Do you want sugar with your tree?

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Why do we plant trees into our landscapes? The answer is easy. We plant them because they filter dust and absorb pollution, provide shade, shelter, deflect and soften noise, reduce wind velocity and glare. The aesthetic of tree lined streets and green spaces have been shown to have positive psychological and health benefits to human society including lower rates of mental illness, violence and crime. Trees also have a symbolic value, they can humanise an urban area, allowing us to acknowledge our affinity for the natural world and provide a focus for community participation in landscaping the urban environment. Business and industry executives have found that attractive landscapes result in above average labour productivity, lower absenteeism and easier recruitment of workers with hard to find skills. For these reasons hundreds of thousands of trees are planted into our urban landscapes on an annual basis. Consequently tree planting guidelines and management strategies exist to ensure optimal survival rates of newly planted trees and non-decline of established mature trees. Concepts such as fertilisation, irrigation, mulching, pest and disease control are well researched and their importance understood.

However, from the trees "point of view", survival, establishment and reproduction (seed set) are critical for the success of the next generation. The way by which a tree achieves these objectives is by the production and expenditure of energy by photosynthesis i.e.

$$CO_2 + H_20 \xrightarrow[\text{Chlorophyll}]{\text{Sunlight}} C_6H_{12}0_6 + 0_2$$

Interestingly, we know what happens to tree growth in the presence of high and low concentrations of carbon dioxide, water (drought/waterlogging) and oxygen. We even know the effects of high (dwarfed growth) and low (etiolated growth) light levels on tree biology. Surprisingly, however, we know little about the effects of the end product of photosynthesis i.e. sugar or more accurately sucrose (the major photoassimilate in *ca*. 90% of UK species), the same type of sugar we use to sweeten our tea and coffee, on tree growth. This then begs the question, what happens to trees when they are supplied with low concentrations of sugars as a dilute feed? I.e. the main process by which a tree establishes, survives and reproduces is no longer of such importance since the end products of photosynthesis (sugars) are supplied as a drench to the root system.

Over the past seven years research at the Bartlett Tree Research Laboratory has been investigating the influence of sugar feeding on tree growth and physiology. An overview of these results and how sugars would be of practical use to professionals involved with tree management are summerised below.

Overcoming Transplant Stress

It has long been accepted that drought related problems are often responsible for poor growth and deaths of newly planted urban trees. As little as 5% of a tree's root system may be moved with a tree following lifting from the nursery bed, in turn significantly reducing the root:shoot ratio and consequently the tree's ability to uptake sufficient water and nutrients for survival of the newly expanding leaf canopy. Although tree root systems can be manipulated to reduce the effects of transplant shock by increasing the amount of root to be transplanted by, for example, root pruning, wrenching or undercutting in the nursery, the effects of these techniques are still inconsistent and a high proportion of the root system can still be lost in the lifting process. This limited root system post planting leads to water stress, resulting in transplant stress that is generally characterized by reduced shoot growth, branch dieback and, on occasion, tree death.

Although a number of factors have been associated with transplanting stress it is now widely recognised that survival of newly planted trees is largely dependant on rapid root growth to absorb water from the soil, replenish water loss and subsequently reduce water stress. Studies by the authors using root-pruned containerized stock of *Betula pendula* (silver birch), *Q.rubra* (red oak), *Prunus avium*, (cherry) and *Sorbus aucuparia*, (rowan) have demonstrated a positive increase in root vigour following the application of sugars such as sucrose as a root drench. Since then, several studies have shown a positive association between sugar application and root stimulation in several tree species. Work at the Scottish Agricultural College demonstrated that supplementing root systems of plants with sugars significantly increased lateral root branching and root formation compared with non-sugar supplemented controls. Further work demonstrated applications of sucrose to a range of tree species enhanced root vigour in terms of root length, number of new roots formed and root dry weight compared to water treated controls. Experiments using soil injections of sucrose to established mature horse chestnut (*Aesculus hippocastanum* L.) silver birch (*Betula pendula* Roth.) cherry (*Prunus avium* L.) and English oak (*Quercus robur* L.) recorded a significant increase in fine root dry weight compared to water injected controls (Photograph 1).

How do sugars promote root growth?

Reasons for enhanced root growth following sugar application include:

1. Gene expression alteration influencing carbon remobilization in favour of root over shoot growth. Researchers at the University of Florida have clearly demonstrated that sugars function not only as substrates for growth but affect sugar sensing-systems that initiate changes in gene expression and subsequent plant growth. For example incubation of root systems in sucrose or glucose leads to the repression of photosynthetic genes, decreased rates of net photosynthesis and carbon remobilisation in favour of enhanced root development (Figure 1; Table 1).

2. Sugar-induced changes in soil microbial and fungal rhizosphere populations altering plant nutrient uptake patterns in favour of root growth. For example mycorrhizal colonisation has shown to be influenced by the sugar content within the root tissue. The general trend of research indicates that the higher the root sugar concentration the greater the degree of mycorrhizal colonisation.

3. The process of recovery following root severance is dependent on the ability of a tree to manufacture abundant photosynthetic carbohydrates such as sucrose. As sugars function as a direct substrate for growth then an abundance of sugars at and around the root zone are available for immediate use. Importantly sugars dissolved in water when added to the soil are taken up quickly and passively (i.e. no energy is required for uptake) by the tree root system.

4. Carbohydrate loading. The importance of high concentrations of carbohydrate reserves within root tissue for survival and growth following transplanting are well recognized. Root growth for example is an energy-consuming process occurring at the expense of available carbohydrate reserves. Recent trials at Barcham Trees, Ely, Cambridge have demonstrated that uptake of sucrose dissolved in water and then applied as a root drench contributed to elevated root carbohydrate levels facilitating greater root formation, root elongation and subsequent root dry weight in turn enhancing survival rates of transplant sensitive species such as beech (*Fagus sylvatica,* Photographs 2-3).

Enhancing stress tolerance

A number of studies on the involvement of sugars in the response of plants to stresses have reported protective effects on the leaf photosynthetic apparatus with the positive effect of sugars on reducing environmental (salt, heat, cold) and chemical (herbicide) damage to leaves related to modifications and protection of photosystem II. Sugars have also been shown to be involved in increasing the stability of plant proteins following heat damage and maintaining chlorophyll levels and photosynthesis following herbicide application. Sugar alcohols have been shown to protect plants against salt and photo oxidative stress caused by high light intensities. Recent work has also shown that application of sugars confer a high degree of tolerance to the electron transport inhibiting herbicide atrazine in seedling material by maintaining high levels of leaf chlorophylls, photo-oxidative protecting carotenoid pigments and photosynthetic efficiency. The authors of this research concluded atrazine in the presence of sucrose was found to have a paradoxically positive effect on seedling development. Atrazine alone arrested seedling development with cotyledon bleaching and seedling death. A positive effect of sugars for the survival of plants under waterlogged conditions has also been demonstrated. Protection of the leaf photosynthetic system is vital for the survival of plants under harsh environmental conditions. If the leaf photosynthetic apparatus remains undamaged then plants can produce the essential carbohydrates required for growth and repair of damaged tissue. If the leaf photosynthetic system is badly damaged then the carbohydrates required for repair cannot be synthesized.

These studies raise the possibility that the stress tolerance of trees may be enhanced by applying sugars at or around the root zone potentially offering a simple system of reducing tree losses caused by environmental stresses such as de-icing salts applied to road surfaces. In a series of experiments at the University of Reading container grown trees of English oak (*Quercus robur* L) and holly (*Ilex aquifolium* L.) were watered with sucrose at a concentration of either 25 or 50g sucrose per litre of water. Seventy-two hours following sucrose application root drenches of de-icing salt (sodium chloride, (NaCl)) were applied at a concentration of either 30 or 60g NaCl per litre of water. Containerized trees were left outdoors until day 15 and then salt damage recorded by measuring the degree of leaf necrosis. As Table 2 demonstrates leaf necrosis was reduced by 33-57% in English oak and by 30-68% in holly where plants were pre-treated with sugars three days before the application of salt.

Another experiment studied the effects of treating plants with sugars once salt damage had occurred i.e. in this instance could sugars help improve recovery rates of salt damaged plants. At two weeks after salt treatment leaf necrosis began to recover whether sugars were present or not, however, sugar treated trees were the most capable of recovery where recovery rates of salt damaged trees were 25-50% higher than non sugar treated trees. Results of this experiment may be appropriate in light of the substantial volumes of de-icing salt applied through-out the UK in 2009/2010.

All studies to date strongly indicate that sugars can enhance the salt tolerance of trees and/or be used as a remedial treatment following salt damage.

Is there an effect of sugar type and what concentration of sugars should I apply?

Although trees contain many types of sugar the four most common within root, shoot and leaf tissue are sorbital, sucrose, glucose and fructose. The influence of these different forms of sugars on enhancing stress tolerance remains unknown but their effects on root stimulation has been studied (Table 3). In general results show little difference between sugar types but in terms of cost effectiveness and availability sucrose is at present recommended.

Research investigating the concentration of sugars to apply for root growth stimulation has found a species specific response. For example supplying sugars at 70g per litre of water to silver birch root systems following severe pruning (90% removal of the root system) to induce transplant stress increased root metabolism by promoting lateral root branching and root formation to a greater degree than applying sugars at 20 and 50g per litre of water. In the case of cherry (*Prunus avium*), however, sugar at 50g per litre of water stimulated root growth to a greater degree than when sugars were applied at 20 or 70g. Based on experimental data of over twelve different tree species by the authors it is recommended that sugars should be applied at 30-50g per litre of water per square metre of ground from the trunk base to 1 metre beyond the canopy drip line.

It is important to emphasize, however that if the sugar concentration is to high this can put the tree under osmotic stress and/or encourage the build up of pathogenic fungi within the soil. As the old saying goes ‘a little is good, too much is bad”

A Case From History

The famous Treaty Oak located in Austin, Texas USA is the last surviving member of, a grove of 14 trees known as the Council Oaks that served as a sacred meeting place for the Comanche and Tonkawa Tribes. Native American legend holds that the Council Oaks were a location for the launching of war and peace parties. In 1989 the tree was poisoned with the powerful hardwood-herbicide known as hexazinone. Laboratory testing showed the quantity of herbicide used would have been sufficient to kill 100 trees. Efforts to save the Treaty Oak included the replacement of soil around its roots, fertilisation and the installation of a system to mist the tree with spring water. In addition the tree was also injected with sugars. The principle behind this was for sugars to act as a “life support” system while the tree recovered. The same principle is used in hospitals where patients to ill to feed themselves are put on a life support drip that contains sugars for use as a energy source. The culprit was apprehended and convicted of felony criminal mischief and sentenced to serve nine years in prison. The Treaty Oak survived and still stands today although more than half of its crown has had to be pruned (Dr Todd Watson, University of Texas A&M, personal communication).

Future Developments

1. Sugar mulches?

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. Research at the University of Reading evaluated 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 European beech, a notoriously transplant sensitive species. In this case application of a pure mulch derived from hawthorn and cherry increased survival rates from 10 to 70%. Further field experiments using apple (*Malus* cv. Gala), and pear (*Pyrus communis* 'Concorde') following field transplanting found crown volume and fruit yield could be increased by 53 and 100% respectively by application of hawthorn and cherry pure mulches. Chemical analysis of pure mulches from hawthorn and cherry showed that these two species were higher in sugars compared to the other pure mulches tested. Indeed, the concept of sugar mulches is not new. At an ISA Conference in Australia one speaker informed the audience that for the past 400 years in Japan a sugar cane type crop is grown that when harvested is used purely for mulches. Ongoing research at the University of Reading is evaluating the impact of conventional commercially available mulches (pine, bark, nuggets etc) combined with sugars and sugar based fertilisers outlined below.

2. Sugar fertilisers

Fertiliser manufacturers have not been slow to realize the potential of this research. A range of carbohydrate or molasses/sugar based fertilisers are now commercially available sold under the trade names Fulcrum CV or Fulcrum Blade. Manufacturers claim these fertilisers can stimulate vigour of root crops such as leek, potato and carrot increasing yields by up to 20%. The effectiveness of these sugar based fertilisers are currently being evaluated by the author for their root promoting and stress enhancing effects.

Conclusions

In conclusion, results indicate applications of sugars offer a multitude of benefits for professionals involved in tree management. This is an area worthy of consideration given the fact that sugars are water soluble, non-toxic, environmentally safe and inexpensive to purchase.

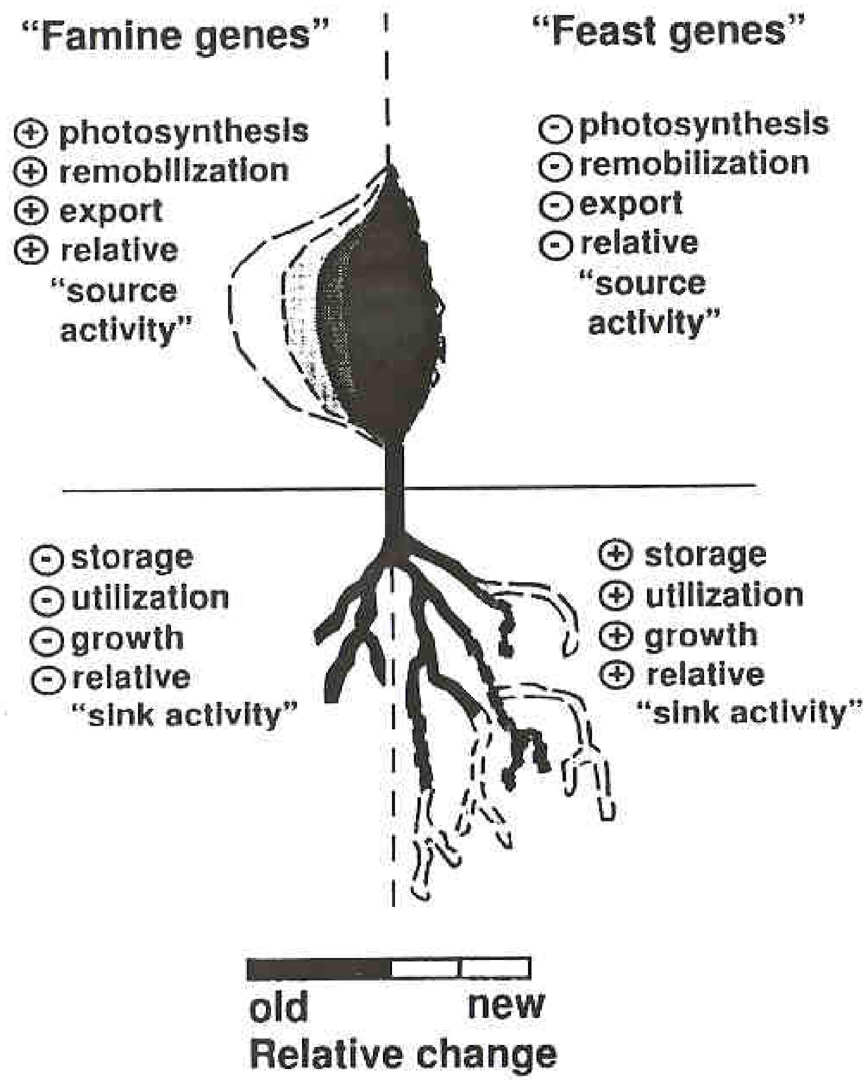

Figure 1 After Koch 1996

Table 1. Genes repressed and enhanced following sugar feeding

Genes repressed	**Function**
Ivr1	Starch breakdown
Sh1	Starch breakdown
Lhcb	Photosynthesis
Genes enhanced	
Sus1	Root growth
Ivr2	Root growth
Patatin class 1	Storage
PAL	Defense
Chalcone synth	Defense
Hrp	Defense

After Koch 1996

Table 2 Prevention of salt (NaCl) induced damage by prior application of sucrose based on leaf necrosis of containerized *Quercus robur* L. at day 15.

Treatment	English oak	Holly
	Leaf necrosis	
30g NaCl	3.5	3.4
60g NaCl	4.2	4.0
Sucrose 25g + 30g NaCl	1.8	1.3
Sucrose 25g + 60g NaCl	2.8	2.8
Sucrose 50g + 30g NaCl	2.5	2.5
Sucrose 50g + 60g NaCl	2.8	2.1

After Al-Habsi and Percival (2006).

Table 3. The influence of sugars on the RGP of silver birch

Control (water)	11
Sucrose	17
Fructose	13
Glucose	14
Glycine betaine	16
Galactose	12

RGP = root growth potential (the number of new roots formed >1cm; a useful indicator of future plant performance (Percival unpublished).

Useful Further Reading

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