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Fungal Threats to our Crops and Trees Transcript

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Fungal Threats to our Crops and Trees

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The last time this happened to me was in 2009 at the centenary meeting of the Royal Society of Tropical Medicine with an audience of 1,500, and the speaker managed to get himself snowbound in Sheffield, and believe you me, less than ten minutes to prepare a lecture! Today, I have been very lucky – I have had forty minutes. It normally takes forty hours to prepare a Gresham lecture, and I have managed to get that down to a very short time.

Now, it has been a stroke of luck on my part. I do not know if any of you have seen these lovely little Oxford University Press books, "A Very Short Introduction to…". I was persuaded last year to write one on parasitism, and I thought this was absolutely marvellous because I know a lot about parasites, and what I did not know is they wanted me to include crops as well, and fungi, something I knew very little about, and I thought I would be very happy with my safety zone, my own comfort zone, of parasites of humans. So, I have learnt a lot reading about it, and I am going to transmit some of that to you today.

For the non-biologists, I think it is very important to realise that the whole of the living world is divided into six different kingdoms. These are the prokaryote, the bacteria, the Animalia (you and me), the Planti, and another strange group called the chromista, and there are a wonderful group of people who are interested in taxonomy and nothing else, and they have spent a lot of time wondering about this group, and then the protozoa, and that is another group that I have been very, very interested in.

I want to start off by trying to define what a parasite is or what parasitism is. It is quite a difficult task, in fact, because no one really knows. It was originally used by the Ancient Greeks in a derogatory way, to talk about those people who fed at the banquets of the rich. They used to be called parasite or parasitos, the Greek word for that. It is now used to apply to politicians and other such people, and bankers, and people who run the utilities who live off us. But that is a good idea because they give you some idea of what a parasite is, or what parasitism is about.

Having got parasitism, it is one of a number of relationships that exist between two organisms, intimate relationships between two separate organisms, and these are, the most important one, the easiest one in fact, comes first, is symbiosis.

Symbiosis is the condition in which two organisms work together to their mutual advantage and one of them cannot exist without the other. The best example of that is a lichen because a lichen is a combination of an alga and a fungus. The alga produces all the photosynthetic material and the fungus just has the framework within which this can actually work. This is a very good example of symbiosis and there are many other examples. For example, termites eat wood, which is rather foolish of them because they have no insides that can digest wood, so what they have to do is fill their guts with various organisms, protozoa and other organisms, and these digest the wood and the termites then thrive. The symbiants cannot live without the termite and the termite cannot live without the symbiants. Another example are the oxpeckers and these feed on the ticks and lice on the outside of large mammals and they pick off the ticks, which is a tremendous advantage to the animal – it loses all these things feeding on its blood, and a great advantage of course also to the oxpeckers who then have a nice supply of blood, which is very, very nutritious.

The third area is called commensalism. You think I have only talked maybe about two, but in fact I mentioned parasitism earlier. Commensalism is when two organisms live together and neither does any harm to the other. They just live communally. Each of us is a host to tens of millions of different commensal bacteria, fungi and things of this kind, do no harm at all – they can live quite well without us, we can live quite well without them, and we get on very well together. There are many more examples of that.

The most difficult thing to define is parasitism itself and this has eluded very many people. At one count, I had 60 different definitions of parasitism, most of them futile of course because every time you try to define parasitism in one way, another way comes up. So, I am going to ignore this one and say simply that the parasitology is the study of parasites and the interaction between the host is called parasitism. Now, parasitology has a very distinguished record. There are Chairs of Parasitology – I actually held one at one stage. There are journals of parasitology and there are books of parasitology. Yet, we do not quite know what they are. So, a lot of attempts have been made to define. Parasitism then is the name given to a situation in which one, the parasite, lives at the expense of the other, the host. These are not necessarily complete, but this is a very good way of looking at this.

Now, I will come back to the parasites. There are lots of them. I have ignored the prokaryotes, the bacteria, and the most important parasites are: the protozoa single-celled organisms; the worms, and there are three groups of worms – the roundworms, the tapeworms and the flatworms, and I am very interested in these; and there are also the fungi, and the fungi are quite a fascinating group. Now, they all have their particular adaptations and,

again, have caused a lot of interest in parasitology, mainly from an evolutionary – not mainly from the evolutionary point of view, but from the point of view of the diseases they cause, and also from an evolutionary point of view.

I am going to touch briefly on the parasites themselves and simply say I think, most of the time, we are totally unaware of parasites, and they are all around us, as I have written in this particular book. Most are so small that we never see them, and some of them only are seen or only recognised when they actually cause overt disease, in ourselves or our animals or our crops. Some are easy to see but are so commonplace that we ignore them when they come.

I am just imagining a walk through a wood on a summer's day, summer in a temperate zone. A mosquito has just bitten one of us. A cat is leisurely scratching to rid itself of fleas. A dog in the long grass has just picked up a tick. A mangy fox wanders miserably past. A mother assiduously combs her child's hair, looking for nits. Looking upwards, we see that some of the leaves on a nearby tree are withering. There is a fungus growing from the trunk and a mass of mistletoe clothes the branches. Young cuckoos are seen in the upper branches there. Their parents have laid their eggs in the nest of another bird, not of their own species, earlier on. Now, we, the child, the cat, the dog, the fox and the unsuspected bird are all hosts to parasites.

Moving further afield, we find a beekeeper bemoaning the fact that his hives have failed, and somewhere a fisherman cannot find any fish. These are all examples of parasitic diseases affecting this huge world we live in.

The examples I have given you are mainly minor irritations, rather than anything else, but in fact, in much of the developing world, parasites are a matter of life and death. For example, three-quarters of a million African children die from malaria every year. There is a vast amount of Africa, and the majority of Africa cannot be used for cattle because of a disease related to sleeping sickness, spread by tsetse flies throughout the whole of this area. So, throughout the world, we have these major diseases. The World Health Organisation, in 1975, drew up a list of the six most important diseases, five of which were parasitic diseases, and I do not think things have changed very much. So, what is important about this is that there are parasites everywhere, and they affect us and our crops, our trees, and everything around us.

What I want to do now, I am going to get onto the topic in hand, and talk, if I possibly can, about the diseases of crops.

There is not a single plant that has not got a number of parasitic infections, and many have more than just a few. The most important infections are fungi – and I will talk a bit more about fungi in a moment – and nematode worms that are roundworms.

Now, fungi are very interesting because we are all familiar with them. I imagine that all our fridges have got something that has got something infected by fungal growth in it. If not, you are cleaner than I am! And our garden is full of things: there is mildew on the trees; my apples are rotting at the moment – they did not ripen quickly enough. These are all due to fungi.

The lifecycle of a fungus is very, very simple. Basically, it consists of a spore, which is the resistant stage, and this spore, when it alights on a host, enters that host and spreads hyphae round. These are the feeding…not roots of course – they are simply cells that spread right throughout the organism, sapping the nutrient from the animal or plant itself. In humans, we have candida for example and we have a number of other infections – Athlete's foot is another one, an example of a fungal infection. A parasitism is not a natural form of life for the fungi. Their natural form of life is in the ground, on the soil, somewhere in the air, where they do no harm, they just multiply, and we have seen them, as I say, we have seen them all, and I mentioned some of these earlier. If they happen to be on the outside of our fruits or our trees, it does not matter – they are not doing any harm at all. So, the cycle is very, very simple: the spore gets into the living organism and then spreads throughout it and draws the nutrient away and, eventually, it dies. I think the best example that I can give you is of course late potato root rot. We have all had that, where you dig up your potatoes, which are absolutely fine, and you have just got a soggy mess at the end of the end of this. That is what is happening the whole time with the fungal infections.

No crop is exempt from fungal infection and every gardener must be familiar with the nuisance they are, and we spend millions of pounds every year on fungicides to try to control these quite natural organisms, which, in some cases, do not do very much harm at all. It is a nuisance: my raspberries were not very good this year; the blackberries are very good – I do not know what happened there; as I said, my apples were not very good. The whole of my vegetables and trees and fruit that I grow has been badly affected in one way or another because the environment has been absolutely right for this: it is moist and warm. And we are moist and warm, which is why we are so susceptible to fungal infections, most of which do not do us any harm.

Fungi feed by feeding on chitin, and of course our nails are full of chitin and our hair, so that is why we get that, but of course, what is important is they get into plants, and the number of plants they get into is absolutely immense. I cannot find a single plant, even eucalyptus, that does not have a number of fungal parasites. Now, these cause an immense amount of loss in various ways, and one of Chris' slides was showing you that and I will

refer to that again in a moment. I paused a moment ago because I realised that Chris had said that in his slide and I will come back to that again in a moment.

The world's most important crops are rice, wheat, maize, potatoes, soybean, and sugarcane, and also, not a food crop, but cotton. Now, these crops are of immense value to everybody because, in fact, in some parts of the world, the success of these crops is the difference between life and death, if you are trying to keep a small farm going in Uganda or Kenya or somewhere like that. You cannot possibly afford to let your crop be taken over by these fungi. It is of massive importance.

Now, I am going to briefly go through some of these. Rice, I think, is probably the most important. I have got some figures here. Rice originally came from Asia. It is produced mainly in Asia at the moment. There are 45 separate species of fungi that attack rice. They attack the roots, they attack the stems, they attack the whole of the rice, and some actually get into the rice grains themselves. So, there are lots and lots and lots of fungi that are attacking our rice, and, as I say, in many parts of the world, rice is the staple crop, and loss of rice can be absolutely tremendous. I have got some figures here. In the world as a whole, and that is including New Zealand and China, there are 700 million metric tons of rice produced every year. Some of that ends up on our plates in the Indian restaurants around here, but most of it, in fact, is the staple diet for people living in some of these countries.

One of the problems with rice is that it grows in water, and water, a moist habitant, is just what you need for the fungi to grow, produce their spores and to spread around, and when they do spread around, it can be absolutely devastating. There are twenty species involved. It is about twenty fungal diseases caused by 45 different species of fungus, so they are very, very susceptible. The great problem is trying to bring this under control because you cannot use fungicides because you cannot pump fungicides into the water where these plants are growing – very, very difficult to control indeed.

If you want another example, wheat, a very good crop, is grown under all conditions and very important, and it is one of our most important food crops. People argue about that, but I think it is sensible. But, it is particularly important to us in the Northern Hemisphere and Australia and New Zealand, where we grow vast amounts of it.

In China, for example, there is an annual production of 700 million tons – the sort of figure that I gave you earlier. These huge amounts are actually produced, these metric tons, here.

Wheat is affected by over species of fungi, so lots and lots of these fungi available to contaminate wheat, and they attack all parts of the wheat. They attack the roots, the stem, and, most important, they actually get into the kernels themselves and sometimes you do not actually see that until the crop has been made, and this is devastating of course, as you can imagine, for the farmers.

There is another problem with wheat because there is a fungus called Claviceps, which is damaging to the plant but it also produces Ergot, and of course, it can contaminate, ergot toxin, a dangerous toxin which can kill animals and humans, and this is very serious, and there are lots and lots of outbreaks of ergotism throughout the world, simply be eating wheat that has been affected in this particular way.

The other loss of course to wheat is to birds that feed on it, and of course, if they feed on the ergot toxin infected wheat, they die as well, so there is a tremendous knock-on effect on the habitat as a whole.

Potato is a major crop worldwide, one of the most important ones. There are 370 million tons produced annually, but it is affected by over 30 species of fungus and, as I said earlier, fungi live in the soil, they like it in the soil, potatoes are in the soil, and it is nice and easy for them to get in, and they are very, very serious indeed. The most important fungal infection of potatoes is late blight, which can kill up to 100% of the crop. This is the one of course which changed the world in the 1840s, when the Irish crop succumbed to this. So, late blight in potatoes has had a very serious effect throughout the world, and the fact that the Irish diaspora is much greater than the number of people in Ireland itself at the moment, is due to the potato blight. My mother was writing when she was a young girl leaving Ireland, even after the potato blight, was very scared that the potato blight would come back again, and she, like many young women of her age at that time, moved out. She went to Canada, just to get away. It was the fear, not the blight itself, but the fear of the blight, and I think it is important to say that. It is often the fear of some of these diseases that are more important here. Lots of species are found in potatoes. I think we have all had them in the gardens and so on, and they are extremely difficult to control.

Soybean is something that we do not think of very much, but it is in fact an extremely major crop indeed. About 262 metric tons of soybean are produced every year, and it is susceptible to over 40 species of fungi, and these take a variety of different forms there. One of the problems here is that one disease is called sudden death of soybean, and that is distressing to the farmers because the crops look absolutely right, they are absolutely perfect, grown up all beautifully, and suddenly keel over dead, so you wake up one morning and find that your whole crop is gone. So, this is really absolutely devastating because you have got no time to go back and many changes that you might want to make.

The next important one is sugarcane. Now, sugarcane is caused by a number of different species of grasses,

and we do not know how many different fungi infect this, because the fungal taxonomists have had a real go at these. I do not know if you know about taxonomy. There are two kinds: there are the splitters and the lumpers. Splitters divide everything into as many forms as they possibly can; and the lumpers lump them all together! So, the net result is that the number of fungal species infecting sugarcane is either six or 30, depending on which textbook you pick up! Nevertheless, it is very, very important indeed, but I think what is important here is that sugarcane is actually the world's largest crop, something we did not understand, and in fact, the number of metric tons produced is 1.8 billion tons of sugarcane produced every year. It is an absolutely massive crop, and, again, it can be absolutely devastating.

The diseases include a whole variety of different things, affecting all parts of the crop, from the root, all throughout the stem, and all of them are very, very difficult to control. I will not go into the whole of diseases there that occur in sugarcane.

The last crop – it is not a crop, really, but the world agriculturalists regard it as one of the major diseases, and that is cotton. It is unlike the diseases so far because, of course, we do not eat cotton, but it is important. It is the most important fibre crop – 26 million metric tons are produced every year, and mainly in the United States, and now in China, as we know if we look at the labels inside our cotton shirts and sweaters and things. Very, very susceptible to fungal infections, and there are over 28 species that infect this particular cotton, and they are everywhere – the root, quite a lot on the root, up through the stem, and of course in the cotton ball. That is the most important thing, in the cotton ball, and we have all heard about the cotton ball weevil in the United States, and fungal infections have much, much more impact than this. These are fungi that thrive in conditions of moisture, humidity, which is just right for the growth of cotton.

I have just talked about those crops at the moment, and how important they are, and how important fungal diseases are to us in the destruction of crops. It is very, very difficult, as you probably gathered when I talked about the number of species a moment ago, it is very difficult to estimate the value, the economic cost, because no one knows what it is. We have got lots and lots of information and we can tell you what the crop in a particular village in Nigeria is, for example, or a part of China, but in most cases, it is very, very difficult to estimate the cost. I am going to come onto one of Chris' slides there, so I will not labour this particular point.

The FAO – and I do trust the FAO and the WHO and the Centre for Disease Control in Atlanta, Georgia, and, apart from that, I do not trust anything from anybody, so obviously, I am very conscious that I am rather pushing the FAO, but I do think they have got some very, very good data, extremely good here. They take together, all together, the five main crop plants, crops as I mentioned earlier there, and the threat there, the total tonnage of these is 4.7 billion tons of crop, of the five major crops there, and it just occurs to me, look, about 10% of it is destroyed by fungal infections. That is an awful lot of fungal infections.

It is not easy, as I say, to estimate what the costs are. Attempts have been made. For example, a different approach is also to look at not the cost, because I will come to costs in a moment there, and the FAO reckon that up to four billion people could be fed for a year on the crops that are lost due to fungi. I think that is a better way of looking at it. Four billion people could be fed if it was not for fungal diseases, and I think that is a very, very important point.

So, a lot has been done to look at this, and we look at the crops, and then, nearer my own area, my own particular field here, you take into account also the malnutrition which occurs if the crops fail and people starve, and that is a very difficult thing – how on earth do you measure that? I do not think you can measure that easily.

I think, in the last few minutes, I have given you some idea of the importance of fungal infections in crops of various kinds, and they are terribly important for the horticultural business in this country and all over the world. This is a huge business. I think, as Roderick Floud has said in his lectures, gardens are big business, huge business, and fungi are very good business for the garden shops of course because you buy more and more of the plants, and you put them in the soil and they die, and they die again, and people do not realise that you can't get rid of the fungi from the soil. You have got to be very, very careful not to replant material there.

There are many fewer fungal infections of trees than there are of the crop plants I talked of earlier there. It is estimated there are about 30 important ones, of which twenty are very important. Now, you know, compare that with the numbers I have been giving you before… That is trees as a whole, not just an individual species of crop. There are about twenty or 30. I think, if I were studying fungi, I would study the fungi of trees because there will not be so many to remember, but that is a little bit selfish!

They attract the attention because of their effects, and newspapers write about these. No newspaper writes about the failure of a rice crop in China. People do write a lot about the fact that their chestnut tree in the garden has suddenly died. So, an awful lot of attention here.

The unseen effects of this, of disease of plants, of trees, is very important because the timber industry is an absolutely massive industry, and the timber industry suffers very, very badly from these trees because you cannot use, in most cases, the wood from these trees.

The fungal infections work in exactly the same way as they did for the crop plants. The fungus gets into the tree and, unlike the crop plants, most get in through the roots and spread through the roots of the tree, and spread up through the tree and actually block the flow of water up through the plant so the tree just withers away and sometimes you get a growth around the tree, a canker round the tree, where the plant has tried to stop these fungi spreading and, in fact, it has simply strangled itself, which is rather sad here. There are lots and lots of these.

The word “dieback” has come quite recently, and dieback is when an infection starts at the far limits of the tree, the shoots and the twigs, moves down the branches to the tree, and it dies back from the outside. So, again, dieback has been very important.

Some of the most important tree diseases are beech bark – this affects beech trees all over the world, and what is interesting about this one in fact is that it has helped by an insect, a scaled insect, here, and the scaled insect climbs up the tree, causes damage, a lot of damage, and spores are able to enter through the damaged part of the leaf. A very important disease here, and, again, there is a lot going on at the moment because this particular fungus can actually block the host’s reaction to it, like our immune system, so the fungus really does get a very good grip indeed.

Chestnut blight, only recognised since 1909, a very, very important one here, and it spreads through our forests, our woods, as you know, and it causes great loss and a great deal of distress to the people who own this.

Dutch elm disease is another interesting one, and one I think which very, very important, and people are talking about this one here. Dutch elm disease has been around for a short time. It is caused by infection with several species of fungi and, again, what is interesting is that these are spread by the elm bark beetle, and the beetle bores holes in the plant, various parts of the plant, the tree, and the fungus enters through these. The damage done, of course, is not just the fungus, but it leaves the tree open to attack by other pathogens as well. So, Dutch elm disease is a very complicated disease indeed.

I have got some figures for this one. It is estimated that since Dutch elm disease occurred in Europe, just over a hundred years ago, 25 million trees have been killed. I have tried to find out what an elm tree costs and really cannot find that because there are different figures from various people, but 25 million is an awful lot, and it is probably about a thousand pounds and, when you think of that, you are talking millions of pounds just for this one disease.

And, again, probably the one that has come our way most recently is sudden oak death. It is caused by a number of fungal infections, including phytophthora, which is the fungus that infects potatoes, a different species, but it is a very wide-ranging fungus and attacks the tree here. This was first seen in the United Kingdom just in 2002, less than twenty years ago, and when you look at it around the country now, you can actually see that oak has been destroyed all over the country. But it does not just go for oak. It has been found in beech, sweet-chestnut, horse-chestnut, northern red oak, turkey oak, home oak, garden larch, and herbaceous plants including rhododendron – that is not a bad thing, but I am not going to comment on that particular thing! Very sadly, there is no cure and no treatment for this, as far as we know at the present time.

I will go back to this phytophthora, the genus phytophthora. The genus phytophthora itself affects a hundred different species of plants.

Now, a disease that I had not come across before was red-band needle blight. This is found in conifers, and it is characteristic by causing red bands on the leaves, the tiny leaves like that, which drop off, and a tree with no leaves does not thrive very well and these trees die very seriously, here. A very important disease indeed. It occurs mainly in Eurasia, Africa and Oceania, and it affects over 80 species of plants, a huge host range. We are not used to that in human infections that only infect a very small range of host – over 80 species here.

Here, the fungi are quite clever because they do not have to enter through a lesion in the tree. They actually get in through the stomata of the tree itself, so they get sticky and they get carried into the tree and then are carried throughout the tree as a whole.

The best-known, and one of the least understood, of the tree fungi is the one that causes ash dieback – it is also called chalara. The infection begins causing wilting, as I say, of the peripheral parts of the plant, which spreads straight down. This has been a very serious disease indeed, and eventually, the whole of the crown is infected, hence the name, as I said earlier on, “dieback”. This is spread by windborne spores – there is no way you can deal with windborne spores.

So, these are some of the trees we see, but the most important ones are those that affect the roots of the trees, and as I said, fungi live in the roots and they spread throughout the soil, and obviously, the roots of a tree are very, very susceptible, and there are a very large number of infections here.

There is one particular species that has a huge range of hosts and mainly conifers, hardwoods and herbaceous

shrubs. Basically, they just feed, at the moment – they are quite cunning. They start feeding on the outside of the root, and they cause no harm, and then suddenly they start getting inside and spreading throughout the tree. So, most of the time, they are not doing any harm, but they are just waiting there to take this opportunity of penetrating the root. After that, what happens is that the fungus spreads up through the tree and it decays from the inside, becomes very sponge-like from the inside, and very like dry-rot, as we see in our houses from time to time. They are known by a whole series of different names and you will have seen them because the most important part is when it comes above the soil and forms a mushroom around the base of the tree. We have all seen these and they have got a variety of different names. They are known as oak fungus or the honey mushrooms. These now spread spores, widespread through the air, up through the soil, mainly through the soil, and they spread a very, very long way indeed, but a less important mechanism of the spread is simply that a fungus can spread over a vast area.
The smallest parasite I know is about half the size of a red blood cell. The largest one I know is caused by amalaria, and the largest one covers over a hundred acres, a single fungus has spread from tree to tree and it is just one entity affecting about a hundred hectares of soil. So, it has attracted a lot of attention. I have advocated somewhere else that this is an ideal fungus for schoolchildren to study because you can see it on the ground, you can look around, and you can look and see what is happening to the tree, and I hope that is taken up there.

It has been reckoned here that, in the United Kingdom alone, just two diseases, red-band needle blight and sudden oak death, cost £9 billion each year, and they can take away my bus-pass to save a few hundred pounds and yet these fungi are causing much, much more damage than that!

As well, it has a massive impact on the timber industry of course, but also on the scenery, the landscape as a whole. Great cities – Edinburgh, Amsterdam, London – have lost many of the city's big trees that used to line the boulevards. They are gone forever. Edinburgh has changed completely. Amsterdam has changed completely. And I think you need not go further than Salisbury and have a look at John Constable's painting of Salisbury Cathedral – all the trees in the front of that have gone now.

So, these fungal diseases are very, very important indeed. Now, what to do about it? Well, fungicides are there, but fungicides are expensive, very expensive, and they are environmentally unfriendly. One of the ways round this one is actually to breed plants that are resistant to these fungi. We have all enjoyed Jersey royal potatoes – Jersey royal potatoes are in fact resistant to late blight and it happened, a single mutation, a long time ago, in the 1900s, and it gave these potatoes a chance to survive.

It takes a very long time to breed a tree, for example, breed a tree or a large plant, and there is a much easier way to do it, and that is by genetic engineering. It is so easy to do, to breed these plants that are genetically resistant to, for example, drought, with increased productivity, in terms of increased crop, better growth of trees, etc. etc. But, we do not like genetically engineered things at all, and so we are very scared about that, and there is very, very little effort going into breeding genetically engineered crops of this kind because of this international dislike of genetically engineered material.