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Review

A review of nursery production systems and their influence on urban tree survival

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ABSTRACT

Urban trees face a myriad of complex challenges growing in the built environment. The most common environmental conditions influencing urban tree mortality are water availability, nutrient deficiency and soil compaction. Long-term survival of recently installed trees has been directly attributed to site conditions, planting technique, and post-transplant maintenance. Tree survival is also dependent on selection of healthy, suitable plant material. Production methods for woody plants include traditional plastic containers (CG), pot-in-pot containers (PIP), and in-ground fabric containers (IGF). Field grown trees may be produced as bare-root (BR) or root ball-excavated and burlap-wrapped (B&B) trees. Each of these methods offers unique advantages in relation to production and installation. Many of the studies reviewed reveal varying post-transplant establishment and survival responses to production methods at a species-specific level.

1. Introduction

Natural ecosystems are being lost or degraded by urbanization, with far-reaching consequences pertaining to species richness, environmental hydrological services, heat island effects, carbon sequestration, and nutrient cycling, among other important ecological processes (Nowak and Crane, 2002; Alberti and Marzluff, 2004; Oliveira et al., 2011). Studies have demonstrated that these urban centers may be improved through the implementation of urban greening initiatives that offer numerous ecological, social, and economic benefits (McPherson et al., 2007). Ecological benefits of urban greening include: lowering ambient air temperatures within urban heat islands, reducing atmospheric carbon dioxide, storm water capture and improving air quality (Nowak and Crane, 2002; McPherson et al., 2007; Oliveira et al., 2011). Urban greening also offers economic benefits to cities, such as reducing energy use and increasing heating/cooling cost savings, increasing property values and creating green industry jobs (McPherson et al., 2007; Nowak and Dwyer, 2007). A review of human health benefits in urban settings has suggested that there is a positive correlation between overall physical health in a population and the amount of accessible urban green space (van den Berg et al., 2015).

In a review of the efficacy of urban forest pollution mitigation, the term “urban forest” was used to describe the collection of all woody plants, lawns and “pervious soils” occurring in urban ecosystems where humans have installed these landscapes or have an influence on their continued protection (Escobedo et al., 2011). Trees are of particular importance for assessment of the benefits of the urban forest because the cost and effort of planning and installation, as well as the biology of tree growth, suggest a long-term investment and interest in their survival.

Many programs have been implemented to increase the number of trees planted in cities, including Iowa’s collaborative program with the non-profit organization Trees Forever, Chicago’s Urban Forest Climate Project, and the Million Trees LA initiative in Los Angeles, California (McPherson et al., 1994; Thompson et al., 2004; McPherson, 2014). In each location, urban trees are being planted in new and previously existing commercial, public, and residential landscapes. Planting spaces include garden beds, lawns, and street tree pits. Overall, results of these programs have been suc-

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cessful in regards to tree survival, growth, and ecological benefits (McPherson, 2014).

Municipalities may not have sufficient funding to cover installation, watering, and long-term maintenance costs for urban trees, and installed trees often don't survive long-term (Stobbart and Johnston, 2012). Tree survival in an urban setting depends on many factors, including planting location, installation, and post-planting care (Jutras et al., 2010). The most common environmental conditions influencing urban tree mortality relate to water stress, nutrient deficiency and soil compaction (Nowak et al., 1990). It has been found that early management and maintenance practices bear as much importance on tree establishment and survival as does the environmental conditions that they are grown in (Nowak et al., 1990). Trees that have been harvested from field-production methods are susceptible to transplant shock as a result of root loss during the harvesting process (Struve, 2009). Trees enduring transplant shock experience abiotic stress due to reduced water and nutrient uptake, and the loss of carbon energy stores (Struve, 2009). The physical spaces allotted to new tree plantings are restricted in urban settings, and the management and routine maintenance practices, including regular watering, are often performed at a minimum threshold or left to homeowners on adjacent land (Nowak et al., 1990).

In a meta-analysis of street tree survival rates found in multiple studies, the population half-life for trees installed into a street tree pit was found to be 13–20 years, and overall street tree life expectancy was found to be 19–28 years (Roman and Scatena, 2011). This survival period is longer than previous estimates of 7 or 13-year average life spans, but without having a defined economic "break-even" point it is difficult to analyze whether the benefits are outweighing the costs (Moll, 1989; Skiera and Moll, 1992). An economic study of urban forest survival and growth revealed that the energy-saving benefits conferred by long-term planting programs in the city of Sacramento, California fell short of the projected savings values due to tree mortality (Ko et al., 2015). Due to the variability in urban tree care during and after planting, it is important to choose individual plants that have a high chance of survival, with minimal supplemental care required beyond the time of installation. Tree nursery production systems have been shown to influence post-transplant establishment and growth of trees (Levinsson, 2013), and thus may be an important parameter in choosing nursery stock relative to planting trees in the urban environment.

Young trees are generally produced using one of three main types of nursery production systems: container-grown (CG), field-grown root ball-excavated and burlap-wrapped trees (B&B), and field-grown bare-rooted trees (BR). The goal of developing each of these systems is to produce healthy nursery stock efficiently and cost-effectively. However, there are differences between these systems both in quality of plant material (particularly root development and subsequent transplanting viability), and affiliated costs (Green et al., 2015). Deeper insight into the effects of nursery production systems on tree morphological and physiological traits may aid in the development and implementation of best management practices to increase post-transplant establishment of urban trees. The intent of this paper is to review the current literature on the influence of nursery production systems prior to planting, and the potential impact of this variable on the performance and survivability of trees after installation in the urban environment.

2. Methods

Research literature outlining nursery production systems, tree survivability, and urban tree performance was reviewed and compared. In the absence of sufficient findings to make direct comparisons between single-species plant performance in each production system, general observations of production system efficacy and long-term survival benefits, as well as plant species-specific responses were noted and compared. Information from professional journal sources was also included in the review. Emphasis was placed on shade trees commonly planted in urban settings in the northeastern United States, and other woody plant studies were also included for a more complete analysis, as appropriate. Plant nomenclature was verified using the Integrated Taxonomic Information System on-line database: http://www.itis.gov.

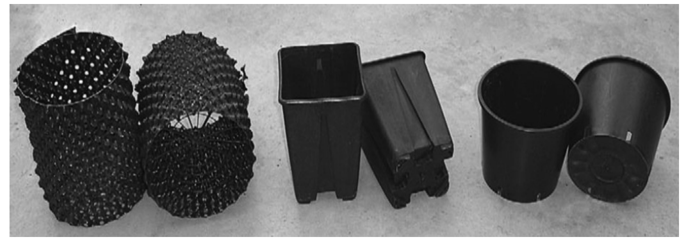

Fig. 1. Three container designs, L-R: Superoots® Air-PotTM (The Caledonian Tree Company, Pathhead, UK), Quadro antispiralizzante (Bamaplast, Massa e Cozzile, IT), and traditional rigid container (Cultistop; ARCA spa, Osio Sotto, IT), (Photo credit: Amoroso et al., 2010).

3. Nursery production systems

Several methods are currently in application relative to the production of woody plant material following initial cultivation of seedlings, cuttings, or tissue-cultured trees. These include transplanting liners (young plants) into various containerized systems including traditional (i.e. rigid) plastic containers (CG), pot-in-pot containers (PIP), and flexible in ground fabric containers (IGF). Trees can also be field grown and harvested as bare-root (BR) and root ball-excavated and burlap-wrapped (B&B) trees. Each of these methods offers unique advantages and disadvantages in relation to production and installation.

3.1. Container-grown (CG) systems

Container-grown systems include traditional plastic containers and other designs (see Fig. 1), which have been developed for ease of handling, appearance, improved drainage and elimination of circling root systems (Appleton, 1993). Due in likelihood to the protection provided by the plastic container and use of lightweight soilless growing media, standard containerized nursery stock is less susceptible to mechanical or human-induced injury sustained in the nursery or during transport as compared to B&B plants (Mathers et al., 2007). Though traditional containers are cost-effective, concerns have arisen about the negative influence of circling tree root development on drought stress tolerance, nutrient uptake capacity, and anchorage, leading to decreases in long-term survivability (Warren and Blazich, 1991). In order to address these physiological disadvantages, a number of newer designs and technologies have been implemented in the production of containerized trees. Improved designs include variably-shaped (i.e. square; pyramidal) containers, and features such as drainage holes, and ribbed or stepped plastic, to minimize circling root growth (Appleton, 1989, 1993). Container-grown nursery stock retains 100% of the root system at the time of planting, in comparison to B&B plants, which may be transplanted with as little as 5% of the original root system (Blessing and Dana, 1987). However, this estimate does not reflect concerns associated with root deformation and necessary pre-transplant pruning, nor does this ensure higher post-transplant survival rates.