Distribution of lucerne roots in summer-dry environments of southern Australia

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Abstract
In recent years, lucerne (*Medicago sativa*) has been widely sown in productive livestock systems to provide nutritious feed to stock under dry summer conditions in southern Australia. While it is well known that lucerne has deep roots that are important for nutrient and moisture capture, little is known about the distribution of those roots in the soil under the Mediterranean environmental conditions experienced in southern Australia. In summer 2014-15, a field study was conducted to quantify the distribution of lucerne taproots by sampling individual lucerne plants up to 50 cm and all roots in soil cores up to 2 m deep in two contrasting environments, Hamilton and Rutherglen, of Victoria, Australia. The results showed that there was a significant ($P < 0.01$) exponential relationship between the biomass (y) of lucerne taproots and soil depth (x) ($y = 3.22e^{-0.092x}$, $R^2 = 0.95$ and $y = 1.44e^{-0.08x}$, $R^2 = 0.94$ for Hamilton and Rutherglen sites respectively). Based on these equations, it is predicted that the majority of the taproots were present in the top 10 cm of the soil and over 90% in the top 30 cm of soil. There were significant ($P < 0.01$) relationships between the biomass of all roots and soil depth, with the equations being $y = 0.20x^{-1.038}$ ($R^2 = 0.87$) and $y = 0.52x^{-1.171}$ ($R^2 = 0.96$) for Hamilton and Rutherglen, respectively. Based on these equations, it is estimated that over 70% of the total root biomass was in the top 30 cm soil at both sites. These data provide critical information for further research and management on lucerne roots.

Key words
Root biomass, root depth, lucerne sward, individual lucerne plants

Introduction
Lucerne (*Medicago sativa*) is a deep-rooted (> 4 m; Ward et al. 2003) perennial legume that is cultivated as a specialty fodder plant around the world (Humphries 2012). In Australia, lucerne is also extensively used for grazing, providing feed that is often complementary to perennial grass dominated pastures. The capacity to fix atmospheric nitrogen, the high levels of summer production and the adaptation to a broad range of agro-ecological environments have made lucerne the most widely sown perennial legume in southern Australia (Dear *et al*. 2008).

Lucerne roots play a critical role in extracting water and nutrient from the soil and improving the macroporosity of subsoil (McCallum *et al*. 2004). The taproots and the crowns of lucerne also act as a storage organ for endogenous reserves of predominantly carbon (C) and nitrogen (N) in response to changes in management and environmental conditions (Teixeira *et al*. 2007). C and N are generally mobilized from these reserves following defoliation and during early-spring when photosynthesis and N fixation are limited by low leaf area and low temperatures (Avice et al. 1996; Li *et al*. 1996). Re-accumulation of C and N reserves occurs in the later stages of regrowth and in autumn around flowering (Cunningham and Volenec 1998; Khaiti and Lemaire 1992). Ensuring an adequate level of C and N reserves in the taproots and maintaining an appropriate balance between the supply and deposition of C and N are crucial to sustaining the productivity and persistence of lucerne pastures.

An understanding of the root biomass distribution down the soil profile is fundamental to determine the appropriate sampling depth for quantifying the root reserve dynamics. However, there is little information about how lucerne roots, especially taproots, are distributed in the soil. Denton *et al*. (2006) measured the root length and biomass of lucerne at different depths up to 1 m and found that the majority of roots were concentrated in the surface soil (0 – 10 cm). The study was conducted using a pot experiment and did not capture the depth and variation that may be seen in field situations. The objectives of this study were to 1) quantify the relationship between soil depth and the biomass of taproots from individual lucerne plants, and 2) quantify the relationship between soil depth and the biomass of all roots under lucerne stands in two contrasting summer-dry environments of Victoria, Australia.

Methods

An experiment was conducted on two lucerne (cv SARDI 7) paddocks at Hamilton and Rutherglen, Victoria, Australia (Clark *et al*. 2015). At the Hamilton site, the soil was a ferric-sodic eutrophic brown Chromosol (Isbell 2002). The long-term (1965-2015) average maximum and minimum temperature were 18.4°C (12.0°C in July – 25.9°C in February) and 7.1°C (4.2°C in July – 10.9°C in February). The long-term average annual rainfall was 684 mm. The pasture was dominated by lucerne with a mean basal frequency of 57.5% measured in November 2014. At the Rutherglen site, the soil was a sub order brown Chromosol. The long-term (1912-2014) average maximum and minimum temperature were 21.7°C (12.4°C in July – 31.4°C in January) and 7.3°C (2.0°C in July – 13.9°C in February). The long-term average annual rainfall was 587 mm. The pasture was dominated by lucerne with a mean basal frequency of 41.1% in December 2014.

Taproot biomass distribution was measured by collecting 7 individual plants to a depth of 50 cm at both sites in summer 2015. The plants were washed, trimmed to remove any green material from the crown and then placed on a bench in their natural shape between two rulers. The roots (including crown) were cut into 3-cm segments (0 – 3, 3 – 6, …) and oven dried at 100°C for 24 hours. The distribution of all roots from lucerne stands was measured by randomly collecting 12 cores up to 2 m at both sites in November 2014. The diameter of the soil cores was 4.2 cm and 3.8 cm for Hamilton and Rutherglen, respectively. The cores were cut to 0 – 10, 10 – 30, 30 – 50, 50 – 70, 70 – 90, 90 – 110, 110 – 130, 130 – 150, 150 – 170 and 170 – 200 cm in the field. Each of the core segments was soaked in 5% sodium hexametaphosphate for 24 hours before being washed using a root washing device (Ridley and Windsor 1992) to collect all roots (tap, lateral and fibrous roots). The roots were then dried at 60°C for 72 hours. Nonlinear regression models were used to quantify the relationships between soil depth and the biomass of taproots from individual plants and all roots under the lucerne swards.

Results and discussion

The relationship between soil depth (x) and the biomass (y) of taproots followed an exponential curve ($P < 0.01$) at both Hamilton and Rutherglen (Figure 1). The equation of the curves was $y = 3.22e^{-0.092x}$ ($R^2 = 0.95$) for Hamilton and $y = 1.44e^{-0.08x}$ ($R^2 = 0.94$) for Rutherglen. This implies that the taproot biomass declined dramatically in the top soil (0 – 10 cm) and upper part (10 – 30 cm) of the subsoil regardless of the site conditions. The reduction in taproot biomass was more gradual from 30 cm onwards. Based on these equations and the estimate of total taproot biomass in the top 2 m soil, the cumulative biomass of taproots along the soil profile and its proportion to total soil biomass were calculated. These results revealed that the majority (58 – 63%) of lucerne taproots from individual plants was in the top 0 – 10 cm soil and over 90% in the top 0 – 30 cm soil (Table 1). This result supports the finding of Denton *et al*. (2006). The taproot biomass of individual plants from Hamilton (mean = 11.6 g/plant) was higher than that from Rutherglen (mean = 5.6 g/plant), reflecting the differences in temperature and rainfall, and possibly soil texture, soil fertility and age of the swards, between the two sites.

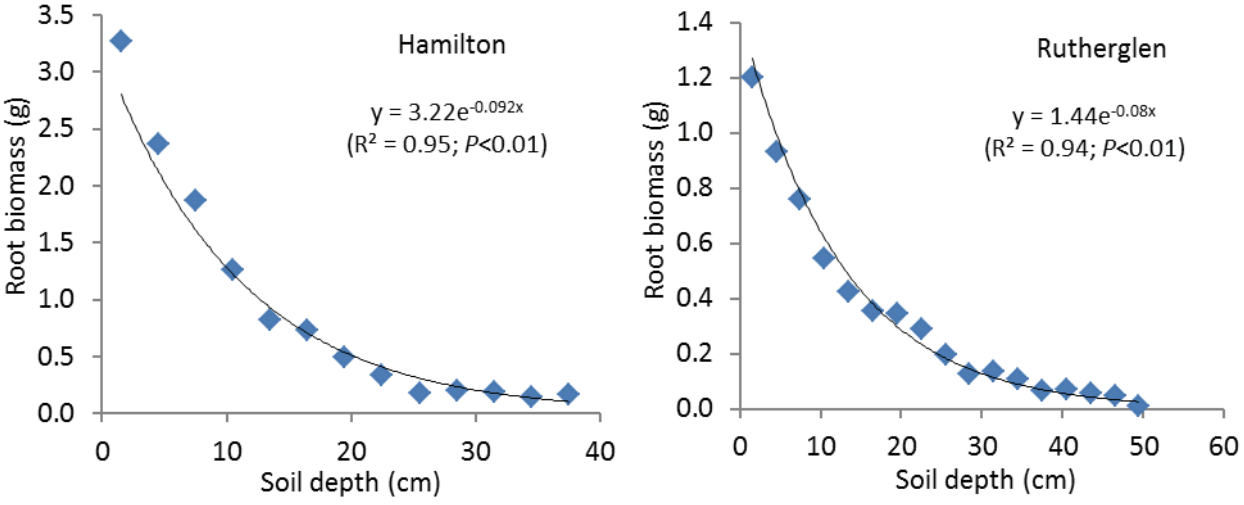

Figure 1. Relationships between root biomass (g in every 3 cm depth) of individual lucerne plants and soil depth at Hamilton and Rutherglen.

There were significant (P<0.01) relationships between the soil depth and the biomass of all roots with the equation being $y = 0.20x^{-1.038}$ ($R^2 = 0.87$) for Hamilton and $y = 0.52x^{-1.171}$ ($R^2 = 0.96$) for Rutherglen (Figure 2). With these relationships, the sharp decline in all root biomass occurred from 0 to 50 cm soil depth, which was deeper than the responses of taproots to soil depth at both sites. This was probably due to the lateral and fibrous roots that may have grown vigorously in up to 50 cm of the soil. Based on the equations and the estimated total biomass of all roots in the top 2 m soil, the cumulative biomass of all roots along the soil profile and its proportion to total soil biomass were calculated (Table 1). Over 50% of the roots were in the top 0 – 10 cm soil, but only over 70% in the 0 – 30 cm soil, which is much lower than the proportion (> 90%) of taproots in this soil depth. The differences in the proportion of the cumulative biomass between taproots and all roots along the soil profile indicate that, while the taproots became fine roots beyond 30 cm depth, there was still a large quantity of lateral and fibrous roots deeper in the soil. These roots may not be able to play a role of storing nutrients for plant regrowth (Teixeira *et al*. 2007), but could function to extract water and nutrients from deep soil, which is critical to lucerne growth (Lamb *et al*. 2000).

Table 1. Cumulative biomass (CM; g) of taproots and all roots and their proportion (%) along the soil profile at Hamilton and Rutherglen based on the equations from Figures 1 (taproots) and 2 (all roots) and the total root biomass in the 2-m soil profile.

Soil depth (cm)	Taproots				All roots			
	Hamilton		Rutherglen		Hamilton		Rutherglen	
	CM	%	CM	%	CM	%	CM	%
10	7.4	63.3	3.5	58.2	0.6	52.6	1.3	62.0
30	10.9	93.7	5.4	90.9	0.8	70.3	1.7	78.0
60	11.6	99.6	5.9	99.2	0.9	81.4	1.9	86.8
90	11.6	100.0	6.0	99.9	0.9	87.7	2.0	91.6
120	11.6	100.0	6.0	100.0	1.0	92.2	2.0	94.7
150	11.6	100.0	6.0	100.0	1.0	95.6	2.1	97.1
180	11.6	100.0	6.0	100.0	1.1	98.4	2.1	98.9
200	11.6	100.0	6.0	100.0	1.1	100.0	2.1	100.0

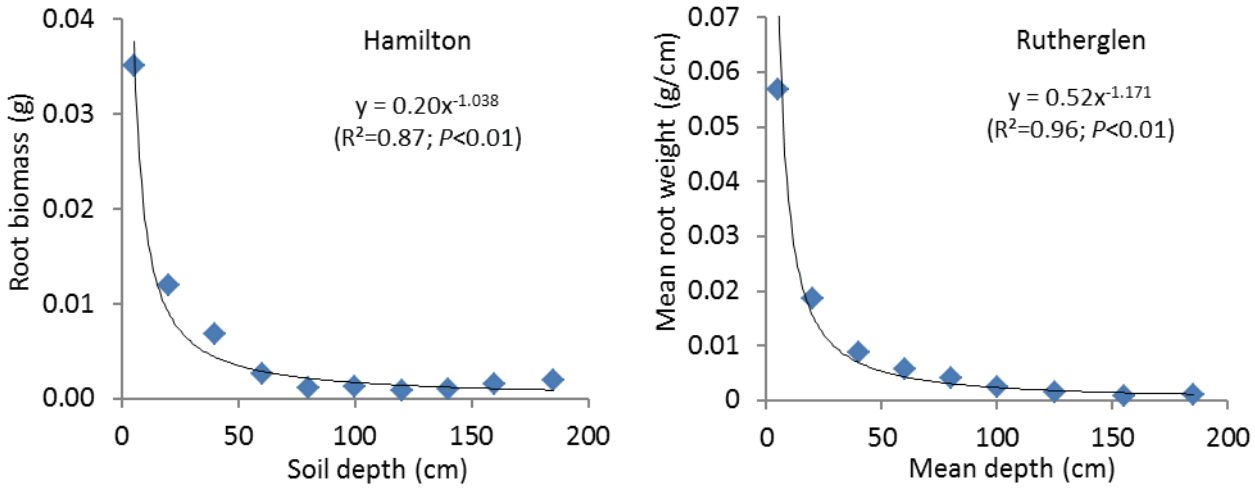

Figure 2. Relationships between the biomass (g in 1 cm depth) of all roots and soil depth at Hamilton and Rutherglen.

Given both the taproot size from individual lucerne plants (Figure 1) and the basal frequency of lucerne in the swards were higher at Hamilton than at Rutherglen, it was expected that the biomass of all roots would be higher at Hamilton as well. Interestingly, the biomass of all roots from the lucerne swards was higher at Rutherglen (1.47 g/core or 0.65 mg/cm^3 soil) than at Hamilton (1.02 g/core or 0.37 mg/cm^3 soil). The cause of this difference is complicated since the biomass of the root systems can be affected by a range of climatic, edaphic and management factors and the responsive level of the plants to these factors (Luo *et al*. 1995; Denton *et al*. 2006). Environmental stress and deficiency of soil nutrients have been reported to increase the root : shoot ratio, the amount of fine roots, the length of root hairs and the production of root material

due to increased allocation of resources to root growth (Barta 1975; Bélanger *et al*. 1992; Powell and Ryle 1978; Gahoonia and Nielsen 2004). Whether these have contributed to the greater biomass of all roots at Rutherglen needs further investigation.

Conclusion

The results clearly demonstrated that, although lucerne is a particularly deep-rooting plant, the majority of the roots in terms of biomass are distributed in the top 30 cm of soil regardless of the differences in site conditions and root types (taproots vs all roots) in the Mediterranean environments of southern Australia. While the dense taproots were concentrated in the shallow top soil (0 – 10 cm) and upper part of subsoil (10 – 30 cm), dense fibrous roots were also distributed in the soil up to a depth of 50 cm. These findings provide important information for lucerne root research and management. Soil nutrient deficiency, bulk density and environmental stress may alter the growth and distribution of lucerne taproots and fibrous roots in these environments, which requires further investigation.

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