Influence of Pure Mulches on Suppressing *Phytophthora* Root Rot Pathogens[1]

G.C. Percival[2]
Bartlett Tree Research Laboratory
John Harborne Building, Whiteknights,
University of Reading, Reading, Berkshire, RG6 6AS

Abstract

Mulching as a means of controlling *Phytophthora* root rot pathogens has become recognised as a potential cultural management system within the arboricultural, nursery and landscape industry. The influence of a pure mulch, i.e., mulch derived solely from one tree species, on reducing *Phytophthora* root rot severity has received little study. The purpose of the conducted research was to determine if a range of pure mulches derived from European beech (*Fagus sylvatica* L.), common hawthorn (*Crataegus monogyna* JACQ), silver birch (*Betula pendula* ROTH.), common cherry (*Prunus avium* L.), evergreen oak (*Quercus ilex* L.) and English oak (*Q. robur* L.) could reduce the development and impact of pathogen severity caused by *Phytophthora cactorum* and *P. criticola* on containerised horse chestnut (*Aesculus hippocastanum*). Irrespective of *Phytophthora* pathogen, leaf area, leaf, shoot, root and total plant dry weight following application of a pure mulch was higher than non-mulched controls. Likewise, leaf chlorophyll content, chlorophyll fluorescence Fv/Fm ratios, photosynthetic rates and root carbohydrate concentration as measures of tree vitality were higher in pure mulched compared to non-mulched control trees. Application of a pure mulch had a significant influence on *Phytophthora* root rot lesion severity. In the case of *P. cactorum* root rot lesion severity was reduced by 39–63%. In the case of *P. criticola* root rot lesion severity was reduced by 33–61%. In conclusion, pure mulches offer positive benefits for those involved in the care and maintenance of urban trees as well as nursery, forestry, orchard and horticultural crop production where *Phytophthora* pathogens are problematic.

Index words: root rot protection, tree vitality, chlorophyll fluorescence, chlorophyll content, tree pathogens, plant health care.

Species used in this study: European beech (*Fagus sylvatica* L.); common hawthorn (*Crataegus monogyna* JACQ); silver birch (*Betula pendula* ROTH.); common cherry (*Prunus avium* L.); evergreen oak (*Quercus ilex* L.) and English oak (*Q. robur* L.)

Significance to the Nursery Industry

Soil borne pathogens such as *Phytophthora* spp. can result in high mortality rates and/or impaired growth during the production of woody ornamental trees and shrubs. The positive benefits of mulching as a means of culturally managing *Phytophthora* spp. are becoming widely recognised. The influence of a pure mulch, i.e., mulch derived solely from one tree species, on reducing *Phytophthora* root rot severity has received little study. Results of this investigation show that use of a pure mulch derived from European beech (*Fagus sylvatica* L.), common hawthorn (*Crataegus monogyna* JACQ), silver birch (*Betula pendula* ROTH.), common cherry (*Prunus avium* L.), evergreen oak (*Quercus ilex* L.) and English oak (*Q. robur* L.) reduced root lesion severity caused by *P. cactorum* and *P. criticola* by 33–63%. Selection of an appropriate pure mulch is important, however, as reductions in *Phytophthora* root rot lesion severity varied between mulches.

Introduction

Phytophthora is a genus of plant-damaging pathogens whose member species are capable of causing enormous economic losses to arable crops worldwide, as well as environmental damage in natural, forest and urban ecosystems (13, 18). *Phytophthora* pathogens are also widespread and damaging to woody plants that are commonly found in managed town and city landscapes (37). Several species of *Phytophthora* attack the fine absorbing roots of plants and may invade larger roots and the root collar. These pathogens grow in the cambium and sapwood causing death of the tissue. Loss of water and nutrient absorbing capacity and stored carbohydrate reserves in the root cause a gradual or sometimes-rapid decline of the above ground portion of the plant (13). Physiologically, stem canker-causing *Phytophthora* species (e.g., *P. cinnamomi* and *P. cactorum*) are known to kill phloem tissue leading to plant death through girdling, and also to colonize and block xylem, leading to altered plant water relations (2). Control of *Phytophthora* species is primarily by the use of synthetic chemical drenches and/or injections around the root collar (37). Increased pathogen insensitivity to chemical plant protection products coupled with public demands to reduce pesticide use, stimulated by greater awareness of environmental and health issues has placed more emphasis on alternative pathogen control strategies (1, 17, 28). Consequently, non-chemical management options are increasingly being sought to preserve valuable infected specimen trees and protect non-infected hosts (37).

Mulching as a means of reducing soil moisture stress, weed suppression and fertilising have been used in arboricultural, agricultural, fruit and ornamental crops production systems for decades (3). Mulching as a means of reducing soil borne diseases such as *Phytophthora* spp, is now recognised as a potentially useful cultural management option (6, 7, 8, 9, 10). Physically, mulches reduce splashing of rain or irrigation water, which can carry spores of disease causing organisms to the stems or leaves of susceptible host species. Additionally, the populations of beneficial microbes that colonize organic based mulches can reduce soil pathogens either through direct competition for resources or through chemical inhibition. Regardless of the mechanism involved, disease reduction is an important benefit of many mulches (3, 8, 33).

Limited studies exist focusing on the efficacy of mulches derived solely from one tree species, defined as an pure mulch for the purposes of this study, on suppression of

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[2]Plant Physiologist/Technical Support Specialist. gpercival@bartlettuk.com.

Phytophthora pathogens. However, information available indicates the use of a pure mulch can have a powerful influence on transplant success and subsequent survival of trees. The effect of fresh and composted pure organic mulches of *Eucalyptus cladocalyx* mulch was found to have a positive effect in transplant performance of *Platanus racemosa* (8) while fresh pine bark was found to affect *Quercus robur* establishment through weed suppression but not through an effect of mulching itself (15). 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 (29).

The purpose of the conducted research was to determine if a range of pure mulches can i) reduce the development and impact of pathogen severity caused by *Phytophthora cactorum* and *P. criticola* spp. on containerised horse chestnut (*Aesculus hippocastanum*), and ii) quantify alterations in host plant vitality with respect to leaf photosynthetic efficiency, leaf chlorophyll content, photosynthetic rates and root carbohydrate concentration.

Materials and Methods

Field site and experimental trees. Two-year-old, bare-rooted stock of horse chestnut (*Aesculus hippocastanum* L.) was obtained from a commercial supplier and planted into 20 litre pots containing a general tree compost (loamy texture, with 23% clay, 46% silt, 31% sand, 3.1% organic carbon, pH 6.6) supplemented with the controlled release nitrogen-based N:P:K (29:7:9) fertiliser Bartlett BOOST (The Doggett Corporation, Lebanon, NJ, USA) at a rate of 5.0 $g \cdot kg^{-1}$ soil. Following potting, trees remained outdoors on a free-draining mypex covered surface at the University of Reading Shinfield Experimental Site, Reading, Berkshire (51°43' N, 1°08' W) subject to natural environmental conditions and watered as required. For the following two years from 2007 to 2009 trees were trained to produce a central-leader system to an average height of 1.0 ± 0.15 m (3.3 ± 0.5 ft) with mean trunk diameters of 8.0 ± 1.5 cm (3.2 ± 0.6 in) at 60 cm (24 in) above ground level. A minimal insecticide and fungicide program to prevent horse chestnut leaf miner and *Guignardia* blotch outbreaks were performed based on the pyrethroid insecticide deltamethrin and triazole fungicide penconazole (product names Bandu and Topas, respectively, Headland Agrochemicals Ltd, Saffron Walden, Essex, UK) and applied every six week during the growing season. All sprays were applied using a hand-held sprayer at 7.5 ml (0.25 fl oz) deltamethrin and 3.5 ml (0.12 fl oz) penconazole per litre (35 fl oz) of water. Trees were sprayed until runoff, generally 0.15 litre (5.3 fl oz) per tree.

Pure mulches. Branches ≤8 cm (3.2 in) of European beech (*Fagus sylvatica* L.), common hawthorn (*Crataegus monogyna* JACQ), silver birch (*Betula pendula* ROTH.), common cherry (*Prunus avium* L.), evergreen oak (*Quercus ilex* L.) and English oak (*Q. robur* L.) were pruned from mature landscape trees and chipped with a commercial brush chipper to produce 4–6 cm (1.6–2.4 in) long chips. Each mulch was used fresh, i.e., immediately after chipping without any form of composting. All mulches were made when trees were fully dormant (February) when, with the exception of evergreen oak, no foliage was present on the tree. All mulches were prepared from trees located at the University of Reading Shinfield Experimental Site, University of Reading, Berkshire (51°43' N, 1°08' W). Each pure mulch was applied to each pot at a depth of 10 cm (4 in) on February 13, 2009. Pots were arranged in a randomized block design with 10 trees per mulch treatment. Non-mulched trees acted as controls. Pots were placed outdoors on black polyethylene mat to avoid under growing weeds at 1.5 m (4.9 ft) spacing to reduce competition for light. Pots were re-randomized every 4 weeks. No fertilizer was applied during the experimental period and any weeds were removed manually from pots when observed. Irrigation was applied as required.

Phytophthora inoculum. Pure cultures of *Phytophthora cactorum* and *P. criticola* were obtained from CBS-KNAW Fungal Biodiversity Centre, The institute of the Royal Netherlands Academy of Arts and Sciences, Centraalbureau voor Schimmelcultures, Utrecht, The Netherlands. Plants were inoculated after bud break with bud break occurring *ca.* April 12, 2009. Inoculum of both pathogens was produced on sterilized rice grains using the protocol of Holmes and Benson (19). In summary 18 ml (0.6 fl oz) of distilled water was added to 25 g (0.9 oz) of long-grain white rice in 250-ml Erlenmeyer flasks; flasks were autoclaved for 30 min and then autoclaved again 24 hr later for 40 min. After sterilizing, three PARPH-V8 agar plugs taken from the margins of actively growing *Phytophthora* colonies were added to the rice. Flasks were then placed in the dark at 25C (77F) and gently shaken daily to ensure uniform colonization of the rice grains. Inoculum was incubated for 14 days. Twelve colonized rice grains were added to each 20.0 litre pot around the peripheral edge of the root ball to a depth of 5 cm (2 in). Plants were watered immediately following inoculation and then watered daily to maintain conditions conducive for *Phytophthora* development. In addition to daily watering, plants were flooded once a week for 24 hr to further encourage root rot development. All plants were located outdoors subject to natural climatic weather for 14 weeks (July 28, 2009) before final evaluation of plant health and *Phytophthora* pathogen severity.

Phytophthora root rot lesion severity. Severity of both *Phytophthora* pathogens was assessed by recording the percent infection of each root system using a modified pre-transformed scale based on Lyles *et al.* (25): 0 = 0% no visible symptoms of *Phytophthora* infection, 1 = 1 to 15% of the root system infected, 2 = 16 to 50% of the root system infected, 3 = 51 to 85% of the root system infected, and 4 = >85% of the root system infected. All plants were harvested and the root system carefully washed. Water soaked, discoloured regions of the root were classified as *Phytophthora* infected (20).

Tree vitality. Five leaves randomly selected throughout the crown per tree were used for chlorophyll fluorescence and chlorophyll content measurements. Leaves were adapted to darkness for 30 min by attaching light-exclusion clips to the leaf surface, and chlorophyll fluorescence was measured using a HandyPEA portable fluorescence spectrometer (Hansatech Instruments Ltd, King's Lynn, UK). Measurements were recorded up to 1 sec with a data-acquisition rate of 10 µs for the first 2 ms and of 1 ms thereafter. The fluorescence responses were induced by a red (peak at 650 nm) light of 1500 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetically active radiation (PAR)

Table 1. Influence of pure mulches on *P. cactorum and P. criticola* root rot lesion severity of horse chestnut (*Aesculus hippocastanum* L.)

Mulch	*P. cactorum*	*P. criticola*
Control (no mulch)	3.8[z]c[y]	3.6c
Common hawthorn	1.8ab	2.0ab
Cherry	2.1ab	2.3b
Silver birch	2.1ab	2.4b
English oak	1.5a	1.7ab
Evergreen oak	2.4b	2.2ab
Beech	1.5a	1.4a
P value	0.037	0.001

[z]All values mean of 10 trees.

[y]Lower case letters indicate significant differences between means ($P < 0.05$) based on Tukey's Honestly Significant Difference test.

intensity provided by an array of six light-emitting diodes. The ratio of variable (Fv = Fm – Fo) to maximal (Fm) fluorescence, i.e., Fv/Fm where Fo = minimal fluorescence, of dark-adapted leaves was used to quantify any effects on leaf tissue. Fv/Fm is considered a quantitative measure of the maximal or potential photochemical efficiency or optimal quantum yield of photosystem II (35). Likewise Fv/Fm values are the most popular index used as a measure of plant vitality and early diagnostic of stress (26).

Leaf chlorophyll content was measured at the mid point of the leaf next to the main leaf vein by using a hand held optical Minolta chlorophyll meter SPAD-502 (Spectrum Technologies, Inc. Plainfield, IL, USA). Calibration was obtained by measurement of absorbance at 663 and 645 nm in a spectrophotometer (PU8800 Pye Unicam, Portsmouth, UK) after extraction with 80% v/v aqueous acetone (regr. eq. $y = 5.66 + 0.055x$; r^2 adj = 0.89, P = <0.01) (23).

The light-induced CO_2 fixation (Pn) was measured in pre-darkened (20 min), fully expanded leaves from near the top of the canopy (generally about 4 nodes down from the apex) by using an Infra Red Gas Analyser (LCA-2 ADC BioScientific Ltd Hoddesdon, Herts, UK). The irradiance on the leaves was 700 to 800 ($mol \cdot m^{-2}$ photosynthetically active radiation saturating with respect to Pn; the velocity of the airflow was 1 $ml \cdot s^{-1} \cdot cm^{-2}$ of leaf area. Calculation of the photosynthetic rates was carried out according to Von Caemmerer and Farquhar (34). Two leaves per tree were selected for measurements.

The carbohydrate (glucose + fructose + sucrose) and starch concentration within root tissue of insecticide and non-insecticide treated trees was quantified using HPLC (36). Fine roots were collected by using a root density corer. Four 20 cm (8 in) deep, 3 cm (1.2 in) diameter cores were taken (North, South, East, West) 10 cm (4 in) from the base of each tree and stored at 4C until processing. Soil was washed from the roots, and horse chestnut roots were separated from debris and by hand.

Effects of mulch application on chlorophyll fluorescence, photosynthetic rates, chlorophyll concentrations and growth were determined by both two and one way analyses of variance (ANOVA) as checks for normality and equal variance distributions were met using an Anderson-Darling test. Differences between treatment means were separated by Tukey's Honestly Significant Difference test (HSD) at the 95% confidence level ($P > 0.05$) using the 'GenStat for Windows 13th edition' statistics system (VSN International Ltd., Hemel Hempstead, UK).

Results and Discussion

There was a significant effect of mulch on growth, tree vitality and the *Phytophthora* root rot lesion severity scale used in this investigation (Tables 1–3). In all cases, however, none of the mulched or non-mulched control trees died following *Phytophthora* infection. Irrespective of *Phytophthora* pathogen, leaf area, leaf, shoot, root and total plant dry weight following application of a pure mulch was, in virtually all instances, significantly ($P < 0.05$) higher than non-mulched *Phytophthora* infected controls. However, differences in the magnitude of growth induced between pure mulches following *Phytophthora* infection were recorded (Tables 2 and 3). Based on increased total plant dry weight as a measure of total plant biomass mulch efficacy following inoculation with *P. cactorum* was in the order hawthorn > cherry > beech > evergreen oak > silver birch > English oak > control. In the case of *P. criticola* mulch efficacy was in the order

Table 2. Influence of pure mulches on growth, tree vitality and survival of containerised horse chestnut (*Aesculus hippocastanum* L.) at week 18 after inoculation with *P. cactorum*.

	Growth					Tree vitality				
Mulch	Leaf area[z]	Leaf DW[z] (g)	Shoot DW[z] (g)	Root DW[z] (g)	Total plant DW[z] (g)	Chlorophyll content	Fv/Fm[y]	Pn[y]	Root carbohydrate concentration[z] ($g \cdot 100g^{-1}$ DW)	Survival (%)
Control (no mulch)	466a[x]	2.98a	34.9a	32.5a	70.4a	31.7a	0.411a	2.18a	1.3a	100
Common hawthorn	1234bc	8.14b	44.5b	50.6c	103.2b	39.0bc	0.703b	3.34b	2.0bc	100
Cherry	1453d	9.29c	41.3ab	47.2bc	97.8b	37.4ab	0.699b	3.69cd	2.2bcd	100
Silver birch	1127b	7.22b	39.4ab	42.6b	89.2b	39.8bc	0.651b	4.07d	2.3cd	100
English oak	1090b	8.00b	37.2ab	41.5b	86.7ab	40.1bc	0.607b	2.77b	2.5d	100
Evergreen oak	1388cd	9.94c	39.8ab	44.2bc	93.9b	44.5c	0.711b	3.55cd	2.0bc	100
Beech	1448d	9.70c	40.1ab	46.1bc	95.9b	43.7bc	0.682b	3.27bc	1.9b	100
P value	<0.001	<0.001	<0.001	<0.001	<0.001	0.006	0.005	<0.001	<0.001	—

[z]Leaf area, leaf, shoot, root, total plant dry weight and root carbohydrate content mean of 10 trees. Leaf chlorophyll content and Fv/Fm mean of 10 trees, 5 leaves per tree. Pn mean of 10 trees, 2 leaves per tree.

[y]Fv/Fm = chlorophyll fluorescence, Pn = light-induced CO_2 fixation.

[x]Lower case letters indicate significant differences between means ($P < 0.05$) based on Tukey's Honestly Significant Difference test.

Table 3. Influence of pure mulches on growth, tree vitality and survival of containerised horse chestnut (*Aesculus hippocastanum* L.) at week 18 after inoculation with *P. criticola*.

	Growth					Tree vitality				
Mulch	Leaf area[z]	Leaf DW[z] (g)	Shoot DW[z] (g)	Root DW[z] (g)	Total plant DW[z] (g)	Chlorophyll content	Fv/Fm[y]	Pn[y]	Root carbohydrate concentration[z] (g·100g^{-1} DW)	Survival (%)
Control (no mulch)	504a[x]	3.17a	35.0a	28.6a	66.8a	27.4a	0.442a	1.98a	1.4a	100
Common hawthorn	1340cd	9.26cd	41.7b	47.1c	98.1b	36.8b	0.654b	2.68bc	1.9b	100
Cherry	1243bc	8.60bc	42.5b	41.8bc	92.9b	38.3bc	0.626b	2.77bc	2.0bc	100
Silver birch	1446de	10.03de	39.0ab	44.9bc	93.9b	37.2b	0.678b	2.53bc	2.0bc	100
English oak	1119b	7.72b	38.1ab	39.4b	85.2b	39.6bc	0.621b	2.40ab	1.8b	100
Evergreen oak	1405d	9.66cd	39.8ab	40.9bc	90.4b	38.0bc	0.696b	2.70bc	2.2c	100
Beech	1571e	10.97e	41.6b	42.0bc	94.6b	43.4c	0.701b	2.89c	2.2c	100
P value	0.001	<0.001	0.007	<0.001	<0.001	0.050	0.039	<0.001	0.001	—

[z]Leaf area, leaf, shoot, root, total plant dry weight and root carbohydrate content mean of 10 trees. Leaf chlorophyll content and Fv/Fm mean of 10 trees, 5 leaves per tree. Pn mean of 10 trees, 2 leaves per tree.

[y]Fv/Fm = chlorophyll fluorescence, Pn = light-induced CO_2 fixation.

[x]Lower case letters indicate significant differences between means ($P < 0.05$) based on Tukey's Honestly Significant Difference test.

hawthorn > beech > silver birch > cherry > evergreen oak > English oak. Following inoculation with *P. cactorum*, leaf chlorophyll content, chlorophyll fluorescence Fv/Fm ratios, photosynthetic rates and root carbohydrate concentration ranged from 18–40%, 48–73%, 50–87% and 46–92% higher in pure mulched compared to non-mulched controls. In the case of *P. criticola* leaf chlorophyll content, chlorophyll fluorescence Fv/Fm ratios, photosynthetic rates and root carbohydrate concentration ranged from 34–48%, 40–59%, 21–43% and 29–57% higher in pure mulched respectively compared to non-mulched controls. Application of a pure mulch had a significant influence on *Phytophthora* severity of both pathogens based on visual root rot lesion severity symptoms. In the case of *P. cactorum* root lesion severity was reduced by 53% (hawthorn pure mulch), 45% (cherry, silver birch pure mulch), 61% (English oak, beech pure mulch) and 39% (evergreen oak pure mulch) compared to non-mulched controls. In the case of *P. criticola*, root lesion severity was reduced by 44% (hawthorn pure mulch), 36% (cherry pure mulch), 33% (silver birch pure mulch), 53% (English oak pure mulch), 39% (evergreen oak pure mulch) and 61% (beech pure mulch) respectively compared to non-mulched controls. In all cases these percent reductions were significant from non-mulched controls.

Results of this study recorded a positive influence of pure mulches on growth and vitality of horse chestnut trees and a reduction in root rot lesion severity caused by *P. cactorum* and *P. criticola* following artificial inoculation of containerised white flowering horse chestnut trees. In the case of *P. cactorum*, reductions in root rot lesion severity ranged from 39–61% while in the case of *P. criticola* reductions in root rot lesion severity ranged from 33–61% following application of a pure mulch compared to non-mulched controls. As *Phytophthora* pathogens destroy the fine absorbing roots of plants leading to loss of water and nutrient absorbing capacity as well as stored root carbohydrate reserves then reductions in *Phytophthora* rot lesion severity would account for the significant improvements in growth (leaf area, leaf, shoot, root and total plant dry weight) and tree vitality (leaf chlorophyll content, chlorophyll fluorescence Fv/Fm ratios, photosynthetic rates and root carbohydrate concentration) recorded in this study (2, 13, 37).

Previous studies have shown mulches can provide an integral cultural control method for suppressing disease development of several plant pathogens. Short-term effects include increased soil moisture, soil temperature moderation, improved soil nutrition, aggregation and drainage. Thus, mulches maintain a soil environment for healthy plant growth and induce a soil environment sub-optimal for opportunistic soil-borne pathogens (33). Likewise the physical presence of a mulch can reduce splashing of rain or irrigation water, which can carry spores of disease organisms up to the stems or leaves of susceptible plant species (3). With respect to elucidating the suppressive nature of mulches on *Phytophthora* pathogens, work by Downer *et al.* (6, 7) has been key to identifying mulching effects on the incidence of *Phytophthora*. Cellulose forms part of the component of the primary cell wall of green plants acting as a structural polymer to provide plant rigidity (12). Following the application of a mulch to a soil surface the concomitant microbial and fungal population buildup promotes a reservoir of enzymatic activity such as cellulase (β-1,4-glucanase) and laminarinase (β-1,3-glucanase) 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 (6, 7). In addition, organic 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) (11).

Growth effects on pure mulched trees recorded in this study may also relate to allelochemicals released as each mulch degraded over time (10, 21, 29). For example allelopathetic testing of water soluble extracts of pure mulches derived from hawthorn, cherry, silver birch, English and evergreen oak positively increased pea seed germination, relative growth rate and photosynthetic efficiency of established seedlings (29). Extracts of box elder have been shown to stimulate the growth of a range of grasses while in recent studies the effect of fresh and composted pure mulch derived from *Eucalyptus cladocalyx* was found to have a positive effect in transplant performance of *Platanus racemosa* (9). Furthermore fresh pine bark mulch has been shown to posi-

tively affect establishment of English oak (15). Both hawthorn and cherry mulches have been shown to be naturally high in carbohydrates such as sucrose, glucose and sorbital (24, 31). Applications of carbohydrates to transplanted trees have been shown to be effective at stimulating root vigor and in turn alleviating transplant stress and increasing survival rates of newly planted trees such as oak, birch and beech (14, 27).

On a note of caution, however, other researchers have found application of water soluble extracts obtained from beech, pine, eucalyptus and acacia mulches suppressed germination of a range of weed seeds (30). Likewise pure mulches derived from cypress trees have been shown to reduce the growth of hydrangea, spirea and viburnum compared to a range of garden centre bought mulches (16). Cypress trees are noted for their resistance to decay fungi which is associated with the presence of phenolics compounds within woody tissue. Consequently, it was suggested these phenolics would be leached into the soil in turn inhibiting root growth (4). Pure mulches derived from *Eucalyptus* foliage have been found to contain phytotoxic organic oil and acid residues three months after application that in turn were toxic to germinating seedlings of several plants (9, 22). Further studies of allelochemicals proving toxic to plants have been reported by Terzi (32) and De Feo (5).

In conclusion, results of this study show that application of a pure mulch can provide a reduction in root rot lesion severity caused by *P. cactorum* and *P. criticola* and subsequent increase in tree growth and vitality. With pressures to find non-chemical means of pathogen control stimulated by public and government demands to reduce pesticide usage pure mulches potentially have a positive impact for those involved in the care and maintenance of urban, nursery, forestry and orchard trees as well as horticultural crop production systems. Although further research is required into determining the mechanistic basis for pathogen suppression, practically pure mulches require little capital investment and only small adjustments to standard management aftercare procedures.

Literature Cited

1. Agostini, J.P., P.M. Bushong, and L.W. Timmer. 2003. Glasshouse evaluation of products that induce host resistance for control of scab, melanose, and *Alternaria* brown spot of citrus. Plant Dis. 87:69–75.

2. Brown, A.V. and C.M. Brasier. 2007. Colonization of tree xylem by *Phytophthora ramorum*, *P. kernoviae* and other *Phytophthora* species. Plant. Path. 56:227–241.

3. Chalker-Scott, L. 2007. Impact of mulches on landscape plants and the environment — A review. J. Environ. Hort. 25:239–249.

4. Crohn, D.M. and M.L. Bishop. 1999. Proximate carbon analysis for compost production and mulch use. Trans. ASAE 42:791–797.

5. De Feo, V., L. DeMartino, E. Quaranta, and C. Pizza. 2003. Isolation of phytotoxic compounds from tree-of-heaven (Ailanthus altissima Swingle). J. Agri. Food. Chem. 51:1177–1180.

6. Downer, A.J., J.A. Menge, and E. Pond. 2001a. Effects of cellulytic enzymes on *Phytophthora cinnamomi*. Biol. Control 91:839–846.

7. Downer, A.J., J.A. Menge, and E. Pond. 2001b. Association of cellulytic enzyme activities in Eucalyptus mulches with biological control of *Phytophthora cinnamomi*. Biol Control 91:847–855.

8. Downer, A.J., B. Faber, and J.A. Menge. 2002. Factors affecting root rot control in mulched avocado orchards. HortTechnology 12:601–605.

9. Downer, A.J. and B. Faber. 2005. Effect of *Eucalyptus cladocalyx* mulch on establishment of California sycamore (*Platanus racemosa*). J. App. Hort. 7:90–94.

10. Duryea, M.L., R.J. English, and L.A. Hermansen. 1999. A comparison of landscape mulches: Chemical, allelopathic and decomposition properties. J. Arboriculture 25:88–97.

11. Elad, Y., I. Chet, and Y. Henis. 1982. Degradation of plant pathogenic fungi by *Trichoderma harzianum*. Can. J. Microbiol. 28:719–725.

12. Eriksson, K.E.L., R.A. Blanchette, and P. Ander. 1990. Biodegredation of cellulose. p. 89–180. *In*: Microbial and Enzymatic Digestion of Wood and Wood Components. K.E.L Eriksson, R.A. Blanchette, and P. Ander, eds. Springer-Verlag, New York.

13. Erwin, D.C. and O.K Ribeiro. 1996. Phytophthora Diseases World-Wide. The American Phytopathology Society, St Paul, MN.

14. Fraser, G.A. and G.C. Percival. 2003. The influence of biostimulants on growth and vitality of three urban tree species following transplanting. Arboriculture J. 27:43–57.

15. Gilman, E.F. and J. Garbosky. 2004. Mulch and planting depth affect live oak (*Quercus virginiana* Mill.) establishment. J. Arboriculture 30:311–317.

16. Gregg, B. 2005. Mulch madness: Effective use of landscape mulch. The Landsculptor. December: 35–37.

17. Gozzo, F. 2003. Systemic acquired resistance in crop protection: From nature to a chemical approach. J. Agric. Food. Chem. *51:*4487–4503.

18. Hansen, E.M., P.B. Hamm, and L.F. Roth. 2008. Alien forest pathogens: *Phytophthora* species are changing world forests. Boreal Environ. Res. 13:33–41.

19. Holmes, K.A. and D.M. Benson. 1994. Evaluation of *Phytophthora parasitica* var. *nicotianae* as a biocontrol for *Phytophthora parasitica* on *Catharanthus roseus.* Plant Dis. 78:193–199.

20. Jackson, T.J., T. Burgess, I. Colquhoun, and G.E.StJ. Hardy. 2000. Action of the fungicide phosphite on *Eucalyptus marginata* inoculated with *Phytophthora cinnamomi*. Plant. Pathol. 49:147–154.

21. Jin, Z., Y. Chung, K. Iiyama, and S. Watanabe. 2002. Changes of chemical components of leaf litter of *Ginko biloba* during mulching. J. Arboriculture 28:171–177.

22. Kohli, R.K. and D. Singh. 1991. Allelopathic impact of volatile components from Eucalyptus on crop plants. Biol. Plantarum 33:475–483.

23. Lichtenthaler, H.K. and U. Rinderle. 1987. The role of chlorophyll fluorescence in the detection of stress conditions in plants. CRC. Crit. Rev. Analytical. Chem. 19:S29–S85.

24. Lindqvist, H. and H. Asp. 2002. Effects of lifting date and storage time on changes in carbohydrate content and photosynthetic efficiency in three deciduous species. J. Hort. Sci. Biotech. 77:346–354.

25. Lyles, J.L., J.D. MacDonald, and D.W. Burger. 1992. Short and long-term heat stress effects on *Phytophthora* root rot of Hibiscus. HortScience 27:414–416.

26. Meinander, O., S. Somersalo, T. Holopainen, and R.J. Strasser. 1996. Scots pine after exposure to elevated ozone and carbon dioxide probed by reflectance spectra and Chlorophyll *a* fluorescence transients. J. Plant. Physiol. 148:229–236.

27. Percival, G.C., G.A. Fraser, and S. Barnes. 2004. Soil injections of carbohydrates improve fine root growth of established urban trees. Arboriculture J. 28:95–103.

28. Percival, G.C. and I. Haynes. 2008. The influence of systemic inducing resistance chemicals for the control of oak powdery mildew (*Microsphaera alphitoides*) applied as a therapeutic treatment. Arboric. Urban. Forestry 34:191–200.

29. Percival, G.C., K. Noviss, and I. Haynes. 2009. Field evaluation of systemic inducing resistance chemicals at different growth stages for the control of apple (*Venturia inaequalis*) and pear (*V.pirina*) scab. Crop. Prot. 28:629–633.

30. Schumann, A.W., K.M. Little, and N.S. Eccles. 1995. Suppression of seed germination and early seedling growth by plantation harvest residues. South African J. Plant and Soil 12:170–172.

31. Symeonidou, M.V. and G.P. Buckley. 1999. The effect of pre-planting desiccation stress and root pruning on the physiological condition and subsequent field performance of one year old *Prunus avium* and *P. cerasifera* seedlings. J. Hort. Sci. Biotech. 74:386–394.

32. Terzi, I. 2008. Allelopathic effects of Juglone and decomposed walnut leaf juice on muskmelon and cucumber seed germination and seedling growth. African J. Biotech. 7:1870–1874.

33. Turchetti, T., G. Maresi, D. Nitti, A. Guidotti, and G. Miccinesi. 2003. Il mal dell'inchiostro nel Mugello (Fi): danni ed approcci di difesa (Chestnut ink disease in the Mugello area: Damage and control). Monti e Boschi 54:22–26.

34. Von Caemmerer, S. and G.D. Farquhar. 1981. Some relationships between the biochemistry of photosynthesis and the gas exchange of leaves. Planta 153:376–387.

35. Willits, D.H. and M.M. Peet. 2001. Using chlorophyll fluorescence to model leaf photosynthesis in greenhouse pepper and tomato. Acta. Hort. 507:311–315.

36. Wilson, R., A. Cataldo, and C.P. Andersen. 1995. Determination of total nonstructural carbohydrates in tree species by high-performance anion-exchange chromatography with pulsed amperometric detection. Can. J. For. Res. 25:2022–2028.

37. Zwart, D.C. and Soo-Hyung, K. 2012. Biochar amendment increases resistance to stem lesions caused by *Phytophthora* spp. in tree seedlings. HortScience 47:1736–1740.