Influence of earthworms on the growth of cotton and wheat plants in contrasting soil types

Geoff Baker[A]

[A]CSIRO Entomology, P.O. Box 1700 Canberra ACT 2601 Australia, Email Geoff.Baker@csiro.au

Abstract
The development and survival of two exotic species of earthworms, *Aporrectodea caliginosa* and *A. longa* (Lumbricidae) were measured in two soils, a grey clay commonly used for cotton production in eastern Australia and a sandy loam available at a commercial garden centre. Most earthworms survived in all treatments, indeed there was evidence of reproduction of *A. caliginosa*, but the growth of both earthworm species was generally less in the clay soil (which had added fertiliser) than in the sandy loam (without fertiliser). Earthworms did not significantly influence the growth of cotton seedlings in either soil type, nor that of the wheat in the clay soil. In the sandy loam however, earthworms positively influenced growth. Overall, the results suggest that earthworms do not influence cotton's early vegetative growth to the same extent as they do that of wheat, and their influences on plant growth can vary with soil type.

Key Words
Earthworms, cotton, wheat, plant production, glasshouse.

Introduction
Earthworms, sometimes referred to as "ecosystem engineers" are well known for influencing soil structure, fertility and plant production in various agricultural ecosystems (Edwards and Bohlen 1996). The benefits earthworms bring include improved aggregate stability, increased porosity, aeration and water infiltration, enhanced nutrient availability, retention of nutrients on-farm (through efficient burial of surface organic matter and fertilisers and prevention of leaching in surface water flow), deeper rooting of plants, and reductions in the incidence of root diseases. Several of these benefits have been demonstrated in Australia, in pasture and cereal cropping systems (Baker *et al.* 2003; Baker 2004). In contrast, very little is known of the biology and functional role of soil macro-fauna such as earthworms under cotton crops in Australia (and elsewhere). Cotton farming in Australia has traditionally presented several potential hazards for soil macro-fauna (e.g. heavy pesticide use, tillage, flood irrigation) and the abundance of such soil animals has generally been considered rare. However, recent trends in the industry such as reduced (and softer) pesticide use, less tillage and retention of organic matter would seem likely to have opened opportunities for population growth and (re)colonisation by soil fauna such as earthworms.

This work tested the potential for earthworms to influence the growth of cotton in a clay soil commonly used for cotton production in Australia. In the absence of rigorous knowledge of the fauna in cotton fields, two species of earthworm, commonly found elsewhere in Australia, were used: an endogeic species, *Aporrectodea caliginosa* (Savigny), and an anecic species, *A. longa* (Ude) (Lumbricidae). Whether or not these two species could survive in the field in cotton growing regions in Australia is unknown. Previous work (Baker 1998; Baker and Whitby 2003) has shown that lumbricid earthworms can survive well and enhance plant growth in sandy loam soils. We therefore included a sandy loam soil and wheat in the work reported here, by way of comparison.

Methods
Earthworm collection
Both *A. caliginosa* and *A. longa* were collected in late winter from a sandy loam soil beneath a pasture in north-western Tasmania (Cape Grim) where they are abundant. The earthworms were used for the experiment within a few days after returning to Canberra with them from Tasmania. They were transported in moist sphagnum moss and were maintained in a constant temperature cabinet (15^{o}C; 12:12 light dark regime) in moist, commercial, sandy loam prior to experimental use.

Earthworm influences on cotton and wheat growth
Glasshouse experiments were conducted in Canberra, using a soil from near Narrabri, New South Wales used for cotton and wheat production (grey clay, Vertisol) and a commercial sandy loam ("Gardener's

Choice”, from Garden World, Hume, A.C.T.). Plastic flower pots (approx 30 cm diameter at the top rim x 30 cm tall, free-draining with a drainage hole covered by fine mesh) were filled with soil (9 kg dry soil/pot). The pots were weighed regularly and the soils watered to 20-25% gravimetric soil moisture content (suitable for earthworm survival and growth). There were 10 replicate pots per treatment. The pots were maintained in a naturally lit, cooled (air conditioners on at 25^{o}C) but not heated glasshouse in which air temperatures fluctuated between approximately 0-30 ^{o}C during the experiment. The experiment ran during late winter to mid spring. Pots were arranged at random in the glasshouse. The two soils differed in various characteristics [e.g. clay and sandy loam respectively: Clay (% w/w) 51.0 and 8.5; pH ($CaCl_2$) 7.5 and 6.9; organic matter (% w/w) 1.9 and 6.5; Olsen P (mg/kg) 14 and 29. Total N (% w/w) was the same for both soils: 0.07].

Earthworms (large juveniles or adults) were washed in water, blotted dry, weighed fresh and then added to the pots requiring them. The period in moss after collection voided the earthworm’s guts and enabled more exact body mass measurements. The weights of the worms were measured in groups of 15 individuals of the same species. Groups were selected such that their biomass varied little. A group of 15 earthworms of each species was added to each pot and the tops of the pots were “sealed” for 3 days with fine mesh to prevent earthworm escape, whilst they settled in. This density of the earthworms is common at the site of collection in Tasmania. Any earthworms that did not burrow into the soil within a few hours were replaced.

Wheat (*Triticum aestivum* var. Janz) and cotton (*Gossypium hirsutum* L. var. Sicot 189 QA) seeds were sown into the pots a week after the earthworms were added. Either 12 wheat or 12 cotton seeds were planted per pot. These were later thinned to 3 seedlings per pot. Fertiliser (5 g of urea) and 0.05 g $ZnSO_4$ was added to each pot, where cotton was to be grown, at time of seeding. Whilst the wheat germinated well, the cotton did not (probably due to cool prevailing temperatures). The cotton seedlings that did emerge were of poor quality. The seedling cotton plants were therefore removed and the same pots were reseeded 7 weeks after the addition of the earthworms. Plants were harvested at 9 weeks from sowing for wheat and 7 weeks for cotton (from second sowing). Plants were cut off at soil level, dried at 60^{o}C for 20 hours and weighed. The soil within each pot was hand-sorted for earthworms at harvest and these were washed in water, maintained on moist filter paper overnight (to again void their gut contents) and then weighed fresh.

The 8 treatments thus were : 1. Clay, no fertiliser, wheat and earthworms, 2. Clay, no fertiliser, wheat and no earthworms, 3. Clay, fertiliser, cotton and earthworms, 4. Clay, fertiliser, cotton and no earthworms, 5. S. Loam, no fertiliser, wheat and earthworms, 6. S. Loam, no fertiliser, wheat and no earthworms, 7. S. Loam, fertiliser, cotton and earthworms, 8. S. Loam, fertiliser, cotton and no earthworms.

Results

Earthworm survival in different soils

The earthworms in the Narrabri clay were distributed evenly throughout the soil when it was hand-sorted. The soil was riddled with macropores, indicating substantial earthworm activity. The earthworms in the commercial sandy loam were mostly confined to the top half of the soil, although macropores were observed lower down. The soil in the lower half of the pots was noticeably much wetter than the top half (much more so than in the Narrabri clay treatment), presumably indicating greater drainage in the sandy loam. Whilst the earthworms from the sandy loam were highly active when washed in water at the end of the experiment, they were less so when from the Narrabri clay.

Most earthworms probably survived throughout the experiment. In several instances, more large *A. caliginosa* were found during hand-sorting of the soils in the pots than were initially added to them (n = 15/pot) (Figure 1a), indicating recruitment which masked any mortality that might have occurred. Small juvenile *Aporrectodea* spp. (most likely *A. caliginosa*, but conclusive identifications were not always possible) and cocoons were found in addition to the larger earthworms in several pots, further confirming that reproduction had occurred. More, large *A. caliginosa* were recovered from the pots with sandy loam and cotton, than from the other pots ($F = 9.47$, $p < 0.05$). Most recruitment of small earthworms occurred in the pots with sandy loam and cotton. [Note : the pots with cotton growing in them were maintained for a few more weeks than those with wheat – thus there was more time in the latter for recruitment of young]. There were no significant differences between treatments for the numbers of *A. longa* recovered from the pots ($F = 1.71$, $p > 0.05$). The biomass/pot for both *A. caliginosa* and *A. longa* decreased during the experiments (Figure 1b). For both species, biomass was greatest in the sandy loam soil and least in the Narrabri clay, at the end of the experiment ($F = 4.04$, $p < 0.05$ for *A. caliginosa*; $F = 11.10$, $p < 0.05$ for *A. longa*).

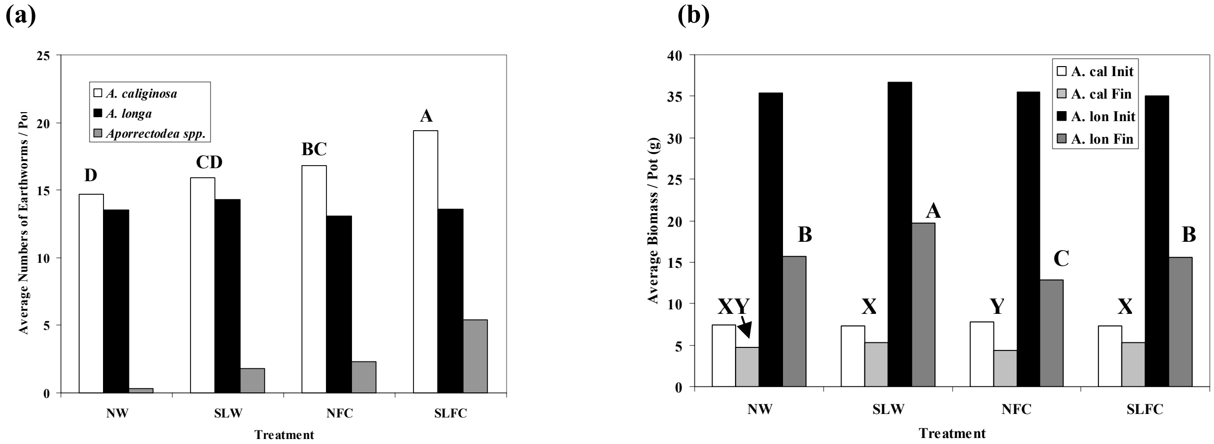

Figure 1. Average numbers (a) and biomass (initial and final) (b) of large *A. caliginosa* and *A. longa* and small *Aporrectodea* spp. after growing wheat (W) or cotton (C) in sandy loam (SL) or clay soil (N) with (F) or without fertiliser. Different letters above the bars indicate significant differences where they occurred between treatments. Small *Aporrectodea* spp. pooled with *A. caliginosa* in (b).

Earthworm influences on cotton and wheat growth

The dry biomass of wheat plants harvested from the pots varied between treatments (Kruskal-Wallis H = 24.84, $p < 0.05$), with greatest biomass in the treatment with sandy loam and earthworms and least in the treatments with sandy loam or Narrabri clay and no earthworms (Figure 2a). Most notably, earthworms appeared to increase wheat biomass in sandy loam, but whilst there was a trend in this direction in Narrabri clay it was not significant. The dry biomass of cotton plants harvested from the pots also varied between treatments (H = 17.55, $p < 0.05$), with greatest biomass in the treatment with sandy loam and no earthworms and least in the treatment with Narrabri clay and earthworms (Figure 2b).

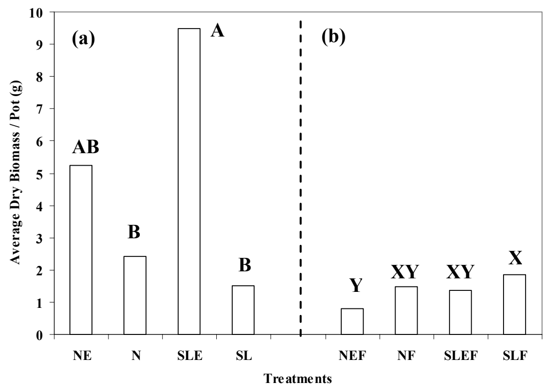

Figure 2. Average dry biomass of wheat (a) and cotton (b) plants growing in sandy loam (SL) or clay soil (N), with or without earthworms (E) and fertiliser (F). Different letters above the bars indicate significant differences between treatments.

Conclusion

These data suggest that earthworms do not enhance early cotton growth. They may of course influence the growth of older plants, but this has yet to be tested. If anything there was a tendency for cotton to grow less in the presence of earthworms. If so, what might be the mechanism? One possibility could be root pruning by earthworms, especially if they are present in high numbers. This has been observed by Cortez and Bouché (1992) for ryegrass in laboratory cultures. In contrast, wheat did respond positively to the presence of earthworms, at least in the sandy loam. It is known that growth responses to earthworms are variable amongst plant species. For example, whilst wheat and oats grew and yielded more in field cages in South Australia which included the lumbricid earthworm, *A. trapezoides*, lupins did not (Baker *et al.* 2003). *A. trapezoides* is very closely related to the *A. caliginosa* we used in this study. Brown *et al.* (1999) also suggested that whilst grain biomass of sorghum and maize can be greatly increased by the addition of earthworms in tropical situations, yields of cowpea and peanuts are reduced. Collectively, these studies suggest that maintenance of high earthworm populations in agricultural soils is not necessarily positive in terms of plant production, and care is called for in terms of using earthworms as indicators of soil "health".

Cotton was grown in this study with fertiliser, whereas the wheat was not. Whilst the variation in fertiliser influenced the growth of the two plant species, it did not influence the impact earthworms had on the plants (G Baker, unpublished data).

This work was a preliminary foray into the importance of one component of the soil biota, earthworms, on cotton production. We used the exotic *A. longa* and *A. caliginosa* as "model" species, involving two very different burrowing and feeding behaviours, to explore potential influences of earthworms on the growth of cotton and wheat, in particular their early growth. The earthworms survived well in the clay soil from Narrabri, but overall didn't respond (in terms of weight gain) as well as in the commercial sandy loam. We now need to survey the various cotton growing regions in Australia to determine the earthworm fauna there, evaluate the influences of the most common species on soil properties and cotton production, and consider the merit in increasing the abundance and diversity of such soil communities.

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References

Baker GH (1998) Recognising and responding to the influences of agriculture and other land - use practices on soil fauna in Australia. *Applied Soil Ecology* **9**, 303-310.

Baker GH (2004) Managing earthworms as a resource in Australian pastures. In 'Earthworm Ecology'. 2nd Edition (Ed CA Edwards) pp. 263-286. (CRC Press: Boca Raton, USA).

Baker GH, Amato M, Ladd J (2003) Influences of *Aporrectodea trapezoides* and *A. rosea* (Lumbricidae) on the uptake of nitrogen and yield of oats (*Avena fatua*) and lupins (*Lupinus angustifolius*). *Pedobiologia* **47**, 857-862.

Baker GH, Whitby WA (2003) Soil pH preferences and the influences of soil type and temperature on the survival and growth of *Aporrectodea longa* (Lumbricidae). *Pedobiologia* **47**, 745-753.

Brown GG, Pashanasi B, Villenave C, Patron JC, Senapati B, Giri S, Barois I, Lavelle P, Blanchar E, Blakemore RJ, Spain AV, Boyer J (1999) Effects of earthworms on plant production in the tropics. In 'Earthworm Management in Tropical Agroecosystems'. (Eds P Lavelle, L Brussaard, P Hendrix) pp. 87-147. (CAB International: Wallingford, UK).

Cortez J, Bouché MB (1992) Do earthworms eat living roots? *Soil Biology and Biochemistry* **24**, 913-915.

Edwards CA, Bohlen PJ (1996) 'Biology of Earthworms' 3rd Edit. (Chapman and Hall: London).