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De-icing salt contamination reduces urban tree performance in structural soil cells☆

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ABSTRACT

Salts used for de-icing roads and sidewalks in northern climates can have a significant impact on water quality and vegetation. Sub-surface engineering systems, such as structural soil cells, can regulate water runoff and pollutants, and provide the necessary soil volume and irrigation to grow trees. However, the ability of such systems to manage de-icing salt contamination, and the impact of this contamination on the trees growing in them, have not been evaluated. We report on an field investigation of de-icing salt contamination in structural cells in two street-revitalization projects in Toronto, Canada, and the impact of this contamination on tree performance. We analyzed soil chemistry and collected tree attributes; these data were examined together to understand the effect of salinity on tree mortality rates and foliar condition. Data collected from continuous soil salinity loggers from April to June for one of the two sites were used to determine whether there was a long-term accumulation of salts in the soils. Results for both sites indicate that both sites displayed high salinity and alkalinity, with levels elevated beyond those suggested before those reported to cause negative tree effects. For one site, trees that were alive and trees that had a better foliar condition had significantly lower levels of soil salinity and alkalinity than other trees. High salinity and alkalinity in the soil were also associated with lower nutrient levels for both sites. Although tests for salinity accumulation in the soils of one site were negative, a longer monitoring of the soil conditions within the soil cells is warranted. Despite structural cells being increasingly utilized for their dual role in storm-water management and tree establishment, there may be a considerable trade-off between storm-water management and urban-forest function in northern climates where de-icing salt application continues to be commonplace.

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1. Introduction

Many studies have established the adverse effects of road salts, especially sodium chloride (NaCl), on water quality, fauna, and flora. These salts are frequently used to de-ice roads and pavements in Northern climates and can accumulate in the environment, affecting water quality (Godwin et al., 2003), changing aquatic ecology by causing high mortality of existing species (Sanzo and Hecnar, 2006), and excluding salt intolerant species (Collins and Russell, 2009).

Road salt contamination is a common problem in urban soils (Cunningham et al., 2008), and this affects our ability to maintain and grow urban trees (Cekstere and Osvalde, 2013), especially in commercial-retail streetscapes. Urban trees are important to sustainability (Willis and Petrokofsky, 2017), as they can ameliorate air pollution (Nowak et al., 2014), mitigate rise in summer air temperature (Vailshery et al., 2013; Greene and Millward, 2017), moderate water runoff (Bartens et al., 2009, 2010; Berland et al., 2017), and provide a pleasing environment that can increase commercial activity (Wolf, 2005), among other benefits. However, growing urban trees is challenging because urban soils are generally not conducive to optimal tree growth. Typically, the high compaction of urban soils (Bassuk and Whitlow, 1987), their low soil volumes (Sanders and Grabosky, 2014), and their low organic matter and nutrient content (Cekstere and Osvalde, 2013; Ghosh et al., 2016), can all reduce the water-holding capacity of soils as well as retard soil-atmosphere gas exchange (Day and Bassuk, 1994;

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Nielsen et al., 2007), thus limiting tree-root development, soil water availability, and tree growth (Koeser et al., 2014).

Moreover, road salt contamination in soils can have a significant impact on trees (Kayama et al., 2003), causing leaf and root necrosis (Fostad and Pedersen, 2000), impeding growth, and causing early death (Byron and Barker, 2002; Munns and Tester, 2008). Trees can still be affected by soil salinity even without showing any symptoms (Munck et al., 2010). While the accumulation of de-icing salts, mostly NaCl, in urban soils has been well documented (Pedersen et al., 2000; Cunningham et al., 2008; Fay and Shi, 2012), its negative effect on urban trees is only starting to be understood (Paludan-Müller et al., 2002; Hanslin, 2011). While salt spray can cause chlorosis and necrosis of leaves and buds (Gałuszka et al., 2011; Snieškienė et al., 2016), salt accumulation in urban soils can increase osmotic stress for urban-tree roots and causes chlorosis (Czerniawska-Kusza et al., 2004; Cekstere et al., 2008), with long-term accumulation enhancing this effect (Equiza et al., 2017). The physical characteristics of the soils, such as soil compaction and texture can influence the degree of this accumulation (Day et al., 2010). De-icing salt accumulation in soils can also displace soil nutrients (Eimers et al., 2015; Kargar et al., 2015), thus further aggravating its effect on tree performance.

Incorporating trees in highly urbanized streetscapes usually requires green infrastructure systems, which are approaches to environmental management in cities that mimic nature, including the restoration of sub-surface soil structures, green roofs, and tree-planting (Tzoulas et al., 2007). Systems such as sub-surface engineering technologies can improve growing conditions for trees by expanding soil volume and ensuring high quality soil (Grabosky et al., 2001; Xiao and McPherson, 2011; Layman et al., 2016). An example of these technologies are structural soil cells, which are an underground framework of rigid structural units that support the above pavement and can be filled with prescribed soils to support trees (Ow and Ghosh, 2017). These cells, like other sub-surface greening technologies, or green-infrastructure systems, such as bio-retention cells (Hunt et al., 2008) and structural soils (Xiao and McPherson, 2011), can collect, absorb, and infiltrate surface water runoff, while also providing a system of passive irrigation for the trees growing in them (Page et al., 2015). Soil cells are frequently successful in establishing trees (Ow and Ghosh, 2017) and are becoming a common component in many urban streetscapes across the world, especially those that have undergone revitalization.

Given the growing interest in using structural cells to sustain and increase urban trees, it is important to understand how these systems manage de-icing salt contamination. However, most research on sub-surface engineering technologies has focused on their ability to manage peak flow mitigation (Hunt et al., 2008) and pollution, especially the most detrimental water pollutants, such as hydrocarbons, heavy metals, and nutrients (Ellis and Marsalek, 1996; Scholz and Grabowiecki, 2007). In northern climates, most research is focused on the ability of these systems to perform despite the cold temperatures (Kratky et al., 2017). Although some studies have assessed vegetation performance despite salinity infiltration in bio-retention cells (Szota et al., 2015), few, if any, have focused on tree performance in structural cells. Also, while there have been plenty of studies on salinity impacts on trees along roadsides, no study has dealt with trees growing in this type of sub-surface engineering technology. Because of this, we do not yet know how de-icing salts contamination in these sub-surface systems can affect the trees growing in them.

This paper responds to this need by reporting on an investigation of de-icing salt accumulation in urban soils in a northern-climate city revitalized with structural cells and its impact on the trees growing in these cells. To achieve this, we set out to: 1) quantify the level of salts in the soil of the structural cells, measured by both sodium concentration and level of electro-conductivity (EC), a proxy for salinity levels in soils (Equiza et al., 2017); 2) determine if there is an accumulation of salts in the soils during one season; 3) explore the association of soil chemistry components; and 4) determine if there is an influence of these soil conditions on patterns of tree foliar condition and tree mortality.

This investigation contributes to our understanding of de-icing salt accumulation in green infrastructure systems, particularly sub-surface engineering technologies, and the impact of this accumulation on urban-tree performance. This understanding can help guide system deployment and the associated tree-planting in places where the application of de-icing salts is frequent.

In the following sections, we provide an overview of the investigated locations, as well as the methods for data collection and analysis. We then present and discuss the results of the study, with specific references to de-icing salt accumulation in structural soil cells and its impact on tree performance. We conclude with management implications and ideas for future research.

2. Methods

2.1. Site description

The study was carried out in Toronto, a city located on the north-western shore of Lake Ontario and the largest urban centre in Canada (Statistics Canada, 2011). Toronto is in the 7a plant hardiness zone (NRCan, 2016) and is characterized by mean daily maximum and minimum temperatures of 12.9 °C and 5.9 °C, respectively, and an extreme maximum and minimum temperatures of 40.6 °C and −32.8 °C, respectively. The city also has a mean annual rainfall of 831.1 mm, a mean annual snow cover of 121.5 cm (based on 30-year climate normal, 1981–2010; see Environment Canada, 2014), and an average of 170 degree-days above 10 °C. The soils of the city, where not replaced by anthropogenic soil deposits or altered by anthropogenic processes, are representative of the Lawrence river soil system, characterized by silt clay and silty till soils from glacial and fluvial deposits (Sharpe, 1980).

This study investigated two structural-soil-cell installations in Toronto: Bloor Street and Queens Quay Boulevard (Fig. 1), covering a total of 287 trees.

The first installation is on Bloor Street, a major east-west thoroughfare in the city, and one of the most important commercial-retail streetscapes in Canada. The sidewalk between Church Street and Avenue Road along Bloor Street was redesigned in 2011 to include structural soil cells for managing storm-water and growing trees. Many of the original trees faced high mortality (62 dead by 2015), and all were eventually replaced in 2015.

The second installation is along Queens Quay Boulevard, an important commercial and entertainment area in Toronto near Lake Ontario. The boulevard contains the Martin Goodman Trail, a multi-use recreation trail that extends continuously along the street. The streetscape between Bay Street and Spadina Avenue was revitalized in 2015 with the installation of structural soil cells under the recreation trail for storm-water management and growing trees. Most of the trees planted as part of this revitalization are alive and in fair or good foliar condition.

These two revitalized streetscapes display different surrounding built environments. However, in both cases, as is common to structural cell installation, the soil environment of the trees is connected to the soil cells underground, and each soil-cell basin, or trench, extends continuously for up to an entire sidewalk block. The texture and organic content of the soil used to fill the cells at the time of tree planting is prescribed to support tree growth (Ow and Ghosh, 2017).

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