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Short rotation forestry – Earthworm interactions: A field based mesocosm experiment

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ABSTRACT

Short rotation forestry (SRF) which consists of planting rapidly growing native and non-native tree species has been introduced to the UK to increase woody biomass production. A largely unknown aspect of SRF species is their interaction with soil fauna, of which the earthworm community is a major component. Earthworms have a pronounced impact on litter decomposition, nutrient cycling and tree growth. Conversely, tree litter and root chemistry can impact on the associated earthworm community development. The aim of this study was to determine direct interactions between SRF species and earthworms. A field-based mesocosm experiment was conducted using *Betula pendula* (birch) and *Eucalyptus nitens* (eucalyptus) with two earthworm species *Lumbricus terrestris* and *Allolobophora chlorotica*. The one year experiment revealed that native birch and non-native eucalyptus had a similar influence on *L. terrestris* population development. However, birch had a positive impact on *A. chlorotica* population establishment compared with eucalyptus. In the presence of earthworms, total tree biomass and leaf nitrogen concentration of eucalyptus were increased respectively by 25% and 27% compared with an earthworm-free control. In the presence of earthworms, surface litter incorporation was greater for both tree species (almost 5 times for birch and 3 times for eucalyptus) compared with controls. This work showed direct SRF-earthworm interactions which differed for tree species.

1. Introduction

Short rotation forestry (SRF) was introduced to the UK as a potentially efficient method to increase woody biomass production for energy generation (Forestry Commission, 2010). Potential SRF practice includes use of rapidly growing native and non-native trees that reach their economically optimum size after 8–20 years; each plant producing a single stem to be harvested at around 0.15 m diameter (McKay, 2011).

Earthworms, which are a major group of soil fauna in temperate systems (e.g. Blouin et al., 2013), have a direct interaction with the plant community (Lee, 1985; Scheu, 2003; Eisenhauer et al., 2009). A range of tree species are known to have a prominent influence on earthworm development and community establishment (Muys et al., 1992; Neirynck et al., 2000; Reich et al., 2005). Alternatively, earthworm species have various impacts on soil structural development, litter decomposition, carbon and nutrient cycling, and subsequently on tree growth and production (Haimi et al., 1992; Welke and Parkinson, 2003). A vital, but largely unidentified aspect of SRF species is their direct interaction with earthworms and the reciprocal effects.

Effects of earthworms on soil nutrient dynamics and plant growth have been extensively studied. Scheu (2003) reviewed 67 papers (1947–2002), which investigated this aspect and showed that in most of the studies (79%), shoot biomass of plants significantly increased in the presence of earthworms. Most of these studies investigated crop plants, mainly cereals, and pastures; very little is known of plant-earthworm interactions in more natural communities. Significantly, few studies have investigated the influence of earthworms on forest tree species (e.g. Marshall, 1971; Haimi et al., 1992; Muys et al., 2003; Welke and Parkinson, 2003; Larson et al., 2010). However, most observed a positive influence of earthworms on forest tree growth, but these investigations (except those of Muys et al., 2003 and Larson et al., 2010) were pot experiments conducted with very young seedlings (<1 year) under controlled environmental conditions.

Some studies have focused on the effects of tree species on earthworm population growth and community development (Muys et al., 1992; Neirynck et al., 2000). Mostly based on field surveys, these investigations suggested that litter quality and quantity are the determining factors for earthworm community development. However, the direct influence of tree root systems on

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earthworms has not been closely investigated in such field surveys.

The aim of the present study was to investigate direct interactions between SRF trees and earthworms under field conditions. Based on a technique used for tree establishment by Bending and Moffat (1997), a field-based mesocosm experiment was designed with selected SRF species and earthworms to provide results after one year. To promote the interaction between tree root systems and earthworms, the trees were grown in soil-filled tubes buried in the field. This technique allowed removal of the whole experimental system from the ground at the end, permitting detailed examination of all component parts. The experiment was designed to achieve the following aims:

- To investigate the influence of selected SRF species on establishment of introduced earthworms.
- To explore the effects of earthworm presence on SRF growth, biomass production and nutrient uptake.
- To assess the influence of earthworms on SRF litter incorporation, nutrient loading and soil properties.

2. Materials and methods

2.1. Experimental site, SRF trees and earthworm species

The experiment was established at the Forestry Commission Research Agency nursery (51°8′12″N 0°50′26″W), Headley Down, Hampshire. The area, with a mean annual temperature of 11.2 °C, receives an annual average rainfall of 630 mm. The local soil type is mapped as a sandy humo-ferric podzol (Jarvis et al., 1983). The experimental plot, which consisted of a relatively infertile sandy soil was recorded as having only very few epigeic earthworms present. Sterilised Kettering loam (see Table A1 in supplementary material for detail) was used as a substrate in the experiment to provide acceptable, if not optimal condition for earthworms and trees. This soil was sterilised by Boughton loam Ltd, UK (prior to sale) using a standard heating method to prevent the inclusion of weed seeds and soil-borne fungi. For the purposes of this work, the "sterilisation" was seen as a useful process as it ensured that no earthworm life stages were present. Supply of soil from this source has been used for 20 years in a diverse range of earthworm experiments (e.g. Butt et al., 1994).

The SRF species used were one year old birch (*Betula pendula*) and eucalyptus (*Eucalyptus nitens*) with mean (±SE) above-ground heights of 0.6 (±0.012) and 0.4 (±0.008) m respectively. One year old seedlings were selected, as this is the standard age for field transplantation of these species. Experimental seedlings were obtained from a Forestry Commission nursery which used standard practices to grow seedlings from seeds. These two SRF species which differ in origin (native/non-native), litter quality including physical and chemical properties (Rajapaksha et al., 2013a), were selected for comparative purposes.

The earthworm species used were a combination of field-collected *Lumbricus terrestris* (anecic) and *Allolobophora chlorotica* (endogeic). *L. terrestris* was selected based on previous earthworm field surveys, as it was the dominant litter-feeding species at most of the UK SRF sites surveyed (Rajapaksha et al., 2013a). *A. chlorotica* was selected with the purpose of testing tree root-earthworm interactions, as this species lives in the upper 0.1 m of the soil and shows a close association with plant root systems (Zorn et al., 2005). Combinations of the above species, from different ecological groupings, were used to minimise competition but maximise resource use efficiency (Lowe and Butt, 1999).

Fig. 1. Experimental set-up in the field: birch (*Betula pendula*) and eucalyptus (*Eucalyptus nitens*) trees were individually grown in PVC mesocosms (h = 0.60 m, d = 0.25 m) and planting distance was 4 m (between rows) × 2 m (between trees). An electrified rabbit fence was established around the plot and as seen, trees were extracted from the ground as complete units at sampling.

Table 1
Earthworm inoculum at the beginning of the 12 months of short rotation forestry (SRF) growth experiment in field-based PVC mesocosms.

Earthworm species	Mean (±SE) individual Biomass (g)	Density (No. tube^{-1})	Biomass (g tube^{-1})
L. terrestris (adult)	4.27 ± 0.12	3	12.8
L. terrestris (juvenile)	0.66 ± 0.02	2	1.3
A. chlorotica (adult)	0.36 ± 0.01	10	3.6

2.2. Tree establishment and earthworm introduction

Commercially available PVC tubes (0.25 m diameter) were used as tree-growing vessels. The tubes were cut into 0.6 m lengths and the base was covered with 1 mm nylon mesh before establishment in the field. Tubes were buried (mesh covered end at the base) in previously marked positions of an experimental plot, leaving 0.2 m protruding above the soil surface (Fig. 1). The mesh was present to prevent earthworm escape/ingress from the base and the raised height above the soil surface was to deter earthworm entry into the tubes during the experiment. Each tube was filled with sterilised Kettering loam to the level of the soil surface (20 kg dry soil per tube) and moistened to 25–30%. The selected SRF species (birch or eucalyptus) were individually planted into the soil-filled PVC tubes (Fig. 1, n = 24 per species). Planting distance was 4 m (between rows) × 2 m (between trees). Tubes were buried in species rows across the nursery plot for practical reasons to permit general maintenance and allow a rapid visual assessment of each. The plot was homogenous, with e.g. no slope and no surrounding vegetation. Each mesocosm acted as an individual system and the surrounding soil did not form a part of the experiment. A continuous drip irrigation system was applied to each tube to maintain the required soil moisture level (25%) for optimal tree growth. An electrified rabbit fence was established around the experimental plot to protect trees from small herbivorous mammals. Trees were allowed to equilibrate in the field, before earthworm introduction.

After 2 weeks, a combination of *L. terrestris* adult (n = 3) and juvenile (n = 2) plus adult *A. chlorotica* (n = 10) was introduced to half of the experimental tubes (Table 1). The second half of the tubes was kept as a control, with no earthworm addition. Treatments were applied through random allocation of binary codes to each fixed tree position. Earthworm density (as shown in Table 1) was set up as twice the maximum recorded at SRF field trial sites (Rajapaksha