Root pruning

Andrew Benson

The primary function of roots is to provide water and solute transport from the soil to the shoots and leaves.

Fine fibrous roots and root hairs facilitate absorption of water and dissolved soil minerals, and thus play important roles in photosynthesis. Carbohydrate reserves play an essential role in all trees, and large woody tissues at the tree base act as storage organs and represent a major sink of non-structural carbohydrates. Non-structural carbohydrates have critical functions in environmental stress recovery and tree defence. Roots are an integral component of anchorage and tree stability, particularly those structural roots in close proximity to the trunk (the root plate). Interactions between woody roots and the soil – such as viscoelastic damping – enable trees to remain upright and dissipate kinetic energy

Root pruning in the urban environment

Root pruning is an injurious practice whereby roots are removed, usually to alleviate some type of conflict between root(s) and infrastructure (e.g. public footpaths). In urban environments, fine roots often develop at shallow depths directly beneath hard surfaces (e.g. pavements) due to favourable growing conditions (e.g. available soil moisture and optimum temperatures), and subsequently cause damage to the hard surface as a result of secondary growth. Whilst the most preferable strategy to resolve such conflicts is through strategic engineering and design, root pruning is commonly undertaken to remedy the damage. Roots may also be pruned during utility trenching, when new underground pipes or ducts are laid, often in the pavement or grass berm.

Guidelines for root pruning vary and are limited by a finite pool of research. Making broadly generalisable recommendations for all circumstances is difficult since the relative tolerances of trees to root removal varies by age, species, tree condition and environmental factors such as soil conditions and water availability. That said, if managed correctly, and root loss is kept to a minimum, trees are often able to tolerate some degree of root pruning.

Root pruning: what we know

Root pruning and tree stability

Loss of tree stability is usually related to an alteration in root system architecture (Strong and La Roi, 1983). When investigating strength loss due to root pruning, the methods often attempt to replicate construction activities, where trenching is used to indiscriminately sever roots at a known distance from the tree base, occasionally as a ratio of diameter at breast height (i.e. two or three times the dbh). Smiley (2008) investigated the effect of linear root cutting at varying distances from the tree base and found a significant difference in the force required to pull young willow oak (*Quercus phellos*) to a trunk angle of 1°, when linear root cutting (trenches) was undertaken closer to the trunk base than three times the trunk dbh. Smiley concludes that 'cutting roots closer than three times the trunk diameter should not be recommended'. Although the effects of root loss on stability may persist for several years (Fini *et al.*, 2013), root system morphology and soil type can also influence anchorage and stability (Dupuy *et al.*, 2005). Ghani *et al.* (2009) found that mechanical stability was not greatly affected by trenching (root cutting) in *Eugenia grandis*, even when the trench was 0.50 m (≈2.3 times trunk diameter) from the trunk, concluding that rooting depth close to the trunk was a major component of tree anchorage.

Research into root loss and tree stability has generally shown that changes to tree stability only usually become apparent when roots are severed near to the tree base, i.e. the structural root plate, or zone of rapid taper. In the context of the urban environment, where trees share their space with people and structures, understanding how root loss affects tree stability is of great importance when tree managers have a legal duty of care to consider risks (such as whole-tree failure) under their control.

Root pruning and tree growth

Trees maintain a dynamic equilibrium between roots and shoots (Shigo, 1991). If part of the root system dies, so too may a part of the crown (Perry, 1982), although there may be a temporal delay (Watson, 1998). Morphological changes such as leaf necrosis, wilting and premature leaf abscission are positive indicators of plant stress, although they may take several years to fully manifest.

Watson (1998) examined how root removal affected tree growth and vitality, adopting linear trenching methods to sever roots at a distance approximately equal to the trunk circumference (≈3 times trunk diameter) from the tree base. Mature *Quercus palustris* were exposed to different trenching treatments, on one, two or three sides; this revealed that more severe trenching (i.e., more trenches) resulted in greater dieback and reduced tree growth (shoot and dbh growth) and vitality when compared to controls.

Root removal negatively affects the root-to-shoot ratio and plants generally respond by promoting root growth and repressing shoot growth to restore the balance (DesRochers and Tremblay, 2009). Shoot growth is repressed due to the preferential allocation of photoassimilates to the roots (Rook, 1971). New root biomass may increase with increasing pruning intensity (Farmer and Pezeshki, 2004), although the response varies between species (Hipps *et al.*, 1999). Traditionally, new shoot elongation is measured (Watson, 1998) and can be used as an indicator of how the root-to-shoot ratio may be affected.

Research into root pruning and tree growth has generally shown that, although the duration of the response varies between species and age, root loss results in curtailment of above-ground growth. Largely this is due to water and carbon limitation (e.g. stomatal closure), as well as plasticity in the allocation of available resources to plant parts (Ledo *et al.*, 2018; Mašková and Herben, 2018), whereby shoot growth is repressed in favour of producing new roots.

Root pruning and tree physiology

Understanding and identifying the physiological responses of trees to environmental stress are advantageous to arboricultural and ecophysiological practitioners. The inflicted imbalance between water usage by the foliage and resupply from the roots elicits a range of tree responses (Pallardy, 2008), and modern analytical equipment can reveal information about tree stress long before the manifestation of visual symptoms (van Kooten and Snel, 1990). Although little attention has been afforded to the physiological responses of urban trees to root pruning, relationships between root severance and a physiological response have been established. Fini *et al.* (2013) found small but noticeable reductions in photosynthetic efficiency and CO_2 assimilation over a four-year period when trenching was undertaken 40 cm from the trunk base (≈4.5 times dbh) of *Aesculus hippocastanum* and *Tilia × europaea* trees. Root pruning also negatively affected leaf water potential, which decreased with increasing pruning intensity. This study revealed the difference in recovery times among species, alluding to different tolerances to root manipulation among taxa.

Dong *et al.* (2016) more recently concurred with Fini's results and found additionally that a small amount (25% of total) of root pruning initiated a stress response, resulting in both elevated physiological activity (photosynthesis and gas exchange) and increased biomass. In earlier work, Teskey *et al.* (1983) observed reduced stomatal conductance and xylem water potential when 43% and 54% of 30-year-old *Abies amabilis* were severed.

Research into root pruning and tree physiology has generally shown that physiological processes can become quickly perturbed as a result of increasing root removal. Many of the physiological responses to root loss can be explained by a chronic but mild water stress in the root-severed trees (Fini *et al.*, 2013).

Some things we don't know

Much of the research which has been done to date provides fundamental theory on how trees respond to root loss in biological and mechanical terms. Very little attention has been afforded to applied research in this field, and quite often, what is prescribed in best practice documents is somewhat anecdotal. For example, root protection areas prescribed with radii equivalent to 12 times dbh are likely to be an artefact of the imperial system of measure (one foot of RPA radius for every one inch of dbh) from the USA. This 'rule of thumb' (Hamilton, 1988) has now propagated throughout much of the industry guidelines, without empirical tests (Watson, 1998).

What we've learned recently

To take what is known about how trees respond biologically to root removal, two recently conducted experiments exposed *Quercus virginiana* to two different root pruning treatment types.

Experiment 1

Thirty-one *Quercus virginiana* Mill. Trees (mean trunk dbh = 34.20 cm) were randomly allocated to one of three treatment groups with eight replicates of each treatment plus seven controls. Root pruning treatments consisted of a single linear trench, offset from the tree base at a distance equivalent to three, six or twelve times the trunk diameter at breast height. Trenches ≈500 mm deep, ≈100 mm wide and ≈10 m long were made between 31 May and 6 June 2017, and all roots were severed at this time (Benson *et al.*, 2019b) (Figure 1).

Experiment 2

Eighteen *Q. virginiana* 'SDLN' (mean trunk dbh = 28.25 cm) were randomly allocated to one of six treatment groups with three replicates of each treatment. Root pruning treatments consisted of a circular trench around the base of each tree (except the control) with a radius defined by its trunk diameter at 1 m. Treatments ranged from 3 to 15 times the trunk diameter in increments of three (3×, 6×, 9×, 12× and 15×) plus control. Trenches ≈ 500 mm deep and ≈100 mm wide were made between 19 and 22 June 2017 and all roots were severed at this time (Benson *et al.*, 2019a) (Figure 2).

Responses to treatments

In both experiments, predawn leaf water potential (a sensitive measure of water stress) was recorded periodically for the 2017 summer growing season (July–September). In Experiment 1, water potential was also recorded at the end of the 2018 growing season (August 2018). Diameter at breast height growth, shoot elongation and leaf area were also recorded at the end of each growing season, to see how the root pruning treatments affected above-ground growth.

Results

In both experiments, all root-pruned trees exhibited signs of water stress at one or more intervals following root loss, characterised by significantly reduced water potential in comparison to control trees ($p \leq 0.05$). In Experiment 1, the water stress symptoms persisted in the 3× treatment for 440 days ($p < 0.01$) (Figure 3a). In Experiment 2, all treatments showed signs of water stress except 15× ($p \leq 0.05$) (Figure 3b).

In both experiments, the above-ground growth of the root-pruned trees was reduced compared to controls. Significant differences emerged in the 12× treatment for shoot elongation and leaf area ($p \leq 0.05$) after one growing season in Experiment 1 (Figure 4), although these had subsided at the end of the 2018 summer. In Experiment 2, differences in the growth responses emerged at the 9× treatment, where shoot elongation was significantly ($p \leq 0.001$) less than controls (Figure 4).

Conclusions and some practical applications

Root loss can be regarded as a condition which predisposes trees to the effects of co-occurring stresses, e.g. drought and temperature extremes, by limiting carbon assimilation and diverting photoassimilates away from such things as defence. These trees were grown under experimental conditions, and as such the growing environments were favourable to tree health. Urban environments are often inhospitable to tree growth (Layman *et al.*, 2016), and the additional stress placed upon tree function by root loss can have more dire consequences. More applied research is needed to further

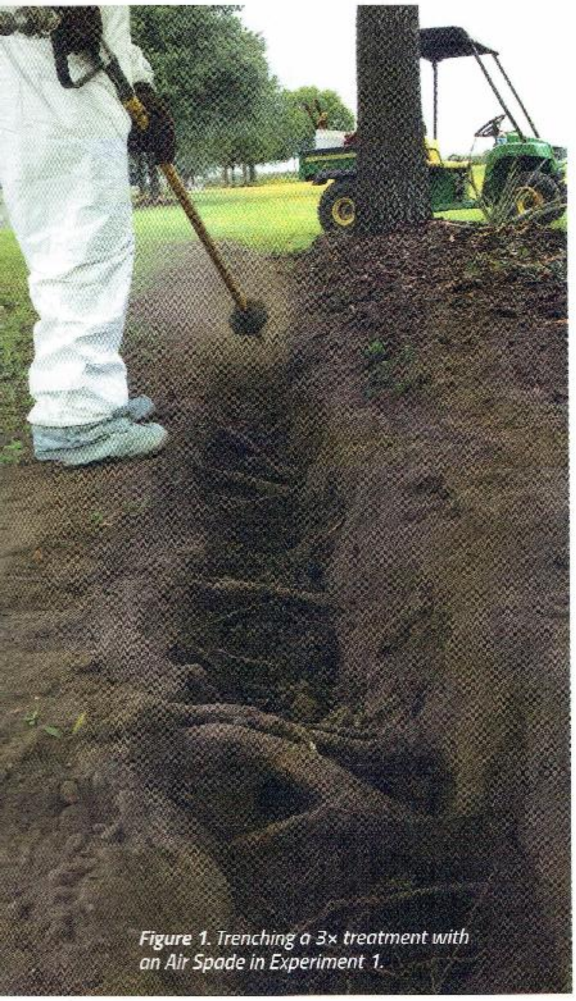

Figure 1. Trenching a 3× treatment with an Air Spade in Experiment 1.

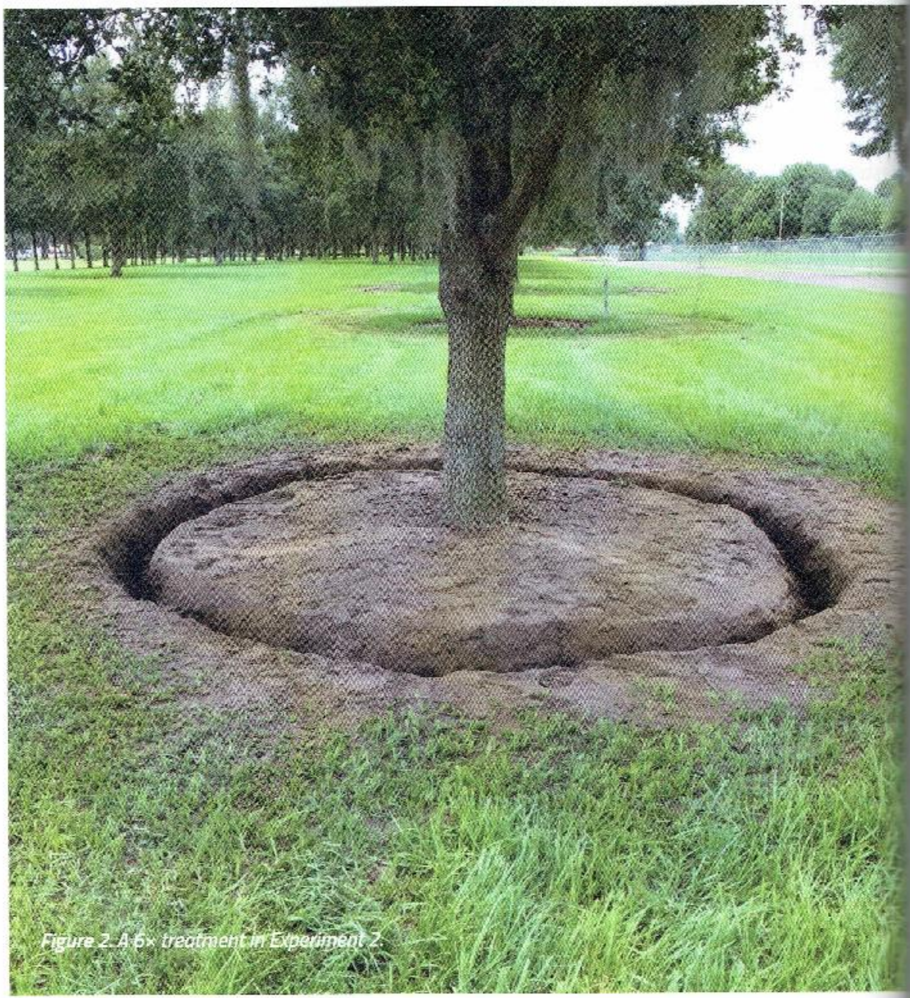

Figure 2. A 6× treatment in Experiment 2.

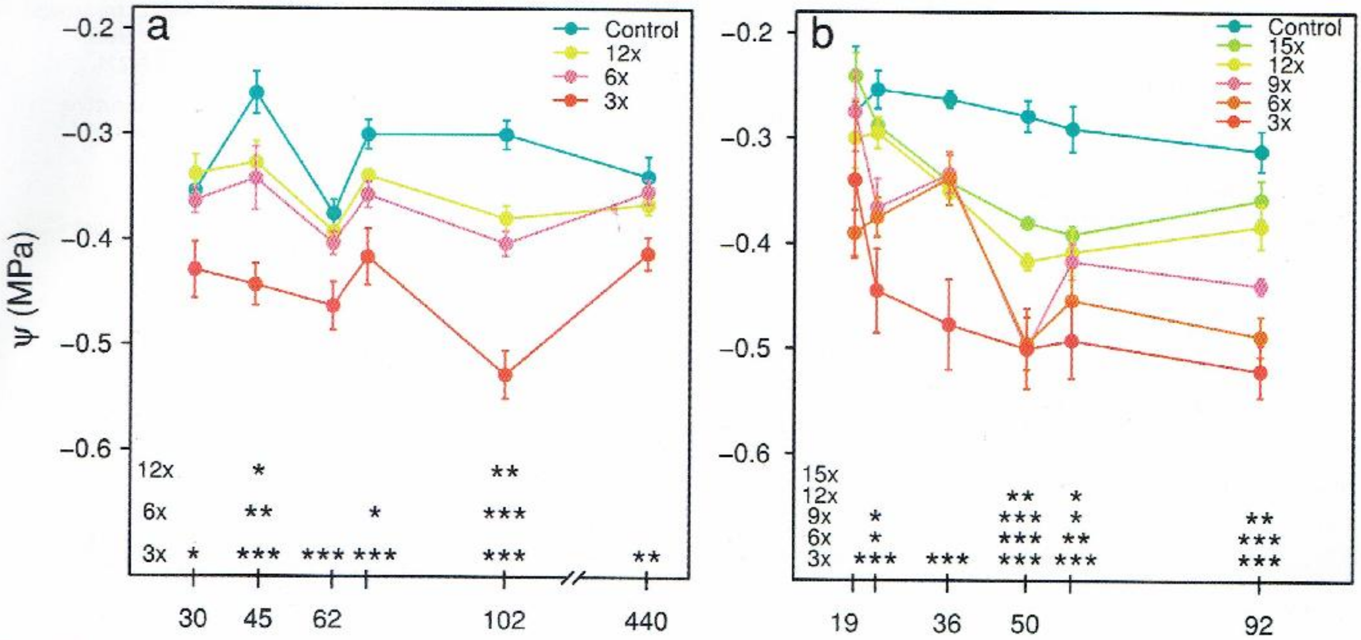

*Figure 3: Treatment mean pre-dawn leaf water potential (Ψ) in MPa plotted against number of days since roots were severed. Error bars show ± one standard error (SE). Asterisks in the inset matrix show significant differences between control and treatment (left-hand side) on a particular day with the following significance codes: * p ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001 for Experiment 1 (panel a) and Experiment 2 (panel b).*

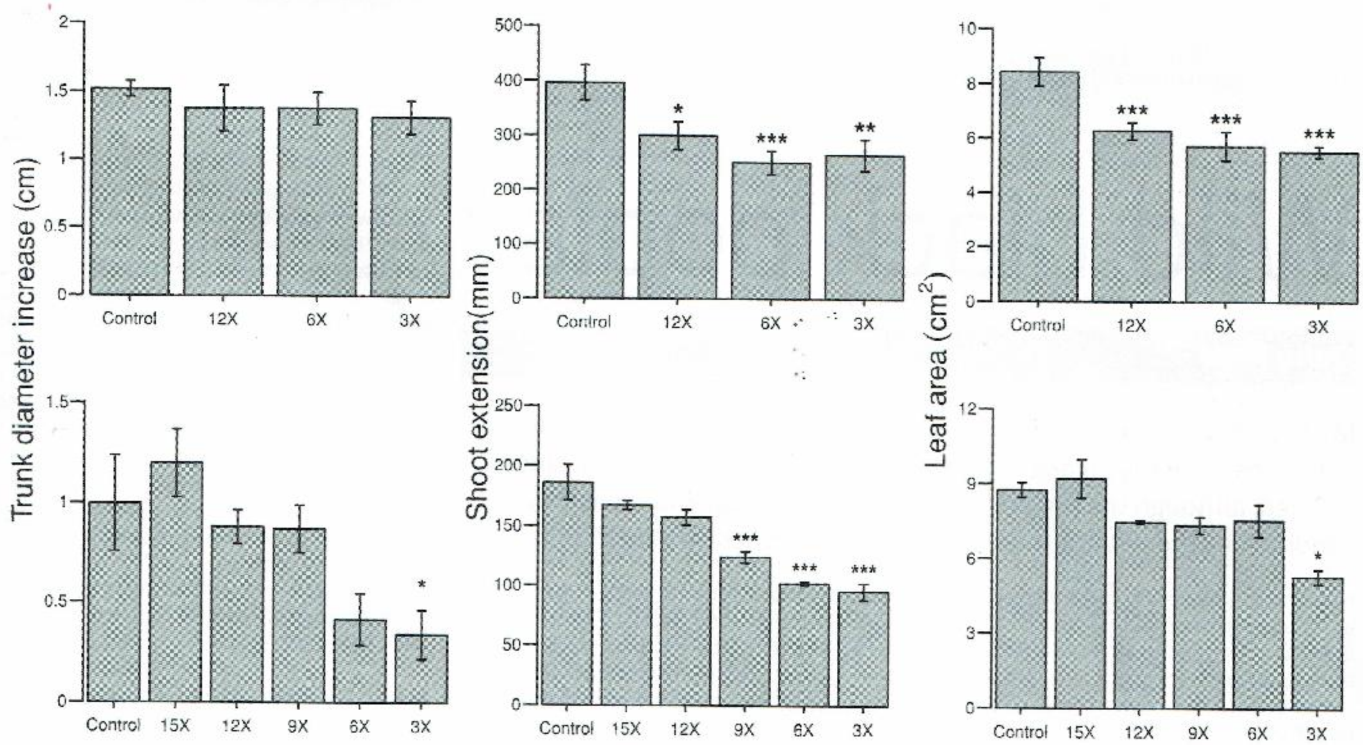

Figure 4: Bar plots showing growth responses to the root pruning in Experiment 1 (upper row) and Experiment 2 (lower row). Error bars on the bar plots show ± one standard error (SE). Asterisks above bars denote significant differences between treatment and control at p ≤ 0.05 (*), p ≤ 0.01 (**) or p ≤ 0.001 (***).

improve our understanding of tree responses to root loss under different circumstances. Whilst these recent investigations were conducted on a single species only, the information is valuable and adds to the limited pool of applied research in this field.

These findings may be of benefit to those who work with trees, their roots and construction. To achieve an optimum standard of tree care, arboricultural practitioners are encouraged to adopt a minimum RPA radius equivalent to 15 times dbh (noting the limits set by the relevant guidelines, e.g. BS5837). When trenching for utilities, avoid root loss if possible and consider trenchless methods as a first option. Avoid trenching any closer to trees than distances equivalent to six times dbh.

Andrew Benson grew up in the UK and after working as a climbing arborist in Wales, emigrated to New Zealand. Andrew completed his PhD at the University of Canterbury (NZ) in December 2019 and currently works as a consulting arborist in Auckland.

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Wild black poplar

Jerry Ross

My hopes for a day without rain on which to hold an event to raise awareness of native black poplars and veteran trees in general were fulfilled, although the previous weeks of steady rain and the windy conditions were not entirely conducive to the practical side of things!

It was nonetheless a successful day, with about 50 people attending, including arboriculturists, professional conservationists and a gratifying number of interested lay-persons, some of whom travelled some way to attend.

The event was hosted by Vernon and Sheila Jones at Upperfields Farm at Llangarron in Herefordshire where, in one of their fields, stands a characterful old wild black poplar (*Populus nigra* subsp. *Betulifolia*). At about 15m, it's not hugely tall (the species is quite capable of achieving heights of over 30m). However, the size of its gnarled bole indicates that it is of some considerable age. It has a girth of 6.5m (diameter 209cm) at 1.5m, but that is affected by some quite widespread burring; at 1.8m up its girth is nearer 5.5m (175cm diam.).

The site is currently fairly isolated, on the edge of a field with an old farm pond to the rear, the species generally being found near water. The tree has also clearly been pollarded, perhaps 'naturally' due to storm damage but more probably by the hand of man. This will have significantly reduced the rate at which its girth will have increased over the years which, along with the burred nature of the trunk, makes any assessment of its age largely a matter of guesswork. The species is generally reckoned to have a life expectancy of about 200 years, although some individuals clearly achieve significantly greater ages and a few may exceed 300 years. My own guess is that this tree is in excess of 250 years old, although it could be a fair bit older.

Although there are many maiden trees, pollarding was not uncommon to provide animal fodder and small timber which was used for a host of purposes including fencing and wattle hurdles as well as for fuel. However, it is notable that while poplar small wood burns well enough as kindling or faggots, the timber has a reputation for being somewhat fire-resistant, so much so that it was sometimes used as flooring 'in servants' quarters to prevent accidental fires' (although whether that was in consideration of the well-being of the servants or merely because servants were considered careless fire-starters, we're not told).

But overall, poplars were regarded as valuable trees. The timber, being light but tough and resistant to abrasion, made it ideal for cart beds as well as brake-blocks and clogs. It's also surprisingly durable providing it is kept dry, as this Herefordshire rhyme suggests: *'Cut me green and keep me dry, And I will oak or elm defy.'* Black poplar's huge, naturally curved branches were used in the A-frame supports in cruck-framed buildings, such as in the 16th-century barn from Cholstrey Court Farm (now at the Avoncroft Museum: www.avoncroft.org.uk/).

More curious uses include artificial limbs and rifle butts, while the bark has been used as a cork substitute to make fishing floats. The inner bark is also said to have been dried, ground and used as flour in times of famine, while the balsam from the buds, known as *Unguentum Populeon*, was thought to be beneficial for bruises, inflammation and gout. Culpeper held that 'the water that drops from the hollows of this tree takes away warts, wheals and breakings out of the body', which you might like to bear in mind the next time *your* body breaks out.

A rarity

Despite these manifold benefits, the tree fell sharply out of favour following the introduction of the much faster-growing hybrid between the European *P. nigra* and North American cottonwood (*P. deltiodes*), a cross that gave