

Isolated Trees in Pasture Landscapes Contribute to and Enhance Soil Health: A Study in Central-West New South Wales, Australia

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ABSTRACT

Isolated farm trees are a distinct feature of the Australian landscape, previously part of a forested landscape, until extensive clearing occurred for agricultural purposes post European settlement. A majority of studies has focused on the beneficial effects of tree clusters, such as shelterbelts and windbreaks and little pertains to characterizing the role of isolated farm trees (also referred as isolated farm trees, IFTs). IFTs are generally older than their tree cluster counterparts, with little to no chance of regenerating in a grazed landscape. Both tree clusters and IFTs contribute to the health of the soil by increasing soil nutrients, protecting pastures and stock from harsh weather, reducing erosion levels, providing habitat for vertebrate and invertebrate species and increasing agricultural productivity. With the loss of the IFTs from the landscape, the many benefits they provide have also been lost. The purpose of the study was to examine the role IFTs have on enhancing soil health in pastures using physical, chemical and biological soil-health indicators. Leaf litter and soil sampling and soil CO₂ efflux readings were made from beneath the canopy and in the surrounding pasture of nine isolated farm trees (*Eucalyptus melliodora*, *E. viminalis*, and *E. bridgesiana*) in Central-west Tablelands of NSW in spring 2014 and autumn 2015. The results indicate IFTs enhance soil health in pasture landscapes with greater arthropod abundance and diversity, higher rates of soil respiration, greater concentrations of total nitrogen and phosphorous, and lower levels of soil compaction closer to the tree compared with surrounding pasture landscape. Collectively these findings point to a positive influence on soil health in grazed pastures by isolated farm trees.

Key Words: Bulk Density; Invertebrates; Isolated Trees; Soil Arthropods; Soil Respiration; Total Phosphorus, Total Nitrogen.

INTRODUCTION

Extensive clearing of *Eucalyptus* woodlands has resulted in agricultural landscapes interspersed with woodland remnant patches and single trees located in areas desig-

nated for crops and pastures. Tree clusters (e.g., remnant patches, shelterbelts, windbreaks, small agroforestry stands) provide an array of ecosystem services, such as habitats for wildlife and for diverse vertebrates and invertebrates. In ungrazed areas, tree clusters consisting

of young trees (*c.* 5 years old) make the majority age group, whereas in grazed areas where previously wooded areas are usually thinned to isolated trees, the age of remnant trees can be up to 140 years (Fischer et al. 2009). These isolated trees (hereafter referred as 'isolated farm trees', 'IFTs') are single trees within pasture landscapes, with the neighbouring tree typically located at least 25 to 30 m away (Ozolins et al. 2001). As per current estimates, IFTs occur over approximately 20 m ha of farms in temperate Australia (Reid and Landsberg 2000). However, there is extensive evidence that the longevity and survival of IFTs is subject to a range of threatening processes. For example, addition of phosphorus-based fertilizers in association with other agri-management practices has resulted in the loss of native grass populations and has reduced the numbers of native trees (Greenslade 1992). IFTs provide a range of ecosystem services. They increase levels of soil nutrients, protect pasture from harsh weather, reduce soil erosion, control water tables and contribute to reduction of salinity, and provide habitats for arboreal fauna and invertebrate and vertebrate species, which play a key role in regulating pestiferous organisms and increasing soil biological activity (Oliver et al. 2006).

Pastures rely on sound soil health for productivity and sustainability. Only a few studies in Australia have examined the changes to soil-health parameters in the

context of IFTs in pastures. These indicate that soil nutrients occur at greater levels in landscapes that include IFTs (Barnes et al. 2009) than in landscapes that do not. On the South Western Slopes of New South Wales (NSW), for example, significantly higher levels of nitrogen (N) and bio-available phosphorus (P) were observed in soil located underneath IFTs compared with surrounding pasture (Eldridge and Wong 2005). IFTs have been observed to influence soil in their vicinity by neutralizing pH, improving soil friability in the root zone (Gibbons and Boak 2002), and increasing soil organic matter (Barnes et al. 2009).

Graham et al. (2004) compared soil properties in proximity to three species of *Eucalyptus* (*E. melliodora* A. Cunn. ex Schauer, *E. viminalis* Labill, and *E. calignosa* Blakely & McKie) and found declining levels of soil pH, carbon (C), and P with distance from trees. Oliver et al. (2006) compared soil properties and soil biological activity (using soil-arthropod populations as an indicator) of *E. nova-anglica* H. Deane & Maiden and found decreasing levels of soil C, P, and N, decreased arthropod abundance and diversity, and increased levels of soil pH and bulk density with distance from each measured tree. Results of IFT studies comparing soil properties beneath *Eucalyptus* trees with adjacent grazed pastures in the Northern Tablelands of NSW and the South Western Slopes of NSW are summarized in Table 1.

Table 1. Mean soil properties beneath IFT canopy and in the pasture at grazed sites in the Northern Tablelands of NSW and the South West Slopes of NSW

Author	Site	pH (CaCl ₂)		Organic C (%)		Extractable P (mg kg ⁻¹)		Total N (%)		BD (g cm ⁻³)	
		canopy	pasture	canopy	pasture	canopy	pasture	canopy	pasture	canopy	pasture
Graham et al. (2004)*	Uralla										
	<i>(E. melliodora)</i>	5.45	5.37	2.63	1.88	42.5	32.8	—	—	—	—
	Tilbuster										
	<i>(E. viminalis)</i>	5.53	5.45	2.78	2.04	30.2	22.1	—	—	—	—
	Rockvale										
	<i>(E. viminalis)</i>	5.50	5.42	4.24	3.50	147.4	129.0	—	—	—	—
	Guyra										
	<i>(E. viminalis)</i>	5.46	5.38	4.59	3.85	129.7	112.5	—	—	—	—
	Sunnyside										
	<i>(E. calignosa)</i>	4.71	4.63	3.44	2.70	41.0	31.6	—	—	—	—
Barnes et al. (2009)*	Armidale										
	<i>(E. melliodora)</i>	5.42	4.97	4.92 [#]	2.73 [#]	19.56 ^s	20.9 ^s	0.41	0.23	—	—
Oliver et al. (2006) [^]	Armidale ***										
	<i>(E. nova-anglica)</i>	5.54	5.69	2.60	1.90	13.3	11.9	0.22	0.19	1.30	1.36
Eldridge and Wong (2005)**	Wagga Wagga										
	<i>(E. melliodora)</i>	5.90	5.70	8.00	7.00	120.0 ^s	50.0 ^s	0.80	0.70	—	—

C: Carbon; P: Phosphorus; N: Nitrogen; BD: Bulk Density ; [#] Total C; ^s Available P ; [^] Figures extracted from graphs

* Northern Tablelands, NSW ; ** South West Slopes, NSW ; *** University of New England, Newholme Field Laboratory

Trees providing shelter for grazing livestock are valuable, since economic benefits in the retention of trees in grazing landscapes of Australia have been demonstrated unequivocally (Graham et al. 2004). Livestock camp beneath the canopies of IFTs in grazed pastures enriching the soil with nutrients from excreta. However, soil may be compacted by the presence of greater numbers of grazing livestock in these camps (Wilson 2002). Soil arthropods are useful biological indicators of either pollution or environmental disturbances due to their large numbers and high species diversity. By monitoring the abundance and diversity of soil arthropods in specific habitats over time, a measure of change within a system is achievable (Gibb and Oseto 2006). In the Northern Tablelands of NSW (30°30' S, 151°39' E) greater numbers of arthropods were found in the soil beneath IFTs compared with the open pasture (Oliver et al. 2006). There were nearly twice as many Formicidae (Insecta: Hymenoptera) under IFT canopies compared with the open pasture with a greater diversity of species also sampled under the tree canopy (Oliver et al. 2006). Collembola (Insecta) reached the greatest abundance around the canopy edge and declined with distance away from the tree (Oliver et al. 2006). The quantity of vegetative litter on soil surface was also greater under the tree canopy, that may provide a better habitat to support arthropod populations (Oliver et al. 2006). High levels of leaf litter under the tree canopy results in higher levels of soil nutrients than in adjoining pastures, thus increasing the composition of the litter layer and habitat for invertebrates (McElhinny et al. 2010).

Against such a background, this study aimed to determine spatial variations in the abundance and diversity of soil and litter arthropods, soil respiration, and selected soil health parameters in the presence of three species of IFTs in a grazed, improved pasture. The selected IFT species were *E. melliadora*, *E. viminalis*, and *E. bridgesiana* R.T. Baker, which occur naturally in the Central-west Tablelands of NSW and exist as isolated trees in grazed pastures (Bower et al. 2002). We sought answers to the following questions:

- (1) Do the selected soil health parameters and arthropod abundance and diversity change with distance from beneath the canopy of single isolated farm trees?
- (2) Do the observed spatial variations in these parameters explain patterns of arthropod abundance and diversity?
- (3) Are there differences in soil health parameters and

arthropod abundance and diversity between the three tree species?

- (4) Are there seasonal differences in these patterns?

MATERIALS AND METHODS

Study Site

The study site (800 m asl) is located on the campus farm of Charles Sturt University (CSU) in the Central-west Tablelands region of NSW (33°14'–33°15' S; 149°06'–149°07' E). The climate is temperate with a mean annual rainfall of approximately 900 mm, which is distributed fairly evenly across all seasons. Mean maximum and minimum temperatures in summer are 26.6°C and 13.4°C, respectively, and 9.4°C and 1.5°C in winter, respectively (Bureau of Meteorology 2014).

The CSU campus farm covers an area of *c.* 500 ha and consists of two soil landscapes: the 'North-Orange' and the 'Macquarie' Soil Landscapes (Kovač and Lawrie 1990). The sites selected for the study lie within the North Orange Soil Landscape, which comprises Ordovician volcanic and metasediments with undulating to rolling low hills, a relief of 20–60 m, and slopes varying from 6 to 30% gradient (Kovač and Lawrie 1990). Soils characteristically comprise red earths on the upper slopes and yellow earths on the lower slopes. The campus farm lies within the South Eastern Highlands Biogeographic Region and includes 173 plant species, of which 31.8% are native, 43.9% are introduced, and 24.3% are planted taxa of Australian native and introduced species (Bower 2012). Eight species of remnant native *Eucalyptus* occur as woodlots, tree clusters, and as IFTs in CSU campus farm (Bower 2012). The perennial pasture of the study site included *Phalaris aquatica* L., *Lolium rigidum*, *Gaudin L. perenne* L., *Holcus lanatus* L., *Dactylis glomerata* L. (Poaceae), *Trifolium subterraneum* L. (Fabaceae), *Trifolium repens* L., *Medicago polymorpha* L. (Fabaceae), *Vulpia bromoides* (L.) Gray, *Hordeum glaucum* Steud. (Poaceae), and *Echium plantagineum* L. (Boraginaceae). A mix of *Bromus willdenowii* Kunth and *B. hordeaceus* L. (Poaceae) also occurred to a lesser extent (Mbuthia et al. 2012, Moulin et al. 2012).

The trees chosen for the study were the Australian natives, *E. melliadora*, *E. viminalis*, and *E. bridgesiana* (Figure 1). These are remnants of the natural vegetation located within the grazed pastures of the campus farm (Bower 2012). The tree specimens were selected on the basis of being located more than 25 m from each other.

The pastures are subject to periodical sheep and cattle grazing, inorganic-fertilizer application, and occasional use of tillage machinery over the past 100 years (Tom et al. 2006). Sampling occurred in spring (September–November) 2014 and in autumn (March–May) 2015.



Figure 1. An isolated *Eucalyptus melliodora* tree, CSU campus farm, Orange, NSW (Provost 2014)

Field Methods

Four linear transects commenced from the foot of each of the nine selected IFTs, thus establishing 36 transects, extending beyond the tree canopy into the pasture. The maximum length of each transect was eight times the radius of the tree canopy (assuming that the canopy is circular). Transects ceased approximately 5 m before any obstruction (Figure 2). The transect orientation was randomly selected. Sampling points on each transect were measured in proportion to the radius of the tree canopy (C). The radius of each tree canopy was initially estimated using satellite imagery and the measurement tool in Six Maps (<https://maps.six.nsw.gov.au/>), followed by measurement in the field using the ‘cross’ method (Blozan 2008).

The position of the first sampling point extended from the foot of the tree into the pasture, to a distance of one-quarter of the tree canopy radius ($\frac{1}{4}C$). This method was replicated for the remaining five sampling points — one-half of the tree canopy radius ($\frac{1}{2}C$), the tree canopy radius (1C), two-times the tree canopy radius (2C), four-times the tree canopy radius (4C), and eight-times the tree canopy radius (8C). Nine sites thus included 24 sample points (six sample points located on each transect), although a fence line voided a single 8C sampling point at one of the sites.

Arthropod Sampling

Arthropods from leaf litter and topsoil were collected from a 25 cm² quadrat at each transect sample point using a vacuum sampler (Victa Vforce+ 40V Lithium-ion Battery Blower and Vacuum, Briggs and Stratton Corporation, Milwaukee, WI, USA) and by coring the soil to 10-cm depth using a hand held 11 cm diameter auger. The leaf litter and soil samples were placed in a Berlese-Tullgren funnel ‘warmed’ by a 15W tungsten-filament pilot light to extract the litter arthropods into a flask filled with 100% ethanol. After four days, the arthropods were extracted from the ethanol-filled flask to a sealable container to be identified to Orders using Harvey and Yen (1989).

Bulk Density

Bulk density was measured using a cylindrical steel corer (5 cm long, 3.65 cm wide) inserted to a depth of 5 cm after the leaf litter was removed from the soil surface. The soil cores were dried in a hot-air oven at 105°C for 24 h and weighed to measure bulk density. The results of each corresponding sampling point of each transect was used to determine the mean for the sampling point.

Total Soil Nitrogen and Phosphorus

Oven-dried soil from bulk-density measurements for each of the four corresponding sampling points were pooled and thoroughly mixed. The samples were analyzed at the Environmental & Analytical Laboratory, Charles Sturt University, Wagga Wagga. Total N was measured using an elemental analyzer (TruMac Nitrogen Determinator, LECO Corporation, St Joseph, MI, USA). Total P was measured using an Inductively Coupled Plasma–Atomic Emission Spectrometer (Varian 710-ES, Agilent Technologies Inc. Palo Alto, CA, USA). Prior to

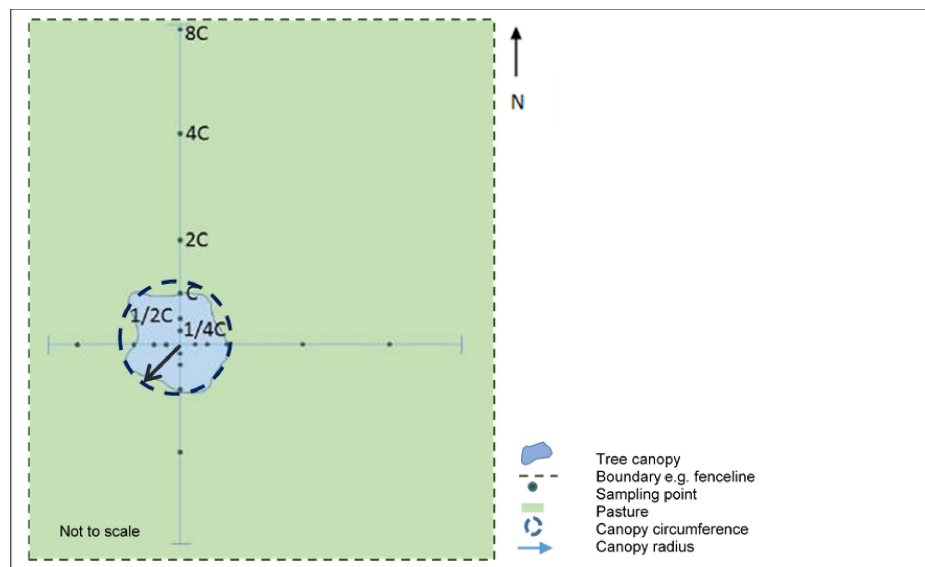


Figure 2. Example of transects extending from IPT base into surrounding pasture ($\frac{1}{4}C$, $\frac{1}{2}C$, $1C$, $2C$, $4C$ and $8C$ sampling points are measured in proportion to tree canopy radius)

total phosphorus analysis, 5 mL of concentrated nitric acid (32% AR grade) was added to each soil sample, allowed to digest and then bulked to 50 mL.

Soil Respiration

Soil respiration was measured using a LI-COR automated CO_2 efflux measurement system (LI-6400XT, LI-COR, Lincoln, NE, USA).

Statistical Analyses

The relationship between distance from the tree (as measured by ratio of the canopy) and bulk density, total P, total N, efflux and arthropod abundance and diversity was examined and an exponential curve was used. Arthropod diversity was determined using Margalef diversity index (D_{Mg}). Arthropod numbers were square-root transformed to meet the normality assumption.

$$D_{Mg} = \frac{(S-1)}{\ln N}$$

wherein, 'S' is the number of arthropod orders present, 'ln' is the natural logarithm, and 'N' is the total number of individuals in the obtained sample. The form of the exponential curve, was calculated using the formula

$$y = A + BR^x$$

wherein, 'y' represented bulk density, total P, total N, efflux, arthropod abundance or arthropod diversity, and 'x' is distance from the tree. A comparison of the

regression curves was made to compare between species and seasons. All analyses were made using Genstat® v.16 (VSN International, Hemel Hempstead, UK).

RESULTS

Soil

Bulk Density

A highly significant exponential relationship was observed between distance from the tree (ratio of canopy) and bulk density of soil around IFTs, for all species in spring 2014 ($R^2=52.2$, $df=2,49$, $F=24.25$, $p<0.001$) and autumn 2015 ($R^2=50.3$, $df=2,49$, $F=25.34$, $p<0.001$). However, no significant difference occurred between seasons, although a significant difference occurred between species in both spring 2014 ($df=2,45$, $F=6.45$, $p=0.003$) and autumn 2015 ($df=2,45$, $F=3.33$, $p=0.045$).

The bulk density of the soil around *Eucalyptus bridgesiana* was greater compared with the soil around *E. melliodora* and *E. viminalis*. Table 2 shows the mean bulk density (spring 2014 and autumn 2016 data pooled) for canopy ($\frac{1}{4}C$, $\frac{1}{2}C$, $1C$) and pasture ($2C$, $4C$, $8C$) highlighting that bulk density of the soil increased with distance into the pasture for each tree species. There was no significant effect of tree species on the bulk density–distance correlation in spring 2014 (Figure 3) and autumn 2015 (Figure 4).

Table 2. Mean bulk density (g cm^{-3}) for each tree species (spring 2014 and autumn 2015 pooled)

	<i>E. bridgesiana</i>	<i>E. melliodora</i>	<i>E. viminalis</i>
Canopy ($\frac{1}{4}$ C, $\frac{1}{2}$ C, 1C)	0.85	0.77	0.67
Pasture (2C, 4C, 8C)	1.05	0.96	0.96

Table 3. Asymptotic values of total phosphorus (mg kg^{-1}) for each tree species

	<i>E. bridgesiana</i>	<i>E. melliodora</i>	<i>E. viminalis</i>
Spring 2014	478	742	598
Autumn 2015	439	660	597

Total Phosphorus

A highly significant relationship occurred between total soil phosphorus and distance from the tree (ratio of canopy) in spring 2014 ($\text{df}=2,45$, $F=9.02$, $p<0.001$) and autumn 2015 ($\text{df}=2,45$, $F=17.80$, $p<0.001$). No significant difference occurred between seasons. The soil underneath *Eucalyptus melliodora* had the highest total phosphorus compared with that of *E. viminalis* and *E. bridgesiana* (Table 3). Table 4 shows mean total soil phosphorus (spring and autumn data pooled) for canopy ($\frac{1}{4}$ C, $\frac{1}{2}$ C, 1C) and pasture (2C, 4C, 8C) indicating total soil phosphorus decreased with distance away from the tree for each species. A significant difference occurred between total soil phosphorus and species in spring 2014 ($\text{df}=2,45$, $F=4.82$, $p=0.013$) and autumn 2015 ($\text{df}=2,45$, $F=6.91$, $p=0.002$). There was no significant effect of tree species on the total phosphorus—distance correlation in spring 2014 (Figure 5) and autumn 2015 (Figure 6).

Total Nitrogen

Total soil nitrogen was found to be strongly correlated with distance from the tree in spring 2014 ($\text{df}=2,45$, $F=17.57$, $p<0.001$) and autumn 2015 ($\text{df}=2,45$, $F=19.59$, $p<0.001$). Total soil nitrogen for all tree species decreased quickly in the first two distance ratios and then tended to an asymptote. No significant difference occurred between the seasons and total soil nitrogen did not differ between species in both spring 2014 (Figure 7) and autumn 2015 (Figure 8). The soil surrounding *Eucalyptus viminalis* had the highest total nitrogen compared with *E. melliodora* and *E. viminalis*. Maximum values are shown in Table 5.

Table 4. Mean total phosphorus (mg kg^{-1}) for each tree species (spring 2014 and autumn 2015 pooled)

	<i>E. bridgesiana</i>	<i>E. melliodora</i>	<i>E. viminalis</i>
Canopy ($\frac{1}{4}$ C, $\frac{1}{2}$ C, 1C)	737	967	844
Pasture (2C, 4C, 8C)	452	707	622

Table 5. Asymptotic values of total nitrogen (mg kg^{-1}) for each tree species

	<i>E. bridgesiana</i>	<i>E. melliodora</i>	<i>E. viminalis</i>
Spring 2014	2,857	4,093	4,120
Autumn 2015	2,894	3,695	4,222

CO₂ Efflux

Efflux data were variable and the percentage variance accounted for was low (9.0 in spring 2014 and 16.0 in autumn 2015). Efflux reduced with distance from the tree into the surrounding pasture, but season and species had no effect on the results in spring 2014 (Figure 9) and autumn 2015 (Figure 10).

Arthropods

Abundance in Soil, Spring 2014

A total of 3,511 individual arthropods were extracted from soil under and around the trees. The Acarina, Collembola, and Hymenoptera comprised 61% (total individuals, 2,133), 27% (946) and 7% (248) of the extracted arthropods, respectively. The remaining 5% (total numbers of individuals shown in brackets) were identified as larvae of Diptera (66), Hemiptera (55), Diptera (26), larvae of Coleoptera (12), Lepidoptera (9), Coleoptera (8), larvae of Lepidoptera (6), and Araneae (2).

Abundance in Soil, Autumn 2015

A total of 2,168 individual arthropods were extracted from soil under and around the trees. The Collembola, Acarina, and Hymenoptera comprised 53% (total individuals, 1,158), 36% (773) and 7% (161) of the extracted arthropods, respectively. The remaining 4% (total numbers of individuals shown in brackets) were identified as Hemiptera (25), larvae of Diptera (16), Coleoptera (12), larvae of Coleoptera (11), Diptera (4),

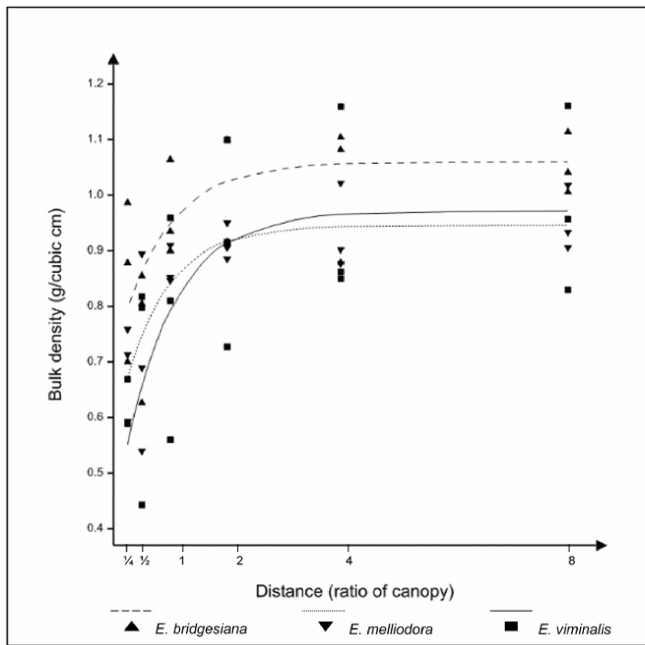


Figure 3. Fitted and observed relationships for bulk density for spring 2014

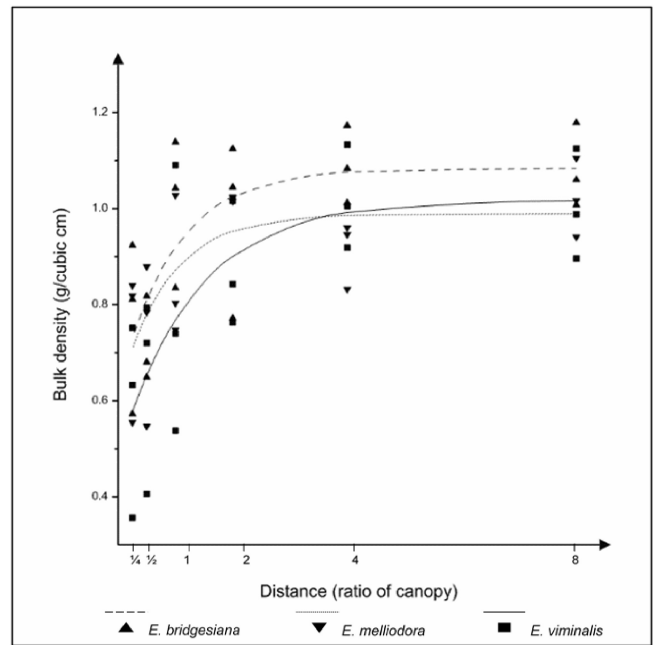


Figure 5. Fitted and observed relationships for total P for spring 2014

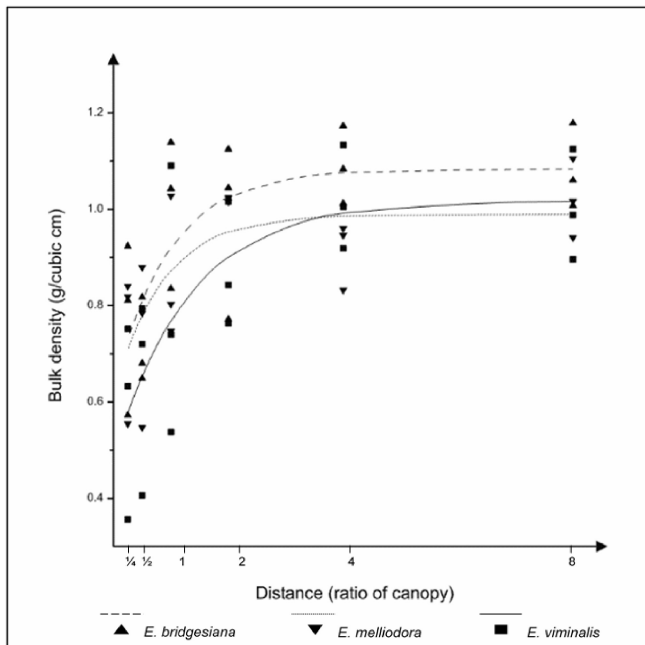


Figure 4. Fitted and observed relationships for bulk density for autumn 2015

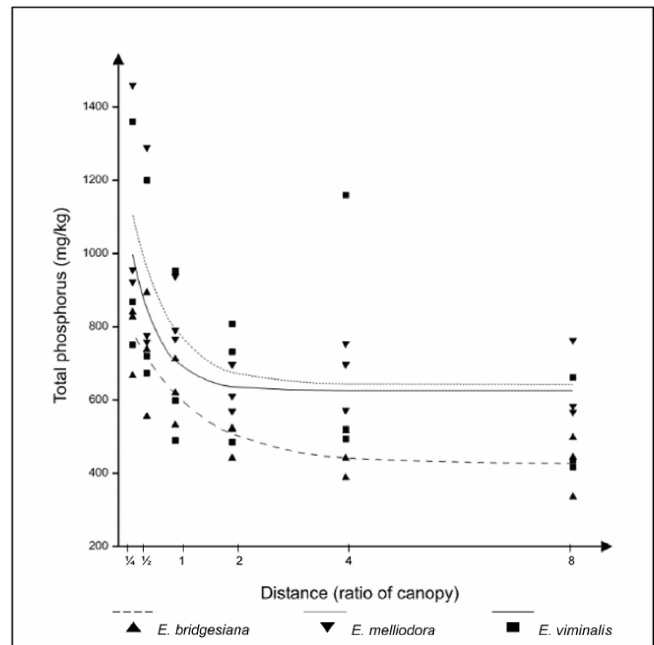


Figure 6. Fitted and observed relationships for total P for autumn 2015

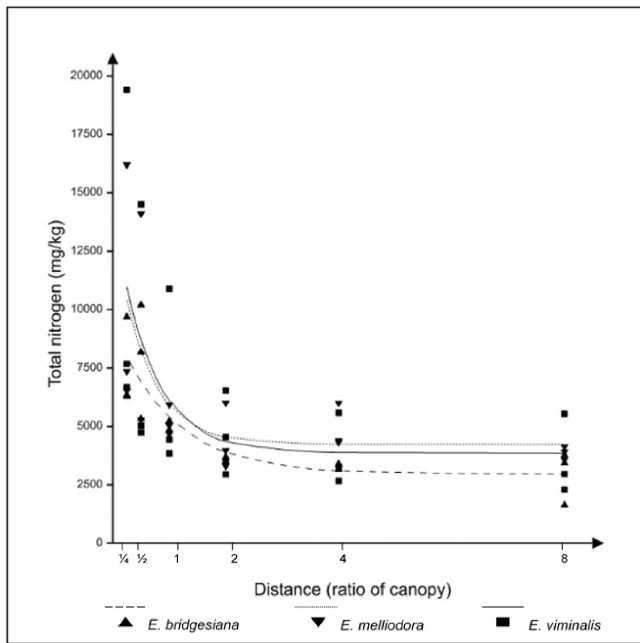


Figure 7. Fitted and observed relationships for total N for spring 2014

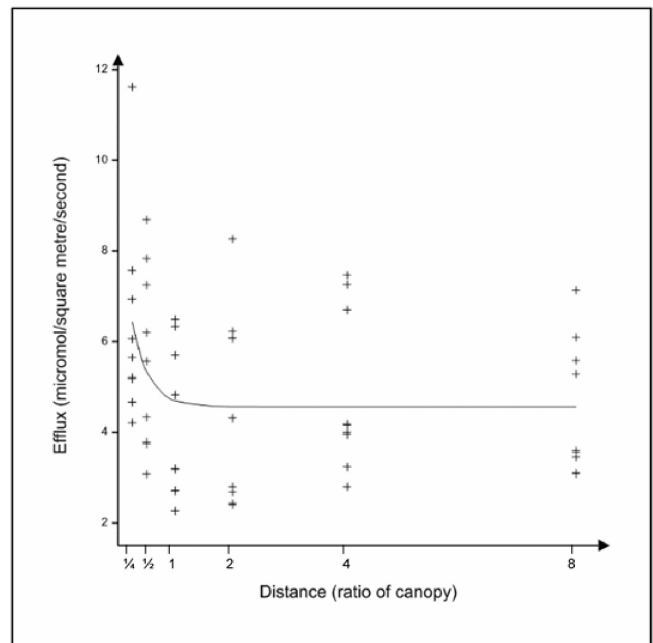


Figure 9. Fitted and observed relationships for efflux for spring 2014 (tree species pooled)

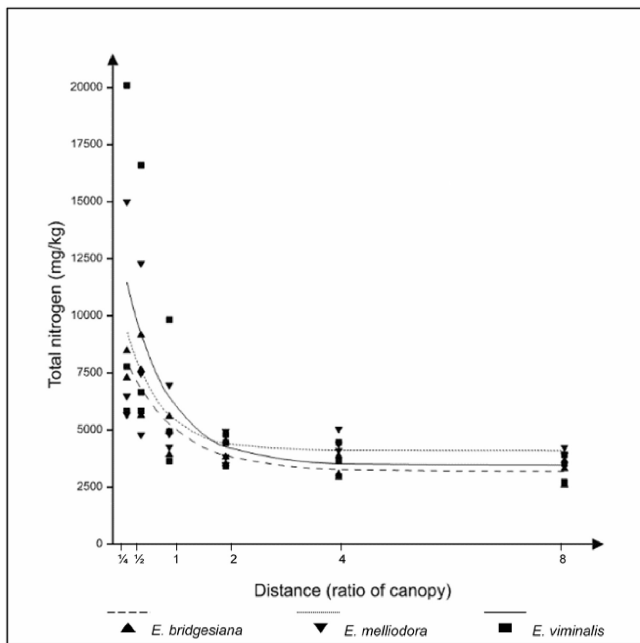


Figure 8. Fitted and observed relationships for total N for autumn 2015

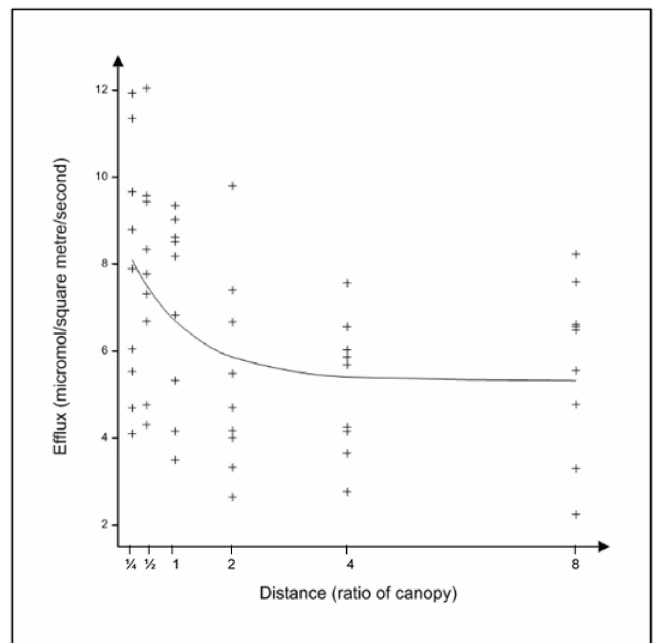


Figure 10. Fitted and observed relationships for efflux for autumn 2015 (tree species pooled)

larvae of Lepidoptera (2), Diplura (2), Araneae (2) Dermaptera (1), and Lepidoptera (1).

Combined Analysis of Arthropod Abundance in Soil, Spring 2014 and Autumn 2015

Combined analysis of spring 2014 and autumn 2015 data indicated a significant difference in arthropod abundance ($R^2=14.4$, $df=2,99$, $F=10.14$, $p<0.001$) with distance from the tree, but no significant difference occurred between the tree species (Figure 11). A significant difference occurred between arthropod abundance and season ($R^2=17.8$, $df=1,102$, $F=5.34$, $p=0.023$), with spring 2014 data showing greater abundance compared with data of autumn 2015 (Figure 12).

Abundance in Leaf Litter, Spring 2014

A total of 8,972 individual arthropods were extracted from leaf litter under and around the trees in spring 2014. Acarina, Hemiptera and Collembola comprised 47% (total individuals, 4,253), 25% (2,221) and 21% (1,889) of the extracted arthropods, respectively. The remaining 7% (total numbers of individuals shown in brackets) were identified as Hymenoptera (218), Araneae (147), Diptera (95), Coleoptera (62), larvae of Coleoptera (38), larvae of Lepidoptera (25), Lepidoptera (14) and larvae of Diptera (10).

Abundance in Leaf Litter, Autumn 2015

A total of 8,928 individual arthropods were extracted from leaf litter under and around the trees in autumn 2015. Collembola, Acarina and Hemiptera comprised 53% (total individuals, 4,726), 31% (2,725) and 10% (924) of the extracted arthropods, respectively. The remaining 6% (total numbers of individuals shown in brackets) were identified as Hymenoptera (234), Diptera (103), Coleoptera (68), Araneae (65), larvae of Lepidoptera (39), larvae of Coleoptera (16), Lepidoptera (10), larvae of Diptera (10), and Orthoptera (8). The total number of arthropods extracted from leaf litter (spring and autumn pooled) was 17,900 which comprised 8,635 from beneath the canopy (¼C, ½C, 1C) and 9,265 from the surrounding pasture (2C, 4C, 8C).

Combined Analysis of Arthropod Abundance in Leaf Litter, Spring 2014 and Autumn 2015

Arthropod abundance did not differ ($R^2=0$) in the leaf litter with distance from trees. A significant difference occurred between arthropod abundance in leaf litter under and around the trees and tree species ($R^2=6.3$, $df=2,101$, $F=4.70$, $p=0.011$). The tree species with the highest arthropod abundance was *E. bridgesiana*. The

asymptote value for *E. bridgesiana* is 15.21 ($\sqrt{}$ value) with a standard error of 0.98, compared to the asymptote value of 12.42 with a standard error of 1.27 for *E. viminalis* and the asymptote value of 10.77 with a standard error of 1.72 for *E. melliodora*. Arthropod abundance did not differ significantly between species in response to distance (Figure 13). No significant difference in arthropod abundance in leaf litter and the season occurred (Figure 14).

Combined Analysis of Arthropod Diversity in Soil, Spring 2014 and Autumn 2015

Combined analysis of spring 2014 and autumn 2015 indicated a significant difference between distance from the tree (ratio of canopy) and arthropod diversity in soil around the trees ($df=2,95$, $F=5.29$, $p=0.007$). However, no significant difference between arthropod diversity in soil and tree species occurred (Figure 15). Similarly, no significant difference was found between arthropod diversity in soil and season.

Combined Analysis of Arthropod Diversity in Leaf Litter, Spring 2014 and Autumn 2015

Combined analysis of spring 2014 and autumn 2015 indicated no significant difference in arthropod diversity and distance from the tree in leaf litter collected from around trees. A significant difference between arthropod diversity and tree species occurred ($df=2,99$, $F=6.06$, $p=0.003$). The tree species with the highest arthropod diversity was *E. viminalis*. The asymptote value for *E. viminalis* is 1.35 with a standard error of 0.09, compared to the asymptote value of 1.14 with a standard error of 0.09 for *E. melliodora* and the asymptote value of 0.98 with a standard error of 0.29 for *E. bridgesiana*. No significant difference occurred in arthropod diversity in response to distance from tree, between different tree species. No significant difference occurred between arthropod diversity and season. Similarly, no significant difference was observed in arthropod diversity in response to distance from tree, between seasons.

Correlation of Soil Data and Arthropod Data

Table 6 shows the correlations between arthropod abundance and diversity with bulk density, total soil P, total soil N and efflux for spring 2014 and autumn 2015. A significant correlation occurred between the abundance of arthropods in leaf litter and bulk density (0.341) in spring and efflux (0.275) in autumn. A significant negative correlation occurred between the abundance of arthropods in leaf litter and total P (-0.395)

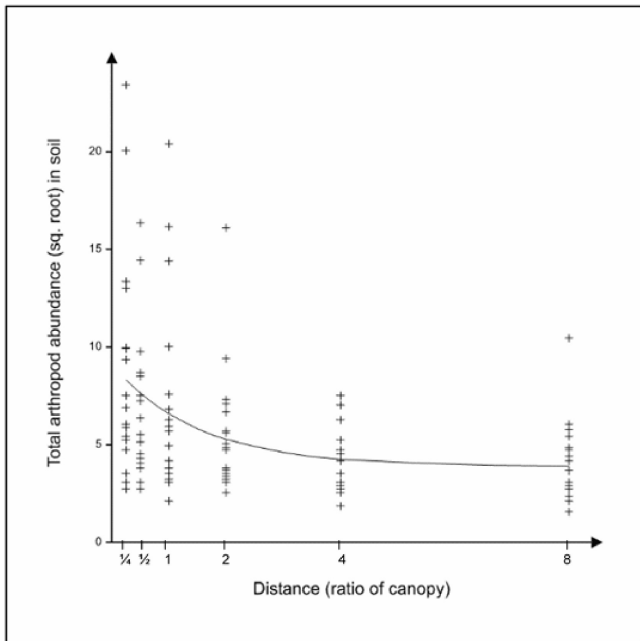


Figure 11. Fitted and observed relationships for arthropod abundance in soil (spring 2014 and autumn 2015 pooled; tree species pooled)

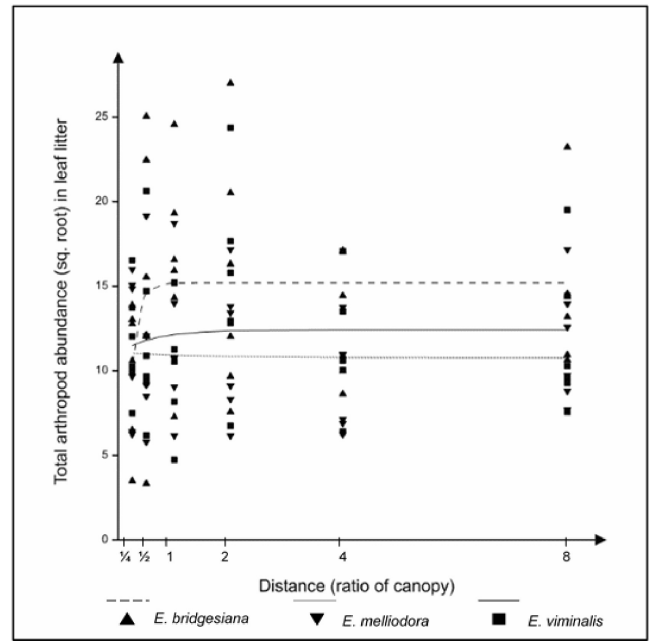


Figure 13. Fitted and observed relationships for arthropod abundance in leaf litter (spring 2014 and autumn 2015 pooled)

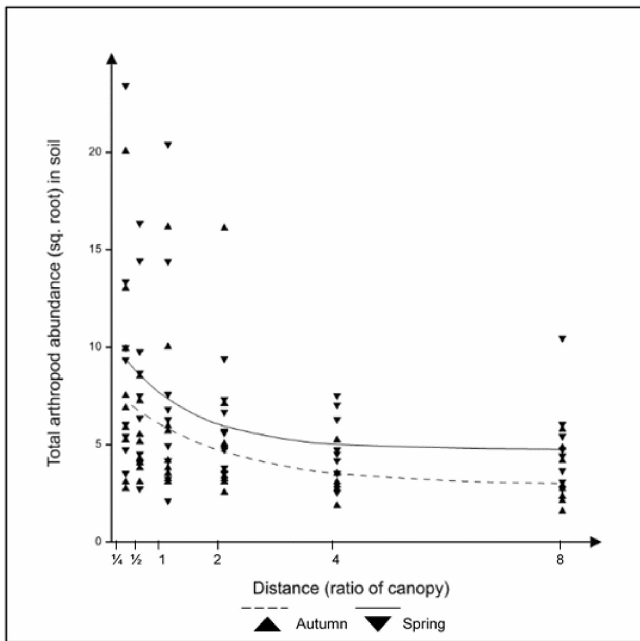


Figure 12. Fitted and observed relationships for arthropod abundance in soil for spring 2014 and autumn 2015

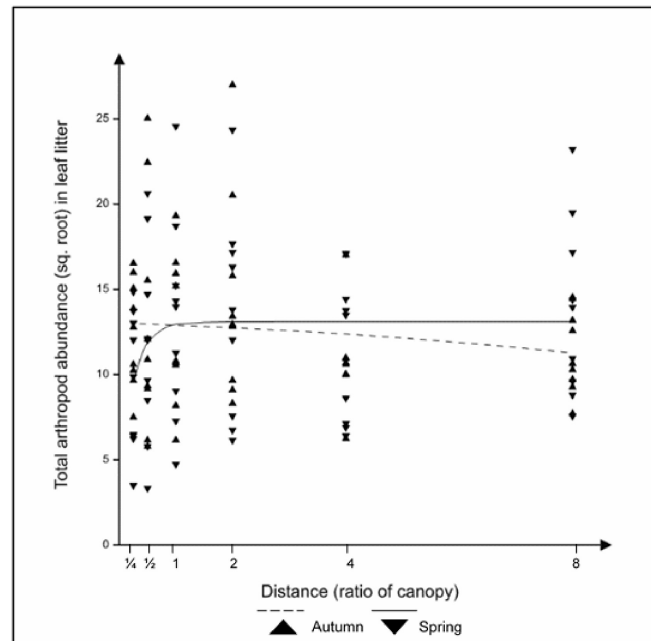


Figure 14. Fitted and observed relationships for arthropod abundance in leaf litter for spring 2014 and autumn 2015

Table 6: Correlations of arthropod abundance and arthropod diversity with soil and litter properties (spring 2014 and autumn 2015)

	Abundance (Leaf Litter)		Abundance (Soil)		Diversity (Leaf Litter)		Diversity (Soil)	
	Spring 2014	Autumn 2015	Spring 2014	Autumn 2015	Spring 2014	Autumn 2015	Spring 2014	Autumn 2015
Bulk density	0.341*	-0.023	-0.445*	-0.399*	-0.285*	0.008	0.063	0.162
Total P	-0.395*	-0.149	0.357*	0.418*	0.460*	-0.026	-0.193	-0.157
Total N	-0.338*	-0.039	0.535*	0.520*	0.270*	0.032	-0.254*	-0.196
Efflux	-0.011	0.275*	0.033	0.385*	0.035	-0.286*	-0.137	0.023

* significant correlation ($p = 0.05$)

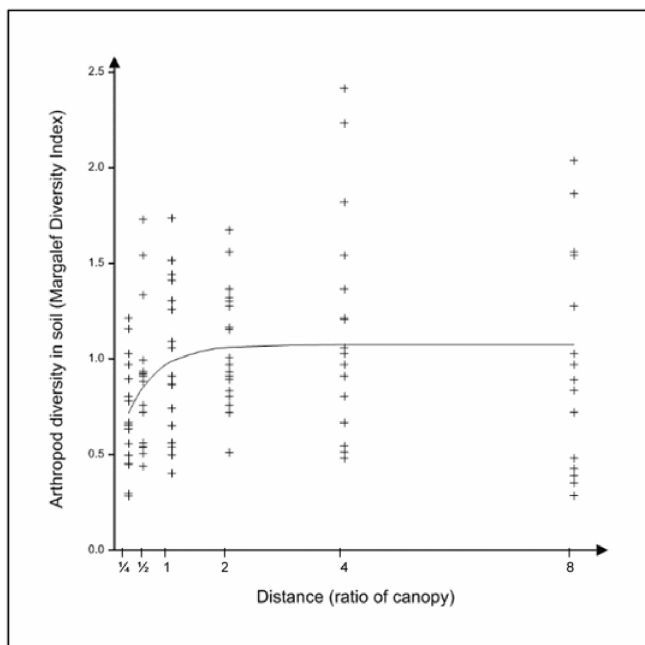


Figure 15. Fitted and observed relationships for arthropod diversity in soil (spring 2014 and autumn 2015 pooled, tree species pooled)

and total N (0.338) in spring. A significant correlation occurred between the abundance of arthropods in soil and total P (0.357) and total N (0.535) in spring and efflux (0.385), total P (0.418) and total N (0.520) in autumn. A significant negative correlation occurred between the abundance of arthropods in soil and bulk density in both spring (-0.445) and autumn (-0.399). A significant correlation occurred between the diversity of arthropods in leaf litter and total P (0.460) and total N (0.270) in spring. A significant negative correlation occurred between the diversity of arthropods in leaf litter and bulk density (-0.285) in autumn and efflux (-0.286) in autumn. A significant negative correlation between

the diversity of arthropods in soil and total N (-0.254) occurred in spring.

DISCUSSION

The present study explored the spatial relationships between soil health and IFTs, utilizing soil-health indicators such as bulk density, total phosphorus, total nitrogen, soil respiration and the biological indicators of arthropod abundance and diversity, in the context of three species of *Eucalyptus*. The results provide insights into the role and functions IFTs have in enhancing soil health in the sustainability of pasture landscapes.

Spatial Patterns in Soil-Health Parameters

Soil bulk density increased with distance from beneath the canopy into the surrounding pasture, for all tree species. A similar trend was found in grazed pastures in Armidale, NSW (Wilson 2002). Soils with bulk density $<1.0 \text{ g cm}^{-3}$ are usually high in organic matter (White 1987) whereas soils with bulk density $>1.6 \text{ g cm}^{-3}$ can restrict plant root growth (Brown and Werrett 2015). In this study, the bulk density ($<1.0 \text{ g cm}^{-3}$) of soil under the trees was well below the compacted range. Given that grazing livestock commonly camp under trees and compact the soil, this suggests that the higher litter loads and resulting soil organic matter enrichment and larger arthropod numbers under the tree may have mitigated compaction by stock.

Total soil P and N levels were higher closer to the trees and decreased with distance into the surrounding pasture. When comparing asymptotic values, soil under *E. melliodora* was the highest for total soil P followed by *E. viminalis* and *E. bridgesiana*. The asymptotic values for total soil N for *E. viminalis* were greater than those

of *E. melliodora* and *E. bridgesiana*. The trend of declining P and N values with distance from the trees into pasture has been noted previously (Graham et al. 2004, Oliver et al. 2006, Eldridge and Wong 2005), although Barnes et al. (2009) found increased levels of P for *E. melliodora* in the soil beneath the tree canopy. The intensity of stock camping beneath trees is greater compared with the surrounding pasture (Wilson 2002) and as P and N are leached from stock excreta into the soil the levels of P and N are found to be higher beneath the tree. Leaf litter from leaf fall is also higher under the tree canopy (Oliver et al. 2006) and the breakdown of the leaf litter results in higher levels of soil nutrients occurring in the soil beneath the tree (McElhinny et al. 2010). Increased levels of soil nutrients may be beneficial for the individual tree however it may also contribute to tree diseases such as 'die-back'. Higher rates of N in soil can result in increased N in foliage, which is palatable to insects, increasing the risk of the tree being more susceptible to insect attack and suffering from die-back (Marsh and Adams 1995).

Efflux measures the level of CO₂ released from the soil to the atmosphere, largely due to root and microbial respiration; the latter arising from organic-matter break down. Soil respiration levels were greater proximal to the tree and reduced with distance into the pasture. This could be due to the greater numbers of arthropods in soil and leaf litter closer to the tree compared to the pasture, which contribute to the cycling of CO₂, as well as the increased CO₂ contribution of tree roots. Measurement of soil respiration however can be highly variable and is affected by temperature and moisture availability.

Spatial Patterns of Arthropod Abundance and Diversity

Greater numbers of arthropods were extracted from soil beneath tree canopies than in soils from the pasture. Soils beneath the IFT canopy contain tree roots and higher levels of stock excreta due to sheltering stock, which may enhance the abundance of arthropods in soils beneath the canopy. Although greater total arthropod abundance occurred in leaf litter, no relationship between arthropod abundance in leaf litter and distance from the tree into pasture was found.

A correlation between arthropod diversity in soil and distance from the tree into the surrounding pasture was observed, however this did not apply to arthropod diversity in the litter. Mbuthia et al. (2012) found arthropod diversity was not affected by distance from shelterbelts in leaf litter, although increasing levels of

diversity with increasing soil depth was evident. Oliver et al. (2006) found higher-ground active arthropod diversity beneath the canopy than the pasture. Arthropods enhance soil health by breaking down organic matter and maintaining soil porosity. Higher arthropod abundance and diversity indicates a more robust soil and as their levels are greater nearer the tree, it is evident that IFTs can enhance soil biological health.

Seasonal Variations in Soil and Arthropod Abundance and Diversity

This study suggests that arthropods may be sensitive to changes in bulk density, total soil P, total soil N and soil respiration levels, across seasons. Although their abundance may differ between seasons, they are not specifically affected by low temperatures (King and Hutchinson 1976) experienced in the Central-west Tablelands. Correlations between arthropod abundance and diversity in leaf litter with bulk density, total P and N are greater in spring compared to autumn 2015. Correlations between these parameters and arthropod abundance in soil occurred in both seasons.

A small increase in bulk density in both spring and autumn correlated with a decrease in arthropod abundance in soil and in arthropod diversity in leaf litter. This indicates arthropods may inhabit the soil when it is less compacted due to higher levels of organic matter present and increased porosity providing more habitable space. Arthropods assist in maintaining soil porosity and lowered bulk density creates a more suitable environment for arthropods.

Soil nutrients (total P and total N) did not differ between the seasons, although increases in soil nutrients in spring and autumn correlate with increases in arthropod abundance in soil and the diversity of arthropods in leaf litter. Oliver et al. (2006) found an increase in soil P and N correlated with increases in arthropod abundance and an increase in soil P correlated with an increase in arthropod diversity. Arthropods perform a role in the nutrient cycling process by mixing and altering the structure of the soil, breaking down organic matter into fragments for easy digestion by microbes which convert inorganic P and N into soluble forms and by feeding on microflora (bacteria and fungi), resulting in nutrient rich arthropod excreta. It can be seen that the greater the abundance and diversity of arthropods, the higher the soil nutrients and vice versa.

Efflux did not differ between the seasons, although Moulin et al. (2012) found soil respiration levels were greater in autumn 2014 than spring 2015. An increase in soil respiration in autumn correlated with an increase in

arthropod abundance in soil and leaf litter. An increase in the arthropod population would result in higher levels of soil respiration occurring. Decreases in soil respiration in autumn correlate with an increase in arthropod diversity in leaf litter which can be explained by the fact that although diversity may increase, the actual population may have decreased, resulting in decreased respiration.

Influence of Tree Species on Spatial Patterns

No differences were found between the three tree species with total N, soil respiration (efflux) or arthropod abundance and diversity in soil under the trees. Significant differences were found between the three tree species for bulk density, total P and arthropod abundance and diversity in leaf litter surrounding the trees. *Eucalyptus bridgesiana* recorded the highest bulk density and is known for its adaptation to heavier and compacted soils (Department of Primary Industries 2010). The highest total P levels were recorded in the soil surrounding *E. melliodora* followed by *E. viminalis* and *E. bridgesiana*. Wilson (2002) found highest rates of stock camping beneath *E. melliodora* which could explain the increase in total P levels due to increased levels of excreta. Additionally, *E. melliodora* has a dense crown (Bower et al. 2002) which provides ideal shading for stock.

The number of arthropods extracted from litter was highest for *E. bridgesiana* followed by *E. viminalis* and *E. melliodora*. Arthropod diversity in leaf litter was found to be greater in *E. viminalis* followed by *E. melliodora* and *E. bridgesiana*. *Eucalyptus bridgesiana* flowers from January to March (Florabank, n.d. (a)), *E. viminalis* flowers from summer to autumn (Florabank, n.d. (b)) and *E. melliodora* flowers from August to December (Florabank, n.d. (c)). Assuming flowering adds to the level of leaf litter, an increase in arthropod abundance and diversity would be expected. Each of the tree species flowered only once, either during the spring or the autumn sampling period. Thus, the flowering period could not be considered a factor in the difference between arthropod abundance and diversity in leaf litter between the tree species. Additionally, *E. bridgesiana* recorded the highest abundance in leaf litter but the lowest diversity, therefore further investigation may be required to determine species effect on arthropod abundance and diversity in leaf litter.

CONCLUSION: IFT AND SOIL HEALTH

Soil is less compacted and soil nitrogen and phosphorus, soil respiration and arthropod abundance and diversity are greater nearer the trees compared to the surrounding pasture. In a pasture context, interactions between trees, stock and soil are complex. King and Hutchinson (1976) observed increased stocking rates reduced the abundance of arthropods and soil pore space, resulting in higher bulk density. The present study found lower bulk density and higher abundance and diversity of soil arthropods closer to the tree compared to the surrounding pasture. Given stock camp beneath the canopy of IFTs for shelter, with trampling focused to a specific location, it would be expected that beneath the tree canopy, bulk density would be higher and arthropod abundance and diversity would be lowered, compared to the surrounding pasture. The results of the present study showed that IFTs can alleviate the expected effects of grazing on soil and therefore validate the presence of the IFT in the pasture landscape and the role it provides in enhancing soil health.

Retaining existing remnant IFTs in the landscape provides many benefits. IFTs provide habitat for birds, invertebrates and vertebrates, they intercept rainwater and radiation, creating a cooler and moister environment beneath the canopy and they are known to have patterns of increased soil nutrients, pH and organic matter levels beneath the tree canopy compared to the surrounding pasture (Wilson et al. 2007). IFTs provide shelter for stock and although stock excreta is rich in nutrients, it has been found that the pattern of increased levels of soil nutrients and pH beneath the IFTs occur regardless of stock activity (Graham et al. 2004, Wilson 2002, Wilson et al. 2007). Increased stocking rates can be detrimental to the tree due to increased soil compaction, root damage and decreases in soil pH.

Tree regeneration is more likely when grazing is absent due to herbivory of young plants and damage to the seedbed from stock trampling. Isolated farm trees are threatened by die-back, senescence and clearing. To protect IFTs from these threats, it is recommended fencing is established in a perimeter around the trees to safeguard the immediate soil surface and to promote regeneration (Bromham et al. 1999, Ozolins et al. 2001). Enhancing awareness amongst farm managers to the benefits of the trees may assist in reducing the rate of clearance (Ozolins et al. 2001).

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Contributions

R. Provost executed the project, did field surveys, and conducted analyses. A. Raman and D. Hodgkins developed the project, designed the study, participated in interpretations and analyses, led writing the paper. H. Nicol offered statistical advice.

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