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Composted sewage sludge and steel mill slag as potential amendments for urban soils involved in afforestation programs

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ABSTRACT

This study aimed to assess the impacts of composted sewage sludge and steel mill slag on urban soil fertility and tree growth. The research was conducted in an urban area (Botucatu, State of São Paulo, Brazil) characterised by extremely unfertile urban soils and with high production of these wastes. Plant growth, soil physico-chemical properties, and chemical composition of leafs were analysed during a 12-month field experiment. Principal factor analysis (PFA) and canonical correspondence analysis (CCA) were applied in the evaluation of the investigated soil-plant system. The results showed that soil fertility was increased by the combination of applied waste materials, which provided good conditions for full plant development and maintenance. PFA showed that the variability of the investigated model was mainly due to the role of soil organic matter as source/sink of soil heavy metals. CCA showed that the investigated soil-plant system was characterised by time-dependent evolution, with an equilibrium reached during the final stages, suggesting that the obtained results may be realistic from a long-term perspective. This study provides evidence that composted sewage sludge and steel mill slag are acceptable alternatives for improving urban soil quality and tree growth. The reuse of these wastes could provide a low-cost alternative for their complex and expensive management and disposal with, additionally, the possibility of turning currently bulky refuse material into a commodity.

1. Introduction

Urban trees are a key component of the urban ecosystems (Schwab, 2009), improving human comfort by directly influencing physical and mental health (Dwyer et al., 1992), as well as providing both environmental and socio-economic benefits (Brack, 2002; Miller et al., 2015).

For full attainment of these benefits and for the reduction of corrective and expensive procedures (drastic trimming, transplantation and even removal), urban forests must be carefully managed through specific actions (choice of plant species, production of seedlings, and/or soil preparation). However, the condition of urban soils often poses the greatest challenge to the maintenance of healthy trees (Scharenbroch and Catania, 2012). These soils are often of anthropogenic origin (anthropogenic soils), as they have formed from anthropogenic materials (artifacts such as asphalt, brick, cardboard, carpet, cloth, coal combustion by-products, concrete, glass, metal, paper, plastic, rubber, and both treated and untreated wood products) or have major properties and behaviours that have been significantly influenced and altered by human activity and tools (Capra et al., 2012, 2015; Soil Survey Staff, 2014). Thus, such soils often possess inadequate chemical, physical, and biological characteristics, such as unfavourable pH, unbalanced/insufficient nutrients, the presence of toxic materials, compaction issues, modified temperature, and the presence of artefacts (Capra et al., 2015). For such reasons, improving soil physico-chemical features before any afforestation activity is often

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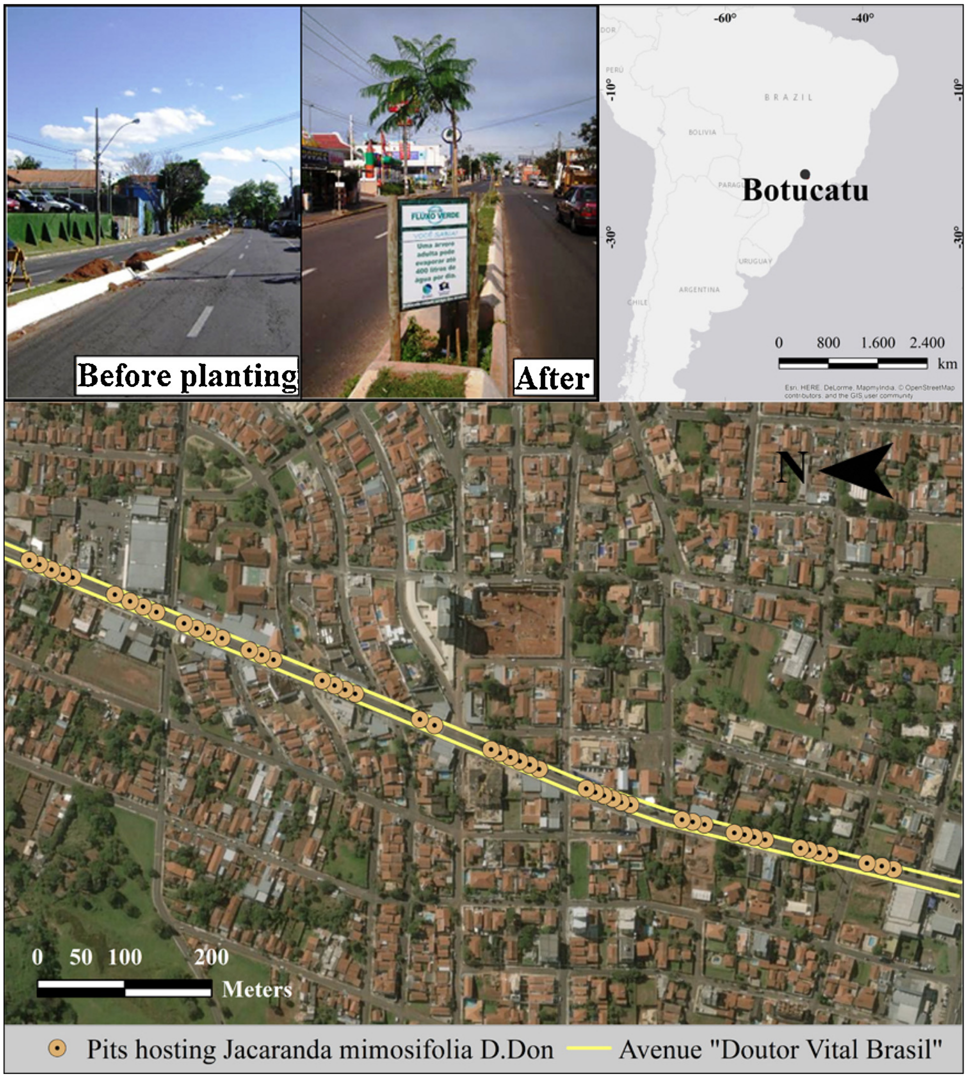

Fig. 1. Location of the study area.

mandatory for ensuring adequate health, development, and maintenance of trees.

This should be achieved sustainably using resources available locally, such as composted solid wastes, treated wastewater, and industrial residues (Scharenbroch et al., 2013; Kumar and Hundal, 2016). In general, after these residues are classified and evaluated for safety, they can be reused for various purposes. Sewage sludge, a common waste material produced in urban areas, typically comes from sewage or wastewater treatment plants and contains considerable amounts of organic matter and nutrients essential to plants (Cheng et al., 2007). Depending on its origin, sludge can contain considerable amounts of heavy metals and pathogenic agents (e.g. helminth eggs, protozoan cysts, *Escherichia coli*, etc.) (Giusquiani et al., 1995; Sampaio et al., 2016). One option for significantly decreasing the pathogenic load of sludge is to transform it into compost (Cheng et al., 2007). This technique, besides eliminating organisms potentially harmful to humans, helps to stabilise the organic matter, resulting in a product that can be used safely, often classified by national and international regulations as an organic fertiliser (Guerrini et al., 2000). For this reason, the reuse of composted sewage sludge (CSS) as substrate for seedling production (Trigueiro and Guerrini, 2003; Rocha et al., 2013) and forests used for wood production (Guerrini et al., 2000; Nolasco et al., 2004; Bobrowski et al., 2009; Guerrini, 2014) is currently the most common technique in Brazil. Because such areas are characterised by quite unfertile sandy soils generally unsuitable for any other agricultural uses (Guerrini, 2014), the use of CSS has been proven a good option for improving their physical, chemical, and biological properties (Nolasco et al., 2004; Sampaio et al., 2012; Sampaio et al., 2016). Additionally, the generated products are not edible, preventing the introduction of contaminants into the food chain.

Slag, a typical industrial waste, is produced in large quantities during ore-smelting for cast iron and the production of other metals (Das et al., 2007). Even if prohibited in some countries, slag is generally stockpiled in outdoor yards, generating serious environmental concerns. Brazil is the world's sixth largest producer of cast-iron, with a yearly output of approximately 25 million tons, generating some 7 million tons of slag annually (Nolasco et al., 2004). In some countries such as Japan, this waste material is extensively used in agriculture especially for rice production (Ma and Takahashi, 2002). In Brazil, because of the high cost of transport, the application of slag to agriculture primarily occurs in the Southeast region, where the major steel mills are located. This slag is used primarily as a corrective for soil acidity but also as source of Ca, Mg, P, Fe, Mn, and Si (Nolasco et al., 2004; Fonseca et al., 2011), an element considered beneficial to plants (Gascho, 2001) owing to several capabilities (strengthening structure, increasing resistance to infestation and insect/disease attack, decreasing drought stress,