resistant phlox plant and kind of shakes it in my face, and says, "Look at this plant! I bought it at the garden center. They told me it was resistant to powdery mildew. And, look at all the powdery mildew on this particular plant!" And, what I have to explain to the person is that if that were a susceptible variety, it would look even worse. Sometimes, even when we have really conducive environmental conditions, if it's really muggy during the summer, even resistant varieties will have a fair amount of powdery mildew. Just keep that in mind as you're weighing your options for management for this particular disease.

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Another very easy to identify group of fungal diseases are the rust diseases. And again, we're really talking about a large group of fungi that can cause these diseases. They're all very closely related, and they can cause problems on a variety of different types of plants. Rust fungi tend to be relatively host specific. In this particular case, I'm showing you an example of what's called rose rust.

And, this is a very classic-looking rust, because what you tend to get with the classic-looking rusts, if you look at the top surface of the leaf, you're going to see some kind of either brownish or orangish spots. But what you really need to do to identify it as a rust disease is basically flip the leaf over and take a look on the bottom surface of the leaf and look for little erupting masses of fungal spores that are being produced. And, these are typically kind of a bright orange or gold-yellow color, or they can be kind of a rusty-brown sort of color. What you can do is actually, if you rub your finger or a Kleenex® or a white handkerchief across the surface of the leaf, if you have a rust, you're actually going to rub off streaks of color. And, that's really the classic way of identifying whether or not you have one of these rust diseases. There are a lot of leaf diseases that are caused by fungi that will produce kind of brownish or orange spots, but it's only the rusts where you actually get this spore production that you can rub off with your finger.

In this particular case, rose rust is what's called an autoecious rust. That means that this particular rust fungus is able to complete its entire life cycle on a single host. So, this particular fungus just lives on rose plants. In addition to these really orange-y, powdery spores that are produced, late in the season, it will start to convert its spore production into an overwintering spore. That's called a teliospore. These orange ones are called urediospores. What I love about the teliospores of this particular fungus, this rose rust, is it looks like a little corn dog. Actually, if you look at it under the microscope, there's a part of it that looks like a frankfurter, and then a part of it that looks like a stalk. And actually, these resting spores, these teliospores, are so large that you can actually see them by eye on the leaf surface. They actually look like little insect droppings. Watch for that. This is a disease that we haven't seen a lot of in Wisconsin. It's more of a warm weather sort of rust, but we're seeing more of it as our climate tends to warm up and we get milder winters. So, you may see this on your roses in the future.

The other major group of rusts are what are called the heteroecious rusts. As opposed the autoecious rusts, the heteroecious rusts require two different hosts in order to complete their life cycle. Probably the most common one that folks tend to see is one called cedar-apple rust. And, that particular rust fungus spends part of its life on red cedar or junipers in general and then the other part of its life cycle on woody rosaceous plants like apple, crabapple, hawthorn, and quince. What you typically see first in the growing season is the stage on junipers, and it's quite vivid. If you've ever seen these large, marmalade-like masses that occur on junipers, particularly red cedar, you've seen cedar-apple rust.

Kind of an amusing story. . . We had a student on campus who told the head of our grounds crew one time that she really loved mid-May to mid-June on campus, because that's when the junipers bloomed. And, what the student was actually seeing were these masses of spores that were being produced by the cedar-apple rust fungus.

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The spores that are produced in those masses do not reinfect the junipers. They actually infect the alternate host, so it's one of those rosaceous plants like apple, crabapple, hawthorn or quince, and then what you start to see midseason on those hosts are very, very distinctive leaf spots that are about the size maybe of a dime or a nickel. They're usually very bright in color, yellow or orange, and if you look at the lower surface, eventually you'll start to see these little tentacles that are formed below the leaf surface, and these produce spores that eventually reinfect the junipers. This fungus bounces back and forth.

Other types of heteroecious rusts that you may have come across. . . There's one called white pine blister rust. And, this can be a serious problem on white pine, where it can kill white pine trees. It actually causes an infection on the branches and causes the branches to die. The alternate host for that particular rust fungus is gooseberry or currants, where you actually see symptoms that are very similar to what I'm showing here on rose. So, you get these very bright orange pustules or masses of spores that are produced on the leaves.

The other alternating rust that you may have encountered is the one that goes to turf. If you've ever walked out into your lawn and gotten orange shoes, you're dealing with an alternating or heteroecious rust. That particular rust spends part of its life cycle on turf, the other part of its life cycle on, of all things, buckthorn. If you're not familiar with buckthorn, it's a very invasive woody ornamental. It will take over understories in wooded areas. And, if you need another reason to hate that particular plant, there are three. It's invasive. It's an alternate host for this grass rust. And then a third reason to hate it, particularly if you're a farmer who grows soybeans, is that it's an overwintering site for soybean aphid.

In terms of management of rust diseases, that really depends upon the type of rust that you're dealing with. Oftentimes, with the autoecious rusts, good cleanup of the infected leaves, also pruning on roses of infected canes, can help with management of that particular disease. With the alternating rusts, sometimes choosing to grow only one of the hosts, for example with cedar-apple rust, you decide whether you're going to be a connoisseur of junipers or a connoisseur of woody rosaceous plants, and grow only one them. Although, quite frankly, in tight urban settings, that doesn't often really work that well, because you may decide that you're going to grow just crabapples, but your neighbor will grow some junipers, and the plants will be close enough for spores to float back and forth. There are also fungicide treatments, but if you're ever interested in that particular option, that's a situation where you'd want to contact someone like me to get a specific recommendation for the particular rust that you're dealing with.

But again, rusts in general are diseases that you should be able to identify by eye. So, definitely watch for those out in the landscape, as you look for plant diseases in the future.

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While powdery mildew diseases and rust diseases are relatively easy to identify, unfortunately a lot of other fungal diseases are going to be much more of a challenge. So, what I'd like to do as we continue talking about fungi is give you kind of a broad perspective on the sorts of symptoms that you might expect to be caused

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by fungal pathogens. One of the most common of the symptoms caused by fungi are spots. These are basically localized, relatively circular infected areas, often necrotic, so dead, that occur on soft tissues, particularly leaves, and you can see an example of this here. This is a disease called black spot. It occurs on elms. There is a black spot disease that you may have heard of that occurs on roses, but that's caused by a different fungus than the one that's involved here. With both of these diseases, what you get are these roughly circular dead areas on leaves. In this particular case, you can see a little bit of a yellow halo around the dead areas. We do sometimes see that with fungal pathogens that occur on leaves, but we more likely are going to see a yellow halo when we're dealing with a bacterial pathogen, and we'll talk about that in just a bit.

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When you see a lot of spotting occurring on a leaf to the point where a portion of the leaf or the entire leaf just collapses, then we start talking about a symptom called a blight. And, probably the most common of the blights that you're likely to encounter are the blights that affect tomatoes. If you've ever had a tomato plant that started to get brown leaves on the bottom and then that works up the plant to the point where the plant is totally defoliated, you've encountered fungal leaf blights. And they're basically two different diseases that are involved that we typically see causing blights on tomato with that bottom up sort of defoliation, and both of those are shown in this particular slide.

On the left is a disease called early blight. If you live around the Stevens Point area, where there's a lot of production of potatoes, you've most likely seen this disease before, because early blight goes both to tomatoes and to potatoes, and so we tend to see a lot of this disease up in that Central Sands region of Wisconsin. The characteristics of the individual spots are that they are relatively large. They usually start out being roughly about 1/2 an inch two 3/4 of an inch in diameter, and you can see several spots of that size on this left leaf. Oftentimes, if you look very carefully at that dead tissue, what you're going to see is something that looks like a target pattern, so some concentric rings. That's very characteristic of that particular disease. And, again you get so many infections by this fungus on a leaf that portions of the leaf and then the entire leaf began to collapse, and I have a black arrow showing you an area of the leaf where there are so many infections where that leaf tissue just started to totally die and eventually this entire leaf will collapse and die as well.

On the right is the other, probably more common, of the leaf blight diseases. It's called Septoria leaf spot. I see a lot of this in home gardens, particularly in the southern part of the state, but elsewhere in Wisconsin as well. With this particular disease, the fungus infects, it forms a relatively small spot to begin with, usually with a very bleached center and a little bit of a dark halo around the edge, usually black or dark maroon color. And again, you get so many infections per leaf that eventually the entire leaf collapses, and you get total leaf death.

These particular diseases can be a challenge to manage. The best time to start managing these leaf blights is actually in the fall after you've had a problem. Make sure you do really good fall cleanup. Collect as much of that old tomato debris that may harbor these fungi as you possibly can, and remove it from your garden. If

you're a good hot composter, where you have a compost pile it gets up to high temperature and you routinely turn that material so that the outer material that's cold gets to the center where it can heat up and decay, if you're a good hot composter, you could actually compost this material. But, if you're like me, and my idea of a compost pile is just that you throw material in a pile in the back of your yard, that's not a good place to put this sort of debris. Because, if you don't get that rotting and heating of the material and that material is just sitting around, it can harbor the fungus over the winter, the fungus will sporulate in the spring, and that can lead to problems next year. So, it's best to collect up that material. If you don't do good hot composting, definitely get it out of your yard and get it away from where you're going to be growing tomatoes next year.

As you go into the following spring and decide that you're going to plant tomatoes again, you may want to consider resistant varieties, although I don't necessarily think that that's a great option in many cases. There are some varieties of tomatoes that have resistance to these common leaf blights. Unfortunately, the flavor of the tomatoes that are produced typically is not that great. What scientists have discovered is that the genes for resistance to these diseases are on the tomato chromosomes very close to the genes for flavor. So, what you tend to get is either a plant that's very susceptible to these leaf blights that tends to have a really tasty tomato or you have a plant that's very resistant that has fruits that taste kind of like cardboard. A lot of the cherry tomatoes tend to have at least some resistance to these leaf blights and unfortunately you know that the cherry tomatoes oftentimes don't have the best of flavors. So that is an option, but it's not, in my mind, the best option for management.

The other thing you should be very aware of when you go to plant your plants the following growing season is try to move your tomatoes to a new area in your garden. You want to keep them away from where you had tomatoes last year. That's because even though you've been really diligent about collecting up all of the old plant material from last year, there are going to be little bits of leaf that you haven't been able to collect that have filtered down into the soil. Those are going to harbor these leaf blight fungi, and those are going to produce spores, and those can potentially lead to additional infections the following year. So you want to move your plants to a new area in your garden, if possible.

Also, make sure that you plant your plants as far apart as you possibly can. What you really want to do is make sure that when your tomato plants are full size, the foliage does not overlap. So, you want to get good spacing between the plants, so you get good airflow, and the reason why you want that is because you want to dry the plants as quickly as possible. So, if the leaves get wet, you want them to dry really quickly, because these leaf blight fungi really require long periods of leaf wetness, again a film of water on the leaf, in order for the spores to germinate and infect. So, good spacing is critical to get good drying. Also, as the plants get larger, you may want to thin them a bit in order to again open up the canopy, increase air flow, and also decrease drying time.

Other things to keep in mind once you get those plants in place is to mulch under your plants. You don't need much of a mulch layer, maybe about an inch. Quite frankly, I would recommend going back to the area where you had tomatoes last year and mulching over that area, as well. What this little inch of mulch is doing is

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forming a physical barrier, so that if you are getting spore production in those little bits of old plant debris in the soil, it blocks the spores from getting out of the soil and to your plants. If you start to see some disease during the growing season, you can pluck off those leaves. That will remove a source of additional spores that might reinfect your plant and will also open up the canopy to promote more rapid drying.

The other really important thing to keep in mind as you're growing tomatoes is how you water. Definitely, do not use a sprinkler to irrigate your tomatoes, because that gets the leaves wet and again, that creates these leaf wetness periods that are very beneficial to these blight organisms and will promote the spores germinating and the fungus infecting. So, if you're going to water your tomatoes, definitely water at the base. And, what I typically suggest is something like a soaker hose that you can just string along the base of the plants and will apply that water very, very slowly into the root zone where it's needed and keep that moisture off the leaves. So, a soaker hose, a drip hose, those are good options for watering tomatoes.

If you get absolutely desperate, there are fungicide treatments that you could potentially use, but in my mind, if you need to apply fungicides to your tomatoes, quite frankly, in terms of cost and time and effort, you're probably better off going to a local farmers market and buying tomatoes there.

Slide 15

Another type of symptom that you can commonly see caused by fungi is something called a canker. Cankers are very similar in a way to leaf spots, in that they are very localized infected areas. But with cankers, they tend to occur on tougher plant parts, things like stems, branches, and trunks. In this particular example, we have a canker that's occurring on a honeylocust tree. You can see this very elongated area where it is sunken and tissue has disappeared due to the infection. This is what's called Nectria canker. *Nectria* is a type of fungus that very commonly causes cankers on a variety of woody ornamentals.

In this particular case, the fungus most likely entered in through a pruning wound. If you take a look at the center of that cankered area, you can see where there was a branch that was cut off. And you'll notice a couple things about this. It's very, very flush cut. That is, it's cut very, very close to the trunk, which made a very, very large area through which the fungus could enter, and what I also suspect happened in this particular case is that the pruning tools of the person who was pruning were probably contaminated. It's very easy to pick up canker fungi on cutting tools, and if you don't decontaminate between cuts, you can actually transfer these fungi from plant to plant as you prune.

The best way to get rid of fungi on pruning tools is to either use something like 10% bleach or, even a little better, 70% alcohol. Bleach can be a little bit corrosive to metal tools, but 70% alcohol works quite well. We can use something like rubbing alcohol or also some of the spray disinfectants. Lysol or other brands oftentimes contain about 70% alcohol, and you can just spray those onto your tools and allow them to air dry.

Also, notice in this particular picture that even though there is a canker there, the tree is trying to respond to that infection. Take a look at those rolls of tissue along

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the edge of the infected area. That's actually what's called callus tissue, and that's the plant's response to try to cover over the wound that's been caused by this infection. Unfortunately, with this particular tree, I know where this tree used to be (notice past tense). This was a honeylocust that was outside my building on the UW-Madison campus. Even though the tree is responding, the fungus is still there. It eventually became active again, the canker enlarged, and eventually the top part of this tree died because the trunk was girdled, and the tree was removed.

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Fungi can also cause a variety of different types of rots. And typically, when we're talking about rots, we modify the word rot by telling you what part of the plant is rotting. In this particular slide, what you're looking at is what's called a crown rot. That's because the infection by the fungus that's involved here has occurred in the part of the plant that's near the soil line. That is the crown of the plant. And, as you can see, there's this kind of mass destruction of this particular plant, which is a hosta.

This specific disease is something called Southern blight. It's one of the nastier of the fungal diseases. Quite frankly, it's about the most aggressive fungal disease that I really encounter on a regular basis. And this particular fungus, it's called *Sclerotium rolfsii* (I love the name of that fungus), is typically more of a tropical or subtropical pathogen. We used not to see it a lot here in Wisconsin. Our typical, very cold, what I consider classic, Wisconsin winters kept this particular pathogen under check. Unfortunately, as our climate has warmed a bit, and we've had milder winters, this particular fungus is able to survive here in the state much more so than it used to be able to.

This is actually a relatively easy disease to identify, if you can look for the right things. You can see a white arrow in this particular picture, and it's pointing to a whole bunch of little, tiny, spherical, tan structures that are clinging to one of the petioles on the leaves, and you can see a lot of these if you look in that crown tissue. These little round structures are what are called sclerotia. They are a resting structure of this particular fungus, and they help the fungus survive during adverse weather conditions. What they are is basically a whole bunch of fungal hyphae packed very tightly together with a little, colored rind, and they can range in color from kind of a tannish color to kind of a reddish color. And they're about the size of an Osmocote pellet or some types of very small seeds. And this particular organism produces lots and lots of them.

The first time I ever encountered Southern blight was in the Allen Centennial Gardens at the University of Wisconsin-Madison, just very close to where I work on campus. They had a flowerbed in front of the garden that was just decimated by something, and they called me over. By the time I got over there to do a diagnosis, they'd lost about 40 square foot of plant material in this bed. That's how aggressive this particular pathogen is. And, when I started looking at all of these dead plants, I kind of moved away the tops of plants and look down towards the base, there were these sclerotia everywhere. They were covering the base of the stems. They were all over the mulch that they had around these plants. And, it was just a mass of sclerotia everywhere. The other thing that you can also see a little bit in this particular photo is a little bit of whitish material. Those are masses of fungal hyphae

Slide 16 (Continued)

that are produced by this particular fungus, and that's the other thing that you can look for to identify Southern blight. So a combination of a lot of dead plants dying very rapidly, the sclerotia, and a little bit of hyphal growth from the fungus.

This is a very difficult disease to manage. What I typically tell folks when they see this is that what they need to do is kind of delimit where they see the infected area. So, watch around the plants on the mulch, and look for sclerotia, find the edge where the sclerotia are forming, go out about a foot to two feet beyond that, and from that outer edge back towards the center, start to remove and dig up plants and bag them in garbage bags in place, and then remove those plants wholesale from the garden. I also tell them to take about an inch of the topsoil, and this is one of the few diseases where I actually tell folks, if you have this, once you've removed all this plant material, come back in and definitely use fungicide treatments, because you really need to try to keep this disease under check. And quite frankly, you will probably, even if you do all of this, continue to have problems with this disease for a while, because it's very easy to pick up those sclerotia on shoes, on tools, on, say, the wheel of your wheelbarrow, and then you can move the fungus from area to area in your garden. In general, it's always important, as you're moving around in your garden, to routinely decontaminate your tools, your shoes, anything that comes into contact with potentially contaminated either plant material or soil. And again, for metal objects, you can use 70% alcohol. For things like shoes, you could use something like 10% bleach.

Slide 17

In addition to crown rots, you can also see fruit rots. This is an example of a squash that's been infected by one of the fungi-like organisms, one of the water molds, called *Phytophthora,* so this is Phytophthora fruit rot. With the fungal rots, oftentimes the tissue that's rotted is quite dry. It isn't really soft and mushy and slimy. You can see a little bit of sliminess at the center of the infection, but that's likely due to other sorts of organisms, like bacteria, entering into the rotted tissue after the *Phytophthora* had done its job. If you look at the lower left edge of this particular fruit, you can actually see kind of the edge of where the infected area is. This fruit has a little bit of a whitish sheen to it. The organism is probably sporulating on the surface, if you looked at it microscopically. But again, there's a lot of kind of dry decay of the fruit tissue. And if you had found this particular fruit in the field, that flat area with the kind of sliminess would probably have been on the soil, because oftentimes, it's where the fruits come into contact with the soil that the *Phytophthora* enters the fruits. *Phytophthora* tends to be a soilborne pathogen.

Slide 18

Other types of rots that are caused by fungi include root rots. This is where you get a decay in the root system. This inhibits water uptake and thus, probably the first symptom that you're going to see associated with a root rot is some sort of wilting, like the wilting that you see in this *Cineraria* which has a root rot caused by the water mold, *Pythium*.

If you saw this particular plant at my house, the problem would not be a root rot. It would be drought stress. I tend to use the “wilt technique” for watering my houseplants. So, if I see a wilted plant, that means it must need water. Now most

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people don't work that way. They tend to water their plants routinely. So, you definitely need to evaluate when you see a wilted plant, what's going on in the soil. You need to feel down in that soil and check to see whether it's moist. At my house, it's going to be bone dry, and you need to add some water. If the soil is really moist, then you're probably dealing with some sort of root rot problem.

Now, what's our typical response when we see a plant like this, though? What do we do? We typically water the plant. And, the plant continues to wilt, and what do we do? We water the plant again. And unfortunately, what you're doing, if you look in the soil, the little root rot organisms are doing kind of a happy dance down there, because what you've done (remember that disease triangle and the corner that said favorable environment?), you've basically made that favorable environment really, really huge, because root rot organisms tend to like wet soils. So, one of the things you need to do, if you think you have a root rot problem, is cut back on water. You need to give the plant enough water to survive, but you want to keep things relatively dry, because that tends to at least partially inactivate these organisms that are causing the root rot.

In a situation like this, with this particular plant, there's enough damage that, quite frankly, I wouldn't even attempt to save this plant. I would just pitch it, pot at all. We usually don't recommend recycling plastic pots, if there's been a root rot problem. People have tried bleaching plastic pots, and it just doesn't seem to work particularly well. My recommended decontamination for plastic when you've had a root problem is, quite frankly, incineration. Now clay and ceramic pots, you can decontaminate those. Typically our recommendation is to soak pots for roughly 20 to 30 minutes in a 10 to 20% bleach solution and then rinse the pots before you use them.

Slide 19

I've mentioned lack of watering and root rots as two reasons why you might see wilting in plants. There is another group of diseases where wilting is a primary symptom. They're called vascular wilt diseases, and what happens with these particular diseases is that the pathogens, in this particular case we're dealing with fungal pathogens, they enter into the plant, they get established in the water-conducting tissue, the xylem, and they lead to blockages in that tissue. So, the plants can take up water, but they can't transport it from the roots to the upper branches, and that leads to wilting and dieback in the plants.

Some of our very, very serious tree diseases are vascular wilt diseases. You've probably heard of Dutch elm disease, probably also heard of oak wilt. These are both vascular wilt diseases. In this particular slide, I'm showing you a third vascular wilt disease called Verticillium wilt. Now, Dutch elm disease is pretty specific to elms. Oak wilt is pretty specific to oaks. With Verticillium wilt though, that particular disease goes to a variety of different types of woody ornamentals. Also, it will go to herbaceous plants. And also, it's a big problem on certain vegetable crops as well. The pathogen is called *Verticillium*. Again, it gets into the plant, gets into the water conducting tissue, and blocks it off.

What we typically see at least initially on the outside of the plant is wilting and dieback. And then, one of the things I look for when I'm trying to diagnose this is I will cut off a branch that is wilting, and I start peeling off the bark. And that's what

Slide 19 (Continued)

I'm showing in this particular slide. When you have these vascular wilt diseases, oftentimes if you peel off the bark and look right underneath the bark (that's where the xylem is located), you'll typically see a lot of browning or some sort of discoloration. It can be a solid mass. It can be streaks. But you will see some sort discoloration. This is called vascular discoloration, vascular browning. It could be vascular greening. Lots of times in maples with *Verticillium*, the discoloration is more of a green rather than a brown, but you'll see this discolored tissue right underneath the bark. And, you can see it here in this particular slide where the black arrow is pointing. And, that's giving you a sense of where the pathogen is colonizing the water-conducting tissue, and I use this as a guide when I'm trying to culture from these wilted branches. So, I take little bits of that discolored tissue, I put it on a growth medium, and I try to get the fungus to grow out of that tissue. And, that's how I eventually identify whether I'm dealing with Dutch elm disease or oak wilt or Verticillium wilt.

These are really, really nasty diseases. Typically when we have oak wilt, Dutch elm disease, Verticillium wilt, basically the trees are going to die. We're really talking about tree removal and then, particularly with Verticillium wilt, because the pathogen has such a wide host range, we have to be very, very careful what we replant in that area.

Slide 20

The second major group of plant pathogens is the group that contains the bacteria. You're probably familiar with these, because certainly there are human diseases that are caused by bacteria. Amongst the plant pathogens, there are about 200 species of bacteria that can potentially cause diseases. These are relatively small organisms, certainly compared to the fungi that we just discussed. You really can't see these organisms with the naked eye. You'd really need a light microscope in order to see individual bacterial cells. The upside to bacteria, compared to fungi, is that they're relatively simple. They aren't complex, don't produce those fruiting bodies like fungi do. They're actually just unicellular organisms, so single celled, and they have relatively simple reproduction. They reproduce by something called binary fission. Inside a bacterial cell, what you basically have is a bacterial wall, there's a membrane inside and then there's this piece of bacterial DNA. It's a bacterial chromosome. And to reproduce, these organisms just basically make a copy of that bacterial chromosome. One copy goes to one end of the cell, the other copy goes to the other end of the cell. You can kind of think of it just kind of pinching off in the center. And you end up with cells each with a copy of that bacterial chromosome, and these bacteria are genetically identical.

Slide 21

As I mentioned, bacteria are very small. In this particular slide, I'm showing you bacterial cells that have been photographed under a light microscope. The magnification here is probably around 1000 times normal size. I've got a black arrow pointing towards a single bacterial cell. The bacterial cell is a little bit elongated. This is what's called a rod-shaped bacterial cell. Most bacteria are either rod-shaped or spherical. Most of the plant pathogens tend to be rod-shaped organisms. And, notice the really pretty purple color. This is not natural. What we did here is stained the bacteria to make them more visible. They tend to be colorless, and so,

Slide 21 (Continued)

they're typically very difficult to see. And the staining actually makes them stand out a little bit.

This particular organism causes a disease called bacterial ring rot. This is a very, very serious disease on potatoes. The organism is a vascular wilt pathogen, just like the fungi that cause Dutch elm disease and oak wilt. This organism gets into the water-conducting tissue in potatoes, and eventually, in the tubers, it will cause decay around that vascular tissue. If you slice open a potato that has this particular disease, you'll see a discoloration in the vascular ring around the edge of the tuber, and if you squeeze that tuber you can actually get this snot-like material that comes oozing out. This is a very destructive pathogen. If it gets into a potato field, it can basically decimate an entire crop. There's no tolerance for this pathogen in seed potato production, so if a seed potato producer finds this, he or she is banned from growing seed potatoes for a long, long period of time, on the order of a decade.

Slide 22

In terms of symptoms caused by bacteria, bacteria oftentimes causal leaf spots. The leaf spots caused by bacteria oftentimes are a little bit different than those caused by fungi. I mentioned with fungi that leaf spots tend to be roughly circular. With the bacterial leaf spots, they're oftentimes angular. That is, if you look at those spots, oftentimes the edges look very, very straight, and that's because oftentimes, bacteria get into leaves, they are able to colonize, but when they get to veins, they're not able to cross the veins, and the veins delimit the edge of the infected area. Also with bacterial leaf spots, oftentimes you see a slight yellow halo around the dead tissue. So, anytime I see an angular leaf spot with a yellow halo, my first thought is that I'm probably dealing with a bacterial pathogen.

The disease shown in this particular slide is one called bacterial brown spot. It's a disease that's near and dear to my heart, because this is the disease that I studied for my PhD work. The bacterium that causes this disease is called *Pseudomonas syringae* pathovar *syringae,* and it's what's called an ice-nucleating organism. I mentioned that bacteria, if you look at their structure, they have that bacterial chromosome, there's a membrane around that, and then an outer wall. In this particular bacterium, there's also an outer membrane, and embedded in that outer membrane is a protein that mimics an ice crystal. So, this particular organism is involved in frost damage on plants. You can usually cool plants like a snapbean plant down to around 28 degrees Fahrenheit before they will spontaneously freeze. If you add a lot of this particular bacterium to the plant, it will actually freeze at a higher temperature, and that's because of this protein in the outer membrane that mimics an ice crystal.

This particular phenomenon was actually discovered at the University of Wisconsin. There was a graduate student in the Plant Pathology Department. He was studying a corn disease, and he was using leaves that were infected with a fungal pathogen. He was grinding those up and then spraying it across his plots as inoculum. And, he did this one afternoon. There was a frost that evening, and all of the plots that he had inoculated frosted overnight, and the ones that he had not inoculated didn't freeze. And, he eventually found that these leaves that he was grinding up were covered with this particular bacterium. In fact, this *Pseudomonas* organism is what's called an epiphyte. It actually naturally lives on leaf surfaces, oftentimes without

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causing disease. In this particular case, there was enough of the bacterium in this mix to induce frost damage on the plants. This particular organism has a useful application. Folks have used *Pseudomonas,* or at least the protein derived from it, to help make artificial snow.

Slide 23

You can get a better sense of the angularity of bacterial infections in this particular slide. This is a disease called bacterial blight of begonia. Notice all of the brown tissue, which is where the bacterium has infected and caused the tissue to die. Also, notice where the black arrow is pointing, you can see where the bacterium got up to a major vein and just wasn't able to get across that vein. So, the vein serves as the edge of the infected area. You can also see the yellow halo around the infected tissue in this particular example.

Slide 24

In order to verify that I'm dealing with a bacterial disease, what I do is take out a little bit of tissue at the interface of the live and dead part of that leaf. I put it in a drop of water on a microscope slide. I slice across it, put a coverslip over the top, and then I look at that cut edge. As I'm looking at it under the microscope, what I look for is granular material that's oozing out from that cut leaf tissue, and you can see that in this slide. There's a dark mass at the bottom, which is the mass of leaf tissue, and then you could see all of this granular material in the upper right. All of those little grains are bacterial cells that are oozing out from the cut leaf surface. This is called bacterial streaming. I don't know exactly which bacterium is causing the problem, but at least I have some initial information that I am dealing with a bacterial infection.

Slide 25

In addition to leaf spots, bacterial pathogens can also cause leaf blights. This is bacterial blight of geranium, a very common disease. If you ever grow geraniums and save your plants year after year, this is definitely a disease that you will probably eventually encounter. The disease typically starts as individual spots. You can see an example of that in the very center leaf in this particular photo. There are a couple of kind of angular, defined leaf spots with yellow halos. Eventually, the infected area will become larger and kind of wedge-shaped. You can see that in the right leaf in this particular photo. You get this movement of the bacteria from the edge of the leaf back towards the petiole, so it will look kind of like a pie-shaped infected dead area on the leaf. Again you can see a yellow halo. And then eventually, when the bacterium gets to the main stem, it will cause the collapse of the petiole and the entire leaf will collapse. And that's why we call it a blight.

Again, this is a disease that you're going to see if you grow geraniums and tend to keep your plants and overwinter them. Oftentimes, geraniums harbor this particular bacterium without showing symptoms, and it's only over time that the bacterial population increases to the point where infection and disease occur.

The best way to manage this particular disease is simply to discard infected plants. There's really no way to clean them up or cure the plants once they have this

Slide 25 (Continued)

bacterial disease, and you don't want to keep them around, because potentially, the bacterium could get transferred from the infected plants to healthy plants and lead to additional disease. Once you've discarded the plants, then what you need to do is decontaminate, and you can use a 10% bleach solution or 70% alcohol to do this. So, decontaminate pots, decontaminate any surfaces that may have come into contact with the infected plants, or any other objects or surfaces that may be contaminated.

Slide 26

Certain bacterial pathogens can also cause soft rots, and these are relatively slimy, kind of juicy-looking decays on plant parts. The most notorious of these is bacterial soft rot, which oftentimes affects different types of vegetable crops including potatoes and broccoli, cauliflower, pretty much any type of plant part can be susceptible. If you've ever had a potato tuber or a bag of potatoes that has kind of liquefied in your refrigerator, then you've encountered bacterial soft rot. What's very interesting about this particular disease is that the bacterium infects and digests the pectin in the plant. Pectin is the glue that holds the plant cells together. So, when you get an infection with soft rot bacteria, they tend to cause the tissue to collapse and kind of liquefy. If you take a look at that liquefied tissue, you will see that there are still live plant cells there. It's just that that glue that holds them together has been eaten away.

This disease can be a really serious issue in potato storage. When they store potatoes commercially, they are in these huge buildings, mountains of potatoes. And, if you end up getting bacterial soft rot, it can liquefy one of these piles in a matter of two to three days. You can actually climb up onto these mountains of potatoes, and you have to be very, very careful, because if there happens to be a pocket of bacterial soft rot, you can take a step as you're walking across the potatoes and end up sinking in. I do know of some people that have been inspecting these stored potatoes, have been walking along, taken a step, and ended up to their waist in rotten, smelly potatoes.

Now, I have to mention that the odor that you associate with rotting potatoes really isn't due to the bacterial soft rot organism. That particular organism really doesn't smell that bad, but what happens is once the bacterial soft rot organism decays the tubers, that decayed tissue becomes a nice growth medium for variety of other types of bacteria, particularly organisms like *Clostridium*, which produce a lot of butyric acid. And, that's really what gives the rotten potatoes their really foul smell. And, I have to say, I'm not a big fan of getting soft rotted potatoes into my lab, because that odor tends to permeate everything. And the worst part is that after a while, when you work with these tubers, you don't even notice that there's a bad smell.

Another interesting story about bacterial soft rot comes from one of my colleagues, who had a friend who worked as an Extension agent in California and was called out to diagnose a problem in a broccoli field. And as it turned out, it was bacterial soft rot. They ended up having to diagnose this particular problem from the road using binoculars, because the stench of the rotten broccoli was so absolutely awful.

Slide 27

In terms of a bacterial disease that you're most likely able to identify by eye, your best bet is probably with this particular disease. It's called bacterial wilt, and it's a problem on a variety of different types of cucurbits. So, that includes the pumpkins, squash, cucumber, those sorts of vegetable crops. This particular bacterium is introduced into plants by cucumber beetles. They actually drop the bacterium off as they are feeding. The bacterium gets into the water-conducting tissue and blocks it off. So, this is actually a vascular wilt disease. And, the bacterium produces a very slimy capsule around its cells, and it's actually, in part, that slimy capsule that blocks up the water conducting tissue in the plant. Initially when you see symptoms of this disease, what you're going to see are individual vines that begin to wilt. You can see a couple of vines in this particular photo that have wilted severely, but if you take a look at the rest of the plant, which is in the upper left corner, you'll notice that the rest of the plant, at least at this point, is still healthy. This bacterium will spread throughout the plant, however, and eventually the entire plant will die. The best way to manage this disease is to keep cucumber beetles in check.

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To confirm bacterial wilt of cucurbits, what you need to do is cut off one of those wilted vines right at the base and then cut off a section that's about six to eight inches long so you end up with two pieces of vine. Hold those apart for about 10 seconds, bring them back together and rub them very gently, slowly for about 10 seconds, and then very slowly pull those two pieces of vine apart. And, if you have bacterial wilt, then what you will oftentimes see are these strands of spider web-like material that will form in between those two cut pieces. I'm showing that here in this particular slide. There's a black arrow pointing towards one of those slimy strands. But, what you're actually doing is pulling out strands of bacteria from the vascular tissue that are all held together by that slimy capsule that I mentioned. Now, this won't work on all types of cucurbits, but if you're dealing with bacterial wilt on cucumber, on that particular host, oftentimes you will see these bacterial strands associated with the disease.

Slide 29

Finally, the last group of symptoms that I tend to associate with bacterial pathogens are the galls. Galls are basically undifferentiated masses of plant tissue that are caused by, in this particular case, infection by a bacterial pathogen. Certainly, there are fungal galls and galls caused by other types of disease-causing organisms. There also galls that are caused by non-diseases, so abiotic factors, but kind of the classic galls, in my mind, are caused by bacteria.

The one that's shown here is something called crown gall. This is caused by a bacterium called *Agrobacterium tumefaciens*. This particular organism is oftentimes found in soil. It will infect roots and also oftentimes infects right at the base of the plant at the soil line, thus its name, crown gall. And, I've got a black arrow pointed to this large undifferentiated mass of plant tissue that's been induced by infection by this particular bacterium. What the organism does is it oftentimes gets in through wounds, and inside the bacterial cell, I've mentioned that there's a bacterial chromosome. This particular bacterium, in addition to that chromosome, also has a second piece of DNA. It's a circular piece of DNA called a plasmid, and there's a

Slide 29 (Continued)

section of that DNA that actually gets cut out of that plasmid and injected into plant cells, where it incorporates itself into the plant chromosomes. That particular little piece of bacterial DNA codes for a variety of proteins. Many of them are enzymes, and these enzymes help produce a group of compounds called the opines, and these opines are one of the favorite food sources for this particular bacterium. As part of all of this protein production from that little piece of DNA, you get this undifferentiated growth, lots of cells. Cells enlarge, and you get this kind of mass of plant growth that's produced, again caused by this infection by the bacterium.

Interestingly, scientists realized that what they could do would be to take that plasma, cut out most of that group of genes that are involved in the formation of the galls, and then they can insert other types of plant genes or other genes in general into that little section of DNA, incorporate that DNA back into the plasmid, and then what they could do is stick the plasma back into the *Agrobacterium* cell, have *Agrobacterium* do its normal infection process. And using this method, they could actually incorporate foreign genes into plants. Use of this bacterium was one of the first methods for genetically engineering plants.

Slide 30

The next group of plant pathogens that I would like to discuss is the group that contains the plant viruses. I really like this particular group of organisms, because the symptoms that they cause oftentimes are very, very beautiful. Oftentimes with fungi and bacteria, I'm dealing with rots and decays, leaf spots. Really, symptoms that aren't particularly pretty, but many of the plant viruses will induce changes in color on leaves or flowers, which can be quite attractive.

What's also interesting about viruses is how small, well, they are. Quite frankly, you cannot see these organisms with a light microscope. You're going to need an electron microscope. And, just to put things in perspective, there are actually viral pathogens of bacteria. So, these organisms are smaller than bacterial cells.

In terms of plant viruses, they're quite simple in terms of their structure. They are basically a piece of genetic material, usually a material called RNA, rather than the DNA that we have in our cells, and this RNA is typically encapsulated with a coat protein.

They really have very simple reproduction as well. If you put a plant virus out on an inert surface like a table, they cannot reproduce on their own. Once you get the virus inside a plant cell, however, the virus takes over the internal functioning of that cell and forces the cell to make more viral particles.

Viruses can be moved around in several different ways. Many types of plant viruses are associated with what are called insect vectors. These are insects that can move the virus from plant to plant. Certainly, this is not the only way that viruses can move around. There are other types of plant viruses that can be moved around by touch. As an example, there's a virus called tobacco mosaic virus. It can sometimes be found in tobacco products, and that one you can pick up on your hands, and if you handle plants, you can move it around and actually inoculate plants as you handle them. So, you have to be very, very careful if you're a smoker not to pick up this virus.

Slide 31

As I mentioned, plant viruses are quite small. This particular slide is an electron micrograph, which is a photo that's taken with an electron microscope. All of the white structures that you see in this slide are viral particles, probably of a virus called cucumber mosaic virus. The magnification here is well over 1,000 times normal size, probably in the range of 5,000 to 10,000 times normal size, and you can see a lot of viral particles in this slide.

As I mentioned, the shape of these viral particles is roughly spherical. Technically, it's an icosahedron. And, this is one of several different shapes that plant viruses can have. The other two primary shapes that we tend to see are rod shaped viruses. One's called a rigid rod. You can think of that as being stiff like a pencil is a rod, and then they're what are called flexuous rods, which are rod shaped viruses that are kind of limp like cooked spaghetti.

Slide 32

Just to keep us honest, sometimes we like our plants infected with plant viruses. If you've ever heard of Rembrandt tulips, or parrot tulips, the original versions of these particular plants were infected with plant viruses. It's actually the virus that gave the flowers of these plants their very striped colors and also very fringed edges.

Nowadays, these types of tulips with those sorts of characteristics are not virus infected. There's too much of a potential for the virus to spread to other plants. So, tulip breeders have bred varieties to have these characteristics without the virus.

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It's virtually impossible to identify specific plant viral diseases based on symptoms. Really, identification of these types of diseases requires some sort of lab test. The techniques that are available for identifying plant viruses use technology that's very similar to that used in home pregnancy tests. On the other hand, there are a lot of very distinctive symptoms that are caused by viruses, and I think you should be able to get a good sense if you're looking at a plant and see particular symptoms, whether or not those symptoms are caused by some sort of viral pathogen.

Probably the most classic of the viral symptoms is the one that's shown here: this kind of blotchy light and dark discoloration to the plant tissue. This is something called a mosaic. And, there are lots and lots of different types of plant viruses that cause mosaic diseases. In fact, if you look at plant virus names, oftentimes, you'll see a lot of them that will have the word mosaic in their name.

In this particular case, we're talking about a disease called poinsettia mosaic, and it's occurring, as the name implies, on poinsettia.

Slide 34

Plant viruses can also cause line patterns. In this case we have an example of *Rose mosaic virus,* and next to the white arrow, you can see this yellow trail in the leaf that's actually induced by the virus that's infecting the plant. This symptom can sometimes look similar to certain types of insect damage. There's this type of insect

Slide 34 (Continued)

called a leafminer that will tunnel trails in leaves. In this particular situation, however, the tissue is intact. It is just discolored. With a leafminer, you would see a hollow trail inside the leaf tissue.

In this photo you can also see ring patterns if you look down towards the lower left. Again, very, very pretty sorts of patterns in the leaves. Quite frankly, if this were not due to some sort of infection, this could be quite attractive and might make a good varietal selection.

Slide 35

Another type of symptom associated with plant viruses is something called color break. This is where there is some sort of discoloration in the flowers of plants. In this particular example, we have a gladiolus that's infected with *Cucumber mosaic virus*, and normally this plant would have a solid red flower. But, because of the presence of the virus, you get these white streaks in the flower.

And again, I mentioned I like viruses because they have very beautiful symptoms, oftentimes. And, I find this symptom, this color break, very, very attractive. I wouldn't mind having a plant of this type in my garden if this sort of symptom weren't caused by a virus. The downside, of course, to having the virus is that the presence of the virus tends to use a lot of nutrients, a lot of energy that the plant would normally be using to grow more plant and to store for making more flowers. And so oftentimes, virus infected plants, if they're flowering plants, after a while will stop flowering.

Slide 36

Other types of symptoms associated with plant viruses include growth distortions. In this slide, if you concentrate on the leaf on the left, you can see that this zucchini leaf is very elongated. This is something called strapping. Also notice how the edge of the leaf is curled and cupped, and you can also see a little bit of mosaic in this leaf. If I were only to see this leaf on the plant, I might first not think of a viral pathogen, but I might think that the problem here might be some sort of herbicide exposure. Because, there are certain types of herbicides, called growth-regulator herbicides, that will induce a lot of growth distortions, as well. But, looking at this leaf and then the fruit that's in the center of the slide, that's kind of a dead giveaway to me that we're dealing with a viral problem. If you take a look at that fruit, it looks stunted. You can see it's got that blotchy, green and yellow discoloration, so there's kind of a mosaic on the fruit. You'll also notice that there are some kind of bumps or warts on the fruits as well. And, that particular combination of fruit symptoms and leaf symptoms really clues me in to the fact that we're probably dealing with a virus of some kind or another.

Slide 37

A lot of plant viruses will also cause a type of symptom called a ring spot, which is shown here. This is a series of concentric rings that will form around the area where the virus has infected. There are other types of diseases that will lead to ring spot patterns, but usually, there's decay associated with those diseases. With a viral

Slide 37 (Continued)

infection, you get the ring spots, but the tissue is intact. So again, if you see ring spots with intact tissue, think about a viral pathogen.

Slide 38

Finally, some types of plant viruses will induce necrotic symptoms, so you actually get some tissue death associated with the infection by the virus. Probably the most common virus that I see that causes this sort of symptom is something called *Impatiens necrotic spot virus*. This particular virus will cause problems on a variety of different types of greenhouse-grown ornamentals, including impatiens and begonias. In this particular case, an infected begonia plant, you can see a lot of little flecks of dead tissue in the leaves on this plant. There's a white arrow pointing to a larger necrotic area where you can get a little bit of a sense of some ring spots in the tissue. Whenever I see begonias with this sort of symptom, I start thinking about *Impatiens necrotic spot virus.*

The next thing that I would probably look for in this plant would be the presence of thrips, because this virus is transmitted by thrips. And, if you're not familiar with what thrips are, let me give you a sense by describing how we scout for this particular insect in a greenhouse. You take a plant, put it on a white sheet of paper, tap it gently, remove the plant from the white sheet of paper, look at any of the dust that's on that white sheet, and if the dust runs away, those are the thrips. These are extremely small insects. They tend to get into floral parts, oftentimes, although they can feed on leaf tissue. And, they can cause a lot of damage on their own, but from our perspective, they're important because they move this virus around. If I really wanted to confirm that this plant is infected with *Impatiens necrotic spot virus*, then I would use a lab test. There are actually what are called immunostrips. They're akin to home pregnancy tests, and these tests have been designed to detect specific types of plant viruses.

Slide 39

Next up are the phytoplasmas, and I have to say I think this is probably my favorite group of plant pathogens. When you get to the phytoplasmas, you're entering the Twilight Zone, because the symptoms that these organisms induce are incredibly bizarre. And, we'll take a look at some photos in just a second.

I often refer to phytoplasmas as quote-unquote, funky bacteria. They are bacteria-like organisms. They're technically in a group of organisms called the mollicutes. They're about the same size though as true bacteria, maybe a little bit smaller, and they are different from true bacteria in that they do not have that nice rigid wall. I mentioned that bacteria have a rod shape or a spherical shape. The phytoplasmas don't have that, and so, they tend to have all kinds of different shapes, and their shape can change depending upon the particular environment that they're in. So, they may start out spherical. They may eventually become rod shaped. They may be some shape in between.

These organisms are what is called phloem limited. That means that they only live in the phloem, which is the food-conducting tissue inside the plant. You can see these organisms with a light microscope, but you need to use special stains in order to do it. Quite frankly, if you really want to see what a phytoplasma cell looks like,

Slide 39 (Continued)

you need to use an electron microscope, just the way that you would for a viral pathogen.

They reproduce in a manner that's very similar to that of true bacteria, binary fission again, and so, they have a phytoplasma chromosome, it replicates to make two copies, those migrate to opposite ends of the cell, the cell pinches off in the center, and you end up with two cells that are genetically identical.

These organisms, like many viruses, are transmitted by insects, in particular leafhoppers. So, we typically see an increase in these sorts of diseases in the environment when we have an influx of leafhoppers come into an area.

Slide 40

As I mentioned, you can see phytoplasma cells inside plant tissue using a light microscope, but you need to use certain types of stains or dyes in order to do this. And, these particular dyes glom onto the DNA inside the phytoplasma cell, and then, when you shine ultraviolet light on these dyes, they glow.

And in this particular case, I have a black arrow pointing toward this glowing mass inside a phloem cell. That's what that long, narrow cell is in the center of the slide. You can actually see a lot of these little glowing areas, and those are phytoplasma cells that have been lit up by this dye under UV light.

Now, you may say, “Well, plant cells have DNA. How do we know we're not looking at the plant DNA?” Well, the phloem inside a plant should be devoid of DNA. That particular tissue is basically just a tubing. It should not have plant DNA inside, so if we start seeing DNA, that's a good indication that we're dealing, most likely, with a phytoplasma issue.

Slide 41

This is my favorite slide of my entire slide collection. On the left is a purple coneflower that's healthy. On the right is a purple coneflower that's been infected with a phytoplasma, specifically the aster yellows phytoplasma.

You can see several different, very bizarre symptoms on this plant. The strappy structures at the bottom of the flower are equivalent to the purple ray flowers or quote-unquote petals on the purple coneflower. This sort of greening of flower parts that normally would have a color is typical of a phytoplasma infection. Also, if you take a look at the cone portion of the infected flower, you'll notice that it's quite leafy, and leafy flower parts is another typical symptom of a phytoplasma infection. And then you see a bouquet of secondary flowers coming up out of that cone, and that cluster, what's called a broom, is another typical symptom of a phytoplasma infection.

So, flower parts that are green rather than their normal color, leafy looking flowers, and brooming, those are all symptoms of a phytoplasma infection.

Slide 42

Another example of brooming. In this case, a tree, an ash tree, that's infected with the ash yellows phytoplasma. You can see where there's not a lot of leaf tissue on this tree. The leaves are few and far between, but you've got all of these little clusters of small branches that are being formed in tufts. And again, this is a symptom called brooming. I tend to refer to this as the poodle tree, because it kind of looks like the tree has had a poodle cut.

Slide 43

Phytoplasmas can also induce a flattening and widening of branches. This symptom is called fasciation. An example of this symptom is shown in this slide on a woody ornamental. Also notice how there are a lot of lateral buds, and that is induced by the presence of the phytoplasma as well. Interestingly, you can go to floral shops and find branches like this that they sell for flower arrangements. Some of these may be due to genetic abnormalities in the plant, but I suspect in some situations that that flattening and widening of the branches is actually due to a phytoplasma infection.

Slide 44

Can you guess what type of plant this is? Look very carefully in the upper left. There are the remains of some flowers there, and if you look very closely, you may get a sense that this plant is a cosmos plant. But unfortunately, a cosmos plant that is infected with the aster yellows phytoplasma.

Typical symptoms that we're seeing here: You'll notice a little bit of yellowing. The diseases caused by phytoplasmas are oftentimes referred to as yellows diseases, because a primary symptom is yellowing of foliage. You'll also notice a lot of distorted growth, so twisting and cupping and curling of leaves and stems. Again, this is a typical symptom that we see associated with phytoplasmas. And then the last of the symptoms are those leafy, green flowers that I mentioned previously.

If I were only to see the foliage on this plant, with the growth distortions and yellowing, I might not immediately think that a phytoplasma is the problem. I might look into possible herbicide issues. Because again, there are certain types of herbicides, the so-called growth-regulator herbicides, that will cause a lot of particularly growth distortions, but sometimes also yellowing in foliage. But, the dead giveaway here that we're dealing with a phytoplasma disease is the presence of those really funky looking flowers that are leafy and green.

Slide 45

The last group of pathogens that I would like to discuss is the group that contains the nematodes. Nematodes are small, worm-like organisms. And, there are all kinds of different types of nematodes. There are nematodes that feed on bacteria. There are nematodes that feed on fungi. There are even nematodes that feed on other nematodes. The group of nematodes that we're interested in are those that can cause plant disease.

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Nematodes, in general, are very complex, probably as complex in their own way as the fungi that we discussed. Nematodes are animal-like. They have a digestive system. They have a sensory system. They also have a reproductive system.

Nematodes are relatively small. Some types of nematodes are large enough that you might be able to see them with the naked eye. But most of the time, if you want to see a nematode, you need to use a light microscope.

As I mentioned, nematodes have a reproductive system, and they reproduce by laying eggs.

Slide 46

To give you a sense of what a nematode looks like, this is a photo of a soybean cyst nematode. You can see that it's very worm-like. The head of the nematode is in the lower right. The tail of the nematode is in the upper left. There's a black arrow in this photo that points to this little dagger-like structure that's in the mouth of the nematode, and that's something called the stylet. This is kind of a modified tooth, and the nematode uses this to punch a hole in plant tissue, and then through that wound, it can feed. If you take a look down the length of the nematode, about a third of the way down, you'll start to see this kind of granular material. That's all ovary. This is a female nematode. And nematodes, in general, have a great capacity to lay lots and lots of eggs.

Slide 47

Plant pathogenic nematodes typically infect plant roots, and the most common nematode disease you're going to encounter is root knot nematode. There's a white arrow in the photo pointing to this swollen area in the root. That's called a gall or a knot, and this growth is induced by nematodes colonizing the root tissue. In particular, it's the females that are the problem. They tunnel into the root. They set up a feeding site, and as they feed, they secrete saliva into the wound, and this saliva stimulates the surrounding plant cells to grow very large. They grow very quickly. And, they divide like crazy, and that's what induces the gall or knot in the root system.

As you can imagine, this overgrowth in the roots can really disrupt water and nutrient movement in the root system, and that induces stunting and what appear to be nutrient deficiency symptoms on the above ground parts of the plant.

The best way to deal with this sort of nematode, if you find it, particularly if you're dealing with this disease on something like tomato (and this is an example of a tomato root system in this slide) is you try to buy a variety of tomato that has resistance to this nematode. What you want to look for when you're looking at tomato varieties is look for that alphabet soup after the variety name. Oftentimes, you'll see a V and an F and maybe two Fs. If you ever see an N, that stands for nematode, and typically those varieties have been bred for resistance to this particular pathogen.

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Most plant pathogenic nematodes colonize plant roots, but there is a genus called *Aphelenchoides* where those nematodes infect plant leaves. This nematode is commonly called the foliar nematode. This nematode is a problem on a variety of different types of herbaceous ornamentals. In this particular slide, an example of this nematode on mum.

You can see a lot of yellowing in the leaves associated with the colonization by the nematode. Also, if you look very carefully, you will see areas where there appear to be somewhat angular leaf spots. With foliar nematode, very similar to what I described with bacteria, the nematode is able to colonize the leaf tissue. It will colonize between the veins, but when it gets to veins, it's unable to cross the veins, so the veins form the edge of the infected area. So, you get these very straight-edged looking spots. If you ever see angular leaf spots on a plant, to try to get a sense whether you're dealing with a nematode problem versus a bacterial problem, look for a yellow halo. Oftentimes, with foliar nematode, you'll get those angular leaf spots, but no halo, while with a bacterial infection you'll get the angular leaf spots with a halo.

Slide 49

We've finally finished talking about the different types of microorganisms that can cause plant diseases. Now, what I'd like to talk about are abiotic factors. These are non-biological sorts of things that can adversely affect plant growth and development. I usually group abiotic factors into four major groups. These include nutritional abnormalities, pesticide exposures, environmental pollutants, and adverse weather conditions.

Slide 50

In terms of nutritional abnormalities, typically what we see are what we call nutritional deficiencies. This is where a plant has less of a particular nutrient than it really needs. And, this is an example of a nutritional deficiency on poinsettia. Notice that there's a lot of yellowing on this leaf, but it's very uniform around the edge of the leaf. This sort of uniform characteristic to symptoms is oftentimes a clue that you're not dealing with a true disease, but some sort of abiotic issue with the plant. In this particular case, it is a nutritional deficiency. And, oftentimes I ask students, “What sort of nutritional deficiency do you think this is?”

One of the first things that comes to mind to most students is a nitrogen deficiency, because that will indeed cause a yellowing of plant tissue. Typically though, with nitrogen deficiencies, it's a very uniform yellowing across the entire leaf, and it's typically on lower leaves.

The other type of nutritional deficiency that students oftentimes guess for this particular slide is an iron deficiency. Again, a lack of iron in the plant will cause yellowing of the leaves, but usually where you see that is between the veins. So, all of that interveinal tissue will be yellow, but the veins themselves will remain dark green. And, where we oftentimes see this sort of nutritional deficiency is in oaks in Wisconsin. We have relatively high soil pH, and that tends to lock iron in the soil, so

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plants like oak can't take it up. And, then what you end up with are these very distinctive interveinal yellowing symptoms on the leaves.

In this particular case, the deficiency in the poinsettia is actually of a nutrient called molybdenum. This is what's called a micronutrient. It's one of those nutrients that you need just a little bit of, but not a lot. But, it tends to be a real issue for poinsettia growers. So, while you might not guess that's the problem with this particular plant, if you are a poinsettia producer, that might be one of the first nutrients that you would try to test for, if you saw symptoms of this type.

Slide 51

On the other end of the spectrum, you can also have nutrient toxicities. In this case, a grape leaf ivy that has this very speckled sort of look to the leaves. It almost looks like a mosaic symptom that you would expect from a viral pathogen. But, in this case it wasn't a virus that was the issue. As it turned out, this particular pattern of symptoms was due to copper toxicity. This plant was grown initially in a copper pot. There was enough dissolution of the copper from the pot into the soil that it led to some problems.

So again, with nutritional abnormalities, you can have either end of the spectrum. Too much of a nutrient. In this particular case, too little of the nutrient.

You can also have situations where you have nutrient imbalances, where two nutrients are well within their normal ranges, but their relative amounts are out of whack. And, that can lead to issues as well. Kind of a common example of this is in corn production. If you get the nitrogen to potassium ratio out of whack (too high), you can end up making the plants more susceptible to lodging, or even stalk rot.

Slide 52

I also tend to see a lot of issues with pesticide exposures. I think a lot of this is because people are more and more interested in having perfect-perfect lawns without any broadleaf weeds. And so, folks are using a lot of herbicides in order to make sure these weeds are kept under control. And unfortunately, these herbicides can drift off of a lawn into a flower bed and cause some issues.

The most common of the herbicides that are used for lawn care are what are called the growth regulator herbicides. These include herbicides such as 2,4-D and dicamba, and these particular herbicides mimic plant growth hormones. So, the types of symptoms that they induce tend to be very odd growth patterns in the plants.

In this slide, I have a picture of a geranium that was exposed to 2,4-D, and you notice how cupped the leaves are. They're kind of fringy around the edge, and if you look at some of the petioles, they look kind of twisted. And, all of these sorts of symptoms are very typical of an exposure to one of the growth regulator herbicides.

Slide 53

If you're suspicious that you have herbicides drifting onto your property, consider planting some tomatoes along the lot line, because tomatoes are very, very sensitive to very, very low rates of growth-regulator herbicides. You can see an example of this in this slide: a tomato plant that was exposed to 2,4-D. And, you can see how the stems are curlicued. You can also see some growth distortions in the leaves. Another great indicator plant, if you think you have herbicides around, is grape. When grapes are exposed to growth-regulator herbicides, what tends to happen is the leaves get very fan shaped. They tend to have fringed edges, and the veins and the leaves tend to be a very distinct yellow color.

Slide 54

Not only can leaves be adversely affected by exposure to growth-regulator herbicides, so can flowers. This is an example of a rose that was exposed to 2,4-D. And you look at that flower, and lots of folks can't really tell that it's a rose. You can get a sense that this really is a rose, if you look in the upper middle. You can actually see a new flower bud that's beginning to form. That looks characteristic like a rose flower bud, but certainly the flower that's open looks very, very bizarre.

The good thing about these sorts of herbicide exposures is that it's typically only the plant parts that are being formed at the time of the exposure that will look really odd. Any plant part that is produced after the exposure typically will look normal. So, plants can outgrow this sort of damage.

Slide 55

Sometimes pesticide issues are not due to herbicides but are due to fungicides. And, this is somewhat ironic because you are supposed to be applying fungicides to help prevent disease issues.

In this particular case, we had a greenhouse grower who was growing geraniums. The grower was very concerned about having a root rot problem and decided to use a product called Banrot. Banrot is a great product for controlling root rots in greenhouse-grown plants. What happened in this situation though, was that the grower, instead of applying the product at the labeled rate, applied it at four times the label rate, and so, at that concentration, the product became toxic, and he ended up with all of this necrosis or death around the edge of the leaves and actually ended up with plants that were less healthy than if he had had a root rot problem.

Slide 56

Air pollutants can also cause plant damage.

This is an example of sulfur dioxide damage on a schefflera. Sulfur dioxide tends to be produced wherever coal is burned, so we tend to see more damage of this type in the vicinity of plants that burn coal as a fuel source. In this particular example, I look at these symptoms, and to me, they really scream that this is not a disease problem. In the lower leaf you see a lot of flecking in the tissue (those kind of gold flecks). You might misidentify that as a mosaic symptom associated with a viral infection.

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But really, that top leaf with a very marginal, very bronze sort of look to the dead tissue is really a sort of symptom that I don't associate with true diseases.

Again, when I see very uniform symptoms around the margins of leaves, that's usually a clue to me that I'm dealing with some sort of non-biological cause to the problem.

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Another example of an air pollutant causing a problem: in this particular case fluorine gas. Fluorine gas is typically produced in areas where there's a lot of manufacture of glass, and it is absorbed by the plants through the stomates. It tends to concentrate around the margins of the leaves, where it causes some problems. What I'm looking at when I look at this particular photo, that kind of again clues me in that we're not dealing with a true disease, but some sort of abiotic factor, is the fact that the symptoms are pretty much marginal. They're around the edges of the leaves. Again, disease-causing organisms typically don't form that uniform of a symptom pattern. The other thing that I see is this very odd-looking necrosis. It almost looks as though that dead tissue is like cellophane. And, this isn't the sort of characteristic that I associate with necrotic tissue that's been produced by some sort of plant pathogen.

Slide 58

Sometimes chemical damage to plants can have a biological origin. In this situation, an arborvitae with a relatively localized cluster of brown needles near the base of the shrub. . . Can you guess what might have caused this?

If you thought that this is due to a dog, you're very correct. This is urea or urine damage. We oftentimes see this on arborvitaes or other types of shrubs where there happens to be a dog in a household. If you see this sort of pattern, always question a client about whether or not they have a dog, or whether there might be neighborhood dogs that might visit that particular shrub.

Slide 59

Extreme weather conditions can also lead to plant injuries.

One of the most common weather-related injuries that we see in plants is cold injury, in this case shown on a spruce tree. There's a bit of irony here, because typically, we think of conifers or evergreens as being very, very cold tolerant. But in the case of spruces, they can be very sensitive to cold temperatures just as the new growth is beginning to emerge in the spring, and that's what happened in this situation. The tree began to push its new shoots or candles, there was a cold snap, very cold temperatures, and that led to death of virtually every growing point on this particular tree.

Slide 60

On the other end of the temperature spectrum, high temperatures can also cause problems: in this case, American ginseng that is experiencing heat injury. American ginseng is a native plant in Wisconsin. It grows naturally in wood understories. It's also grown commercially, and the roots are harvested for export to China. It's typically grown under shade to keep it cool and to keep the light levels down, but this particular photo was taken in 1988, which was an extremely hot and very dry year in Wisconsin. And, all of the kind of cellophane-y, brown, tannish tissue that you can see on the leaves of these plants is due to excessive heat. The plants are very, very sensitive.

Ironically, if I were to see this sort of injury much earlier in the growing season (this particular photo was taken in July). . . but if I would see this injury in say, April, then I would be more suspicious of something like cold injury, because frost injury on ginseng produces very, very similar symptoms.

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And then, there are a variety of problems related to water availability in plants.

One of the most common water stress issues that we tend to see in conifers in the spring is something called winter injury or winterkill. I probably see this most commonly on yews, which is what is shown here, and this is basically due to the plants dehydrating over the wintertime. In this case, I suspect that there was a layer of snow on the ground up to the bottom of where you see the brown needles on this shrub. There was probably a cap of snow on the top of the shrub, and those needles that are now brown were likely exposed to the air. I suspect we got a nice warm day, so that those needles started to transpire, that is naturally lose moisture through the needles, but the root system of the shrubs were not warm enough to be able to take up sufficient water to replenish the water that was being lost through the needles. And, that led to a dying of the needles in that exposed area.

The best way to deal with this problem is to make sure that conifers and other types of evergreens are watered adequately in the fall. I normally recommend that these sorts of trees and shrubs receive about an inch of water per week, either from natural rain or supplemental watering all the way up to the point when either we get a significant snowfall or the ground freezes.

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Water stress can also occur during the summertime, if we don't get significant rainfalls, and if we're not watering trees and shrubs and other types of plants adequately. One of the most common symptoms that I see related to water stress on things like conifers, particularly spruces, is a purpling of the needles, typically at the tips of the branches or the top of the tree working its way down or in. And, this purpling can eventually progress to a browning and death of the needles.

Again, the best way to overcome this sort of problem is to make sure that trees and shrubs are getting adequate water, again, about an inch of water per week, either from natural rain or from supplemental watering.

Slide 63

We've covered a lot of information in this presentation and I want to make sure that you have resources where you can go if you have questions about the material that we've covered today or about diseases of plants in general. And so, I'm providing you on this slide, information on how to contact me if you do have questions.

Have my mailing address here at the Plant Disease Diagnostics Clinic in Madison, also my phone number and also my email address. Feel free to contact me at any time. Probably the best way to get ahold of me is either phone or email.

Also, I have a website that has a lot of information on many of the diseases that we have talked about today. One page fact sheets, called the UW Plant Disease Facts are available on my website. Also, I provide kind of a weekly update on the diseases that I'm seeing in the clinic, if you'd like to follow along about that.

Also, I do have a Twitter account. Usually, what I announce there are new fact sheets as they become available, and also, I will put out an announcement as I prepare my weekly disease summaries. So, if you'd like to follow, you can follow me @UWPDDC.

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And finally, another lab that I think you should be aware of is our soil lab. If you ever have issues that you think are nutrient related, this is a place where you can send a soil sample and a plant tissue sample, and they can analyze the sample for levels of particular kinds of nutrients. Their phone number is here as well as their website.

Thanks for listening and again, if you have any questions for me feel free to contact me in the future.