Distribution of Fine Roots of Ponderosa Pine and Douglas-Fir in a Central Idaho Forest

Gabriel Dumm, Lauren Fins, Russell T. Graham, and Theresa B. Jain

ABSTRACT

This study describes soil horizon depth and fine root distribution in cores collected at two distances from the boles of Douglas-fir and ponderosa pine trees at a study site in a central Idaho forest. Concentration and content of fine roots extracted from soil cores were compared among species, soil horizons, tree size, and distance from bole. Approximately 80% of litter and humus samples contained no fine roots. The highest fine root content and concentrations of fine roots occurred in deep mineral soil for both species (1.24 g and 2.82 g/l for Douglas-fir and 0.98 g and 2.24 g/l for ponderosa pine, respectively). No statistically significant differences were found in fine root content or concentration between species in any of the four soil horizons. Tree size was not a significant factor in fine root distribution in this study. Significant variables were horizon, distance from bole, and interactions among tree size, location of sample, and soil horizon. This study, which was part of a larger US Forest Service study to develop a predictive model of postfire tree mortality, provides baseline information that may be useful in predicting postfire damage to fine roots.

Keywords: fine root content, fine root concentration, conifer roots, soil profile, fine root distribution

Since the turn of the 20th century, the combination of fire suppression, exclusion of cultural fire, spread of exotic diseases, heavy grazing, and timber harvest has altered forest structure, stand composition, and critical ecological processes in many habitats in conifer forests of the Inland Northwestern United States (Steele et al. 1986, O'Laughlin and Cook 2003, Stephens and Fulé 2005). Generally, stand densities have increased and now include higher proportions of small-diameter trees, stand compositions have shifted toward higher proportions of shade-tolerant species, and the currently higher surface fuel loadings have altered fire regimes beyond their historic range of variability (Arno et al. 1997, Brown et al. 1999, O'Laughlin and Cook 2003, Stephens 2005). For example, before Euro-American settlement, ponderosa pine (*Pinus ponderosa* Dougl.) stands in much of central Idaho were typically open and parklike with few understory trees, a condition that was likely maintained by low-intensity fires with 10–22-year return intervals (Steele et al. 1986). Over the last century, however, Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) and either grand fir (*Abies grandis* [Dougl.] Forbes) or white fir (*Abies concolor* [Gord. & Glend.] Lindl.) have encroached into the once-open areas between the ponderosa pines. Furthermore, uncharacteristically high fuel loadings in these stands have elevated the probability of intense and widespread fires (Steele et al. 1986, Arno 1988, O'Laughlin and Cook 2003). Such changes are likely to have increased the risk of mature tree mortality and soil and root damage when fires do occur. Thus, successful use of fire to restore these ecosystems to a more open condition and to maintain sustainable management regimes will ultimately depend on understanding how fires affect both the aboveground and the below-ground components of the system.

The absence of periodic fire in dry forests has created conditions that favor an increase in fine roots in soil horizons close to the surface of the forest floor (Swezy and Agee 1991, Dumm 2003). Fine roots are critical structures for water and nutrient absorption from the soil, but those near the soil surface may be particularly vulnerable to damage by fire. When fire is reintroduced in areas where it has been absent for some time, damage or loss of fine roots could potentially place even mature trees at risk for disease and/or insect infestations, or simply weaken them by reducing their ability to absorb water and nutrients from the soil.

The primary objective of this study was to provide baseline information on the distribution of fine roots of ponderosa pine and Douglas-fir trees in a ponderosa pine/Douglas-fir stand on the Boise National Forest of central Idaho. More specifically, our objective was to describe and quantify fine root distributions in four soil horizons, as related to tree species, tree size, and distance from the bole. This study is part of a larger US Forest Service study of the physiological effects on forest trees of using prescribed burning to reduce accumulated fuels in mid-aged ponderosa pine/Douglas-fir forest stands (Progar et al. 2002). Results of our study provide information on the distribution of fine roots and may be useful in determining whether that distribution is related to postfire tree mortality.

Our hypotheses were as follows:

1. Depth (thickness) of the surface organic horizons varies with tree species, tree size, and distance from tree bole.
2. Both fine root content and fine root concentration differ among species, soil horizons, tree size, and distance from tree bole.

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Materials and Methods

Study Area

The study area is in the southwestern Idaho Boise Basin on the Emmett District of the Boise National Forest in central Idaho. The Danskin drainage is approximately 12 miles east of the town of Garden Valley in Idaho. Historically, ponderosa pine dominated the forest in this area, but the tree species mix in the project area at the time of the study was approximately 39% ponderosa pine and 61% Douglas-fir. The number of trees per hectare varies widely in the study area, from 49 to 183 in representative stands, with basal areas ranging from 1.2 to 18 m^2 (information on file, Emmett Ranger District, US Forest Service, Boise National Forest). The drainage generally has a southerly aspect but comprises numerous spur ridges and steep slopes. Soils are granitic and considered moderately to highly susceptible to surface erosion. The drainage includes both forested and nonforested areas, with the differences in vegetation generally associated with elevation and aspect. Forested areas, where the study was located, consist mostly of the warm, dry Douglas-fir/moist ponderosa pine Potential Vegetation Type (PVT), with lesser amounts of dry ponderosa pine/xeric Douglas-fir and cool, moist Douglas-fir PVTs (Hessberg et al. 2000). The historic fire interval in the ponderosa pine forests in this area was generally between 10 and 22 years, and fire intensities were typically low (Steele et al. 1986, Sloan 1998). Our study sites were located on south-facing aspects in stands with a minimum density of 50 trees per hectare.

Study Design and Sampling Procedure

The 77 trees included in this study (38 Douglas-fir and 39 ponderosa pine) were a subset of a larger US Forest Service study, and trees were selected using the same selection protocols as those in the other two studies (Progar 2002, Dumm 2003). Trees were distributed across three replications.

Sample trees ranged in dbh from approximately 18 to 64 cm. For the analyses reported in this study, trees were assigned to one of two size classes within species: for Douglas-fir, $\leq$43 cm and $>$43 cm; for ponderosa pine, $\leq$48 cm and $>$48 cm). Circular perimeters established around each sample tree were delineated by standardized drip lines based on dbh size class, with radii ranging between 3.44 and 5.36 m from the exterior of the tree bole (Dumm 2003). Sample trees were selected such that these perimeters did not overlap. Visibly unhealthy trees and trees with obvious defects were excluded from the study.

Soil Core Extraction

Soil cores were collected in October of 2001 using an impact-driven soil-coring device, or "thumper." Removable clear plastic tube inserts (38.1 cm long $\times$ 7.62 cm wide) were used to extract soil cores and retain the integrity of the cores during transport and storage. Maximum functional length of the tubes was approximately 30 cm.

Two soil cores were collected on the uphill side of each sample tree bole, one at the canopy drip line and one at the halfway point between the drip line sample point and the bole of the selected tree. Soil cores were not collected where the sample point fell on a substantial rock outcrop. Organic and soil layers of the cores were marked on the plastic sleeve to the nearest 0.5 cm. Horizon designations were litter, humus, shallow mineral soil (from 0 to 10 cm below the surface of the mineral soil), and deep mineral soil (from 10 cm below the soil surface to end of soil core). Individual cores varied in both length and the specific horizons they included. Cores were refrigerated at approximately 10°C within 8 hours of extraction.

Laboratory Procedures

Soil horizon depth was recorded as marked on the plastic core sleeves. Each horizon was individually removed from core samples and weighed to the nearest 0.01 gram. Gravel $\geq$2 mm was separated from the organic matter (e.g., needles, leaves) and weighed to the nearest 0.01 gram.

All visible roots were removed from each core layer and refrigerated in plastic bags with approximately 50 ml of water. Since few understory plants were present at the study sites, and the majority of an individual tree's roots can be found beneath its drip line, the fine roots extracted from the core samples were considered to have come from the tree associated with that sample. The extracted roots were gently rinsed free of soil and re-refrigerated.

Living roots were distinguished and separated from dead roots following Visser (1995). Roots were oven-dried (24 hours at 80°C) and weighed to the nearest 0.01 gram following Vogt and Persson (1991). Roots less than 0.7 cm in diameter were considered "fine roots" and were weighed and analyzed separately from those greater than or equal to 0.7 cm, consistent with the range of threshold sizes used in previously published research (Swezy and Agee 1991, Vogt and Persson 1991, Brady and Weil 1999, Oliveira et al. 2000).

Volume of each horizon was estimated (to the nearest 0.01 liter) using the standard formula for calculating the volume of a cylinder ($\pi r^2 \times$ height). Soil bulk density was calculated by dividing the estimated volume by the oven-dry weight of each horizon. Fine root content is reported as dry weight (grams) of fine roots per sample; fine root concentration is reported as dry weight of fine roots in grams per liter.

Statistical Analyses

The statistical design was a randomized factorial with four factors: species, horizon, tree size, and distance from bole, with response variables of fine root content and fine root concentration (transformed using the natural logarithm). Using a mixed analysis of variance (ANOVA), subsamples were nested within replicates and were considered the random variable. The α level in all analyses was $P = 0.05$ (Schabenberger and Pierce 2002). The residual error versus predicted error was used to assess homogeneity of variances; a residual normal probability plot was used to validate the normal distribution of errors. Equation 1 shows the mixed ANOVA model. Tukey's pairwise comparison was used to evaluate statistically significant terms.

$$Y_{ijk} = \mu + \alpha_j + \beta_k + \gamma_l + \delta_m + \alpha\beta_{(jk)} + \alpha\gamma_{(kl)} + \alpha\delta_{(jm)} + \beta\gamma_{(kl)} + \beta\delta_{(km)} + \gamma\delta_{(lm)} + \alpha\beta\gamma_{(jkl)} + \alpha\beta\delta_{(jkm)} + \beta\gamma\delta_{(klm)} + \alpha\beta\gamma\delta_{(jklm)} + \varepsilon_{i(jk)} \quad (1)$$

where Y_{ijk} is the natural log transformation of root content or root concentration; μ is the grand mean; α_j is the effect due to two species, ponderosa pine and Douglas-fir; β_k is the effect due to horizons (litter, humus, shallow mineral soil, deep mineral soil); γ_l is the effect due to tree size (ponderosa pine $\leq$48 cm versus $>$48 cm dbh; Douglas-fir $\leq$43 versus $>$43 cm dbh); δ_m is the effect due to distance from tree bole (drip line versus half way between bole and drip line); $\alpha\beta_{(jk)}$, $\alpha\gamma_{(kl)}$, $\alpha\delta_{(jm)}$, $\beta\gamma_{(kl)}$, $\beta\delta_{(km)}$, $\gamma\delta_{(lm)}$, $\alpha\beta\gamma_{(jkl)}$,

Table 1. Probability values for main effects and some interactions.

Effect	df[a]	Horizon depth	Fine root content	Fine root concentration
Species	1	0.39	0.39	0.24
Horizon	3	0.0001[b]	0.0001[b]	0.0001[b]
Tree size	1	0.59	0.27	0.49
Location	1	0.6	0.01[b]	0.051
Size × location	1	0.56	0.03[b]	0.0008[b]
Horizon × size × location	3	0.2	0.23	0.01[b]

[a] df, degrees of freedom.
[b] Statistically significant at $P < 0.05$.

$\alpha\beta\delta_{(jkm)}$, $\beta\gamma\delta_{(klm)}$, and $\alpha\beta\gamma\delta_{(jklm)}$ are interaction terms; and $\varepsilon_{i(jk)}$ is the experimental error.

Results

Tables 1 and 2 summarize probability values for statistically significant effects and mean values for horizon depths (horizon thickness), and fine root content and concentration by horizon.

Soil Horizons

Mean depths of soil horizons were significantly different from each other ($P < 0.0001$), primarily reflecting the difference between the litter and humus horizon layers (Tables 1 and 2). Horizon depth was not associated with species, tree size, sample location (distance from bole), or any of the interactions among the independent variables.

Fine Root Content and Concentration

Mean fine root content and concentration did not vary by species ($P = 0.39$ and 0.24, respectively) or size class ($P = 0.27$ and 0.49, respectively) (Table 1), but they did vary between soil horizons ($P = 0.0001$). Approximately 80% of the litter and humus samples contained no fine roots, and both fine root content and concentration were higher in deep mineral soil than in shallow mineral soil for both species (Table 2). The interaction between tree size and sample location was also statistically significant for both fine root content ($P = 0.03$) and concentration ($P = 0.0008$) (Table 1). Fine root content varied significantly between sample locations ($P = 0.01$), and fine root concentration varied significantly in the interaction of horizon, tree size, and sample location ($P = 0.01$) (Table 1). Mean fine root concentration was near statistical significance for sample locations, with $P = 0.051$ (Table 1).

Discussion and Conclusions

The results of our study can be summarized by three main findings.

1. The distribution of fine roots varied significantly among soil horizons for both Douglas-fir and ponderosa pine, with very few fine roots in the litter and/or humus, and the highest content and concentrations in the deep mineral soil for both species (Table 2).
2. Although Douglas-fir tended to produce more fine roots than did ponderosa pine, no statistically significant differences in fine root content or concentration were associated with the different species.
3. Tree size was not a main effect for variation in either fine root content or concentration, but there was a significant interaction between tree size and sample location, with the highest mean fine root content and concentration at half the distance from the bole to the drip line in small trees, but higher content and concentration at the drip line for large trees (Figure 1). Variation in root concentration was also a function of the three-way interaction among horizon, tree size, and sample location (Figure 2).

Perhaps the most intriguing result was the interaction of tree size and location of the samples, with essentially opposite results for larger versus smaller trees, suggesting a difference in root architecture and, therefore, a potential difference in the extent and severity of root damage as a result of fire.

One surprising result was the lack of difference in fine root content or concentration between the two species in any of the horizons. Relatively dry soil conditions, plasticity in root architecture, and variation in root distribution due to age differences may be contributing factors to these results.

The small numbers of fine roots in litter and humus may be related to a variety of causes, such as low moisture and high temperature regimes, frequent disturbance, sloughing of organic material on the steep slopes, or differences in litter quality. The relative proportion of bark in the litter may also affect both the root distribution and the quality and intensity of fire moving through such an area. Regardless of cause, the relative paucity of fine roots in the organic layers of our samples suggests that light burning may have little deleterious effect on trees in this environment.

Nonetheless, the effects of fire on fine roots are likely to be complex and vary with characteristics of the stand, available fuels, fire behavior and size, the soil properties which influence heat transfer, available nutrients, and impacts to the health of the tree following the fire. Hotter fires and/or smoldering fires could potentially damage fine roots in the shallow and/or slightly deeper mineral soils. Clearly, more extensive

Table 2. Mean horizon depth and fine root content and concentration of Douglas-fir and ponderosa pine by horizon layer (standard errors in parentheses).

			Fine root content[a]			Fine root concentration[b]		
Horizon[c]	N[d]	Depth (cm)	Douglas-fir	Ponderosa pine	P value	Douglas-fir	Ponderosa pine	P value
			(g)			(g/l)		
Litter	3	2.27 (0.109)	0.01 (0.001)	0.02 (0.01)	0.99	0.11 (0.01)	0.20 (0.11)	0.99
Humus	3	3.46 (0.374)	0.30 (0.20)	0.16 (0.03)	0.75	1.49 (0.75)	1.20 (0.33)	0.88
Shallow mineral	3	10 (0.0)	1.10 (0.15)	0.78 (0.07)	0.77	2.57 (0.34)	1.85 (0.17)	0.65
Deep mineral	3	10.78 (0.914)	1.24 (0.14)	0.98 (0.16)	0.99	2.82 (0.10)	2.24 (0.12)	0.96

[a] Dry weight of fine roots in horizon layer
[b] Dry weight of fine roots per liter of horizon material.
[c] Both fine root content and concentration were significantly different across horizons ($P = -0.0001$), but no statistical difference was found when comparing the two species.
[d] Number of replicates; samples nested within replicate in the analysis.

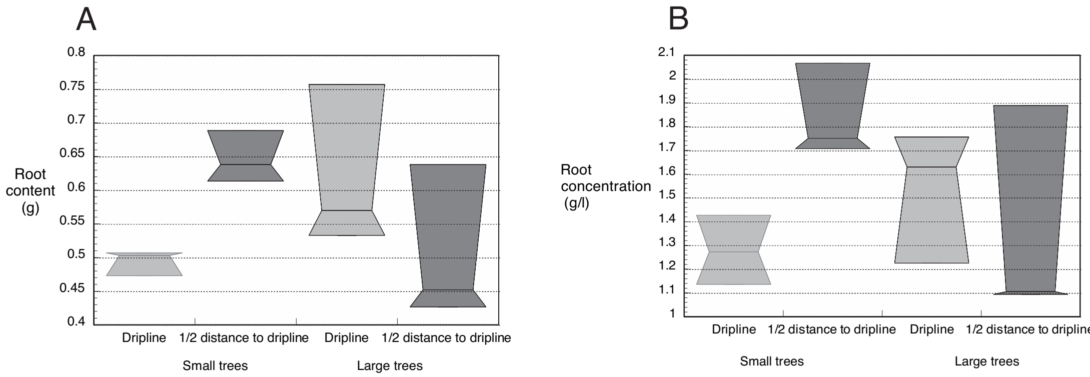

Figure 1. A, Fine root content as a function of sample location and tree size ($P = 0.02$). B, Fine root concentration (g/l) as a function of sample location and tree size ($P = 0.0008$).

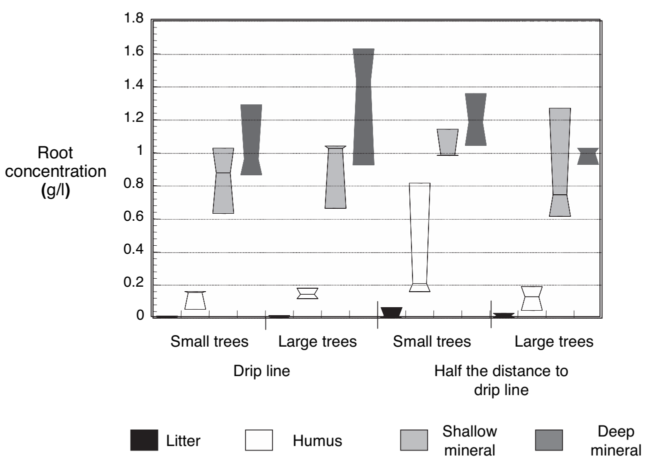

Figure 2. Fine root concentration as a function of the interaction of tree size, sample location, and horizon layer ($P = 0.01$).

studies of these variables and effects would provide useful information on both root architecture of these species and the potential damage that may result from prescribed and/or natural fire.

Our data should prove useful in providing baseline information on the quantity and distribution of fine roots as a potentially important predictive variable in a fire mortality model. Further research into biological thresholds and repercussions of reductions in fine root biomass due to fire may provide insight into postfire tree health and/or mortality rates over the short and long term.

The effects of anthropogenically altered fire regimes on susceptibility to damage by fire are uncertain and likely to vary by species, season during which burning takes place, fine root depth and distribution, accumulation of duff, and fire severity, among other forest conditions (Swezy and Agee 1991). Even fire-adapted species such as ponderosa pine can be susceptible to damage. Working in mature ponderosa pine stands in Crater Lake, Oregon, researchers documented 50–75% reductions in postfire fine root dry weight in the litter/duff and top 10 cm of mineral soil (Swezy and Agee 1991).

Studies of below-ground ecosystem components are difficult to conduct, and differences in methodologies may limit comparisons across studies. Nonetheless, we suggest that additional baseline studies similar to ours be conducted across a wide variety of field conditions so that the potential for fire-related changes in root systems can be evaluated and ultimately predicted, with the goal of protecting ecosystem integrity, sustainability, and forest health.

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