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Original article

Investigating the relationship between various measuring methods for determination of establishment success of urban trees

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ABSTRACT

Establishment is a key concept in urban forestry but it is currently inconsistently defined and measured. Thus, several different methods are being used to determine establishment success but their consequences and applications are rarely discussed. With this paper we would like to stimulate an increased discussion regarding these concepts both in relation to a theoretical definition but also to their practical use. The problem was approached through an experiment using sweet cherry (*Prunus avium* L.) and northern red oak (*Quercus rubra* L.) trees and the most common methods used for determination of establishment success. The trees were studied during the first three years after transplant and the association between the different measuring methods was examined. A Principal Component Analysis showed that terminal and lateral shoot length were strongly correlated, and that midday- and pre-dawn shoot water potential, and stomatal conductance were strongly correlated. We developed an index for nightly recovery of water status, which showed that terminal shoot growth was not related to nightly recovery until the third year after transplanting. Our results suggest that successful tree establishment is determined differently depending on which method is used for determination but that the differences might decrease with time. The lack of a firm definition of the term establishment may complicate communication, both within the scientific community and in practice.

1. Introduction

Although not clearly defined, the term establishment is often used to describe a tree's status after transplanting. Within practice, successful establishment is often demanded from contractors and promised by tree nurseries. Furthermore, numerous scientific studies have set out to compare the effects of various production, planting and/or management techniques on trees' and tree seedlings' capacity to become fully established (e.g. Struve, 1993; Gilman and Beeson, 1996; Gilman, 2004; Ferrini and Baietto, 2006; Davis et al., 2008; Jacobs et al., 2009). There are several different approaches on how to measure establishment success. It is often determined by survival, or shoot, leaf, or stem growth (Struve and Joly, 1992; Day et al., 1995; Radoglou and Raftoyannis, 2002; Harris et al., 2008; Pinto et al., 2011; Dostalek et al., 2014; Woolery and Jacobs, 2014; Sherman et al., 2016), or the treés resumption of pre-transplant shoot or trunk growth rates (Gilman and Beeson, 1996; Struve et al., 2000). Establishment success is sometimes determined by measurements of physiological attributes such as hydraulic conductivity or water potential (Carlson and Miller, 1990; Beeson 1994), or through a combination of both physiological and morphological attributes (Harris and Gilman, 1993; Lauderdale et al., 1995; Gilman et al., 1998). Gilman et al. (1998) used both growth and water potential measurements in a post-transplant study of trees exposed to different irrigation volumes, but the conclusions on establishment success were based on stem and height growth. In another study, Harris and Gilman (1993) based their conclusions regarding tree establishment success on both physiological and morphological determinations. Struve et al. (2000) considered trees established once they showed no signs of drought stress even under mild drought, and thus concluded that they did not need further irrigation.

Struve (1990) has mentioned that there is no workable definition of the term establishment. As a consequence, establishment is defined, and measured, in different ways. It can be seen as a biological process (Rietveld, 1989) during which the transplanted tree becomes fully connected to the hydrologic cycle of the growing site (Grossnickle, 2005). It has been suggested that an urban tree might be considered established when it does not need further irrigation (Day and Harris, 2007), a definiton that is only applicable to trees that are being irrigated. However, it is unclear exactly when a transplanted tree is fully coupled to the hydrologic cycle and no longer needs further irrigation, and several methods for determining the water status during the establishment process are being used. A tree may also be considered

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established when it reaches a productive phase, that is, when it starts fulfilling the purpose for which it was planted (Day and Harris, 2007); this definition is based upon a functionality perspective rather than a biological one. For an urban tree, the purpose of planting is connected to the expected environmental and aesthetic benefits associated with urban forests (Schroeder and Cannon, 1983; Akbari, 2002; Nowak and Crane, 2002; Saebo et al., 2012). Significant growth and high crown density may thus be considered necessary attributes for an urban tree to be considered as established, leading to determination of establishment success being based on morphological characteristics rather than physiology (Summit and Sommer, 1999; Day and Harris, 2007).

The aim of our study was to highlight how differently the concept of establishment has been approached in the field of urban forestry and what effect the approach has on determinations of establishment success. We did this by comparing the relationship between different methods for measuring establishment, both morphological and physiological. We analysed data from two commonly used urban tree species during the three consecutive years directly after planting. The analyses were performed on trees exposed to different post-transplant management regimes to allow for general validity. We compared measurements of midday and pre-dawn shoot water potential, stomatal conductance, terminal and lateral shoot growth, leaf area, and survival, all of which are commonly studied attributes in determinations of establishment. Measurements were performed to capture both seasonal and annual changes throughout the study. We also calculated a nightly recovery index, as a value for water status including both midday- and pre-dawn status.

2. Materials and Methods

2.1. Trees and study site

In this study, 50 trees of *Prunus avium* and 50 trees of *Quercus rubra,* were used. They originated from two nurseries, situated in the south of Sweden. All trees within the same species came from the same nursery and they were selected early in the spring of 2007, before growth had started. All trees within a species originated from the same seed source, and they had been treated according to Swedish standards for field cultivation of trees until the start of the study (LRF, 2012). Their selection was based on stem circumference and general appearance, with the intention of choosing as uniform plant material as possible. Stem circumference was 14–17 cm at one metre above the root collar (standard measuring procedure in the Swedish nursery industry) and the nine-year-old trees were about four metres tall. They were randomly assigned one of five different root treatments – root pruning, bare-rooted, balled and burlapped, spring-ring cultivation (Superoots® plastic, The Caledonian tree Co., Edinburgh, UK), forming an Air-Pot® and root control bag cultivation in in-ground fabric container (Smart Pot®, High Caliper, OK, USA), as described in a parallel paper (Levinsson et al., 2014). The trees were then treated according to standard procedures for the assigned production system during the last growing season before transplanting (LRF, 2012). The production systems of urban trees can be seen as an integrated result of several production variables such as e.g. container design/root treatment, irrigation, and substrate/soil. Each treatment included 10 trees of each species. The bare-rooted and the balled and burlapped trees were left undisturbed in the field, and the root-pruned trees were pruned without being removed from their growing spots. For the two other treatments, the trees were harvested and the treatments were carried out at two different nurseries specialising in the particular production system. The trees were kept in the nurseries until the spring of 2008, when they were transplanted at two different sites; in the city of Malmö and in the experimental fields at the campus of the Swedish University of Agricultural Sciences, Alnarp. Four trees of each species and production system were planted in the city of Malmö and the trees were managed by the municipality and included in their establishment management program during the first two post-transplant years of the study. They were irrigated approximately every second week. All trees were planted at the same depth with the root collar at the soil surface, in a three-metre-wide grass strip, alongside a street in a high-rise residential area. They were irregularly planted with a minimum distance of four metres. A one metre in diameter circle around the trees was covered with small-sized gravel to reduce grass competition. At Alnarp, the trees were planted in a field, with 4.5 metres between each tree in every direction. The soil was covered with a single layer of black polypropylene ground cloth (Mypex®) to inhibit weed growth. A drip-irrigation system was installed where the hose made a circle around each tree at the perimeter of the root ball to ensure that water was available for the planted root mass. The plant water availability was determined regularly using an HH2 moisture meter (Delta T Devices Ltd., Cambridge, UK) at 10, 20, 30 and 40 cm depths to ensure that the trees were never drought stressed during the two following growing seasons. The probes for the moisture meter were installed just beyond the planting zone, with controls installed in to the root balls of the air-potted and root control bag cultivated trees, as the growth substrate in these root balls varied substantially from the texture of the sandy loam at the experimental fields. Irrigation permitted the soil water content to remain near field capacity or just below. No tree at either site received any irrigation during the third year of the study and none of the trees were given additional nutrients.

2.2. Determinations

Measurements were performed during the three seasons after transplanting (Table 1). Midday shoot water potentials (Ψ_m) were determined between 11.30 am and 16.00 pm and pre-dawn shoot water potentials (Ψ_{pd}) were determined the following day approximately one hour before sunrise. The time of the pre-dawn measurements varied over the season, depending on the time of sunrise. The determinations were performed with a three-week interval, except when bad weather prevented measurements and measurements had to be postponed. A pilot study showed that there were very small differences in shoot water potential within each tree, allowing us to use a single shoot from each tree at each occasion. Two to three cm of the shoot tip was cut off from a branch at the middle height of the crown and immediately installed in a pressure chamber (Model 1000, PMS Instrument Company, OR, USA). Pressure was increased in the chamber at a constant rate of 0.05 MPa/s (Turner, 1988). Before cutting the shoot for the water potential determination, leaf stomatal conductance (g_s) was determined on two fully sun-exposed leaves on each shoot during the daytime measurements. Conductance was determined each year after transplanting using a leaf porometer (model SC-1, Decagon Devices, Pullman, WA, USA).

Shoot elongation measurements were performed each season, after shoot elongation cessation. Both species grew with one flush per year. Two terminal and two lateral shoots in the south, the north, the east, and the west, from the middle height of the crown were measured. To reduce the impact of removing mature leaves from the small trees in 2007, leaf size was determined by measuring the leaves that had grown on the shoots cut off for water potential measurements. Three leaves on each shoot (the first, third, and fourth leaf, counting from the shoot tip) were scanned within one day after they had been sampled from the tree, with a total of nine leaves per season. Leaf size was analysed using ImageJ (http://imagej.nhi.gov/ij version 1.4.3.67, Broken symmetry software, USA). For determinations of survival, all trees were revisited in 2013 and the status of each tree was assessed as good, in decline or dead. Examples of signs of decline were dead main branches, low crown density, and/or discolouration.

2.3. Statistical analyses

Principal Component Analyses (PCA) were performed using R (version 2.15, R development Core team, 2014) running the