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Interactive effects of composted green waste and earthworm activity on tree growth and reclaimed soil quality: A mesocosm experiment

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ABSTRACT

On reclaimed landfill sites, the addition of organic matter such as composted green waste (CGW) to soil-forming materials can support tree survival and growth. CGW addition may also assist the establishment of sustainable earthworm populations, and in turn these organisms can promote further soil development through their burrowing and feeding activity. Despite such potentially mutual benefits, little research has been carried out into CGW and earthworm interactions with trees on reclaimed land. A twelve month, open field nursery experiment revealed the responses of the interactions between two tree species; *Alnus cordata* (Betulaceae) and *Acer platanoides* (Sapindaceae), CGW and the earthworms *Aporrectodea longa* (Lumbricidae) and *Allolobophora chlorotica* (Lumbricidae) in reclaimed soil. Controlled mesocosm conditions permitted a detailed investigation into the factors affecting tree growth and nutrient uptake, soil nutrient cycling and earthworm population dynamics. Results revealed that *A. cordata* growth was unaffected by CGW or earthworm addition. There was, however, a significant positive synergistic effect of earthworm activity and CGW addition on *A. platanoides* growth. CGW addition significantly increased levels of organic carbon and essential plant macro-nutrients in reclaimed soil while earthworm activity assisted decomposition of both leaf litter and CGW. Findings showed that CGW may serve as a suitable early source of organic matter to support earthworm population establishment on reclaimed sites. This experiment demonstrates that CGW improves reclaimed soil quality, thereafter supporting tree establishment and growth on reclaimed landfill.

1. Introduction

Creation of a suitable soil resource is essential for sustainable greenspace establishment, to provide necessary soil chemical and physical conditions and restore normal soil biological functions (Scullion, 1992). There is increasing industrial and scientific interest in improving the soil materials used in reclamation projects, particularly through the addition of organic matter from waste streams, such as Composted Green Waste (CGW) (Foot et al., 2003; Moffat, 2006; Nason et al., 2007; Forest Research, 2015). However, at present there is limited research into the effect of CGW on tree growth and soil quality on reclaimed land (Ashwood et al., 2014). The few available field experiments have demonstrated some benefits of CGW on tree establishment, and this appears to be dependent on the rate and depth of incorporation (Foot et al., 2003; Moffat et al., 2008).

The addition of organic waste materials to reclaimed soil may also enable the establishment of sustainable earthworm populations, which can in-turn support tree growth and the delivery of ecosystem services (Lowe and Butt, 2002, 2004; Blouin et al., 2013). Certain earthworm species (e.g. anecic, deep-burrowing) actively incorporate and mix organic waste materials into soils, enhancing mineralisation and benefiting soil fertility (Piearce and Boone, 1998; Lowe and Butt, 2002). The addition of earthworms may therefore be an effective way to enhance the benefits of organic wastes such as CGW during land reclamation. However, studies into the utilisation of earthworms during the restoration of brownfield sites to woodland are few in number, and have experienced limited success, particularly due to inappropriate earthworm species selection and the use of excessively hostile substrates without sufficient amendment (see the reviews of Butt, 1999a,b, 2008). Those studies which have investigated the influence of earthworms on forest tree species in natural soils have mostly observed a positive influence of earthworms on tree growth (e.g. Marshall, 1971; Haimi et al., 1992; Muys et al., 2003; Welke and Parkinson, 2003; Larson et al., 2010). However, such results are unlikely to be directly comparable to the specific conditions presented by reclaimed land.

There is overwhelming agreement that tree species differently influence soil quality and soil faunal population development through the quality and quantity of their leaf and root litter (Swift et al., 1979;

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Pigott, 1989; Muys et al., 1992; Reich et al., 2005; Rajapaksha et al., 2013). It is therefore of value, when planning land reclamation to a woodland end-use, to understand whether the tree species planted are likely to provide litter which enables native soil faunal communities to establish, thus supporting soil development and local ecosystem service provision (Kibblewhite et al., 2008; Rajapaksha et al., 2013). Certain tree species, such as *Alnus cordata* and *Acer platanoides* are recommended for planting on reclaimed or ex-industrial land, based on their tolerance to high soil pH and dry soil conditions, and potential for Short Rotation Foresty (SRF) based on fast growth rates (Hibberd, 1986; Forest Research, 2011). Currently however, there is a paucity of knowledge regarding the interaction between these two non-native tree species and native UK soil biota, making these pertinent tree species to investigate further and compare to previous research with similar native species (Rajapaksha et al., 2013; Ashwood et al., 2017).

The aim of this mesocosm experiment was to investigate the interaction effects between earthworms, trees and soil quality after CGW addition, in order to inform future land restoration activities. The experimental design is based upon the study done by Rajapaksha et al. (2014), which successfully demonstrated a beneficial earthworm-tree interaction between native UK earthworms and an exotic eucalypt tree species. Specific objectives of the present study were to: (i) measure the effect of composted green waste (CGW) and earthworm activity on tree growth and nutrient uptake in reclaimed soil; (ii) investigate the effects of CGW and tree species on earthworm community density in reclaimed soil; (iii) assess the effects of CGW, tree species, earthworm activity and their interactions, on reclaimed soil carbon and nutrient status.

2. Materials and methods

2.1. Study site and experimental design

The experiment was located at the Forest Research Headley Nursery Enclosure, Hampshire (Nat. Grid Ref: TQ 54929 84214), previously used for similar experiments (McKay et al., 1999; Moffat, 2000; Broadmeadow et al., 2005; Rajapaksha et al., 2014). It utilised a planting-tube mesocosm technique, similar to that employed by Rajapaksha et al. (2014). The mesocosms consisted of 0.25 m diameter, 3 mm thick PVC tubes cut to 0.6 m lengths. The base of each tube was covered with fine mesh (1 mm, supplied by Amari Plastics) to prevent earthworm ingress/egress. Earthworms were further confined inside the open-top mesocosms through the application of two unbroken strips of adhesive plastic hook ('velcro') tape applied to the inside of the tubes, following the design of Lubbers and van Groenigen (2013). Tubes were buried in the ground to 0.4 m depth, with 0.2 m protruding above ground level. This technique allows removal of whole soil/root system from the tube at termination of the experiment and permits detailed examination for desired soil depths and has been successfully used for tree root experiments (Bending and Moffat, 1997) and tree growth/earthworm interaction experiments (Rajapaksha et al., 2014). Each tube was filled to 0.4 m depth with a soil treatment, and a tree was planted in the middle of each tube (detail in 2.2.). The experiment began in June 2014 and ran until July 2015.

Fig. 1 shows the layout of tubes within the experimental plot, which consisted of five blocks, each containing a randomised placement of 9 planting tubes (4 treatments X 2 tree species, and 1 soil-only control). Each block contained a representative of each tree species in all four treatment combinations, and a tree-free control tube, which contained de-faunated reclaimed soil only, to account for the effect of tree species alone on soil parameters. Each of the nine tree-treatment combinations had five replicates, totalling 45 tubes in this experiment. Each block was separated by a 3-m buffer zone, and within the blocks, each planting tube was separated by 1.5 m. The wider experimental plot itself was homogenous and each planting tube was separated from the surrounding soil. As such, each tube acted as an individual experimental unit (e.g. replicate), irrelevant of location on-site. The perimeter

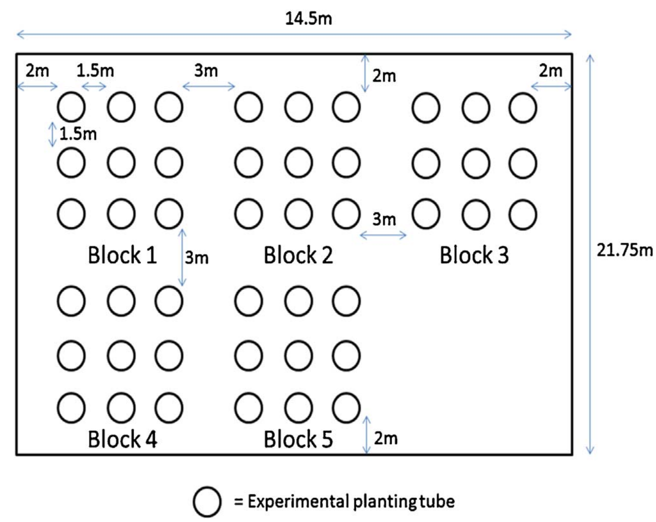

Fig. 1. Experimental layout of planting tubes at Headley Nursery.

of the experiment location was surrounded by an electrified rabbit-proof fence to prevent damage to trees by small herbivorous mammals. Following tree planting, a continuous drip irrigation system was applied to each tube to maintain soil moisture level at 25–30% for optimal tree growth (Fig. 2).

A single Prenart Super Quartz soil water sampler (PTFE suction cup lysimeters, 25 mm diameter, 95 mm length) was installed in each tube, within the upper 0.1 m of the soil profile, to allow for soil solution samples to be taken by connecting it to a vacuumed bottle. These were subsequently found to be unable to remove sufficient soil water samples for chemical analysis, despite soil in tubes being kept sufficiently moist through irrigation (perhaps due to high clay and stone fraction of reclaimed soil media preventing good contact) and so this method of sampling was abandoned.

2.2. Experimental treatments

This experiment employed four treatment combinations: no treatment (control); CGW addition only; mixed-species earthworm addition only; and CGW and mixed-species earthworm addition. For CGW-treated tubes, the soil included incorporation of screened 0–25 mm PAS 100 "Soil Improver" grade CGW (courtesy of Viridor Ltd) at a rate equivalent to 500 kg Total N ha^{-1}, which amounted to 31.4 g $tube^{-1}$. This amendment rate was chosen to reflect the legal limit set by Nitrates

Fig. 2. Inspection of mesocosms. In the foreground the drip-irrigation system is visible, as are the white velcro strips within the experimental tubes to prevent earthworm escape.