The Influence of Sugars on Root Vigour of Trees©

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Established semi-mature trees of four species (*Tilia tomentosa, Malus floribunda*, *Acer campestre*, and *Quercus robur*) showing symptoms of decline (leaf necrosis and branch die-back) were subjected to soil injections of sucrose at 25, 50, and 70 g·L^{-1} of water, applied at 1 L·m^{-2}. Trees were injected to an area 1 metre beyond the canopy drip line. Root dry weight was recorded 5 months later. Soil injections of sucrose significantly increased root dry weight compared with water-injected controls. Growth responses were influenced by species and the concentration of sucrose applied. Results indicate soil injections of sucrose 50 g·L^{-1} water were able to improve root growth of declining mature trees. Such a response is desirable as root damage following construction activities is a frequent problem encountered by trees growing in U.K. urban landscapes. The results have implications for nurseries producing trees and shrubs for transplanting.

INTRODUCTION

Within U.K. urban landscapes, trees frequently grow, or are planted, in close proximity to buildings and infrastructure. The process of developing land can be devastating to root systems of established trees and reduce survival of newly planted ones. For example, soil de-oxygenation caused by impeded drainage, mechanical compaction, or impermeable surface coverings is a common consequence of construction operations that results in physical impedance to root growth and reduced soil aeration. Trenching damage to roots is also implicated in the death of urban trees (Baines, 1994). Root damage reduces the root : shoot ratio and consequently the tree's ability to take up water and nutrients. This leads to water stress and reduced shoot growth, branch dieback, and ultimately tree death (Bellet-Travers et al., 2004; Davies et al., 2002; Fraser and Percival, 2003).

It is now recognised that the survival of trees following root damage is largely dependant on the rapid extension of the existing root system (Watson and Himelick, 1997). Consequently, a range of plant growth regulators (e.g., auxins), commercially available root biostimulants, and mycorrhizal products have been tested for their root-promoting abilities (Percival and Gerrittsen, 1998; Smiley et al., 1997; Fraser and Percival, 2003). While many of these have proved to possess some degree of root-promoting properties a number of problems have been encountered. These include cost, environmental impact and, most importantly, marked differences in growth responses between tree species. Ideally an inexpensive, nontoxic, and environmentally benign compound that can be applied to tree root systems after soil-damaging operations to stimulate root growth and restore the root : shoot ratio is required.

Sugars such as sucrose, glucose, and fructose form the end products of photosynthesis. Supplementing root systems with sugars affected root metabolism by significantly increasing lateral root branching and root formation compared with controls (Bingham and Stevenson, 1993; Bingham et al., 1997, 1998). Likewise, application of sucrose, glucose, and fructose as a soil drench to containerised and field-planted 4-year-old trees has been shown to significantly improve root dry weights compared with water-treated controls (Percival, 2002). This raises the possibility that the growth pattern of trees may be altered in favour of enhanced root formation by treating a damaged or severed root system with sugars such as sucrose.

Objectives of this investigation were to determine if soil injections with sucrose would improve the density or development of fine roots on established trees growing in urban environments. Sucrose was chosen as a test sugar as this form of sugar is the major photo-assimilate transported from source to sink tissues in most U.K. tree species (Lindqvist and Asp, 2002; Salisbury and Ross, 1985).

MATERIALS AND METHODS

Plots consisted of four mature oaks *(Quercus robur)*, eight silver lime (*Tilia tomentosa*), six field maple (*Acer campestre*), and four ornamental apple (*Malus floribunda*) located at the University of Reading campus (oak, silver lime) and University of Reading experimental field site at Shinfield (field maple, apple). All trees were surrounded by grass. Tree size and soil conditions at each location are presented in Table 1. Soil phosphorus, potassium, magnesium, sodium, and calcium concentrations were determined using inductively coupled plasma emission spectroscopy following digestion in concentrated hydrochloric and nitric acids (Anon, 2002). Soil organic matter was determined following oxidisation with potassium dichromate, sulphuric acid, and orthophosphoric acid, and subsequent titration with ferrous sulphate solution (Walley and Black, 1934) and pH determined using a soil pH electrode at a depth of 20 cm.

Treatments consisted of the following soil injections:

- Sucrose at 70 $g \cdot L^{-1}$ of water
- Sucrose at 50 $g \cdot L^{-1}$ of water
- Sucrose at 25 $g \cdot L^{-1}$ of water
- Water control

Sucrose was obtained as domestic table sugar from a local supermarket. Quadrants beneath and to 1 m beyond the drip line of each tree were randomly assigned to each treatment. Injections were made to a depth of 20 cm on 1.0 m × 1.0 m spacing. Injection pressure was 80 psi and 1.0 L of the sugar solution was injected into each hole. Injection holes were marked with colour coded flags to indicate location of treatment. Treatments were made 22 April 2009. Root ingrowth cores (RlCs) were installed 26 April 2009 to monitor new root development (Marx et al., 1995). Root in-growth cores are 7.6 cm diameter by 20 cm deep plastic screen cages which allow in-growth of roots. They were filled with root-free, treated soil and were located within 15 cm of an injection site. Total herbicide (glyphosate) was applied 2 weeks prior to the experiment and periodically to the treatment area to eliminate grass and weed root contamination. Six RICs per quadrant were removed 5 months after treatment (22 Sept. 2009). Soil was gently removed from the RIC by gently shaking the root system after lifting from the ground and washing with water through a 4-mm screen. Root dry weight per RIC was then recorded after oven drying at 85°C for 48 h. Effect of sugars on root dry weight was determined using analyses of variance (ANOVA) for each species individually following appropriate checks for homoscedasticity (Anderson-Darling test). Differences between control and treatment means for each species were separated by the Least Significance Difference (LSD) at the 95% confidence level (P>0.05) using the Genstat for Windows 2000 program.

RESULTS AND DISCUSSION

Soil injections of sucrose increased fine root growth of all four test species 5 months after application compared with water-injected controls. In some cases, however, root growth increases were not significant (Table 2), i.e., applications of sucrose at 25 $g \cdot L^{-1}$ of water — where root dry weight was higher, but not significantly so, than control trees. This indicates injections greater than this concentration are required to significantly increase fine root growth of established English oak, silver lime, field maple, and ornamental apple. Applications of sucrose equal to or greater than 50 $g \cdot L^{-1}$ of water significantly increased, in the majority of cases, root dry weight of all tree species (Table 2). Reasons for improved root growth following sucrose application include the fact that the process of recovery following root damage is dependent on the ability of a tree to manufacture abundant sugars such as sucrose (Lonsdale, 2001). As carbohydrates function as a direct substrate for growth, then an abundance of sugars at and around the root zone is available for immediate use (Salisbury and Ross, 1985). In addition, work by Koch (1996) has shown that in plants, sugars such as sucrose affect sugar sensing-systems that initiate changes in gene expression and subsequent plant growth (Koch, 1996). Sucrose depletion, for example, upregulates genes for photosynthesis, carbon remobilisation, and export resulting in shoot growth. In contrast, incubation of root systems in sucrose solutions leads to the repression of photosynthetic genes, decreased rates of net photosynthesis, and carbon remobilisation in favour of enhanced root development. Finally, soil applications of sugars have been shown to stimulate changes in populations of naturally occurring soil microbes and fungi around the roots resulting in alterations to plant nutrient uptake patterns and growth (Finnie and Van Staden, 1985; Martinez-Trinidad et al., 2009). Use of sucrose as a direct substrate for root growth coupled with alterations in gene expression and microbial-plant interactions may account for increased root growth recorded in this investigation.

CONCLUSION

Applications of sucrose via a soil injection system should be considered to stimulate fine root development of established trees which in turn should improve water and nutrient absorption following construction damage and aid in their recovery (Percival, 2003). This is an area worthy of consideration given the fact that sugars are water soluble, nontoxic, environmentally safe, and inexpensive to purchase.

The nursery industry might also consider trials on the potential benefits of sucrose treatments pre-lifting or pre-despatch of trees and shrubs intended for landscape planting, especially of those species known to be sensitive to transplant stress or intended for planting where soil damage may be expected.

REGIONAL EDITOR'S NOTE

The conference discussion following this paper also raised the possible link between the results presented and the use of high-sugar substances such as honey as practiced by growers in some IPPS regions to aid rooting in difficult-to-root cuttings.

Table 1. Growth and soil characteristics of experimental trees and their location.

	Quercus robur (n = 4)	*Tilia tomentosa* (n = 8)	*Acer campestre* (n = 6)	*Malus floribunda* (n = 4)
Girth (cm)	207 ± 20.1	40.5 ± 4.3	30 ± 4.8	28.3 ± 3.66
Height (m)	7.10 ± 0.80	6.9 ± 1.1	4.2 ± 0.3	5.1 ± 0.62
Soil				
pH	6.7 ± 0.6	6.9 ± 0.7	7.1 ± 0.6	6.3 ± 0.8
Potassium ($mg \cdot L^{-1}$)	60.3 ± 5.33	59.8 ± 7.55	50.4 ± 10.30	63.7 ± 9.76
Phosphorous ($mg \cdot L^{-1}$)	395.0 ± 35.52	434.2 ± 38.27	576.7 ± 70.34	404.0 ± 36.54
Organic matter (%)	4.0 ± 0.03	5.1 ± 0.05	4.7 ± 0.09	4.6 ± 0.07
Magnesium ($mg \cdot L^{-1}$)	266.2 ± 32.54	285.9 ± 40.20	225.8 ± 21.66	229.8 ± 21.35
Calcium ($mg \cdot L^{-1}$)	1830.1 ± 189.2	2511.3 ± 114.60	3134.5 ± 379.05	1971.4 ± 126.92
Sodium ($mg \cdot L^{-1}$)	60.5 ± 7.36	70.5 ± 8.21	52.6 ± 3.98	49.9 ± 7.82
Type	clay	sandy loam	clay loam	clay loam

Girth and height values are the mean of n trees. Soil nutrient values are the mean of 5 soil analysis per tree. ± = standard deviation of the mean. All soil nutrient values refer to available, i.e., extractable soil nutrients.

Table 2. Mean fine root dry weights, expressed in grams per cubic metre of soil at month 6 after treatment.

	Species			
Treatment	*Quercus robur* (n = 4)	*Tilia tomentosa* (n = 8)	*Acer campestre* (n = 6)	*Malus floribunda* (n = 4)
Water control	0.28	0.22	0.13	0.10
Sucrose 25 $g \cdot L^{-1}$	0.33ns	0.30ns	0.18ns	0.09ns
Sucrose 50 $g \cdot L^{-1}$	0.93*	0.78*	0.22ns	0.29*
Sucrose 70 $g \cdot L^{-1}$	0.45*	0.80*	0.38*	0.17ns

Note: ns = not significant, * = $P<0.05$ – significant from control value.

Fine root dry weights are mean of n trees, 6 RICs per tree.

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