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Research article

Effects of deep tillage and municipal green waste compost amendments on soil properties and tree growth in compacted urban soils

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ABSTRACT

Large trees are often seen as a means of offsetting negative consequences of growing urban densification. To increase the tree canopy cover of dense urban landscapes, developers, planners and urban tree managers are often forced to plant into damaged and compacted sites. Compacted urban soils can hinder the establishment and growth of deep rooted, woody plants by: 1) impeding root exploration and development which is critical for water and nutrient acquisition; 2) reducing infiltration of water into the soil and the availability of water to plants; and 3) reducing gas exchange and the balance between anaerobic and aerobic conditions.

At three sites in Melbourne, Australia with compacted and damaged soils, we established four soil remediation treatments: 1 & 2) tillage to 0.25 m with and without 50% (v/v) municipal green waste compost (MGWC) additions, and 3 & 4) tillage to 0.5 m with and without 50% MGWC addition, plus a non-remediated control. Each treatment was replicated (n = 3), and one *Corymbia maculata* (spotted gum) tree was planted into the centre of each 2 × 2 m treatment plot (n = 15), at all three sites (n = 45).

Bulk density and field-saturated hydraulic conductivity were improved by tillage, at least in the short-term. The use of MGWC may maintain these changes for longer. Depending on site soil conditions tree growth may be improved by tillage alone. At one site, we found that additions of MGWC lead to nitrogen immobilisation due to site soil conditions. At another site, deep tillage (with or without MGWC) led to significantly improved tree growth.

Compacted and degraded urban soils may be improved through simple tillage and/or organic amendment strategies for the successful establishment of deep rooted woody plants. However, site soil conditions will dictate whether the addition of MGWC is beneficial or not, as one site showed no positive response to any tillage or MGWC. This research has examined a technique that can be used by landscape managers to improve soil physical characteristics and, in certain circumstances, can improve deep-rooted woody plant establishment and growth in challenging compacted urban soil conditions.

1. Introduction

Globally, more humans are living in cities than ever before (Desa, 2014). As a result, our cities are becoming more dense as scarce land is used to house the increasing urban population (Yokohari et al., 2000). The process of urbanisation may result in urban soils that have reduced ability to support healthy plant growth. Urban soils can be compacted by vehicle traffic, heavy machinery use, the transport and storage of materials, and the construction of roads and paths, buildings and other above and below ground infrastructure (Abdul-Kareem and McRae, 1984; Craul, 1994; Randrup and Dralle, 1997). Urban soils can be removed, replaced and redistributed, inverted, and sealed during construction activities (Scalenghe and Marsan, 2009).

The consequence of these urban disturbance activities is that soil often has poor physical characteristics that leads to slower infiltration (Chen et al., 2014) and reduced water storage (Haase, 2009). Similarly, urban soil disturbance can disrupt the natural cycling of nutrients within soils (McDonnell et al., 1997), reduce the organic carbon levels in soils (Chen et al., 2013), and cause soil crusting and erosion (Lorenz and Lal, 2009). Rehabilitation of damaged urban soils may only treat surface soil problems (Layman et al., 2010) which may lead to soils with intermittent waterlogging and drought characteristics (Scalenghe and Marsan, 2009). All these negative effects on urban soils will reduce the growth of most trees planted into those soils, particularly when the trees are young and developing their root systems (Jim, 1998; Pregitzer et al., 2016).

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Trees require water, nutrients and an adequate and accessible volume of soil from which tree roots access these resources. Root growth requires suitable levels of water and oxygen, a soil matrix with a mix of pore sizes, and soil temperature within an appropriate range (Ruark et al., 2012). Larger, long-lived trees can provide bigger benefits to their environment but their roots also require a larger volume of soil to support them and their resource requirements (Dawson, 1996). These conditions are unlikely in damaged and compacted soils, or in poorly remediated soils (Layman et al., 2016). Trees planted into such soils often experience a high mortality rate and those that survive experience a slow growth rate (Gilbertson and Bradshaw, 1990; Nowak et al., 1990).

Compacted soils can be remediated by tillage (Day and Bassuk, 1994; Sax et al., 2017). Soil tillage can be achieved by many methods (Day et al., 1995) including ripping, ploughing, and rotary hoeing. Tree establishment and growth may still be hindered by soils that have compacted subsoils (Millward et al., 2011). Compacted soils can also be remediated with amendments of organic matter (OM), incorporated into tilled soils to further improve physical, chemical and biological characteristics beyond that achieved by tillage alone (Cogger, 2005; Scharenbroch et al., 2013). Many of studies only focus on adding the OM into the top portion of soils (0–0.15 m) (Loper et al., 2010). The results of these amendment experiments have been varied, with some showing no improvement in plant growth (Gilman, 2004), while others show an improvement in plant growth as the amount of OM added reaches a level of 20–30% by volume (Cox et al., 2001; De Lucia et al., 2013).

There are many benefits that adding OM to soils may achieve (Vidal-Beaudet et al., 2018). Perhaps most importantly among these benefits are a reduction in bulk density and an increase in porosity (Khaleel et al., 1981). These changes allow for enhanced root growth and improved hydrological movements and gas exchange. Other benefits may include provision of nutrients (Curtis and Claassen, 2009; Loper et al., 2010), and improvements in the soil structure as aggregate formation is promoted by the breakdown of OM and an increase in soil biota (Diaz et al., 1994; Whalen et al., 2003). However, adding large volumes of OM into soils may also have negative consequences. OM will decompose and can lead to anaerobic conditions developing as oxygen is consumed, and continued anaerobic decomposition can produce compounds that are deleterious to plant root activity (Leake and Haege, 2014). Similarly, decomposing OM can also immobilise critical soil nutrients into the soil microbial biomass and therefore unavailable for plant root uptake.

To investigate whether OM can be incorporated into compacted and degraded urban soils to improve critical soil properties and tree establishment and growth, we evaluated tillage with and without OM, in the form of municipal green waste compost (MGWC), addition to a shallow (0.25 m) and deeper depth (0.5 m) using a scoop and dump technique (Layman et al., 2010; Rolf, 1991). The objectives of this study were to: (1) evaluate whether soil physical properties can be improved with tillage plus MGWC beyond tillage alone; (2) assess whether MGWC can be incorporated at depth without creating anoxic conditions within the soil; and (3) explore whether there are significant tree growth benefits from (3a) deep tillage when compared with shallow tillage; and (3b) tillage with added MGWC compared with tillage alone.

2. Methods

The study used three sites with compacted and/or damaged soils in Melbourne, Australia (Fig. S2); 1) Old Poplar Road: a gravel parking lot (Parkville 37.781419, 144.954749; 2) Sims Street: a small parcel of green space, close to the tidal river estuary (Fig. S2), with significant concrete debris within the soil, and completely surrounded by heavy transport roadways (West Melbourne 37.807039, 144.908513); and 3) Yarra Boulevard: a road construction staging site with a stratified soil profile (Burnley 37.831127, 145.017076). Melbourne has a warm temperate climate with a mean maximum temperature of 20.9 °C and with an average rainfall of 648 mm yr^{-1}. In the year the experiment commenced the mean maximum temperature was 20.9 °C and the annual rainfall received was 411.8 mm and in the concluding year the mean maximum temperature was 20.4 °C while the annual rainfall was 409.6 mm. In both years the rainfall was slightly less than two thirds of the expected annual rainfall.

At each site, any existing ground-level vegetation was killed using glyphosate solution weed-killer two weeks prior to plot establishment. Then, in June 2014, four soil amendment treatments and an unamended control were established in a fully-randomised, block design (4 treatments + control x 3 repetitions = 15 plots (each of 2 × 2 m)) at each site:

1) a control (no amendment),
2) tillage to a depth of 0.25 m,
3) tillage to a depth of 0.25 m with the addition of 50% v/v MGWC,
4) tillage to a depth of 0.5 m,
5) tillage to a depth of 0.5 m with the addition of 50% v/v MGWC.

The four tillage treatments were installed using a small backhoe to “scoop and dump” the soil with or without MGWC to the set soil depth (Layman et al., 2010; Rolf, 1991; Sinnett et al., 2006) (Fig. S1).

The OM (Enviromix Pty Ltd, Dingley Village) consisted of MGWC that was pasteurised and composted according to the Australian Standard (AS 4454). The MGWC had a pH of 6.6, electrical conductivity of 3.1 dS m^{-1}, and carbon to nitrogen ratio of 34. Due to the application of the ‘scoop and dump’ method of tillage used in this experiment MGWC was distributed heterogeneously throughout each tilled profile.

In early July 2014, a single *Corymbia maculata* (Spotted Gum) sapling was planted in the middle of each 2 × 2 m plot and irrigated with five litres of water per tree in the first and second months after establishment. The saplings were approximately 0.3 m tall and had been nursery grown, and ‘hardened’ outside in 1.5 L air-prune pots (S1020 – Trentcom Pty. Ltd., 95C Beaumont Rd Berwick, Victoria, Australia, 3806. *Corymbia maculata* is widely planted in eastern Australian cities in parks and as a street tree. *Corymbia maculata* is a deep-rooted plant with roots that can grow deeper than two meters into soil (Falkiner et al., 2006). The plots were mulched to a depth of eight centimetres with coarse wood chips soon after planting to suppress weed growth (Fig. S1).

2.1. Soil measurements

Soil bulk density, soil texture, field saturated hydraulic conductivity, pH, and the electrical conductivity (EC) were measured at the three sites prior to establishing treatments from soil samples retrieved from three soil pits dug across a transect of each site (Table 1). Initial bulk density was measured using metal rings driven into the soil in the 0–0.1 m, 0.1–0.2 m, 0.3–0.4 m and 0.4–0.5 m depths. The bulk density was calculated as the oven dried soil mass (48 h at 105 °C) divided by the ring volume.

Subsequent bulk density samples collected at three and 15 months from establishment were taken from pits dug into a corner of each plot to minimise disturbance to the soil. In the control and the 0–0.25 m (shallow) treatments samples were taken at 0–0.1 m depth only, while for the 0–0.5 m (deep) treatments samples were taken at 0–0.1 m and 0.4–0.5 m.

Soil hydraulic conductivity was measured in each plot at all three sites using a falling head, small-diameter, single-ring infiltrometer (Nimmo et al., 2009). PVC tubes 150 mm in length and 104 mm in diameter (internal) were inserted 50 mm into the soil surface. A ruler was attached to the inside of each tube to visually monitor water level change. The PVC tubes were kept full of water until saturation was achieved in the soil. Once a steady-state rate of water infiltration was reached the tubes were refilled with water. The decrease in the water