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Branch-rooting the weeping willow: *Salix babylonica* growth rates

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Abstract
Weeping Willow *(Salix babylonica)* growth rates are quantified in terms of tree height, trunk diameter at base, leaf stem length, and root system expansion. Experimentally, these rates are found to be *the same for the parent and replanted cutting* – in other words, "like father, like son". Leaf stem growth is stimulated by gravity induced *tensile stress*, whereas root system growth is stimulated by *compressive stress* ahead of the root tip. These results may be applicable to the concept of *mechanosensing*. The aim of this study is regenerating the *Salix babylonicae* (Weeping Willow Trees) rapidly from branch cuttings.
The results indicate that the success rate for replanting the entire willow tree is 75% [68% CI: 54% to 96% (N=4)]. The leaf stem and root system growth rates differ by a factor of 50 or more, but are observed to be the same, 16 ft/yr (5.0 m/yr) and 3.0 in/yr (6 - 7 cm/yr) respectively, both for the branch cutting, and the tree. The conclusion is that the the success rate of propagating branch cuttings, i.e. "branch rooting", is 25% [68% CI: 15% to 40% (N=8)], similar values are reported by others. This may require branch diameters from 0.6 cm to 1.6 cm.

Keywords: growth, leaf physiology, plant restoration, reforestation, root development, stem physiology, mechanosensing, Weeping Willow tree, *Salix babylonica*

Introduction
The Weeping Willow tree *(Salix babylonica)* grows at an incredible rate, in terms of *height* [m/yr.], *trunk diameter* [cm/yr.], *leaf stem length* [m/yr.], and *root system* [cm/yr.] compared with other local trees, i.e. walnut, maple, pine, locust, elm, chestnut, sycamore, oak, etc. The *Salix babylonica* has a particularly active cambium layer, and perhaps because of this factor, is unique in its ability to propagate via branch rooting.
Although *branch-rooting*, is an unconventional technology, there is still a lot to learn in terms of the precise details of this type of propagation. Hershey (1994) discusses these planting techniques and growth rates, measured in terms of overall tree weight [Kg/yr]. Perfecting reliable *reforestation techniques* is the primary motivation for this study.
Kuzovkina & Volk (2009) [11] discuss growth rates of various *Salix* plants and trees, including *Weeping Willows*, in terms of coppicing, biomass production, rooting and potting techniques. Cremer (2003) reports on the remarkable growth rates of *Salix* trees and plants in Australia, so active that the main problem is *restricting* their unlimited propagation. Kefeli, Lininger, and Shultz (2007) [9] measure the effects of various types of *auxin* hormones on the rooting rates of *Weeping Willows*, comparing the rate effects of planting in spring, summer, fall, or winter.
Commercial applications - The transplantation technique of branch-rooting, if proven successful, can potentially result in 10 to 20 next generation trees from each parent, each with a jump start advantage of 2 to 3 years in terms of initial growth. Pounders *et al.* (1992) [15], Vahdata *et al.* (2002), and Arrillaga *et al.* (1992) [1] discuss the difficulties of rooting Ash, Walnut and Hemlcok trees.

Materials & Methods
Willow trees. Four *Salix babylonica* (Weeping Willow) saplings were planted, each 8–feet tall (2.4 meters) [trunk diameter at base 3–inches (7.5 cm)] to 30-feet tall (9 meters) [trunk diameter 8–inches (20 cm)], a remarkably rapid vertical growth rate of 0.75 to 1.0 meters/year (2.5 to 3 feet per year). Trunk growth rate was 1.6 cm/year (0.63 inches per year trunk diameter). Initially, the root ball of these trees was 0.9 meter in diameter (3 ft.) at the time of planting in 1995, planted in a 1.2 meter (4-foot) diameter hole. Szekely & Dagmar (2011) report overall dimensions, but not rates, of various *Salix* trees.
Willow branch rooting. Eight Weeping Willow branches were cut using a "lopper" or hack-saw, and planted in the ground, Fig. 1b, *"rooting"* at a depth of 0.3 to 0.4 meters (12-inches to 16-inches).
Procedure. Two each of four different diameters (Figure 1b) of branch cuttings were planted: 0.6 cm (1/4–inch diameter), 0.9 cm (3/8–inch diameter), 1.3 cm (1/2-inch diameter), and 1.6 cm (5/8-inch diameter). Growth rates are measured by observing the length of time it takes for a leaf stem or root system to traverse a given distance.
Soil, Lighting, Hydration - The soil composition for the experiments, existing flowerbeds of ordinary topsoil, situated over a substrate of gravel, clay and sand (often called *"hard-scrabble" or "hard-pan"*), and partial sunlight lighting conditions. Natural rainfall was the only hydration during the course of the experiment. However, using "winter cuttings" is a standard preferred technique Howard & Harrison (1988) [8], for rooting various hardwood species, although laboratory experiments are usually conducted at elevated temperature and humidity.

Results

Fig 1a: Two severed Weeping Willow branches (foreground), age 8 months (May 2015), are shown rooted in the garden soil of a local patch of ivy. No new leaf stems have developed at this stage.

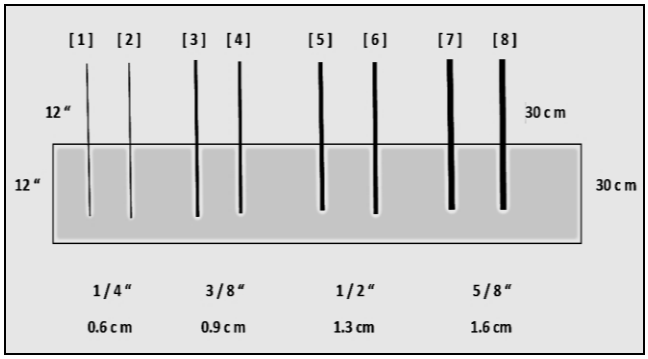

Fig 1b: Schematic diagram showing diameters and lengths of the experimental branch-rootings.

Figure 1 shows the yield percentage from 8 branch-rootings, 2 survived, 25%, as shown. Thus, using small sample size statistics, the survival rate using these transplantation techniques ranges from 10% to 40% [68% CI: 0.097 to 0.403(N=8)]. In terms of transplanting the entire Weeping Willow tree, using a standard compacted root ball wrapped in burlap, our survival success rate is 75% [68% CI: 54% to 96% (N=4)].

Fig 2: The same two severed Weeping Willow branches as Fig. 1, now age 10 months, July 2015, start to generate characteristically long leaf stems (Niklas *et al.*, 2009) [13], each stem 0.3 to 0.4 meters in length. (Fern plant at lower left is transplanted from a dormant root system.)

Figure 2 shows the Leaf Stem Growth Rate leaf stems (12 to 16-inches in length, 0.3 to 0.4 meter) have developed on both re-rooted branches, growing at a rapid rate (12 to 16 feet per year, 3.7 to 4.9 meters/year), directly comparable to the leaf stem growth rates on the tree. Greene *et al.* (2015; 2016) discuss bending, buckling and growth of stems and leaves.

Fig 3: A transplanted Weeping Willow branch is pulled from the ground, revealing the newly developing root system. 8 to 9 new roots, 1 to 2 mm in diameter, 1 to 2 cm long, were generated by the original plant during the Winter and Spring. 4 are sheared away from friction during extraction.

Figure 3 shows root growth rate of 3.0 in/yr (6 - 7 cm/yr) at a depth of 12-inches (30 cm) is observed below the local frost-line in the Northeast U.S.

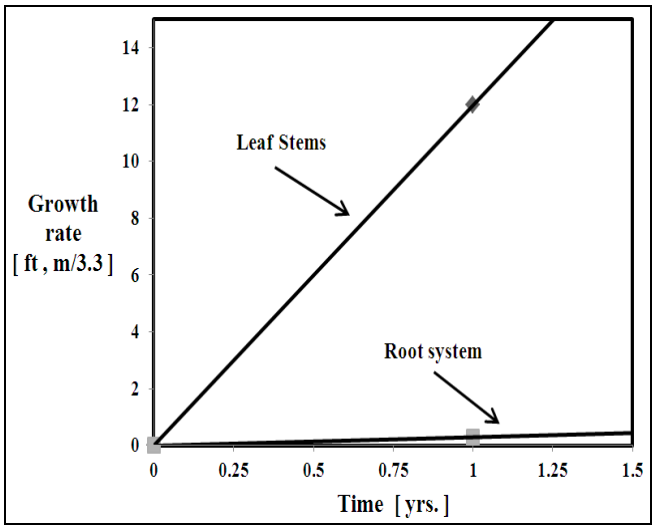

Fig 4: Leaf stem growth rate compared with root system growth rate, differing by more than a factor of 50. Growth rates are the same for the transplanted branch-cuttings and parent tree.

Figure 4 shows the observed rapid growth rates for Salix babylonica leaf stems (4 m/yr, 14-feet/yr) and roots (6 cm/yr, 3-inches/yr), from either the tree or a transplanted branch, are identical.

Fig 5: *Salix babylonica* branches from the lower part of the crown typically grow all the way to the ground, then stop.

Figure 5 shows branch bending for the Salix babylonica. Left un-pruned, these branches will grow all the way to the ground. Beismann *et al.* (2000) reports measurements of bending stiffness and yield for Salix babylonica branches.

Discussion

Four Salix babylonica saplings (Weeping Willow trees) and eight transplanted branch cuttings are quantified, in terms of growth rate (branch-rooting). Survival success rate for the full size trees is 75%, for the re-rooted branch cuttings, 25%. These numbers compare with other researchers' findings. Statistics indicate that there is considerable variability in these results, so that this "branch-rooting" technique may have a 40% survival rate. Interestingly, it is found that the leaf growth of the transplant suddenly stops, once the branch hits the ground, suggesting "mechanosensing". Important applications include generalizing this technique to other tree species, for the purpose of re-forestation.

Frost Line **-** Temperature effects may be critically important to the success of this type of *branch-rooting*, Mencuccini *et al.* (1988). For the most part, laboratory experiments on branch-rooting (Mencuccini *et al.* (1988); Szekely & Dagmar (2011); Vahdati *et al.* (2002); Vesk (2006)) are done under controlled circumstances in a greenhouse at elevated temperature and humidity.

Thermal Effects **-** Mencuccini *et al.* (1988) investigate temperature effects on the rooting of olive cuttings in the range 18 to 30 ^{0} C., reporting success ratios (yield percentages) from 34% to 70%, compared with 10% to 40% as reported herein. Below the frost line, it is estimated that the *Salix babylonica* roots are at 35 to 45 ^{0} F. (20 to 70^{0} C.) throughout most of the winter.

Mechanosensing **-** During the growth phase, the Weeping Willow leaf stems are driven by gravity-induced *tensile stress*, whereas the root system growth is stimulated by *compressive stress* from soil compaction ahead of the root tip. That is to say, the opposite *sign* (+) or (-) of the driving force provides the rate limiting step in these growth mechanisms, differing by a rate factor of 50 or more, Fig. 4. Mechanosensing is discussed by Greene & Greene (2015).

Summary

Weeping Willow trees (*Salix babylonica*) are well known to flourish in marshy areas all around the world. In some areas, notably Australia, *Salix* plants and trees are so prolific (of their own volition, reproducing without extra help from man), that the research emphasis is on containment and restriction of unrestricted growth, rather than promoting their propagation. Nevertheless, as a research model, the Weeping Willow tree is worth studying, because of its rapid growth-rates, as reported here. These research techniques may be applicable to other more resistant forest species, (i.e. pine, oak, maple, eucalyptus, etc.) with the principle objective being rapid reforestation after forest fires. Although a relatively small sample size, our experimental experience to date indicates that, here in the Northeastern United States, transplantation of the entire *Weeping Willow* tree has survival success rate of only 75% [68% CI: 54% to 96%, (N = 4)], whereas propagation by means of branch re-rooting, as reported here, has survival rate of only 25% [68% CI: 9.7 % to 40.3 %, (N = 8)]. In terms of economics, weeping willow trees (7' to 10') cost $250 to $500 US, whereas branches are available for rooting, at virtually no cost.

Conclusions

In terms of reforestation, the transplantation technique of branch-rooting, as described here, is well worth our research effort. If proven successful, branch-rooting can potentially result in 10 to 20 next generation trees from each parent, each with a jump start advantage of 2 to 3 years in terms of initial growth. *Aspens* and *Poplars* may be similar in this regard, as per Zsuffa *et al.* (1993) [22]. The observed rapid growth rates for *Salix babylonica* leaf stems (4 m/yr) and roots (6 cm/yr), from both the full sized tree or a re-rooted branch cutting are the same, as shown in Fig. 4.

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