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Effect of Shelterbelts on the Abundance and Diversity of Earthworms in Pastures in the Central-West Tablelands of New South Wales, Australia

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ABSTRACT

Earthworms are key indicators of soil health. Their biological actions incorporate organic matter, increase the number of water-stable soil aggregates, improve water infiltration, aeration, and root penetration, and they also enhance soil-microbial activity. Shelterbelts within agroecosystems facilitate localized wind velocity, thus influencing the microclimate within the agroecosystem by favourably modifying the air temperature, soil temperature, air humidity, soil moisture, evaporation, transpiration, and CO_2 concentration. Shelterbelts have been generally shown to improve the abundance and diversity of soil microorganisms and micro- and macrofauna in the neighbourhood. The influence of shelterbelts on the abundance and diversity of soil fauna, especially those of non-earthworm soil invertebrate biota in adjacent agroecosystems, has been well investigated in Australia. However, no published reports on earthworm—shelterbelt—pasture correlation occur. This study therefore addressed that gap. The study was carried out in three, 12-year old shelterbelts integrated with pasture located within the Orange (NSW) campus farm of Charles Sturt University. Earthworms were sampled at increasing distances from mid-points of shelterbelts in mid-spring (October 2012, Period 1) and mid-autumn (April 2013, Period 2). Populations of the taxa *Apporectodea trapezoides*, *A. caliginosa,* and *Octolasion cyanaem* (Annelida: Clitellata: Lumbricidae) were measured in Periods 1 and 2. The results show that the population density and biomass decrease with increasing distance from the shelterbelt in Period 1, whereas both factors increased with increasing distance from the shelterbelt in Period 2.

Key Words: Microclimate; Species Diversity; Biomass; *Aporrectodea trapezoides*; *A. caliginosa; Octolasion cyanaem*

INTRODUCTION

Soil environment includes a variety of soil organisms, which facilitate decomposition of complex-organic materials and enable the release of nutrients. Soil organisms physically alter the soil profile by modifying the environment and the flow of materials through the soil (Bardgett 2009). Earthworms are the most common and widespread soil-macrofaunal elements, which occur in nearly all landscapes of the world (Lee 1985). In temperate forests, earthworm biomass has been shown to be as high as 60% of the total soil-faunal biomass (Peterson and Luxton 1982), whereas in temperate grasslands, earthworms have been shown to contribute to about 40% of the total-gas exchange mediated in soil (Persson and Lohm 1977). The earthworm populations in Australia include both native and introduced species (Blackmore 1999). The main effect of earthworms on the soil structure is the formation of raindrop-stable soil aggregates (Blackmore 1999). Such aggregates are keys to soil health, since they strengthen drainage and moisture-holding capacity of the soil (Lavelle et al. 1992). Earthworms also play an important role in improving soil fertility through mineralization of organic matter (Edwards 2004), in regulating the populations of pestiferous arthropods, parasitic nematodes, and even plant-pathogenic soil microbes (Brown et al. 2004), in breaking down and releasing biologically active compounds (Harti et al. 2001), and in actively collecting, ingesting, digesting and egesting seeds (Brown et al.

2004). That due to earthworm activity, plant growth and productivity enhances has been variously shown (Baker et al. 1997, 1999; Eriksen-Hamel and Whalen 2007).

Shelterbelts are tree clusters developed in specific designs (e.g., strips) following agroforestry principles and are intended to mitigate the intensity of surface winds by deflecting the wind over tree tops and letting through the inter-tree spaces (Burke and Wilson 1997). Shelterbelts reduce wind velocity and alter its direction of flow and turbulence (Brandle et al. 2004). Shelterbelts have been used extensively to protect soil from wind erosion, crops from direct-wind damage, and livestock from wind exposure (MacDicken et al. 1990). A direct result of the reduction in wind velocity and turbulence is the modification of the microclimate in a shelterbelt (McNoughton 1988). Different investigations have demonstrated that the shelterbelts alter patterns of abundance and diversity of soil organisms, such as bacteria and actinomycetes (Dluzniewska and Mazurek 2009), fungi and arthropods (Mbuthia et al. 2012), nematodes (Dmowska 2007), and enchytraeids (Nowak 2007). This impact is best evident whenever a shelterbelt borders a crop field. In general, microbial and faunal biomass increases gradually from the midpoint of the crop field towards the shelterbelt. Althought different studies have reported that varying distances from the shelterbelt into the neighbouring pasture or crop system influence the microclimate and biological processes significantly, it is generally accepted that 10 times the average height of the shelterbelt is the maximal distance of significant effect (Wang and Takle 1995).

The influence of earthworms in the productivity of pastures (Chan and Heenan 2006) and the influence of shelterbelts on the abundance and diversity of arthropod fauna in adjacent agroecosystems have been investigated in Australia (Mbuthia et al. 2012, Gamez-Virués et al. 2009, 2010, Thomson and Hoffman 2013, Tom et al. 1996, Moulin et al. 2013). The present study therefore aimed at investigating the earthworm-shelterbelt-pasture association in an Australian context and more specifically, to determine whether a correlation exists between the abundance and diversity of earthworms in a pasture bordering a shelterbelt and distance from the shelterbelt.

STUDY SITE

The study was conducted at the Orange campus farm of Charles Sturt University (33° 15' S, 149° 07' E; 875 m above sea level) in the central-west tablelands of New South Wales. The soil is a shallow, well-structured Brown Dermosol (Isbell 1996). The A1-A2 horizons extend down to a depth of 25 cm, the B-C interface extends between 25 and 60 cm, and the C horizon occurs beyond 60 cm. Top-soil textures are loamy with clay content gradually increasing with depth. At 1 m depth, a near impermeable layer of highly weathered mudstone-siltstone occurs (Cattle and Southorn 2010). The climate is characterized by cold-wet winters (2-10°C) and mild summers (12-25°C); rainfall usually occurs uniformly throughout the year, ranging between 700 and 950 mm (Bureau of Meteorology 2013). Three shelterbelts named Leeds Parade, College 4, and Weston 1 (hereafter referred as Sites 1, 2 and 3, respectively) were used. The sites were selected for the present study as they share multiple similar characteristics. They occur within previously established long term perennial pasture land, each is approximately 100 m long and 15-25 m wide, oriented in a northerly-southerly direction, and receiving the easterly downwind. Each shelterbelt was fenced off from the paddock at the time of its establishment. The pastures are grazed periodically by sheep and cattle and subject to occasional applications of phosphate fertiliser at standard rates. The shelterbelts have not been fertilised nor have grazing animals been admitted since their establishment. The sites were established in the year 2000 with a mixture of seedlings of Australian native trees and shrubs to build on the benefits the shelterbelts provide when integrated with a perennial pasture agroecosystem. Tree taxa in the shelterbelts include *Eucalyptus blakelyi, E. macrorrhyncha, E. melliodora, E. pauciflora, E. viminalis* (Myrtaceae), *Acacia dealbata, A. implexa, A. vestita* (Mimosaceae), *Casuarina cunninghamiana* (Casuarinaceae), *Callistemon sieberi* and *Leptospermum myrtifolium* (Myrtaceae). Pasture species include *Phalaris aquatica, Lolium rigidum, L. perenne, Holcus lanatus*, *Vulpia bromoides, Hordeum glaucum* (Poaceae), *Trifolium subterraneum, T. repens* (Fabaceae) and *Echium plantagineum* (Boraginaceae).

METHODS

Experimental Design

The average heights of the shelterbelts were used to determine the distances of sampling positions from the shelterbelts. These average heights were calculated by averaging the heights of 15 randomly selected trees in each shelterbelt (Department of Environment and Climate Change n.d.) (Table 1). Two transects (T1 and T2) were constructed (Figure 1) and marked with sampling positions. A maximum of 10 tree heights (10H) was chosen as the most distant sampling position from the mid-point of the nominated shelterbelt.

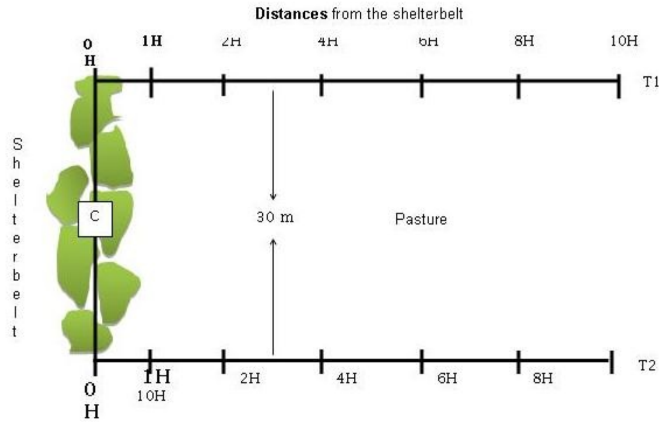

Figure 1. Experimental lay out. C - shelterbelt midline-point, H - tree height and various qualifying numerals indicate distance travelled into the pasture and earthworm sampling points [1H - one tree height, 2H - two tree height, 4H - four tree height, 6H - six tree height, 8H - eight tree height, 10H - ten tree height).

Table 1 Distances calculated based on tree heights*

Site	Mean tree height, m	1H	2H	4H	6H	8H	10H
1	4.6	4.6	9.2	18.4	27.6	36.8	46
2	6.4	6.4	12.8	25.6	38.4	51.2	64
3	5.6	5.6	11.2	22.4	33.6	44.8	56

Earthworm Sampling

Earthworm sampling was done in mid-spring (15-29 October 2012) and mid-autumn (11-22 April 2013) (hereafter referred to as 'Period 1' and 'Period 2', respectively) in all the three sites. Any vegetation growing at a sampling position was removed down to the soil surface and a 31.6 cm^2 quadrat was marked at each sampling position using a square-metal frame. Using either a hoe or a spade, soil was dug up to a depth of 30 cm and collected on a plastic sheet, manually broken up, and sorted for earthworms. The earthworms obtained were maintained alive in a sample bottle provided with moist soil. After sorting, the soil was returned to the hole. The procedure was repeated at each of the remaining sampling positions in all the three sites. The earthworms were moved to the laboratory where they were rinsed gently in running water, blotted in paper towels, and determined to species level following Baker and Barrett (1994). Earthworms of each species were counted, and weighed for their fresh mass in an HM-200 electronic balance (A & D Weighing Scales, Sydney, Australia).

Soil Moisture Determination

Soil-moisture was determined of soil samples obtained concurrently with earthworm sampling at each sampling position in all the three sites. Soil-moisture content for each sample was calculated following Gliessman (2000) as follows:

Soil moisture % =
(Fresh mass - Dry mass) x 100/ Dry mass

The moisture content of soil from a particular sampling position was calculated by averaging the moisture contents of the 0–15 cm and 15–30 cm depth samples from the position.

Data Analysis

In the study, the six sampling positions on each transect served as treatments. With two transects per site, each treatment was therefore replicated two times per site to obtain a total of six replicates for the three sites in one period. The data were analyzed using S-plus 8.2 for Windows for summary statistics and to establish correlations between distance from the shelterbelt and soil-moisture content, earthworm density and soil-moisture content, earthworm biomass and soil-moisture content, distance and earthworm density, and distance and earthworm biomass. A linear-regression model considering the variables soil-moisture content, and distance from the shelterbelt was developed considering different factors such as the total earthworm density and biomass.

RESULTS

Three exotic earthworm species were collected in Periods 1 and 2: *Aporrectodea trapezoides, A. caliginosa*, and *Octolasion cyanaem* (all Annelida: Clitellata: Lumbricidae). Table 2 shows the percentage contribution of each of the species to the total numbers and biomass obtained in both periods.

Table 2. Percentage contribution of earthworms to the total numbers and biomass obtained

	Total Collected	Percentage Contribution		
		A. trapezoides	*A. caliginosa*	*O. cyanaem*
Period 1				
Number	287	50.2	46	3.8
Biomass (g)	68	55.9	42.8	1.3
Period 2				
Number	4996	13.4	77.3	9.3
Biomass (g)	1538.73	18.8	74.7	6.5

Soil Moisture and Distance From the Shelterbelt

No significant changes in soil moisture content with increasing distance from the shelterbelt were noted. However, soil moisture levels were higher for each sampling position in Period 2 than in Period 1 by between 0.28 and 1.92% (Figure 2).

Soil Moisture, Earthworm Density and Biomass

The earthworm density and biomass were correlated with soil moisture content both in Period 1 ($p<0.05$) (Figure 3) and Period 2 (Figure 4).

Earthworm Density and Biomass, and Distance from the Shelterbelt

In Period 1, the highest earthworm density was recorded at 0H distance (Figure 5). Thereafter, density decreased with increasing distance from the shelterbelt with no earthworms occurring beyond 4H. In Period 2, a higher earthworm density was obtained at 0H than at 1H (Figure 5). From 2H, the density increased reaching a maximum at 8H followed by a decrease at 10H. Similar trends were obtained for earthworm biomass in both periods (Figure 6).

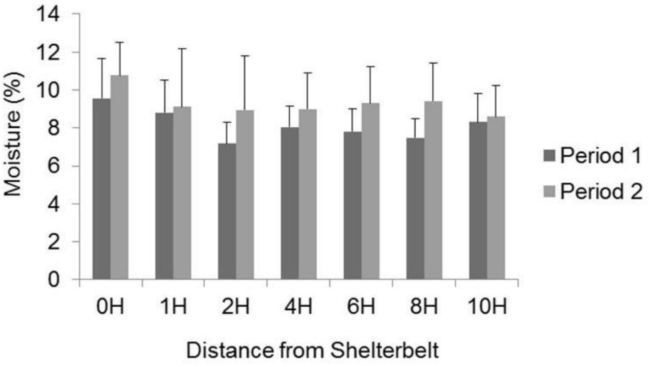

Figure 2. Differences in soil moisture between Periods 1and 2.

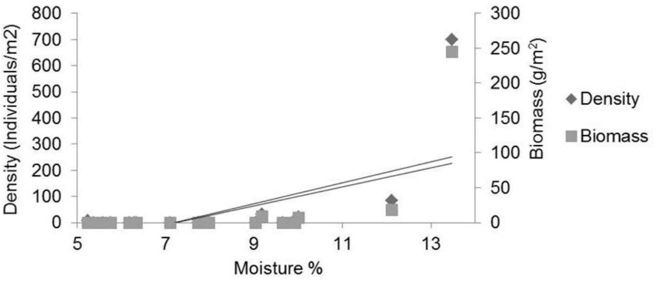

Figure 3. Fitted and observed relationships for earthworm density and biomass in relation to soil moisture in Period 1.

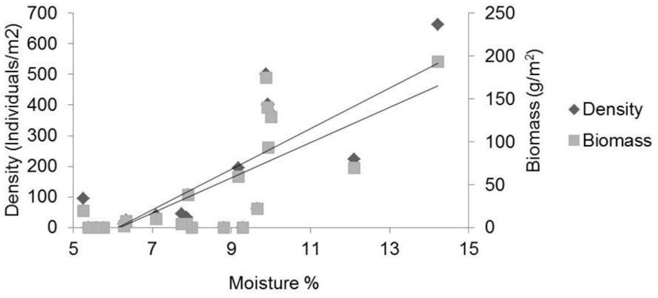

Figure 4. Fitted and observed relationships for earthworm density and biomass in relation to soil moisture in Period 2.

Analysis between distance and density and, distance and biomass showed a correlation ($p<0.05$) in Periods 1 and 2. In Period 1, the density and biomass decreased with distance (Figure 7) whereas in Period 2 it increased with distance (Figure 8).

DISCUSSION

The density and biomass of earthworms obtained in the study ranged from 0 to 589 individuals m^{-2} and from 0 to

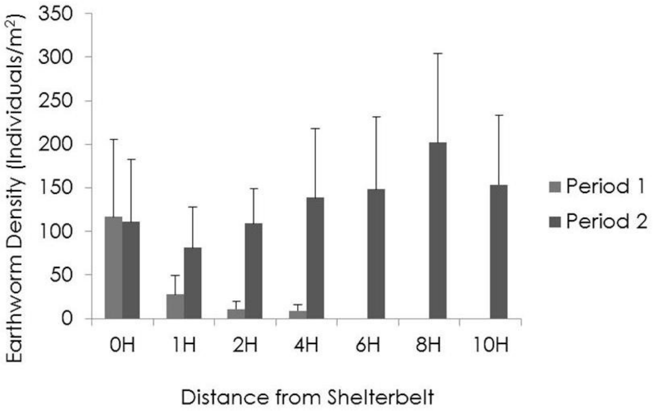

Figure 5. Earthworm density with increasing distance from the shelterbelt in Periods 1 and 2.

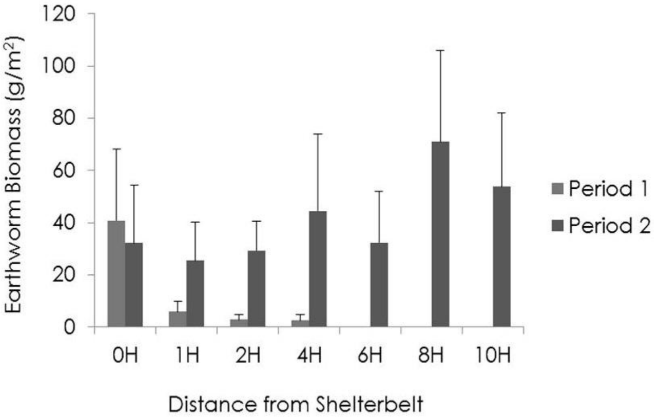

Figure 6. Earthworm biomass with increasing distance from the shelterbelt in Periods 1 and 2.

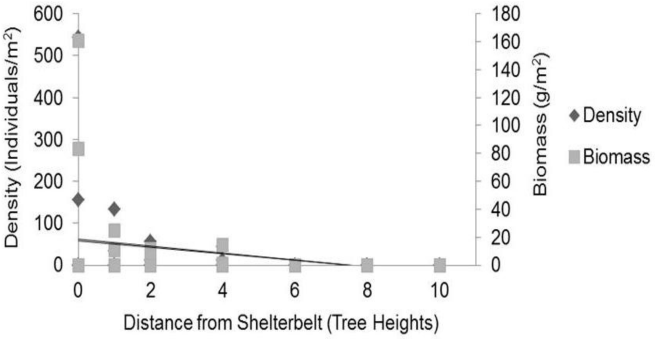

Figure 7. Fitted and observed relationships for earthworm density and biomass in relation to distance in Period 1.

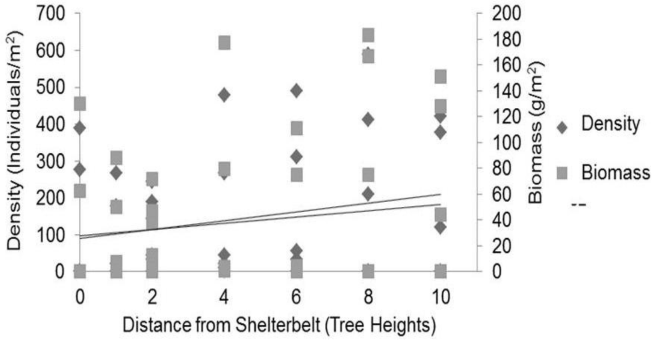

Figure 8. Fitted and observed relationships for earthworm density and biomass in relation to distance in Period 2.

183.2 g m^{-2}, respectively, in Periods 1 and 2. These values occur within the range of abundance and biomass values obtained in pasture lands in Australia using the hand-sorting method. For instance Barley (1959) recorded 460-625 individuals m^{-2} and 62-78 g m^{-2} fresh mass, whereas Baker et al.. (2004) obtained 0-608 individuals m^{-2} in pastures in South Australia. A 1995-survey of 560 pastures in south-eastern Australia found the densities of earthworms varying from 0 to 1,262 m^{-2} (Baker and Barret 1994, Baker et al. 1992).

Of the three earthworm species obtained in the present study, *A. trapezoides* and *A. caliginosa* are abundant in temperate Australia. Together with *A. rosea*, they dominate pastures in southern Australia (Baker 2007). In the present study *A. caliginosa* contributed 46-77.3% to the total density and 42.8-74.7% to the total biomass, whereas *A. trapezoides* contributed 13.4-50.2% and 18.8-55.9% to the total density and total biomass, respectively. *Aporrectodea trapezoides* and *A. caliginosa* feed close to roots and remain active up to 20 cm depth; they dig tunnels of about 2 mm in diameter and are capable of mixing organic matter up to 20 cm depth. *Octolasion cyanaem* also occurs in temperate regions of Australia (Baker and Barret 1994). This species is active up to 40 cm soil depth and creates wider and deeper tunnels; they are also common in pastures, but never in high numbers (Department of Environment and Primary Industries 2011). In the present study, this species contributed to 3.8-9.3% of the total density and 1.3-6.5% of the total biomass. Pastures on soils in which these earthworm species are present therefore stand to benefit from increased organic-matter content, nutrient availability, improved soil structure, water infiltration, aeration, and root penetration (Lee and Foster 1991). The study also shows that the density and biomass of earthworms correlated positively with moisture in all the three sites. This result was expected because adequate moisture is one vital environmental requirement for earthworms. Earthworms' inability to persist and survive in a water-deficient environment is known, since their water-conservation mechanisms are poorly developed (Lee 1985).

Shelterbelts have the effect of conserving soil moisture in adjacent areas through the reduction of evaporation (Caborn 1957). In the present study, however, no significant changes in soil moisture content with increasing distance from the shelterbelt were noted in both periods. Rainfall received averaged 0.3mm in Period 1 and 0.7mm in Period 2; and for every sampling position, soil moisture in Period 2 was higher by between 0.28 and 1.92% than in Period 1. Total earthworm numbers and biomass obtained were 17 and 23 times higher, respectively, in Period 2 than in Period 1. Rainfall incidence explains the patterns of variance in earthworms (Baker 1988). Rainfall incidence explains the patterns of variance in earthworm numbers than any other variable in a range of agricultural soils in areas with annual rainfall varying from 230 to 1,150 mm in southern Australia. This may explain the results obtained since the study sites occur in the central tablelands of New South Wales, where the annual rainfall usually ranges between 700 and 950 mm.

At 7.18-9.56% and 8.60-10.77% in Period 1 and 2, respectively, the soil-moisture levels at the study sites were lower than what has been reported for lumbricids in other parts of the world. In Europe, lumbricids remain active beyond 25% soil-moisture level and die at <20% (Baltzer 1956, Zisci 1958). In Argentina, *A. caliginosa* and *A. rosea* are abundant in soils at 25% moisture level, but decrease with dropping moisture levels; no earthworms are recorded at <15% of soil-moisture level (Ljungström et al. 1971, 1973). In South Africa, *A. caliginosa* prefer a 30% soil-moisture level and do not occur in soils at <18% level (Reinecke and Ryke 1970). This indicates that the optimum soil-moisture levels are not generalizable for earthworms and that even within populations of the same species considerable scope for adaptation to local-environmental conditions occurs (Lee 1985). The earthworm populations obtained in the present study show a tolerance to lower moisture levels, probably because of an adaptive capacity to local environmental conditions. The higher numbers obtained in Period 2 suggest a recovery of populations with an increase in soil-moisture level.

The earthworm density and abundance were the highest in the shelterbelt but decreased with distance from the midpoint of the shelterbelt in Period 1. This is consistent with the findings of Olechowicz (2004) and Makulec (2004), who have recorded the highest density and biomass of lumbricids within shelterbelts and declining numbers with distance from the midpoint of the shelterbelts extending into crop fields. Low densities and biomass in adjacent areas were attributed to low-plant species richness (the sites included higher populations of maize, followed by wheat) compared with the shelterbelt and reduced soil quality from deep ploughing and application of agrochemicals. The earthworms recorded in the present study viz. *A. trapezoides, A. caliginosa* and *O. cyanaem* thrive in agroecosystems including pastures (Blackmore n.d.) and the pastures used this study are neither tilled nor treated with agrochemicals except for occasional applications of phosphate fertiliser at standard rates (Izak Malherbe, Manager, Charles Sturt University Farm, personal communication). Various studies have shown that besides moisture, soil temperature plays an important role in regulating earthworm abundance. Rundgren (1975) showed that high temperatures (up to 18.3 °C) accompanied by low soil moisture content (pF 3.2-3.6), resulted in a portion of adult *Aporrectodea caliginosa* and *A. rosea* burrowing below 50 cm. A similar reaction was observed in winter when temperatures dropped below 2-4 °C. Nordstrom (1975) observed that between 0 and 20 °C and soil moisture content below pF 4.2, lumbricids showed heightened activity. *Apporectodea* species on the other hand were active between 2 and 4 and 14 and 16 °C and moisture content above pF 3.2-3.5. On the other hand, studies with shelterbelts have shown that soil temperatures are generally slightly higher in the sheltered zone of a shelterbelt than in the open during the day (McNaughton 1988, Rosenberg 1966). In the present study, no earthworms were recorded beyond 4H in Period 1. It is therefore possible that, at the moisture levels recorded between 0H and 4H (8.06-9.56%), soil temperatures were conducive to earthworm activity.

In contrast, the earthworm density and biomass in Period 2 increased with increasing distance from the midpoint of the shelterbelt. This is the expected trend for earthworm species that thrive more in pastures than wooded areas especially when the soil environment has elevated levels of moisture as in Period 2. These results agree with the results of Zeithaml et al.. (2009) who showed both density and biomass of earthworms correlate positively with distance from a forest edge into a crop field. In their study, soil moisture was not a limiting factor and two of the 11 earthworm species and subspecies collected were *A. caliginosa* and *A. trapezoides*, which together accounted for 76.1% to 92%

of the total earthworm density at each of their sampling sites. However, it is likely that the increasing trend in density and biomass would have flattened out with increasing distance.

For pastures to derive maximum benefits from the activities of earthworms, it is dependent on the management style and design of the agroecosystem, since these influences the earthworm populations directly by physical disturbance and indirectly by altering the physicochemical environment and the food supply. Various studies have shown that integrating a shelterbelt with a pasture agroecosystem will result in improved pasture productivity (Curry 2004, Benkovits 1955, Radcliffe 1985).

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