Impact of landuse on profile distribution of fine root biomass in NSW, Australia

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Abstract

Profile distribution of fine root biomass (FRB) is a quantifiable indicator of belowground storage and sequestration of carbon. We compared the yield and depth distribution of FRB among three adjacent landuses: native pasture, improved pasture and woodland on the northern tablelands of NSW. We extracted 12 intact soil cores (32 mm diameter) per landuse during the Spring of 2009. Cores were divided into 0.0 – 0.1, 0.1 – 0.3, 0.3 – 0.5, 0.5 – 0.7 and 0.7 – 1.0 m segments and stored at 5 ^{o}C prior to processing. Fine roots (FRs) were recovered using root washing drums and oven-dried for FRB determination. We fitted exponential decay functions to the data, to investigate the relationship between soil profile depth and FRB distribution. Landuse interacted strongly ($P < 0.01$) with depth distribution of FRB. We observed highest FRB (2196 g m^{-2}) under improved pasture, while the lowest FRB (1171 g m^{-2}) was under the woodland. Over 78% of the FRB under improved pasture was in the top 0.0 – 0.1 m, compared to 67% under woodland. The FRB under both native pasture and woodland was more evenly distributed with depth than under improved pasture, reflecting an evolutionary adaptation of native vegetation to wide-ranging environmental stresses common in NSW. Further studies are needed to quantify between-site differences in FRB production and distribution with depth, the rate of turnover of FRB carbon with depth and how these vary across the landuses, before the potential of these landuse systems to sequester carbon belowground can be unravelled.

Keywords

Carbon storage, landuse differences, root decay model, root litter inputs

Introduction

The depth at which plants are able to grow roots has important implications for instance in terms of ecosystem hydrological balance and nutrient cycling. According to Canadell *et al*. (1996), Rasse *et al*. (2005) and Denef and Six (2006), the depth at which roots descend and decompose ultimately determines the fate of root carbon (C) and thus, the potential of any ecosystem to sequester C belowground (Canadell *et al*., 1986). They explain that polyvalent cations like Al^{3+}, Fe^{3+}, Ca^{2+} and Mn^{2+} which tend to be concentrated in deeper soil horizons might form organo-mineral complexes with that C, rendering it less decomposable (Rasse *et al*., 2005). Soil temperature which is a major driver of the rate of litter decomposition also decreases with soil depth (Baker et al., 2007). This might decrease microbial respiration and in turn inhibit root decay. Root distribution and rooting depth are functions of time through their dependence on evolving root biomass (Arora and Boer, 2003). Biomass in units of kilograms per square meter is closely associated to carbon content (kg C m^2) since the ratio r_c of carbon to biomass is fairly stable at about 0.5 (Ajtay *et al*., 1979). Thus, the amount of root biomass and the depth to which it is placed are quantifiable indicators of the potential of any landuse system to store and sequester carbon.

The availability of water to individual plants depends partly on local climatic and soil factors and also on the depth, lateral spread and degree of overlap of plant root systems (Christian 1977; Casper and Jackson 1997). Roots tend to descend down the soil profile in response to the advancing wetting front as shallow layers dry up (Schenk and Jackson, 2002). This process can continue as long as root growth and exploration of the soil volume is not constrained by soil, plant, age and season-induced limitations (Clarke

et al., 2003). Most plant roots tend to be concentrated in the top 50 cm of soil (Hendrick and Pregitzer, 1996; Lodge and Murphy, 2006; Guo *et al*., 2008). These roots play an important role in the extraction of water as well as nutrients from the shallow layers especially during the wet season (Canadell *et al*., 1996; Qin *et al.* 2005). However, as the top soil layers dry, there is a progressive shift towards using water from deeper soil horizons to survive the dry season (Canadell et al.1996). This study evaluates the impact of landuse on the production and profile distribution of fine root biomass on a Chromosol on the northern tablelands of New South Wales (NSW), Australia.

Materials and methods

This study was conducted on the Northern Tablelands at Newholme Field Laboratory (NFL), University of New England (UNE) located 10 km north of Armidale, New South Wales (NSW), Australia. The NFL lies on latitude 30?31'S and longitude 151?40'E. The climate is temperate with mean temperatures of 1 – 13?C (winter) and 13 – 27?C (summer) with a mean of 94 frosts per year. Mean annual rainfall is 790 mm which is evenly distributed throughout the year but with slight dominance during summer. The NFL covers an area of 1945 ha of which improved pasture, native pasture and woodland, occupy 174, 949 and 822 ha, respectively. The landuses studied were on a mid-slope position with elevations ranging from 1020 – 1028, 1025 – 1033 and 1024 – 1029 metres above sea level for improved pasture, native pasture and woodland, respectively. All the three landuses were on a Yellow Chromosol (soil derived from granite with a sandy loam A horizon of thickness 25 – 35 cm and approximately 80% sand underlain by a clayey B horizon on top of a coarse weathered granite C horizon. The soil is low in nitrogen (< 0.07% N), available phosphorus (12.2 – 15.3 mg kg^{-1} P) and organic matter (1.8 – 2.2% OM) with moderate acidity (pH 6.0 – 6.3) (Li *et al.*, 2007).

Native pasture is predominated by wallaby grass (*Austrodanthonia richardsonii* (Cashmore) H.P.Linder **APNI**), kangaroo grass (*Themeda australis* (R.Br.) Stapf **APNI**) and *wire grass (Aristida ramosa* R.Br. and *A. warburgii* Mez.). Under-sowing of native pasture with Phalaris (*Phalaris aquatica* L. **APNI**) and clovers like white clover (*Trifolium repens* L., **APNI**) and red clover (*T. pratense* L.) and application of superphosphate fertilisers characterised pasture improvement. The typical woodland is characterised by over 40% tree cover, mostly red gum (*Eucalyptus blakelyi* Maiden), red box (*E. melliodora* Cunn. Ex Schauer), ribbon gum (*E. viminalis* Labill.), apple box (*E. bridgesiana* R. Baker) and New England peppermint (*E. novaanglica* Deane & Maiden) (Li, 2001). The dominant grasses under the tree canopies are weeping grass (*Microlaena stipoides* (Labill.) R.Br. **APNI**) and red grass (*Bothriochloa macra* (Steud.) S.T. Blake **APNI**).

It is important to note that all the landuses considered had been in place for over 10 years.

Each landuse was partitioned into four intensive sampling units (with each unit as a pseudo replicate within a landuse) of 25 x 25 m^2. The intensive sampling units were representative of a larger portion of a paddock. At each sampling unit, three intact soil cores (diameter 32 mm) were extracted to one metre using a hydraulic soil corer during the spring of 2009. Each core was segmented into 0.0 - 0.1, 0.1 – 0.3, 0.3 – 0.5, 0.5 – 0.7 and 0.7 – 1.0 m. Samples were sealed in Ziploc bags and stored below 5 ^{o}C prior to processing to recover fine roots (FRs). The process of extracting FRs from the soil involved: soaking each soil core portion in tap water overnight, gently stirring and emptying contents into the external cylinder of root washing drums, followed by application of hydraulic pressure and trapping FRs on the fine screens (aperture 0.2 mm) fitted at the bottom of inner cylinders of the root washing drums. The FRs were floated on clean water and picked manually using tweezers. The water was again passed through a 0.2 mm sieve and any trapped roots were collected before the contents were discarded. Samples were oven-dried at 40 ^{o}C for 72 hours before they were weighed to determine FR biomass (FRB). The data were normalised by square root transformation and subjected to ANOVA using the R statistical programme (Version 2.7.2). The relationship between soil profile depth and distribution of FRB was established for each of the three landuses by fitting exponential decay functions to the data. The FR mass density (y) at any given depth (x) could be estimated by an exponential decay model modified from Jackson *et al*. (1996) and Arora and Boer (2003) such that:

$$y = a\, e^{-bx}$$

Where: *a* is the initial fine root mass density in the top 0.1 m and *b* is the fitted parameter which defines the rate of decrease in fine root mass density (FRMD) with depth *x*.

Results and Discussion

Impact of landuse on depth distribution of fine root biomass (FRB)

Mean FRB yields for the three landuse systems and their standard errors for the respective profile depths are presented in Table 1. There was a progressive decline ($P < 0.01$) in FRB from improved pasture to woodland. The higher FRB under improved pastures is consistent with the results of Lodge and Murphy (2006) who found that exotic species produced higher FRB than native pastures on the north-west slopes of NSW. This may be explained by a number of factors. First, introduction of exotic species and fertiliser application, which were part of management practices under improved pastures, might improve FRB production. Secondly, soil from the woodland appeared to be evidently drier than soil from the other two landuses. This coupled with the predominance of tough course tree roots meant that sampling was not possible below 0.7 m (Table 1). Thirdly, the presence of grasses in the woodland might have forced the tree roots to descend deeper than 1.0 m. Finally, root systems of the grasses may interact negatively with those of eucalyptus trees, resulting in total decline in FRB at depth. Related research (Guo *et al*., 2008) indicated a net loss of SOC 16 years after the replacement of native pasture with a planted pine forest in NSW.

Table 1. Depth distribution of fine root biomass in spring among three landuses on a Chromosol in Newholme, NSW, Australia

Soil profile depth (m)	**Fine Root Biomass (g m^{-2}) Per Landuse**		
	Improved pasture	Native pasture	Woodland
0.0 – 0.1	1709.90(312.63)	1142.24(126.94)	784.47(128.78) ‡
0.1 – 0.3	396.65(47.07)	405.68(62.53)	276.42(33.18)
0.3 – 0.5	51.56(5.48)	85.50(20.48)	99.44(49.17)
0.5 – 0.7	26.85(5.99)	33.97(8.83)	10.78(8.26) ‡‡
0.7 – 1.0	11.45(4.71) †	15.11(7.76) ††	NA
Total	**2196.41**	**1682.50**	**1171.11**

Key to the symbols used in Table 1: † n = 6 while for the rest of profile depths in that column, n = 10; †† n = 11 compared to 12 for the other depths; ‡ n = 12, ‡‡ n = 4 while for the rest of depths n = 11. Values in brackets are standard errors for the respective mean FRB yields.

The relationship between landuse and depth distribution of fine root biomass

Root mass density (g m^{-3}) declined exponentially with depth (Figure 1) across all the three landuse systems. From the shape of the curves, it is apparent that the higher the value of *a*, the steeper the rate of decrease in FRMD. The value of *a* also varied substantially among all landuses whereas *b* did not vary

as much. The steepest decline in FRMD with depth was under improved pasture, followed by native pasture, which did not differ significantly from the woodland. Our results are in agreement with those from earlier studies by Jackson *et al.* (1996) and Arora and Boer, (2003) who found that the distribution of root biomass with depth for a range of geographical sites could be well explained by first order decay rates. However, we did not factor in the effects of species composition, age of the plants and seasonal changes on root distribution as this study was conducted through a one-time sampling.

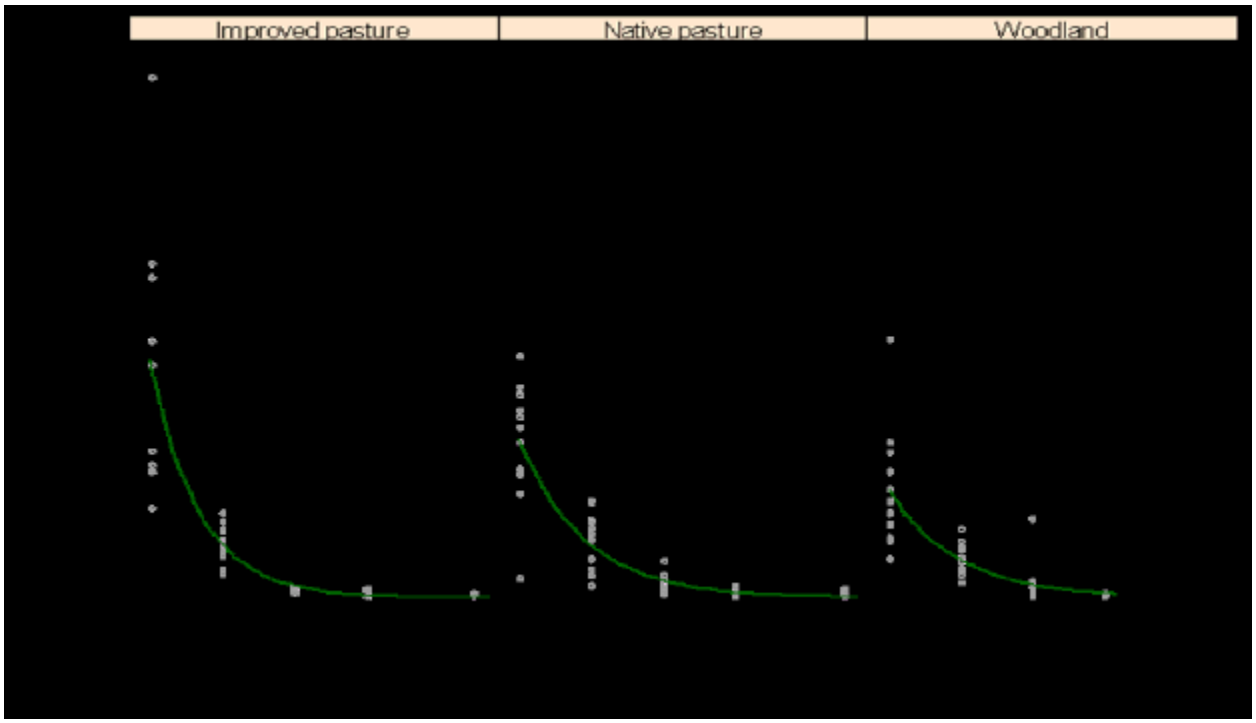

Figure 1. Variation in root mass density with soil depth under improved pasture, native pasture and woodland at Newholme, NSW

Conclusion

This preliminary study has shown that improved pastures produce more total FRB (2196 g m^{-2}) than either native pasture (1683) or woodland (1171). However, as much as 78% of that FRB is in the top 10 cm whereas the FRB under native pasture and woodland is more evenly distributed with depth. Furthermore, a model has been proposed to predict the profile distribution of FRB under the three landuse systems based on fitting root mass data to exponential decay functions. In-depth studies must consider the additional factors such as plant age, botanical composition as well as soil biophysical and biogeochemical conditions that are known to influence root production and depth distribution of fine root biomass.

References

Akinnifesi, F.K., A.J.M. Smucker and B.T. Kang. 1999. Below-ground dynamics in Agroforestry systems. *Annals of Arid Zone 38(3&4):239-273*.

Arora, V.K. and G.J. Boer. 2003. A representation of variable root distribution in dynamic vegetation models. *Earth Interactions 7(6): 1 – 19*.

Canadell J., R. B. Jackson, J. R. Ehleringer, H. A. Mooney, O. E. Sala, E. D. Schulze. 1996. Maximum rooting depth of vegetation types at the global scale. *Oecologia 108: 583 – 595*.

Casper B. B. and R. B. Jackson. 1997. Plant competition underground. *Annual Review of Ecology and Systematics*. 28: 545 – 570.

Clark L. J., W. R. Walley and P. B. Barraclough. 2003. How do roots penetrate strong soil? *Plant and Soil 255: 93 – 104*.

Christian K. R. 1977. Effects of environment on the growth of alfalfa. *Advances in Agronomy 29: 183 – 227.*

Denef K., J. Six. 2006. Contribution of incorporated residue and living roots to aggregate-associated and microbial carbon in two soils with different clay mineralogy. *European Journal of Soil Science 57: 774 – 786*.

Ford H.A., J.R. Walters, C.B. Cooper, S.J.S. Debus, V.A.J. Doerr. 2009. Extinction debt or habitat change? – Ongoing losses of woodland birds in north-eastern New South Wales, Australia. *Biological Conservation 142: 3182–3190*.

Fujita K., K. G. Ofosu-Budu and S. Ogata. 1992. Biological nitrogen fixation in mixed legume-cereal cropping systems. *Plant and Soil 141: 155 – 175*.

Guo, L. B. A. L. Cowie, K. D. Montagu., R. M. Gifford. 2008. Carbon and nitrogen stocks in a native pasture and adjacent 16-year-old *Pinus radiate* D. Don plantation in Australia. *Agriculture Ecosystems & Environment, 124 (3-4): 205-218.*

Hauggaard-Nielsen H. and E. S. Jensen. 2005. Facilitative root interactions in intercrops. *Plant and Soil 274: 237 – 250*.

Hendrick R. L. and K. S. Pregitzer. 1996. Temporal and depth-related patterns of fine root dynamics in northern hardwood forests. *Journal of Ecology 84: 167 – 176*.

Li J. (2001) Disturbance ecology in temperate pastures on the New England Tablelands of NSW, Australia: herbaceous vegetation, *Eucalyptus blakelyi* and the environment in relation to anthropogenic influences. PhD thesis. University of New England, Armidale.

Li J., J.A. Duggin, W.A. Loneragan and C.D. Grant. 2007. Grassland responses to multiple disturbances on the New England Tablelands in NSW, Australia. *Plant Ecol 193:39–57*

Lodge, G. M. and S. R. Murphy. 2006. Root depth of native and sown perennial grass-based pastures, North-West Slopes, New South Wales. I. Estimates from cores and effects of grazing treatments. *Australian Journal of Experimental Agriculture 46: 337 – 345*.

Jackson RB, Canadell J, Ehleringer JR, Mooney HA, Sala OE, Schulze ED (1996) A global analysis of root distribution for terrestrial biomes. *Oecologia 108: 389 – 411*.

Qin, R., P. Stamp and W. Richner. 2005. Impact of Tillage and Banded Starter Fertilizer on Maize Root Growth on the Top 25 cm of the soil. Agronomy Journal, Vol. 97: 674 – 683.

Rasse DP, Rumpel C, Dignac MF (2005) Is soil carbon mostly root carbon? Mechanisms for a specific stabilisation. *Plant and Soil 269: 341 356*.

Schenk H. J., R. B. Jackson. 2002. Rooting depths, lateral root spreads and belowground / aboveground allometries of plants in water-limited ecosystems. *Journal of Ecology 90: 480 – 494*.