Do I have the required soil bioengineers?

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Abstract
Earthworm species beneficial to pastures are not indigenous to New Zealand and because there has been no systematic release of earthworms, their distribution is patchy. The findings from an on-farm survey in the Central North Island in spring 2009, reinforces this with only 14% of paddocks sampled containing species from all three earthworm functional groups. At a field site, where both endogeic (surface acting) *Aporrectodea (A.) caliginosa* and anecic (deep burrowing) *A. longa* had been introduced 26 and 20 years earlier, respectively, healthy populations of both species were observed. The average rate of spread of anecic *A. longa* from the release site was 12.5 m/yr, similar to the rates reported previously for *A. caliginosa*. A strong case can be made for introducing epigeic and endogeic (both surface active) earthworms to pasture using proven technologies. Evidence is mounting of the benefits of introducing anecic earthworms to pastoral soils.
Keywords: invertebrates, earthworms, bioengineering, introductions

Introduction
Earthworms are the most obvious of the soil organisms. They play a critical role in sustaining a wide range of soil attributes (e.g. soil aggregates, pore structures) and processes (e.g. nutrient cycling). These underpin the majority of the soil provisioning (e.g. supply of nutrients, water, physical support) and regulating (e.g. filtering, greenhouse gases, flood mitigation, processing of dead matter) services required for sustainable pastoral agriculture.

Indigenous earthworm fauna (Megascolecidae) of New Zealand number 171 species (Glasby *et al.* 2009). Megascolecidae did not evolve under grazed pastures and have largely disappeared from areas converted from forest to pasture (Springett *et al.* 1998). Earthworm species that thrive under farmed pasture soils are exotic and were unintentionally introduced during European colonisation. These introduced species survived the long ship journey within the soil of potted plants and ships ballast from the United Kingdom and Europe (Smith 1893). Because there has been no systematic release of exotic earthworms, the number of species introduced is limited compared to the species diversity found in European farmland soils. The lack of earthworm species diversity was reflected in a nationwide survey in 1984-85 that revealed the presence of epigeic *Lumbricus (L.) rubellus* and endogeic *Aporrectodea caliginosa* in the majority of farm soils, while anecic earthworms, *A. longa* and *L. terrestris* were rarely found (Springett 1992). After a Canterbury survey, Fraser *et al.* (1996) reported similar species diversity, with a slightly greater diversity under pasture than under cropping.

New Zealand research suggests the introduction of earthworms into soils with no earthworm activity could increase pasture production by 10-30% (Stockdill 1982; Springett 1985a). There are limited data on the productivity that could be gained from introducing additional species beyond those active in the topsoil. Syers & Springett (1983) reported a 20% increase in plant production when anecic *A. longa* was introduced to pasture soils in which only epigeic and endogeic earthworms were previously present. Recent findings (Schon *et al.* 2010) highlight the importance of earthworm diversity, with anecic earthworms offering support and potentially acting as a substitute for the actions of epigeic earthworms under high stock treading pressures.

This paper reports on the findings of an on-farm survey assessing the earthworm species richness on farms in the Central North Island and on the establishment, abundance and rate of spread of *A. caliginosa* and *A. longa* from introductions to a volcanic hill country soil in 1984 and 1989, respectively. Techniques for introducing earthworms to pasture soils are also summarised.

Materials and Methods
Central North Island survey
In 2009, an on-farm survey of earthworm species diversity and abundance was carried out in the central North Island in a triangle bounded by Taupo in the South, Hamilton in the North and Rotorua in the East. Samples were collected from 116 paddocks on over 40 farms, predominantly dairy pastures (101), with a few established sheep, beef and deer pastures (15).

Of the 116 paddocks surveyed, 59 had been converted from exotic forest to pasture in the previous 5 years. The balance of paddocks had were under long-term (>50 years) permanent pasture. Soil textures ranged from sand through to clay. Twenty-seven paddocks had received dairy shed effluent from either a sump or pond. Pasture production levels reported by farmers ranged from <6 000 to >12 000 kg DM/ha and Olsen P from 10-100 µg/ml. The relationship between soil texture and management is reported elsewhere (Gray *et al.* 2010).

In each paddock, five 20 x 20 cm spade squares to a depth of 25-30 cm were collected and earthworms and other macrofauna (e.g. *Wiseana cervinata* (porina) and *Costelytra zealandica* (grass grub)) were hand-sorted and identified. Earthworms were sorted into species and aggregated into the three earthworm functional groups (epigeic, endogeic and anecic).

Earthworm introductions study

In March of 1984, MAF established an earthworm introduction trial on two hill-country sites within Mounganui Station on the Taihape-Napier Road. Both sites had been recently converted from tussock and scrub to pasture before the introduction. The only exotic earthworms observed were *Octalasion sp*. *Octalasion* is an endogeic earthworm, but considered to be of little value in pastoral systems (Springett 1985b). At each site *A. caliginosa* was introduced at a rate of 750 m^2. In 1989 *A. longa* was introduced a rate of 250 m^2 at the second site. In November 2009, in excess of a 150 soil cores (15 cm diameter, 20 cm deep) and/or spade squares (20 x 20 cm) to depth of 25-30 cm were taken at increasing distances in two directions from the release points at each of the three introduction sites, to assess the extent of spread of the introduced earthworm species.

Results and Discussion

Central North Island survey

Earthworms were absent in 53% of paddocks surveyed on farms located on the Central Plateau Pastoral Group (Gray *et al.* 2010). The majority of these paddocks where earthworms were absent had been recently converted from exotic forest to pasture land. Elliott & Hawke (2007) also reported low earthworm numbers in pastures recently converted from exotic forest. As the presence and activity of earthworms is important, so too is the presence of all three earthworm functional groups as they occupy different parts of the soil profile (Fig. 1) and play distinct roles in the maintenance of soil structure and nutrient cycling (Lee 1985; Schon *et al.* 2010). While European soils usually contain all three earthworm functional groups (Bouche 1987) only 14% of the paddocks sampled in the Central Plateau contained all functional groups (Table 1).

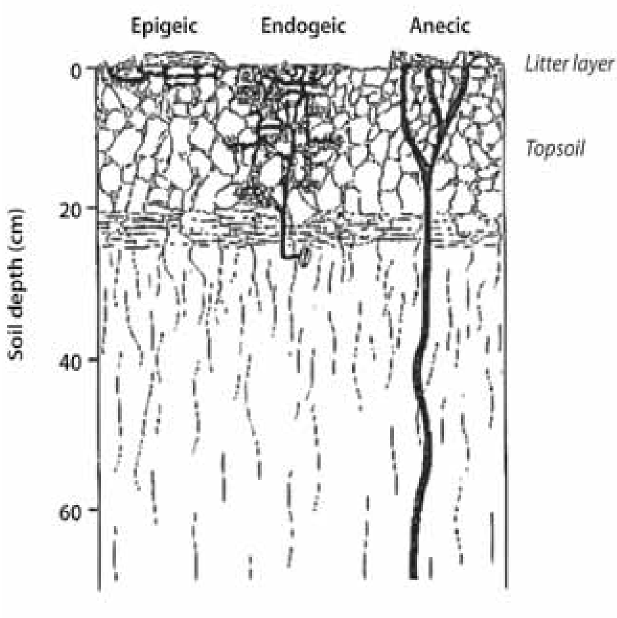
Table 1 Earthworm functional groups and species diversity in the central North Island on-farm survey. The functional groups and number of species detected in surveyed paddocks are given. Epigeic species include *Lumbricus rubellus*; endogeic earthworms include *Aporrectodea caliginosa*, *A. rosea*, *A. trapezoides*, and *Octalasion cyaneum;* anecic earthworms include *A. longa and L. terrestris*.

	Number of paddocks	Percent of total
Earthworms		
Present	54	47
Absent	62	53
Functional group*		
Epigeic	45	39
Endogeic	48	41
Anecic	22	19
Functional groups present**		
One	9	8
Two	29	25
Three	16	14
Species present**		
One	9	8
Two	20	17
Three	13	11
Four	9	8
Five	2	2
Six	1	1

* The presence of a particular functional group within a single paddock. Note: there may be more than one functional group detected per paddock.
** Number present in a single paddock.

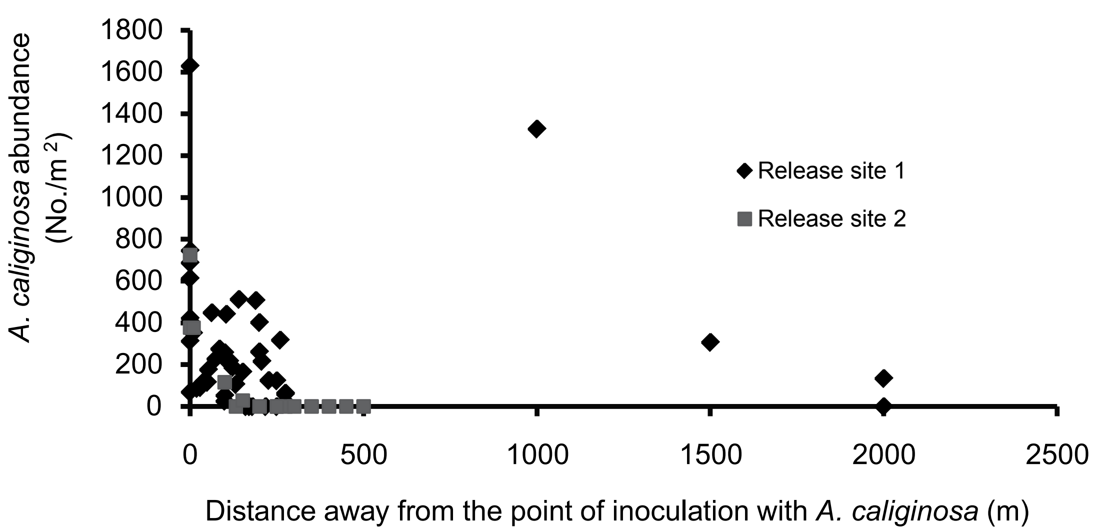
Only two or three earthworm species are commonly found under any given pasture in New Zealand (Stockdill & Cossens 1966) even though European grassland soils often have between four to nine Lumbricid species (Bouche 1987). In the present survey three or more earthworm species were detected in only 8% of paddocks (Table 1), a much lower percentage than the 50% of New Zealand farms reported by Springett (1992). This reflects in part the fact that a high proportion of the paddocks sampled in the present study had been recently converted from exotic forest to pasture land. Fraser *et al.* (1996), while finding up to five earthworm species in a Canterbury survey, 80% of the population was *A. Caliginosa*. The current study reinforces the fact that earthworm introductions to New Zealand have occurred largely by accident. Unless introduced either accidentally or intentionally, beneficial earthworms will be absent from pastures regardless of the years in permanent pasture or management practices.

Figure 1 Depth of activity of the three functional earthworm groups (Fraser & Boag 1998).



Three functional earthworm groups are categorised largely by species burrowing behaviour.
Epigeic earthworms live in the top soil and litter layer on the soil surface where they feed on dung and plant litter.
Endogeic earthworms build complex lateral burrow systems through all layers of the upper mineral soil and rarely come to the surface.
Anecic earthworms build deep permanent, vertical burrows that extend from an opening at the soil surface down through the mineral soil layer. They are generally large earthworms that feed on decaying litter on the soil surface.

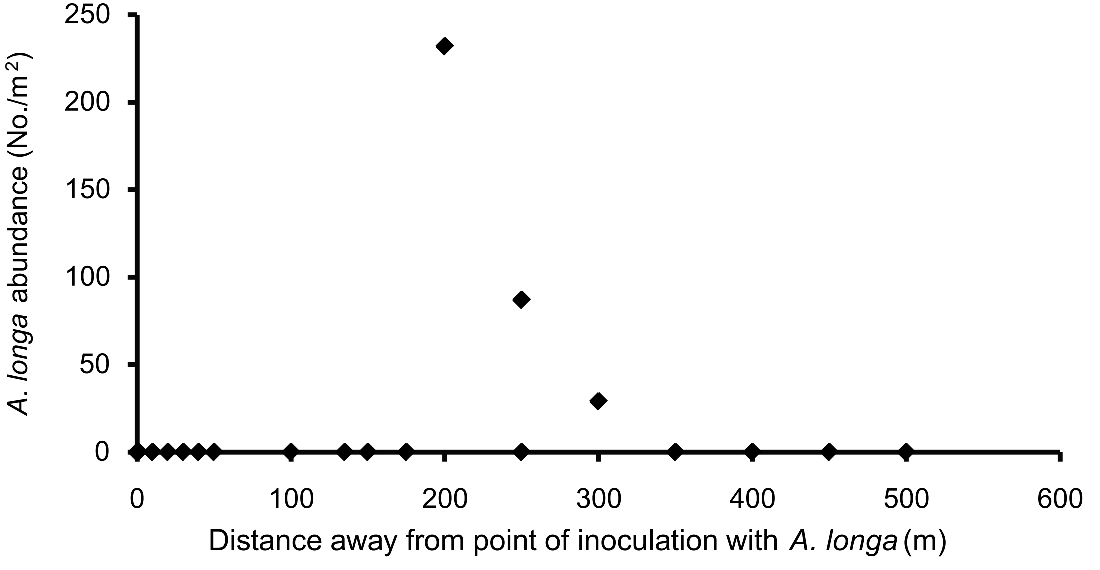
Figure 2 Abundance of *A. caliginosa* (No./m^2) recorded after digging and hand-sorting along transects away from the point of inoculated with *A. caliginosa* in 1984 (26 years earlier).



Earthworm inoculations

The successful establishment and spread of populations of both *A. caliginosa* and *A. longa* in coarse textured volcanic soils, 26 and 20 years, respectively, since initial introduction, provides a basis on which to evaluate the merits of earthworm introductions to a soil for which there are few data. The rate of spread of *A. caliginosa* varied between the two introductions sites, despite little difference in the soil properties. At one site *A. caliginosa* was found up to 2 000 m from the release point in two directions, but most were within 500 m (Fig. 2). At the second site *A. caliginosa* was

Figure 3 Abundance of *A. longa* (No./m²) recorded after digging and hand-sorting along transects away from the point of inoculated with *A. longa* in 1989 (20 years earlier).



found up to 100 m from the release point, with most of the population within 50 m of this point. At 100 m and 2 000 m spread after 26 years, the rate of spread varied from <4 m to about 80 m each year. Stockdill, cited in Lee (1985), found initial rates of spread of *A. caliginosa* of 1-2 m/yr, increasing to rates of up to 10 m/yr, subsequently. Earthworm dispersal and spread through the soil is often an active process, relating to their search for food. However, the high rates of spread at the first site suggested that earthworms had been "transported" passively beyond the initial introduction site in eroded soil, on the feet of stock, by birds or by agricultural machinery. The farm manager at the time recalls that after 3-4 years the grass was greener and more vigorous in the areas where the earthworm introductions had occurred. This reflects the behaviour of the endogeic species that live in the topsoil, burrow laterally and mix the soil, consuming the thatch of dead plant matter (the significant pasture production problem that was resolved by the original earthworm introduction trials) and improving soil porosity and fertility.

Populations of *A. longa* were found up to 250 m from the 1989 site of introduction (Fig. 3). This equates to a rate of spread of 12.5 m/yr. We are not aware of any other data on the rate of spread of this anecic species in a volcanic soil. The spread of anecic *A. longa* in reclaimed temperate soils in the UK was similar to epigeic and endogeic species, spreading at a rate of 4-6 m/yr (Butt *et al.* 2004). Edwards & Bohlen (1996) reported surface dwelling species can reach rates of spread over 10 m/yr in pasture soils. If the behaviour was similar to that reported for *A. caliginosa* the rate of spread may have increased through time, suggesting *A. longa* was actively dispersing.

Case for the introduction of invertebrates

Few technologies target improvements to soil services through assistance to the soil biological community or through modification of function. Biopesticides (e.g. Bioshield™) containing live non-spore forming bacterium (*Serratia entomophila*) to treat grass grub (*Costelytra zealandica*), a soil macrofaunal pasture pest (Jackson 2007), is a recent example. Nitrification inhibitors (e.g. DCD), which prevent the conversion of ammonium to nitrate by blocking the active site on the enzyme (ammonia monooxygenase) in both *Nitrosomonas* and *Nitrosospira* bacteria, to reduce nitrogen loss, is another. Technology exists to introduce exotic earthworms residing in the topsoil (epigeic and endogeic) to pastures in New Zealand (Stockdill 1982), but not the deeper dwelling anecic species. In the 1980s a low-cost, on-farm *A. longa* breeding scheme was developed and tested (Springett, 1984). The scheme required the construction of bins that where filled with alternating layers of soil and sheep dung to which lime and 50 mature *A. longa* were added. After 12 months the content of the bins were spread by the spadeful onto pasture. There are no data on the impacts of these introductions, beyond that reported from small plots by Syers & Springett (1983).

In the UK, successful commercial introductions of *L. terrestris* have been made (Butt *et al*. 2004). Butt *et al.* (1997) described the use of the 'earthworm inoculation unit' (EIU) to introduce anecic species. The EIU contains a few individuals of the desired earthworm species and a small mixture of moist soil and dung to provide food for the earthworms. For this method to be successful a culture of earthworms needs to be available to reduce time consuming field collections. This method may prove to be an efficient and potentially commercial viable way of distributing anecic (and other) earthworm species to provide greater biological support to New Zealand pasture soils.

ACKNOWLEDGEMENTS

Members of the Central Plateau Pastoral Group and financial support from MAF-SFF, Ballance Agri-nutrients, Environment Waikato, and FRST contracts C02X0405 and C10X0604. The MAF staff from the 1980s showed vision in establishing earthworm populations in soils previously found to void of such species.

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