Influence of Pure Mulches on Survival, Growth and Vitality of Containerized and Field Planted Trees[1]

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Abstract

Mulching as a means of reducing soil moisture stress, suppressing weed growth and improving soil fertility is widely recognised throughout the arboricultural, nursery and landscape industry. The influence of a pure mulch, i.e. mulch derived solely from one tree species, has received little study. The purpose of this research was to evaluate 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.) on survival and growth of two commonly planted urban trees (European beech, common hawthorn) following containerization and two economically important fruit trees (apple (*Malus* cv. Gala), pear (*Pyrus communis* 'Concorde') following field transplanting. In the case of beech, a highly sensitive transplant species, survival rates were increased from 10 to 70% following containerization. In the case of hawthorn, a transplant tolerant species, no difference in survival rates between mulched and non-mulched controls were recorded, however, marked differences in growth between, and compared to, non-mulched control trees existed. In field planted apple and pear trees crown volume and fruit yield could be increased by 53 and 100%, respectively, by application of an appropriate pure mulch. Allelochemical testing of water soluble extracts of each pure mulch indicated positive benefits in terms of enhanced seed germination and seedling relative growth rates with one exception — a mulch derived from beech where no positive benefits were found. 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. Pure mulches require no capital investment and only small adjustments to standard management aftercare procedures.

Index words: root vigour, tree vitality, chlorophyll fluorescence, chlorophyll content, tree establishment.

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.), apple (*Malus* cv. Gala), pear (*Pyrus communis* 'Concorde'), pea (*Pisum sativum* 'Maestro').

Significance to the Nursery Industry

High mortality rates and/or poor growth during the initial years of establishment often occur following field planting or containerization of bare rooted ornamental trees. The positive benefits of mulching as a means of enhancing transplant survival rates are well documented. Consequently, mulching is recommended to reduce transplant losses and improve growth after planting. The influence of a pure mulch, i.e. mulch derived solely from one tree species, has received little study. Results of this investigation show that use 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.) can be of benefit in reducing transplant losses and enhancing growth of two commonly planted urban trees following containerization and two economically important fruit trees following field transplanting. Selection of an appropriate pure mulch is important, however, as effects on growth and vitality vary markedly between mulches.

Introduction

Plant moisture stress caused by drought has become a major cause of tree decline within UK landscapes (6, 29). In areas where newly planted trees are not irrigated, initial establishment relies heavily on precipitation. If the transplant does not receive sufficient precipitation during the period of new root regeneration, its internal water deficits increase considerably due to excessive water transpiration and non-absorption of water from the soil (21). In addition, the transplanting procedure causes, by definition, a reduction of the root system. In the case of bare rooted trees this loss may be as high as 95% of the root length (36) or up to 84% of the root dry weight (13) even when acceptable nursery practices have been followed. Following leafing out, the capacity of the roots to supply the leaves with water can be severely restricted. Water deficits are therefore regarded as the major causes of failure of newly planted trees planted within urban landscapes (18).

Mulching as a means of reducing soil moisture stress as well as weed suppression and fertilising have been used in arboricultural, agricultural, fruit and ornamental crops production systems for decades (4). Benefits of mulches include minimizing fluctuations of soil temperature and soil moisture, thus inducing root growth, weed suppression, enriching the soil with nutrients, preventing soil erosion from heavy rains, regulation of pH and cation exchange capacity in favor of the tree, suppressing pathogens, inducing soil microbial activity and improving aeration (3, 12, 30). In addition, mulches can prevent mower and trimmer damage to the tree trunk and act as a buffer in preventing excess de-icing salts from percolating into the soil to around the root zone (35).

Landscape mulches usually include both inorganic (e.g. crushed stone, crushed brick, gravel, polyethylene films) and organic compounds (shredded branches and leaves, softwood and hardwood tree bark, wood chips, sawdust, pine straw,

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recycled pallets and mixes of the above). The use of organic rather than inorganic mulches in urban landscapes is suggested as superior for improved growth of establishing and established trees (2, 10, 16, 23).

Even though organic mulches are widely recommended and applied, few studies exist focusing on the efficacy of organic mulches derived solely from one tree species, defined as a pure mulch for the purposes of this study, on transplant success. Of the information available, 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 (14).

The purpose of the conducted research was to evaluate a range of pure mulches on transplant survival and growth of i) two commonly planted urban trees, namely European beech (*Fagus sylvatica* L.) and common hawthorn (*Crataegus monogyna* JACQ.) following containerization, and ii) two economically important fruiting trees within the UK, namely apple (*Malus* cv. Gala) and pear (*Pyrus communis* Concorde) following field transplanting. In addition, allelochemical testing of each pure mulch on seed germination and relative growth rates of seedling material was determined.

Materials and Methods

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).

Fifteen cuttings, 6 cm (2.4 in) long from each test species were inserted into a 100 ml (3 fl oz) centrifuge tube with the cutting bases in 10 ml (0.3 fl oz) distilled water. Cuttings were centrifuged for 1 h at a speed of 2000 rpm (1090 g) and temperature of 20C (68F). After centrifugation, the 10 ml (0.3 fl oz) water soluble extract solution was filtered through Whatman No 1 filter paper (19). Evaluation of allelopathic properties was determined by a pea seed bioassay. The system works on the premise that seed germination is extremely sensitive to any form of soil contamination (10). Consequently 50 pea (pea (*Pisum sativum* 'Maestro') seeds were soaked in each water soluble extract for two hours and then sown into a seed tray containing a general purpose seed compost (loamy texture, with 23% clay, 46% silt, 31% sand, 3.1% organic carbon, pH 6.6). Percent germination was then assessed at day 10 after sowing. Of the seeds that had germinated, the relative growth rate between days 10 and 25 was assessed.

$$RGR = (\log_e W_2 - \log_e W_1) / (t_2 - t_1)$$

Where W and W are total dry weight at times t_1 and t_2 respectively.

In a separate experiment, individual pea plants were germinated and at day 20 after germination, ten plants were sprayed with each water soluble extract and effects on photosynthetic efficiency as a measure of tree vitality recorded using a non-destructive chlorophyll fluorescence index (27). All allelopathy experiments were conducted under glasshouse conditions, i.e. 22 ± 2C (72 ± 36F), supplemented with 400W high pressure sodium lamps (SON/T) providing a photoperiod of 16 h light/8 h dark and minimum 250 $\mu mol \cdot m^{-2} \cdot s^{-1}$ Photosynthetically Active Radiation (PAR) at the seed compost surface.

Bare-rooted *Fagus sylvatica* L. and *Crataegus monogyna* JACQ. (transplant sensitive and resistant respectively) trees were obtained from a commercial nursery grower (Farnham Common Nurseries Ltd., Slough, UK). The physical characteristics of twenty trees selected at random were destructively analyzed to provide an estimation of stock uniformity for experimental purposes. Hawthorn: height = 92.3 ± 7.40 cm (36.9 ± 3.0 in), stem diameter = 3.1 ± 0.18 cm (1.24 ± 0.07 in), height:stem diameter ratio = 29.8 ± 0.98, shoot dry weight = 19.9 ± 1.38 g (0.71 ± 0.05 oz), root dry weight = 15.8 ± 0.86 g (0.57 ± 0.03 g), root:shoot ratio = 0.79 ± 0.04, root area = 389.6 ± 27.2 cm^2 (155.8 ± 10.9 in^2). Beech: height = 87.1 ± 5.56 cm (34.8 ± 2.22 in), stem diameter = 2.36 ± 0.12 cm (0.94 ± 0.05), height:stem diameter ratio = 36.9 ± 2.01, shoot dry weight = 28.9 ± 3.20 g (1.03 ± 0.11 oz), root dry weight = 72.7 ± 7.04 g (2.60 ± 0.25 oz), root:shoot ratio = 2.49 ± 0.32, root area = 1023.5 ± 68.90 cm^2 (409.4 ± 27.6 in^2). All remaining experimental trees were then further root pruned by removal of about 65% (*Crataegus monogyna* JACQ.) and 85% (*Fagus sylvatica* L.) of total root volume to produce a root:shoot ratio of 0:33; a ratio associated with transplant shock in trees (1). Trees were then sorted into bundles of 20 trees, sealed in plastic bags, placed inside larger paper bags, and stored at 6 ± 0.5C (43 ± 33F) in darkness. Trees were removed from cold storage (February 8, 2005) and containerized into 7.5 liter (1.9 gal) pots containing a John Innes No. 2 compost medium (bulk density: 800–950 $g \cdot liter^{-1}$, (28.5–33.9 $oz \cdot 0.26\ gal^{-1}$) moisture content: 15–30% by weight, pH: 6–7, conductivity: 400–600$\mu S \cdot cm^{-1}$). Each pure mulch (see mulch preparation) was applied to each pot at a depth of 15 cm (6 in) on February 10, 2005. Pots were arranged in a randomized block design using 20 trees per mulch treatment. Non-mulched trees acted as controls. Pots were placed outdoors on a black polyethylene mat to avoid under growing weeds at 1.5 m (4.95 ft) spacings to reduce competition for light. Pots were re-randomized every 4 weeks. No fertilizer was applied during the experimental period and weeds were removed manually from pots when observed. Irrigation was applied as required. The effect of each pure mulch on survival, growth and tree vitality were recorded at week 20 (September 5, 2006) after bud break with bud break occurring *ca*. April 18, 2006.

The apple trial site consisted of a 0.75 ha (1.9 A) block of apple (*Malus* cv. Gala) and the pear trial site consisted of a 0.90 ha (2.3 A) block of pear (*Pyrus communis* 'Concorde'). Planting distances were based on 3 × 3 m (9.9 × 9.9 ft) spacing and all trees were planted in mid-January 2006. Trees used for experiments had an average height of 1.5 ± 0.15 m (5 ± 0.5 ft) with mean trunk diameters of 10 ± 1.2 cm (4 ± 0.5 in) at 45 cm (18 in) above the soil level. Each tree was mulched to a depth of 12–15 cm (5–6 in) using one of the six pure mulches (see mulch preparation), and all mulches were applied at the same time as the pear and apple trees were planted The mulched zone around each tree was 2 × 2 m (6.6 × 6.6 ft) and none mulched trees acted as controls. The field trial sites were located at the University of Reading Shinfield Experimental Site, University of Reading, Berkshire (51°43'N, –1°08'W).

The soil was a sandy loam containing 4–6% organic matter with a pH of 6.4. Weeds were controlled chemically using glyphosate ((Roundup; Green-Tech, Sweethills Park, Nun Monkton, York, UK) prior to planting, and by hand during the trial. No irrigation was required and no fertilizer was applied to trees during the experiment. A minimal insecticide and fungicide program based on the residual pyrethroid insecticide deltamethrin (Product name Bandu, Headland Agrochemicals Ltd, Saffron Walden, Essex, UK) and triazole derivative penconazole (Product name Topas, Syngenta Crop Protection UK Ltd, Whittlesford, Cambridge, UK) was applied every three months during each growing season commencing in May 2006 to September 2006. All sprays were applied using a Tom Wanner Spray Rig sprayer at 40 ml (1.2 fl oz) deltamethrin and 150 ml (4.5 fl oz) penconazole per 100 liters (26 gal) of water. Trees were sprayed until runoff, generally 0.25 liters (0.07 gal) insecticide/fungicide per tree. All treatments were applied in randomized complete block design with 10 replications. The effect of each pure mulch on growth and vitality were recorded at week 20 (September 19, 2006) after bud break with bud break occurring *ca.* April 28, 2006.

Five leaves that were randomly selected throughout the crown per tree were used for chlorophyll fluorescence and chlorophyll content measurements. Leaves were then tagged to ensure that only the same leaf was measured throughout. 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) intensity provided by an array of six light-emitting diodes. The ratio of variable ($Fv = Fm - Fo$) to maximal (Fm) fluorescence, i.e. $Fv{\cdot}Fm^{-1}$, where Fo = minimal fluorescence, of dark-adapted leaves was used to quantify any effects on leaf tissue. $Fv{\cdot}Fm^{-1}$ is considered a quantitative measure of the maximal or potential photochemical efficiency or optimal quantum yield of photosystem II (37). Likewise $Fv{\cdot}Fm^{-1}$ 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; $P \leq 0.01$) (24).

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.

Containerized trees were destructively harvested, and leaf, shoot, and root dry weight recorded after oven drying at 85C (185F) for 48 hr. Leaf areas were quantified using a Delta-T area meter. Stem diameter was quantified using Manta blue precision calipers (Langsele, Haglof AB, Sweden) at 60 cm (24 in) above ground level. Height was recorded by measuring the distance from the tip of the leading apical shoot to the soil surface. Soil was gently removed from the root system by gently shaking the root system after lifting using a garden fork and then washing with water through a 4 mm (0.16 in) screen to collect any roots accidentally removed during the shaking and washing process. Once the soil was removed the root system was easily distinguishable. The number of new white roots >1 cm (0.4 in) was counted as a measure of the root growth potential (RGP) and the root length (the straight line distance from the trunk to the furthest root tip) was measured.

Effects of pure mulches on field transplanted trees was quantified by recording mean fruit yield per tree by weighing all fruit on each tree at harvest and dividing by the number of trees per treatment.

Crown volume (Cv) was estimated from the crown width (D) and crown depth (L) using the paraboloid form of the crown (22).

$$Cv = \Pi \frac{D^2 L}{8}$$

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 9th edition' statistics system (VSN International Ltd., Hemel Hempstead, UK). Data for each species was analyzed separately. The binary data obtained (0 for death/no seed germinated, and 1 for survival/seed germinated) was subjected to survival analysis statistics using the Wilcoxon-Gehan method.

Results and Discussion

Allelopathy testing. In virtually all cases soaking of pea seedlings or direct spraying of water soluble extracts from each pure mulch onto an established plant had a positive influence on germination, relative growth rates and photosynthetic efficiency where values were increased by 11–19, 6–13 and 19–114%, respectively. The only exception to this trend were pea seeds soaked in a diffusates derived from beech where germination and RGR values were lower than controls (Table 1).

Containerized trees. There was a significant effect of mulch on the majority of growth and tree vitality parameters used in this investigation (Tables 2–3). In the case of

Table 1. Allelopathy properties of pure mulches on germination, relative growth rates and vitality of pea.

Mulch	Germination[z]	RGR[y] (g/g/day)	PI[x]
Control (no mulch)	73ab[w]	0.097a	2.49a
Common hawthorn	90c	0.111c	5.3c
Cherry	90c	0.107bc	4.19bc
Silver birch	82bc	0.108bc	4.7cd
English oak	88c	0.103ab	4.6c
evergreen oak	86b	0.103ab	5.90d
Beech	60a	0.096a	3.06ab
P value[v]	<0.071	<0.050	0.001

[z]Germination analysis statistics using the Wilcoxon-Gehan method

[y]RGR = relative growth rates; RGR values mean of germinating seeds from an initial number of 50.

[x]PI = Photosynthetic index. PI values mean of 10 plants.

[w]Lower case letters indicate significant differences between means (P = 0.05).

[v]$P < 0.05$ are considered significant based on Tukey's Honestly Significant Difference test.

hawthorn, none of the mulched or non-mulched control trees died following containerization. Survival rates for beech varied widely. Lowest survival rates were recorded in the non-mulched controls (10%) and highest survival rates (70%) recorded in trees where a pure mulch derived from hawthorn was used. Irrespective of species, root growth potential, root length, leaf area, leaf, shoot, root and total plant dry weight following application of a pure mulch was, in virtually all instances, consistently higher than non-mulched controls. However, marked differences in the magnitude of growth induced between pure mulches was recorded (Tables 2–3). For example, in the case of containerized beech, increases in total plant dry weight ranged from 28 (beech pure mulch) to 319% (hawthorn pure mulch) greater than non-mulched controls. In the case of hawthorn, increased total plant dry weight ranged from 7 (evergreen oak pure mulch) to 30% (cherry pure mulch) greater than non-mulched controls. Similar variations in all other growth parameters measured in this study (height, RGP, root length, leaf area, leaf, shoot, root dry weight) were recorded in response to pure mulching after containerization (Tables 2–3). Based on increased total

Table 2. Influence of pure mulches on growth, tree vitality and survival of containerized beech (*Fagus sylvatica* L.) at week 20 after bud break.

	Growth									Tree vitality			
Mulch	Height (cm)	RGP[z]	Root length (cm)	Leaf area	Leaf DW[z] (g)	Shoot DW (g)	Root DW (g)	Total plant DW (g)	R:S[z]	Chloro-phyll content	$Fv·Fm^{-1}$[z]	Pn[z]	Survival[y] (%)
Control (no mulch)	24.0a[x]	3.9a	19.0a	16a	0.85a	9.9a	21.8a	32.6a	2.2e	3.06a	0.212a	2.08a	10a
Common hawthorn	105.7bc	8.7b	46.6cd	973b	6.04bc	48.9d	49.3b	104.2c	1.0a	6.09b	0.723b	4.01b	70d
Cherry	139.4c	6.2ab	51.0d	1390b	8.32c	40.3cd	48.5b	97.1c	1.2ab	5.97b	0.692b	3.56a	50cd
Silver birch	96.7 b	5.0a	39.3bc	1036b	1.71ab	16.1ab	23.8ab	41.6ab	1.5bc	6.49b	0.606b	4.33b	30abc
English oak	94.0b	5.5a	33.0b	579ab	3.46abc	26.0abc	39.9ab	69.4abc	2.0de	9.27c	0.584b	3.01ab	40bc
evergreen oak	124.0bc	6.0a	43.0bcd	1009b	6.29bc	34.1bcd	45.0ab	85.4bc	1.3ab	4.20a	0.574b	3.33ab	40bc
Beech	92.2b	4.2a	21.0a	119a	0.68a	17.2ab	27.3ab	45.2ab	1.7cd	3.22a	0.556b	2.98ab	20ab
P value	0.020	<0.001	0.025	0.004	<0.001	<0.001	<0.001	<0.001	0.145	0.007	0.033	<0.001	0.123

[z]RGP = root growth potential; DW = dry weight (g), R:S = root:shoot ratio, $Fv·Fm^{-1}$ = chlorophyll fluorescence, Pn = light-induced CO_2 fixation.

[y]Survival analysis statistics using the Wilcoxon-Gehan method.

[x]All values mean of surviving trees from an initial number of 20. Lower case letters indicate significant differences between means (P = 0.05). $P < 0.05$ are considered significant based on Tukey's Honestly Significant Difference test.

Table 3. Influence of pure mulches on growth, tree vitality and survival of containerized common hawthorn (*Crataegus monogyna* JACQ.) at week 20 after bud break.

	Growth									Tree vitality			
Mulch	Height (cm)	RGP[z]	Root length (cm)	Leaf area	Leaf DW[z] (g)	Shoot DW (g)	Root DW (g)	Total plant DW (g)	R:S[z]	Chloro-phyll content	$Fv·Fm^{-1}$[z]	Pn[z]	Survival[y] (%)
Control (no mulch)	122.8ab[x]	6.7a	45.8ab	630a	7.46a	30.0ab	23.0a	60.5a	0.8a	13.4ab	0.63a	3.77a	100a
Common hawthorn	136.0ab	8.4ab	52.4abc	1665c	15.28cd	32.0ab	32.5cd	79.8b	1.0a	19.1c	0.67a	4.02a	100a
Cherry	115.2a	9.2ab	61.0c	1686c	16.11d	35.2b	34.9d	86.2c	1.3c	16.4bc	0.65a	3.59a	100a
Silver birch	155.4b	10.5b	54.6bc	1267bc	12.54b	30.7ab	30.4bcd	73.6abc	1.0ab	10.6a	0.68a	4.11a	100a
English oak	128.2ab	7.2a	50.2abc	1027ab	10.97b	29.1ab	27.7abc	67.8ab	1.2bc	16.4bc	0.59a	3.86a	100a
evergreen oak	153.4b	7.5a	43.4a	1197bc	12.15bc	26.3a	26.5ab	65.0a	1.0ab	14.4b	0.64a	3.60a	100a
Beech	118.8a	8.0ab	44.8ab	1588bc	14.51cd	26.0a	34.6d	75.1abc	1.8d	15.8bc	0.59a	3.56a	100a
P value	0.012	<0.001	0.052	0.009	0.203	0.864	<0.001	<0.001	0.304	0.003	<0.091	<0.036	—

[z]RGP = root growth potential; DW = dry weight (g), R:S = root:shoot ratio, $Fv·Fm^{-1}$ = chlorophyll fluorescence, Pn = light-induced CO_2 fixation.

[y]Survival analysis statistics using the Wilcoxon-Gehan method.

[x]All values mean of surviving trees from an initial number of 20. Lower case letters indicate significant differences between means (P = 0.05). $P < 0.05$ are considered significant based on Tukey's Honestly Significant Difference test.

Table 4. **Influence of pure mulches on growth, tree vitality and survival of field transplanted apple (*Malus* cv. Gala) at the cessation of the growing season.**[z]

	Growth		Tree vitality			
Mulch	**Crown volume**	**Yield/tree (kg)**	**Chlorophyll content**	**$Fv·Fm^{-1}$**[z]	**Pn**[z]	**Survival (%)**[y]
Control (no mulch)	0.42a[x]	4.96a	18.4a	0.68a	3.23a	80a
Common hawthorn	0.83cd	7.62c	26.3cd	0.73a	3.45a	100b
Cherry	0.84d	7.57c	22.9bc	0.71a	3.60a	100b
Silver birch	0.63b	6.35b	21.5ab	0.69a	3.18a	100b
English oak	0.63b	6.14b	26.4cd	0.77a	3.36a	100b
evergreen oak	0.72bc	6.46b	23.5bcd	0.79a	3.72a	100b
Beech	0.49a	5.54ab	27.0d	0.80a	3.50a	80a
P value	<0.001	<0.001	0.002	<0.001	0.008	0.099

[z]$Fv·Fm^{-1}$ = chlorophyll fluorescence, Pn = light-induced CO_2 fixation.

[y]Survival analysis statistics using the Wilcoxon-Gehan method.

[x]All values mean of surviving trees from an initial number of 10. Lower case letters indicate significant differences between means ($P = 0.05$). $P < 0.05$ are considered significant based on Tukey's Honestly Significant Difference test.

plant dry weight as a measure of total plant biomass, mulch efficacy following containerization of beech was in the order hawthorn > cherry > evergreen oak > English oak > beech > silver birch. In the case of hawthorn mulch efficacy following containerization was in the order cherry > hawthorn > beech > silver birch > English oak > evergreen oak. Application of a pure mulch increased the root:shoot ratio in containerized hawthorn indicating greater resource allocation in favor of roots over shoots. Mulch application had no influence on chlorophyll fluorescence $Fv·Fm^{-1}$ ratios or photosynthetic rates of containerized hawthorn. However, leaf chlorophyll content ranged from 7–30% higher in mulched compared to non-mulched controls. In the case of containerized beech, mulching increased chlorophyll fluorescence $Fv·Fm^{-1}$ ratios, photosynthetic rates and leaf chlorophyll content by 260–341%, 30–192% and 5–306%, respectively, over non-mulched controls.

Field experiments. A significant effect of mulch on the majority of growth and tree vitality parameters used in this investigation was recorded (Tables 4–5). Following out-planting, survival rates of apple ranged from 80 (non-mulched control, beech pure mulch) to 100% (all remaining pure mulched trees). In the case of pear, survival rates following out-planting ranged from 90 (non-mulched control, beech and evergreen oak pure mulch) to 100% (all remaining pure mulched trees).

In both apple and pear, crown volume and fruit yield were higher in mulched compared to non-mulched controls at the end of the growing season. Marked differences in the magnitude of crown volume and fruit yield was recorded depending on the type of pure mulch used (Tables 4–5). In the case of apple, increases in crown volume ranged from 16 (beech pure mulch) to 100% (cherry pure mulch) over non-mulched controls while increases in fruit yield ranged from 11 (beech pure mulch) to 53% (hawthorn pure mulch) over non-mulched controls. In the case of pear, increases in crown volume ranged from 23 (beech pure mulch) to 286% (hawthorn pure mulch) while increases in fruit yield ranged from 8 (English oak pure mulch) to 30% (cherry pure mulch) over non-mulched controls. Based on increased crown volume over non-mulched controls, mulch efficacy following out-planting of apple was in the order cherry > hawthorn > evergreen oak > English oak > silver birch > beech. In the case of pear, pure mulch efficacy following out-planting was in the order hawthorn > cherry > silver birch > evergreen oak > English oak > beech. Irrespective of species, mulch application had no influence on chlorophyll fluorescence $Fv·Fm^{-1}$

Table 5. **Influence of pure mulches on growth, tree vitality and survival of field transplanted pear (*Pyrus communis* Concorde) at the cessation of the growing season.**

	Growth		Tree vitality			
Mulch	**Crown volume**	**Yield/tree (kg)**	**Chlorophyll content**	**$Fv·Fm^{-1}$**[z]	**Pn**[z]	**Survival (%)**[y]
Control (no mulch)	0.51a[x]	8.75a	20.5a	0.70a	3.85a	90a
Common hawthorn	1.46e	12.39cd	27.1c	0.77a	4.22a	100b
Cherry	1.33e	12.47d	28.5c	0.79a	4.56a	100b
Silver birch	0.99d	10.62b	26.1bc	0.81a	3.97a	100b
English oak	0.71bc	9.51ab	27.9c	0.73a	4.04a	100b
evergreen oak	0.88cd	10.15ab	23.0ab	0.77a	3.70a	90a
Beech	0.66ab	10.85bc	28.5c	0.77a	4.13a	90a
P value	<0.001	<0.001	0.010	0.007	0.011	0.677

[z]$Fv·Fm^{-1}$ = chlorophyll fluorescence, Pn = light-induced CO_2 fixation.

[y]Survival analysis statistics using the Wilcoxon-Gehan method.

[x]All values mean of surviving trees from an initial number of 10. Lower case letters indicate significant differences between means ($P = 0.05$). $P < 0.05$ are considered significant based on Tukey's Honestly Significant Difference test.

ratios or photosynthetic rates. However, leaf chlorophyll content ranged from 16–30% (apple) and 9–28% (pear) higher in mulched compared to non-mulched control trees.

Results of this study recorded a positive influence of pure mulches on survival, growth and tree vitality of both containerized and field planted stock. In the case of beech, a highly sensitive transplant species, application of a pure mulch increased survival rates from 10 to 70%. In the case of a transplant tolerant species such as hawthorn, no difference in survival rates between mulched and non-mulched controls were recorded; however, a marked increase in growth between, and compared to, non-mulched control trees existed. A similar response is recorded in field planted apple and pear trees. Crown volume and fruit yield were increased by 53 and 100% respectively following pure mulching, although survival rates between mulched and non-mulched controls were comparable.

In all cases the greatest increases in growth and fruit yield of both containerized and field planted stock were recorded following the application of a pure mulch derived from hawthorn or cherry. In virtually all cases, lowest increases in growth and fruit yield were recorded following the application of a pure mulch derived from beech. Allelopathetic testing of each mulch recorded, in the majority of cases, a positive increase in pea seed germination, relative growth rate and photosynthetic efficiency of established seedlings, with highest rates recorded following application of water soluble extracts obtained from hawthorn and cherry. The exception to these positive responses was following application of a water soluble extract obtained from beech where germination and relative growth rates were lower than control plants. Conflicting seed germination responses between mulches and their water soluble extracts is well documented (4, 10, 33) and indicates that the marked growth effects on containerized and field planted stock recorded in this study may relate to allelochemicals released as each mulch degrades over time (10, 17). For example, pure mulches derived from cypress trees have been shown to slow down the growth of hydrangeas, spirea and viburnums compared to a range of other garden center bought mulches (15). As cypress trees are noted for their resistance to decay fungi, which is associated with the presence of phenolics compounds in the wood, it was suggested some of these phenolics would be leached into the soil in turn inhibiting root growth (5). Likewise, pure mulches derived from *Eucalyptus* foliage have been found to contain phytotoxic residues (organic oils and acids) three months after application that in turn were toxic to germinating seedlings of a range of plants (9, 20). One of the most famous allelopathic trees is black walnut (*Juglans nigra*) with many reported effects of allelopathic chemicals produced by the root system of this tree inhibiting growth or even killing neighboring trees. The chemical responsible for the toxicity in black walnut is known as juglone, with plants exposed to this chemical exhibiting symptoms such as wilting, chlorosis (foliar yellowing), and eventually death (33). Toxicity has been observed in all soil with black walnut roots growing in it but is especially concentrated closest to the tree, under the drip line due to greater root density and the accumulation of decaying leaves. The Tree-Of-Heaven (*Ailanthus altissima*) is a recent addition to the list of allelopathic trees. Ailanthone, an allelotoxin extracted from the root bark of Ailanthus, is known for its potent post-emergence herbicidal activity (7). Pine, eucalyptus and acacia mulches plus their water soluble extracts have all been shown capable of suppressing germination of a range of weed seeds (31).

Contrary to this, other chemicals have been shown to be effective at stimulating plant growth. Both hawthorn and cherry wood have been shown to be naturally high in carbohydrates such as sucrose, glucose and sorbital (25, 32). 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 (11, 28). Stimulation of root vigor following planting out has been shown to be a critical factors influencing transplant survival (6, 28, 35). Application of a pure mulch increased the root:shoot ratio in containerized hawthorn indicating greater resource allocation in favor of roots over shoots. Due to the low survival rates of containerized beech, no definite conclusions on root:shoot ratio effects could be derived. 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 positively affect establishment of English oak (*Quercus robur*) (14).

Mulches have also been shown to be useful in suppressing disease development. Physically, mulches will reduce splashing of rain or irrigation water, which can carry spores of disease organisms up to the stems or leaves of susceptible species. Additionally, the populations of beneficial microbes that colonize many mulch materials can reduce soil pathogens either through direct competition for resources or through chemical inhibition. Work by Downer *et al.* (8) identified both short-and long-term effects of mulching on the incidence of *Phytophthora* root rot while Crohn and Bishop (5) found that Western red cedar *(Thuja plicata)* heartwood contains thujaplicin, a water-soluble tropolone inhibitory to various bacteria and fungi. In addition, organic mulches may also contain a variety of soil microbes that can exert biological control over pathogens, either through resource competition or enzymatic degradation. Many microbes produce cellulase enzymes that attack the cell wall of pathogens such as (*Phytophthora cinnamomi*) (8). Suppression of soil borne diseases or promotion of beneficial micro-organisms around the root zone may have contributed to the increase in crown volume growth and fruit yield recorded under field conditions in his study.

In conclusion, although the mechanistic basis remains to be elucidated, results of this study show that application of pure mulches can provide many beneficial effects. Establishment rates of difficult to transplant tree species such as beech can be improved from 10 to 70%, while fruit yields of young trees can be increased by 100%. Such benefits have a positive impact not only for those involved in the care and maintenance of urban trees but nursery, forestry, orchard and horticultural crop production. Importantly, pure mulches require no capital investment and only small adjustments to standard management aftercare procedures.

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