The green horse chestnut at the front has been treated with biochar + phosphites + willow mulch. No chemicals, just boosting the tree's own immune system. The tree on the right was treated at half strength and the one at the back (the horse chestnut leaf miner infested one) is the control.

Controlling tree diseases: thinking outside the box

Glynn Percival, Bartlett Tree Research Laboratory

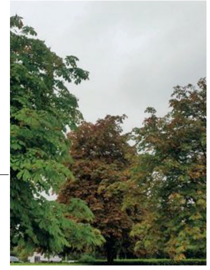
Over the past 10 years professionals involved in urban tree management have had to contend with a dramatic increase in pest and disease epidemics including *Pseudomonas* bleeding canker, sudden oak death, horse chestnut leaf miner, oak processionary moth, Massaria canker of London plane, acute oak decline and Chalara ash dieback. Unmanaged these pest and diseases will potentially prove devastating to some of our major tree genera.

It can be argued that increases in global commerce, travel and the continual purchasing of non-native tree species from abroad that potentially harbour pathogens may have facilitated the spread of these problems. Although work is being undertaken in the field of global plant security to focus on eliminating the introduction of foreign plant diseases, a major problem is that trees which do not visibly appear to have disease symptoms can still be carriers for a hidden pathogen. Scientists refer to these trees as asymptomatic. One issue all experts agree on, however, is that pest and disease issues will only become worse. Sweet chestnut blight, *Ceratocystis* of London plane, emerald ash borer and Asian long-horned beetle are all of major concern.

In most instances government advice states that there are limited treatments for pests and diseases, with recommendations largely based on tree removal and destruction, primarily by burning. However, continual reliance on this approach has its drawbacks. Work with horse chestnut infected with *Pseudomonas* bleeding canker has shown some trees have overcome initial infections without human intervention. Recent data (unpublished) from the Bartlett Tree Research Laboratory shows a similar response with acute oak decline. Consequently, premature removal before trees have the opportunity to demonstrate resistance could result in resistant trees being lost. Removal also obliterates a tree species which is important not only to people but to wildlife. Close to 3 million larch trees have been felled in an attempt to slow down the spread of *Phytophthora ramorum.* One question that is rarely asked is how many billions of insects, fungi and bacteria have been destroyed because of this policy. With these concerns in mind the Bartlett Tree Research Laboratory has initiated several research projects, to include funding of two PhD students, and successfully obtained funding from the 2016 TREE Fund Hyland Johns Grant to investigate a potentially unique and environmentally benign system of preventing and managing major pest and disease outbreaks.

How do we currently control pests and diseases of trees?

If tree removal and destruction is not considered an option then managing pest and disease outbreaks relies primarily on treating the tree with either an organic natural and/or synthetic plant protection product, i.e. a fungicide, insecticide or bacteriocide. Application of these products is mainly via spray technology (high volume, electrostatic). On occasion some products can be soil applied (drench), while recent developments in



Biochar, a form of activated charcoal.

in trunk injection offer potential for the future. The main issue here is that trees are being treated with a product that has direct toxicity against the pest or pathogen in question. Consequently, use of these products has led to a number of concerns such as the impact on non-targets caused by spray drift, groundwater contamination, accidental contact with the public and build-up of pesticide resistance by target populations. As a result there is a general reluctance to use any form of chemical protection within an urban landscape. Likewise, increased government legislative restrictions regarding the use and application of plant protection products, the expense of application and the significant training required for staff who will apply these products can prove costly. There is now a fundamental requirement to develop new systems of pest and disease management.

How do we currently control pests and diseases of humans?

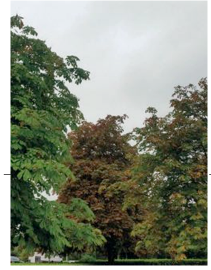
The concept of repeatedly spraying oneself with artificial chemicals to protect against pests and diseases would be considered ludicrous in today's society. Western medicine dictates that prevention of infectious diseases (typhoid, diphtheria, measles, hepatitis, smallpox) is primarily via vaccination. In such circumstances the human body is injected with a weakened or attenuated strain of a disease. This in turn stimulates the body to produce antibodies against that specific disease, which in turn confers immunity. Immunity is defined as 'the ability of the human body to tolerate the presence of material indigenous to the body ("self"), and to eliminate foreign ("nonself") material'. This discriminatory ability provides protection from infectious disease, since most microbes are identified as foreign by the immune system. Immunity to a microbe is usually indicated by the presence of antibody to that organism. The principles of vaccination to prevent infectious diseases have been recognised since 1796 when Edward Jenner performed his famous experiment by vaccinating an eight-year-old child with milk-pox having noticed that that milkmaids who suffered the mild disease of cowpox never contracted smallpox, one of the greatest killers of the period. In essence Edward Jenner used a mild form of pox (milk-pox) that boosted the human immune system and protected against the more deadly form, smallpox. Importantly a 'one-off' vaccination can confer immunity for many years (at least 10) and in some cases last an entire lifetime.

Can we use these vaccination principles for trees?

The answer is yes. Vaccinating plants against pests and diseases is not a new concept: the idea of inducing resistance in response to plant diseases was recognised in the early 20th century when heat- or cold-treated *Botrytis cinerea* (grey mould) was exposed to *Begonia* plants: instead of causing infection as expected, this resulted in the plants developing resistance. It was later demonstrated that inoculation of a single leaf of tobacco with tobacco mosaic virus reduced the severity of subsequent infections on other leaves throughout the plant. Since then hundreds of papers have been published demonstrating how a plant's own defence mechanisms can be 'switched on' by prior treatment with either a biological (weakened disease) or chemical (inorganic potassium and phosphate salts) agent.

Interestingly tree defence responses are superior to those of a human in that an injection against typhoid, for example, would only confer immunity against typhoid. Further separate injections would be required if immunity against diphtheria or measles was required. In trees, however, a single vaccination causes alterations to several plant biochemical and physiological processes. These include the accumulation of antimicrobial proteins, fungi-toxic enzymes, phenolics and terpenoids within leaves, stems and

Horse chestnut leaf miner.



Ash dieback.

roots. At the whole-plant level leaves become thicker and more lignified, increasing resistance to degradation of the leaf surface caused by enzymes released by the invading pathogen. In conifers enhanced resin production, production of phenolics and initiation of a wound periderm occur. Importantly, because multiple defence mechanisms are switched on at the same time, it is it highly unlikely that pests and diseases can develop resistance to this measure. In addition, a single vaccination has been shown to provide resistance against biologically different pathogens (fungal, bacterial, virus) over a growing season, to include fire blight (bacterial), *Phytophthora* root rot (algae), powdery mildew (fungal), *Ceratocystis* spruce wilt (vascular wilt fungus) and horse chestnut leaf miner (insect). Current plant protection technology would require the use of three different chemicals, i.e. a fungicide, a bactericide and an anti-viral product, to achieve any degree of control.

A small but significant step

A few years ago field trials were conducted at the Bartlett Tree Research Laboratory using four-year-old horse chestnut (*Aesculus hippocastanum* L.) to assess the efficacy to two products known to 'switch on' tree defence systems. These were potassium and silicon phosphite, which were being evaluated as plant protection agents against the bacterial pathogen *Pseudomonas syringae* pv *aesculi* (*Pae*), the causal agent of *Pseudomonas* bleeding canker of horse chestnut. Results demonstrated that application of both phosphites reduced *Pae* lesion size, the main proxy of *Pae* success or aggressiveness. However, the uniqueness of this result was that these phosphites were applied as a root drench as well as a foliar spray. Applying products as a root drench opens up many opportunities to manage tree pests and diseases without the need to spray and raises the real possibility that tree resistance can be acquired by exposing a tree to natural and/or synthetic soil amendments applied at the time of planting or around the base of established trees using, for example, air-spade technology.

With funding secured from the TREE Fund Hyland Johns Grant, 'Can soil amendments reduce disease severity in trees?' research at the Bartlett Tree Research Laboratory aims to evaluate four potentially powerful, stable and non-toxic soil amendments singly and in combination: chitin, phosphites, biochar (a form of activated charcoal) and pure mulches, i.e. a mulch made from a single tree species such as willow or eucalyptus. Importantly, most of the products tested (biochar, chitin, mulch) are derived from waste materials that would otherwise go to landfill.

Chitin

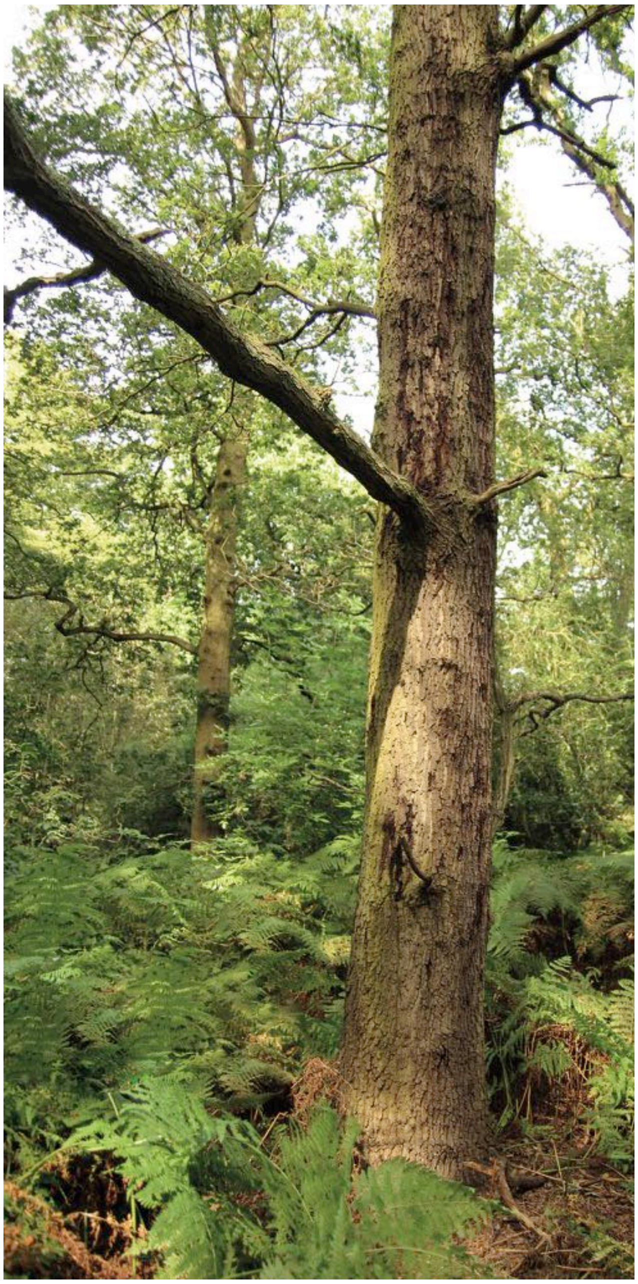
Chitin is a naturally occurring constituent of fungal cell walls that can also be sourced from waste crustacean shells (crabs, lobsters, crayfish, and shrimp). Chitin, or a derivative known as chitosan, has been shown to enhance bio-control efficacy when applied to soils in combination with other bio-control fungi (*Trichoderma*) and bacteria (*Bacillus*). Applied alone, chitin and chitosan have shown potential for the control of soil-borne diseases. Chitin acts as a 'food' source in soils, stimulating soil microorganisms to release chitinolytic enzymes to break down the chitin molecule. An increased level of soil chitinolytic enzymes aids in the suppression of pathogenic fungi such as *Rhizobium* and *Fusarium* root rots, while the increase in chitinolytic bacteria such as *Bacillus licheniformis*, *Stenotrophomonas maltophilia* and *B. thuringiensis* aids in the control of Oomycetes such as *Phytophthora cactorum*. Recently, chitosan has also shown potential as an insecticide, controlling a range of aphid species and lepidopteran pests via ingestion of foliage, with chitosan either applied to the leaf surface or translocated within the vascular system of a plant.

Biochar

Several articles show soil fertility and quality are improved with the addition of biochar (see references). As well as altering the physical and chemical properties of the soil around the rhizosphere, biochar also alters the biological dynamics of a soil through several mechanisms. Biochar is initially sterile and therefore has no indigenous populations of microorganisms. Instead, the physical structure of the biochar encourages colonisation by various arbuscular mycorrhizal fungi, nematodes and bacteria. Biochar adsorbs humic acid, which is used as sustenance by soil microbes, and humic acid adsorbs fertilizers, preventing them from leaching out of the soil. Roots can access this stored fertilizer.

Oak processionary moth.

Numbers of plant-enhancing microorganisms, such as *Trichoderma*, are boosted in soils amended with biochar. Studies have shown a significant interaction between biochar and *Fusarium oxysporum* that strongly reduces disease severity. Recent research has shown that soil-applied biochar also induces resistance to fungal diseases such as *Botrytis cinerea* (grey mould) and *Leveillula taurica* (powdery mildew) as well as the insect mite pest *Polyphagotarsonemus latus*. Zwart and Kim (2012) identified that a 5% biochar application (by soil volume) resulted in a significantly greater stem biomass in *A. rubrum* compared with plants inoculated with *Phytophthora cinnamomi*, suggesting that biochar amendment has the potential to alleviate disease progression and physiological stress caused by *Phytophthora* canker. It has also been suggested that the beneficial microorganisms encouraged by biochar application could produce antibiotics to directly affect bacterial plant pathogens. Ultimately, biochar offers the potential to be used in conjunction with other biologicals to increase treatment efficacy.



Acute oak decline.

Phosphites

Inorganic phosphite salts are a family of potential plant protection agents. When applied to plants as a foliar spray or soil drench, phosphites exhibit two modes of action: acting directly on the disease and indirectly by stimulating plant host defence responses, such as the accumulation of plant antibodies (phytoalexins), hypersensitive cell death, cell wall lignification and the formation of lytic enzymes that in turn inhibit pathogen growth. Research has found potassium phosphite salts to be effective in the control of Oomycetes such as *Phytophthora* root rot and canker pathogens, fungal pathogens such as *Venturia inaequalis* (apple scab) and pathogenic bacteria such as *Erwinia amylovora* (apple fire blight) and *Pseudomonas syringae* pv *aesculi* (bacterial bleeding canker).

Pure mulches

Previous studies have shown mulches can provide an integral cultural control method for suppressing the development of several plant diseases. Cellulose forms part of the component of the primary cell wall of green plants, acting as a structural polymer to provide plant rigidity. Following the application of a mulch to a soil surface, the concomitant microbial and fungal population build-up promotes a reservoir of enzymatic activity such as cellulase and laminarinase to induce mulch decomposition. Cellulose microfibrils in *Phytophthora* cell walls are susceptible to enzymatic destruction, particularly by cellulases present in mulch litter layers that cause cell wall lysis and, by default, a subsequent reduction in *Phytophthora* pathogen severity. In addition, mulches also contain a variety of soil microbes that can exert biological control over soil-borne pathogens, either through resource competition or antibiosis (production of antibodies).

Limited studies exist focusing on the efficacy of mulches derived solely from one tree species, defined as pure mulch, on the suppression of diseases. However, information available indicates the use of a pure mulch can have a powerful influence on transplant success and the survival of trees. Pure mulches derived from the common hawthorn (*Crataegus monogyna* Jacq.) and common cherry (*Prunus avium* L.) increased survival rates of European beech (*Fagus sylvatica* L.) from 10% to 70% following containerisation and under field conditions enhanced fruit tree crown volume and fruit yield by 53% and 100% compared to non-mulched trees. Disease-suppressive effects may also relate to allelochemicals released as mulches degrade. For example, allelopathetic testing of water-soluble extracts of pure mulches derived from hawthorn, cherry, silver birch, English oak and evergreen oak positively increased pea seed germination, relative growth rate and the photosynthetic efficiency of established seedlings.

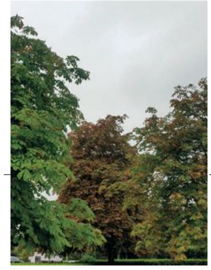
A pure mulch derived from willow (*Salix*) will be the focus of attention for this study. Willow tissue is naturally high in salicylic acid, a powerful stimulator of plant defence pathways. Indeed application of salicylic acid to plants has been shown to confer resistance against several plant pathogens including early blight of potato (*Alternaria solani*), powdery mildew (*Erysiphe cichoracearum*), tobacco mosaic virus, fire blight (*Erwinia amylovora*), *Sclerotinia sclerotiorum* and *Phytophthora palmivora*.

Conclusions

All studies to date suggest that the use of the soil amendments outlined above offers a feasible alternative for controlling a broad spectrum of economically important foliar and root fungal diseases of urban trees. Many of the products to be used are in essence waste or by-products of industry (chitin, biochar, wood chip mulch) which present a ‘green’, environmentally benign approach to pest and disease management. It is also important to emphasise that these products should not be used as a ‘standalone’ treatment for pest and disease management. Management should also rely on promoting tree vitality and alleviating all forms of stress where possible. Aftercare is always critical to pest and disease management. This should include:

- Frequent inspections for health and structural issues.
- Soil de-compaction if required.
- Monitoring of soil moisture to protect against over- and under-irrigation.
- Prescription fertilisation for optimal tree nutrition.
- Mulching the critical root zone.

See overleaf for references.



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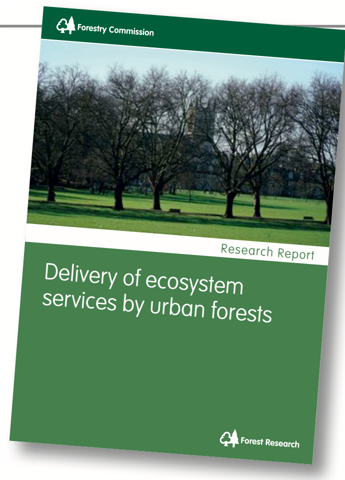
New report explores trees' urban role



A research report published by the Forestry Commission offers new insight into the specific roles which trees play within the wider range of ecosystem services provided by greenspace in town and cities.

The report, which is based on a literature review, shows that woodlands, street trees, parks and other greenspace are given broad attention in the scientific literature. Papers focusing on green infrastructure as a whole are also common. However, it found that there is very little reference in the literature to scale, and therefore whether it is individual trees, lines of trees or clusters of trees which principally provide each of the benefits.

A key objective of the report is therefore to illustrate the specific role of trees in providing benefits to society, as opposed to provision being assigned to green infrastructure in general, or to a particular greenspace type. To this end it investigates scale-based urban forest elements, including single trees, lines of trees, clusters of trees, and woodland. The ecosystem services they provide are grouped into provisioning, regulating, and cultural services, and each service is considered in turn.

The author, Dr Kieron Doick of Forest Research, said, 'Information about the ecosystem services provided by single trees, lines of trees, tree clusters and woodland is helpful for mapping and quantifying ecosystem service delivery over a given area.

'It is also helpful for determining how and where the urban forest can be bolstered in support of ecosystem service provision, including a reduction in ecosystem disservices.

'By understanding which component parts of the urban forest are frequently associated with the benefit, policymakers and urban forest practitioners in Britain can make informed decisions about how to improve the long-term and sustainable provision of ecosystem services for a more resilient society.'

The report looks at a broad range of urban forest-based ecosystem services and disservices and, using a literature review, links their provision with four aspects of urban forests. These are: physical scale and management; physical structure; location and proximity to people; and land use and ownership.

Entitled 'Delivery of ecosystem services by urban forests', the report is intended to be useful to urban planners, local authorities, tree officers and urban forestry practitioners, as well as academics working in urban forestry, green infrastructure, and nature-based solutions to climate change.

It is available to download from the online publications catalogue at *www.forestry.gov.uk/publications*.