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Root Mass and Elemental Concentrations in an Irish Oak Woodland

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Abstract—Fine roots (< 2 mm diameter) are key for nutrient and carbon cycling in forests but less well studied for oak than other European trees. To better understand controls on root mass and nutrient concentrations in oak stands, a study was conducted at Glendalough in Ireland. Roots were removed from soils and measured for biomass, length and nutrient concentrations along with soil nutrients. Fine root mass was 360 gm^{-2} and comparable to other oak stands. Whilst root N concentrations were high, P concentrations were low and N, P, K, Mg, but not C or Ca were at greater concentrations in fine roots compared to coarse (2-5 mm) roots. The root Ca:Al ratio suggested Al toxicity although this was less marked in organic-rich soils. Neither root mass nor root nutrient concentrations showed particularly strong correlations with soil nutrients or pH. Whilst this data agrees well with other similar studies, improved analysis by separating live and dead roots will further advance our understanding of controls on forest fine root dynamics.

INTRODUCTION

Roots are the key organ through which plants obtain nutrients and water from the soil. Roots are a dynamic component of ecosystems and can be responsible for more than half of forest net primary productivity playing an important role in forest biogeochemical cycling (Vogt *et al*. 1986). Additionally, they act as carbon stocks in forest ecosystems and return organic carbon and other elements to the soil upon their senescence. Whilst we know that root biomass can be influenced by forest above-ground biomass (Finér *et al*. 2011), stand age (Leuschner & Hertel 2003; Singha *et al*. 2020), climate (Leuschner & Hertel 2003), seasonality (Lalnunzira *et al*. 2019) and soil fertility (Aber *et al*. 1985; Brearley 2011) among others, clear controls over forest fine root (< 2 mm diameter) biomass are still not fully understood. This is important for a better understanding of forest carbon dynamics. In general, root biomass decreases in more fertile soils as trees do not need to invest so much in below-ground components to obtain essential resources but toxic elements such as aluminium may negatively affect roots in acidic soils. Roots contain a sizeable proportion of ecosystem nutrient stocks and the ratios between elements in plant tissues ('ecological stoichiometry') can be used to help us understand nutrient limitation in ecosystems (Yuan *et al*. 2011), stress due to soil acidity (Vanguelova *et al*. 2007) and other physiological or biogeochemical processes. Roots often proliferate into moister and more nutrient-rich patches in soil to obtain the resources within and this may then influence their nutrient budgets and it has been shown that root nutrient concentrations are broadly associated with nutrient concentrations in soil (Yuan *et al*. 2011) but also differ according to plant type and biome. Numerous studies of root biomass have been conducted in European forests (Leuschner & Hertel 2003; Wang *et al*. 2019a) but oak has been less studied than other tree taxa. The aim of this study was, therefore, to determine root biomass and nutrient concentrations and the linkages between them in an oak woodland in Ireland.

MATERIALS AND METHODS

Root mass was determined in a sessile oak (*Quercus petraea* (Matt.) Liebl., Fagaceae) stand at Glendalough (53° 0' N, 6° 19' W) in eastern Ireland in October 2006. The trees here are about 150-200 years old having been replanted after intensive coppicing. Soil cores were taken with a cylindrical 4.2 cm diameter x 10 cm depth corer and live and dead roots were removed by washing the cores over a sieve (1 mm) and picking all identifiable root material off using tweezers. Root length was estimated by the gridline intersect method of

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Newman (1966). Roots were then divided into two diameter classes (< 2 mm diameter and 2-5 mm diameter), oven-dried and weighed. Soils were taken from each core hole and analysed for pH with a 1:2.5 suspension in deionised water using a Sartorius PB-11 pH meter. Loss-on-ignition was determined by ignition at 550 ° C for 5 hours and total carbon and nitrogen were assessed using a Leco TruSpec CN elemental analyser. Extractable phosphorus and cations were determined by extraction with Mehlich 1 solution (1:10 soil:solution ratio) and analysis on a Thermo iCAP 6300 Duo ICP-OES. Root elemental concentrations for both of the root diameter classes were assessed by using a Leco TruSpec CN elemental analyser or a microwave-assisted nitric acid digestion followed by dilution with deionised water and subsequent analysis on a Thermo iCAP 6300 Duo ICP-OES.

RESULTS AND DISCUSSION

Mean fine root (< 2 mm) mass was 360 ± 104 (standard deviation) g m^{-2} (Figure 1) which falls within the range of data from European *Quercus* stands presented by Leuschner & Hertel (2003) that was 163 to 415 g m^{-2}. Coarse roots (2-5 mm) contributed a similar mass of 385 ± 179 g m^{-2} (Figure 1) which contrasts with Leuschner *et al.* (2001) who found this category of roots to contribute about three-quarters of

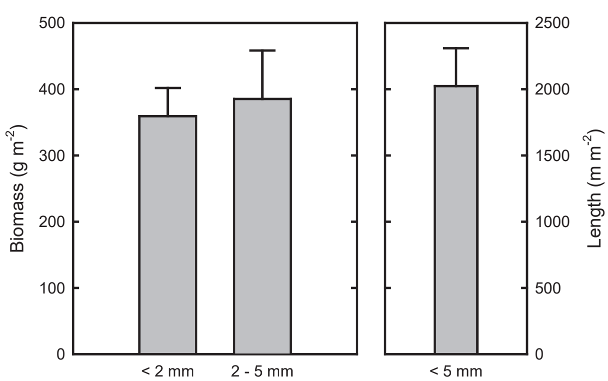

Fig. 1: Root Mass and Length in a *Quercus petraea* Woodland at Glendalough, Ireland. Bars Represent Mean ± Standard Error

the root biomass in the upper soil horizon in a German woodland. Of course, we have to take care when making such comparisons with other studies as this study included both live and dead roots that will increase the overall mass, but it only examined the top 10 cm of soil which is shallower than many other studies thereby decreasing the comparative mass. Nevertheless, oak appears to have a lesser root biomass than other deciduous species (Leuschner & Hertel 2003; Jagodzinki *et al.* 2016). The total root length for all roots (< 5 mm) was 2020 m m^{-2}, i.e. just over 2 km, and the specific root length including both diameter classes was 634 ± 351 cm g^{-1}.

The soils were acidic although the organic matter, and hence nutrient concentrations, were quite variable among samples (Table 1). Fine root (< 2 mm) mass was positively correlated with soil nutrients and negatively with pH; the only one of these that was statistically significant was the correlation between fine root mass and soil P ($p < 0.05$). Correlations between total (< 5 mm) root mass or root length were generally much weaker. This was broadly in agreement with the study of Wang *et al.* (2019a) who showed soil C concentrations were a strong predictor of fine root biomass (and necromass) across a number of studies, however, they also found pH to be positively correlated with root mass in contrast to this study. This data also indicates that root mass of oak is not insensitive to soil acidity as suggested by Leuschner & Hertel (2003) and actually increases in more acidic pH soils although this could be related to such soils having a greater amount of organic matter within them and this could be a mechanism to obtain nutrients from more recalcitrant litter. Alternatively, the data presented here could represent an increase in root necromass in more acidic soils, but this suggestion would need further work for confirmation.

Table 1: Soil Nutrient Parameters in a *Quercus petraea* Woodland at Glendalough, Ireland. Values Represent Mean ± Standard Deviation

Parameter	Value
pH	3.57 ± 0.20
Loss-on-ignition (%)	24.9 ± 14.7
Total C (%)	12.6 ± 7.6
Total N (%)	0.77 ± 0.30
Extractable P (μg g^{-1})	72.2 ± 55.2
Extractable K (μg g^{-1})	186 ± 132
Extractable Ca (μg g^{-1})	237 ± 194
Extractable Mg (μg g^{-1})	203 ± 242

Fine root nutrient concentrations showed a C:N:P of 750:19:1. Compared to the global mean for root nutrient concentrations in Wang *et al.* (2019b), N concentrations were greater whereas P concentrations were less (Table 2), leading to an N:P ratio of 19:1 which is wider than the global mean of 12:1 in Wang *et al.* (2019b) and suggestive of an ecosystem leaning towards P, rather than N, limitation which is supported by the correlation between fine root mass and soil P concentrations. Also likely is that the inclusion of dead roots in our analysis led to a wider N:P ratio (Yuan *et al.* 2011). Nitrogen, K and Mg were at greater concentrations in the fine (< 2 mm) roots (P showed a similar magnitude of increase but was not significantly different) whilst no differences were seen for C and Ca between diameter classes (Table 2). This agrees with the overall analyses of Gordon & Jackson (2000) and Yuan *et al*. (2011) who showed declines in N, P and Mg with diameter but not Ca or K although there is some variation with K (Yanai *et al*. 2018). Correlations between fine root mass and soil nutrient concentrations were mostly positive although not statistically significant. The Ca:Al ratios mostly averaged around 0.40 in broad agreement with the study of ten European *Quercus* stands by Bakker (1999) but one root sample that was actually from the most acidic soil had a Ca:Al ratio of around 5, due to markedly lower Al concentrations. The soil this sample was removed from was much more organic-rich compared to the others and it has been shown that Ca:Al ratios in organic horizons are generally greater than unity (Vanguelova *et al*. 2007).

Table 2: Root Elemental Concentrations in Two Diameter Classes in a *Quercus petraea* Woodland at Glendalough, Ireland. Values Represent Mean ± Standard Error and the Final Column Shows Differences between Diameter Classes using a *t*-test with * = $p < 0.001$, ** = $p < 0.01$, *** = $p < 0.05$, and ns = Not Significant

	< 2 mm	2-5 mm	
Carbon (%)	47.5 ± 0.09	46.8 ± 0.06	ns
Nitrogen (mg g^{-1})	12.1 ± 0.71	9.0 ± 0.59	**
Phosphorus (mg g^{-1})	0.63 ± 0.09	0.44 ± 0.08	ns
Potassium (mg g^{-1})	1.97 ± 0.07	1.09 ± 0.12	***
Calcium (mg g^{-1})	1.36 ± 0.15	1.32 ± 0.46	ns
Magnesium (mg g^{-1})	0.93 ± 0.05	0.60 ± 0.09	*

In conclusion, this study adds data on root mass and nutrient concentrations from this Irish *Quercus* stand and found they were comparable to other European oaks from which there is surprisingly little data compared to members of the Pinaceae. Additional sampling and comparison of deeper soil layers along with separation of live and dead roots and more detailed analysis of root morphology will further improve our knowledge on oak root ecological functioning.

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