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Interactions of native and introduced earthworms with soils and plant rhizospheres in production landscapes of New Zealand

Young-Nam Kim[a], Brett Robinson[b], Stephane Boyer[a], Hong-Tao Zhong[a], Nicholas Dickinson[a,*]

[a] Department of Ecology, Lincoln University, Lincoln, 7647 Christchurch, New Zealand
[b] Department of Soil and Physical Sciences, Lincoln University, Lincoln, 7647 Christchurch, New Zealand

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ABSTRACT

Native and exotic earthworms and plants co-exist on the margins of agricultural land in New Zealand. Remnants of native vegetation support mixed assemblages of depleted populations of native Megascolecid earthworms together with apparently increasing invasive populations of introduced Lumbricidae. We question whether the survival and viability of these earthworm populations is a function of soil preference and whether there are significant differences in terms of how the two groups are influenced by and modify soil properties and plant growth. Choice chamber and mesocosm experiments, with and without plant rhizospheres, were used to study five species of native earthworms, two of which could be identified only by DNA barcoding, and four introduced exotic species. Both natives and exotics preferred agricultural soils to a plantation forest and a native forest soil. Earthworms also modified the physico-chemistry of soils and greenhouse gas emissions, with a marked interaction with root morphology of two native species of tea tree. Lesser differences were found between native and exotic earthworms than between functional groups. It is concluded that New Zealand's production landscapes provide novel habitats with clear benefits both to threatened species conservation and to soil ecosystem services.

1. Introduction

Due to a long period of geographic and evolutionary isolation, and the former absence of mammals, New Zealand is one of the world's biodiversity hotspots; more than 80% of most floral and faunal groups are endemic and found nowhere else (Trewick et al., 2007). Human colonization and introduction of mammalian pests to these islands has been relatively recent, but native biodiversity has been impacted particularly severely (Lee, 1961; Sparling and Schipper, 2002; MacLeod and Moller, 2006). Agricultural modification of landscapes, vegetation and soils has certainly been to the detriment of native earthworms (Lee, 1959a; Molloy, 1988; Bowie et al., 2016).

Megascolecid earthworms are naturally well represented in the endemic fauna of New Zealand, with 177 recognized species (Lee, 1959a; Sims and Gerard, 1985; Lee et al., 2000; Glasby et al., 2009) that are otherwise poorly described in the scientific literature, compared with the 17 species of exotic introduced lumbricids. One of only a few recent field surveys of New Zealand's native earthworms revealed extensive cryptic taxonomic diversity with about 48 additional species (Buckley et al., 2011). The province of Canterbury on South Island has 25 recorded species, many of which are dispersed through the lowland plain that has been largely converted to intensive agriculture (Winterbourne et al., 2008). Several additional species found in Canterbury by two authors of the present paper (SB and YK) are currently in the process of formal recognition subsequent to DNA barcoding.

Native earthworms apparently disappeared quickly following conversion of land to agriculture, which was then colonized intentionally or unintentionally by introduced exotic European Lumbricidae, predominantly *Aporrectodea caliginosa*,*Aporrectodea longa*, *Aporrectodea rosea*, *Aporrectodea trapezoides*, *Lumbricus rubellus* and *Octolasion cyaneum* (Lee, 1961; Springett et al., 1992; Fraser et al., 1996; Springett et al., 1998). Endemic earthworms have found refuge beneath small remnants of native vegetation on the borders of agricultural land, which account for less than 0.5% of the vegetation cover of Canterbury (Winterbourne et al., 2008). In these restricted areas we have found that it is common to find coexisting assemblages of both native and exotic earthworms. It is recognized that ground disturbance through burning, vegetation clearance and ploughing played a major role in the demise of native

* Corresponding author.
E-mail address: Nicholas.Dickinson@lincoln.ac.nz (N. Dickinson).

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megascolecids, as is the case elsewhere in the world (Edwards and Bohlen, 1996; Hendrix, 2006). However, little is known of the interdependence and interactions between soil properties and the presence, absence or combinations of natives and exotic species. This lack of knowledge has much relevance in terms of both conservation of endemic species and the potential benefits of native earthworms to soil quality and ecosystem services.

Earthworms are known to mediate structural and functional processes in soil including aggregate stability, porosity, organic matter dynamics and nutrient cycling (Lee, 1985; Edwards, 2004; Al-Maliki and Scullion, 2013). They facilitate the mineralization of nitrogen and phosphorus from organic matter, thus stimulating plant growth and development (Blakemore, 1997; Sizmur and Hodson, 2009). These beneficial effects are weighed against the potentially detrimental effect of earthworm burrowing enhancing the preferential flow pathways for water and nitrate movement to waterways and increasing the release of greenhouse gases (Kernecker et al., 2014). Clearly, earthworms potentially have an important role both in management and mediation of the environmental footprint of production systems.

The aims of the present study were (i) to elucidate the predilection of native earthworms for soils that have become nutrient enriched and otherwise modified by agriculture and forestry, and (ii) to begin to understand the functionality and role of native earthworms alongside introduced species on marginal land, refugia and restoration plantings within production landscapes. A series of laboratory and glasshouse experiments were devised to compare the interactions of native and introduced earthworms with variously-modified soils and two native plant rhizospheres.

2. Materials and methods

2.1. Soils

Surface soils (0–15 cm) were collected from two Lincoln University farms situated close to the Lincoln University campus (Table 1). One is an intensively-managed, irrigated and fertilized dairy farm (referred to as DF) soil, well represented on intermediate terraces in Canterbury (Molloy, 1998). A second soil from a nearby dryland sheep farm (referred to as SF) has a lower-capacity for storing water due to a high stone content, although the collected surface horizon of soil beneath the turf was largely free of stones. Sheep-farming since the mid-19th century will have involved some degree of ploughing, top-dressing and reseeding, but this site had no recent history of fertilization or intensive management. A third Canterbury soil was collected from a relatively undisturbed plantation forest (referred to as PF) of non-native *Pinus radiata* that was established in about 1930 on land that had been used for perhaps the previous 50–80 years by European settlers for extensive sheep grazing. The original vegetation was probably degraded through burning by Maori in the centuries before this, but remnants of native plants (dominantly *Kunzea robusta*, Myrtaceae, kānuka) still exist. By way of further contrast, a fourth soil was collected from a native forest (referred to as NF) on the west coast of South Island. This soil has had little modification from its natural state, and incorporated a substantial organic component from plant litter. This location has much higher rainfall of >2000 mm, compared to mean annual regional rainfall of 630 mm at the Canterbury sites, and supports luxuriant indigenous broadleaf forest (Hahner et al., 2013; Rhodes et al., 2013).

Stones were removed from soils, using 4 mm sieves, and soils were stored for periods of up to 3 months prior to use in experimental work.

2.2. Earthworms

Five native species of earthworms representing epigeic, anecic, and endogeic functional groups were collected from locations in South Island, New Zealand. Three of these species have been described (*Deinodrilus* sp.1, *Maoridrilus transalpinus*, and *Octochaetus multiporus*) and are known to occur in Canterbury, but the remaining two are abundant but appear to be undescribed and are likely to be new to science (Table 2). We also collected specimens of four exotic species of lumbricid earthworms. Three of these (*Aporrectodea calginosa*, *Octolasion lacteum*, and *O. cyaneum*) are endogeics that are well represented on agricultural land, amongst about 19 species of exotics in New Zealand. The fourth exotic species, *Eisenia fetida* (an epigeic species), was collected from local compost heaps. The species of the present study were selected largely by virtue of ease of collection in large enough numbers by digging, abundance of adults during field sampling, most easily-recognizable morphology, and survivorship under laboratory conditions. Native species were initially identified morphologically using keys and descriptions from Lee (1959a,b), followed by molecular methods using a DNA barcoding approach based on the cytochrome oxidase subunit 1 (COI) and 16S rDNA regions, as described previously (Boyer et al., 2011).

For each part of the experimental work, earthworm species were further selected on the basis of the visually most viable and healthy laboratory cultures on each set-up occasion (Table 3).

2.3. Choice-chamber experiments

Simple choice chamber pieces of apparatus were constructed (Fig. 1) to investigate whether earthworms had clear preferences for the different soils in a series of separate assays. A commercially-available organic compost (intelligro.co.nz) that provided a suitable medium for maintaining the cultures, was placed in a fourth chamber. A moisture content of 30 % was established and maintained in each soil by weighing. The species of earthworms in each assay was dependent of the availability, numbers and viability of cultures that were being maintained in the laboratory

Table 1
Location and description of the four soils collected for experimental work. Distance is related to DF.

	Dairy farm (DF)	Sheep farm (SF)	Plantation forest (PF)	Native forest (NF)
Location	43°38’11.27″S, 172°26’17.56″E University grounds	43°38’39.48″S, 172°23’28.07″E Gammack Estate	43°25’24.55″S, 172°18’28.14″E Eyrewell	42°8’38.39″S, 171°19’50.36″E Punakaiki
Distance (km)	0	5	25	200
Classification	Templeton (immature Pallic)	Eyre (immature Pallic)	Lismore (orthic brown)	Karoro (sandy to orthic brown)
Description	Well-drained, fine sandy to silty alluvium. High WHC. Ryegrass paddock.	As for DF, but stonier, freer draining, with lower WHC. Ryegrass, Cocksfoot paddock.	Very similar to SF, but more stony. Mature *Pinus radiata*	Leached soil on sandplain of old marine and river terraces. Broadleaf, Podocarp.