Short Communication

Coarse soil can enhance the availability of nutrients from fine soil*

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Abstract

A recent trial found that the presence of coarse soil in fine soil increased nutrient uptake by two plant species (Smaill et al., 2014). To determine if the additional nutrient uptake was derived directly from the coarse soil, the changes in coarse soil nutrient stocks were assessed. In most cases nutrient stocks increased, despite being associated with greater plant nutrient uptake. This suggests coarse soil can promote nutrient release from fine soil through some currently unknown mechanism.

Key words: soil fraction / soil particle size / plant nutrition / nutrient flux

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1 Introduction

The coarse soil fraction (material > 2 mm in diameter) contributes to plant nutrition over time frames that are relevant to plant growth (Wang et al., 2000; Ugolini et al., 2001; Koelle and Hildebrand, 2008; Smaill et al., 2014). Various processes drive nutrient release from coarse soil, including abiotic weathering (Ugolini et al., 2001), fungal activity (Jongmans et al., 1997), and bacterial activity (Uroz et al., 2011). However, results presented in Smaill et al. (2014) suggest that the plant nutrient uptake associated with coarse soil may not be solely due to nutrient release from coarse soil itself. Smaill et al. (2014) found that the additional uptake of N, P, and Mg in the presence of coarse soil was 50%, 70%, and 39%, respectively, of the total stock of these nutrients in the coarse soil. With the trial lasting 9 months, it was considered unlikely that such large proportions of the coarse soil nutrient stocks could be made available within this time frame. To investigate this further, the stocks of N, P, K, Ca, and Mg in the coarse soil at the start and conclusion of the Smaill et al. (2014) trial were determined, and these data compared to the uptake of these nutrients by plants when grown in the presence of the coarse soil. The results of this analysis are presented here.

2 Material and methods

2.1 Coarse soil extraction and analysis

Soils for this study were collected from Balmoral (42°48’ S, 172°37’ E) and Granville (42°19’ S, 171°39’ E) forests in New Zealand at depths of 0–100 mm and 200–300 mm (abbreviated as B100, B300, G100, and G300). A full description of the soil sampling sites, the design and results of the Weinmannia racemosa L. f. (kamahi) and Nothofagus solandri var. cliffortioides (mountain beech) seedling nutrition trial is given in Smaill et al. (2014). Coarse soil (defined as material 2–4 mm in diameter) was re-extracted from soil samples that were air-dried and archived at the completion of the nutrition trial, using the same methodology employed to separate the fractions from the original whole soil samples (Smaill et al., 2014). Briefly, soils were sieved repeatedly, then examined microscopically (Leica Microsystems, Wetzlar, Germany) to ensure that separation of soil fractions was acceptable. The masses of fine and coarse soil recovered were compared to that added to the pots at the start of the earlier trial to confirm a satisfactory level of separation had been achieved. The concentrations of N [LECO CNS-2000 analyzer, modified Dumas technique (Kirsten and Hesselius, 1983)], P, K, Ca, and Mg [ICP-OES analyzer, Mehlich-3 extraction (Mehlich, 1984)] in these coarse soil samples were determined on the same instruments that were used to determine nutrient stocks in six replicated subsamples of coarse soil from the four site and sampling depth combinations at the start of the nutrition trial (Smaill et al., 2014).

2.2 Preparation and statistical analysis of nutrient data

To determine (1) the extent of changes in nutrients stocks during the trial and (2) if changes in coarse soil nutrient stock matched the additional nutrient uptake by plants, the following equations were used:

\[
\text{Change in nutrient stock (\%)} = \frac{\text{Nut}_{CSF} - \text{Nut}_{CSI}}{\text{Nut}_{CSI}} \times 100.
\]  

*This short communication expands on results previously published in Smaill et al. (2014) by answering further questions posed in this article. This was achieved by performing additional experimental work with archived materials from the trial described in Smaill et al. (2014).
\[ \Delta \text{Nut} = \left( \text{Nut}_{\text{CSF}} + \text{Nut}_{\text{PCS}} - \text{Nut}_{\text{CSI}} \right) / \text{Nut}_{\text{CSI}} \times 100, \]  

where Nut, CSF is the stock of a given nutrient in the coarse soil at the end of the nutrition trial, Nut, CSI is the stock of a given nutrient in the coarse soil at the start of the seedling nutrition trial, Nut, PCS is the additional plant uptake of a given nutrient in the presence of coarse soil, and \( \Delta \text{Nut} \) is the balance of nutrient movement between the coarse soil and plant, expressed as a percentage. When \( \Delta \text{Nut} \) equaled 0%, the plant nutrient uptake associated with the presence of the coarse soil fraction equaled the loss from the coarse soil fraction over the course of the trial, whereas negative or positive \( \Delta \text{Nut} \) values indicated that the coarse soil fraction exerted non-additive effects on nutrient availability. T-tests were used to determine if nutrient stocks in the coarse soil were significantly different at the start and end of the trial, and if \( \Delta \text{Nut} \) was significantly non-zero at \( \alpha = 0.05 \). All statistical analysis was performed with R 3.0.0 (R Development Core Team, 2013).

### 3 Results

The recovery of coarse soil from the archived samples averaged 97% of the original masses, which was satisfactory. The coarse soil nutrient analysis confirmed that the mean stock of several nutrients had increased during the seedling nutrition trial (Table 1). Increases were predominantly observed for the Balmoral coarse soils; no decreases for either soil were evident. Plant species did not statistically influence changes in nutrient stocks, so means were presented independent of plant species. Significantly positive \( \Delta \text{Nut} \) values were identified for all nutrients for the B100 coarse soil, and were also common for the B300 and G100 coarse soils (Table 2). The only coarse soil in which positive \( \Delta \text{Nut} \) values were not the majority was G300, with four negative and four zero \( \Delta \text{Nut} \) values. Positive \( \Delta \text{Nut} \) values were much more common with mountain beech than kamahi in the Granville soils.

### Table 1: Comparison of changes in coarse soil nutrient stocks with coarse soil origin.

<table>
<thead>
<tr>
<th>Site and soil depth</th>
<th>Species</th>
<th>Mean change in nutrient stocks in coarse soil fraction / %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Balmoral 0–100 mm</td>
<td>Beech</td>
<td>+11 (3)</td>
</tr>
<tr>
<td></td>
<td>Kamahi</td>
<td>+122 (11)</td>
</tr>
<tr>
<td>Balmoral 200–300 mm</td>
<td>Beech</td>
<td>+25 (3)</td>
</tr>
<tr>
<td></td>
<td>Kamahi</td>
<td>+9 (3)</td>
</tr>
<tr>
<td>Granville 0–100 mm</td>
<td>Beech</td>
<td>+481 (20)</td>
</tr>
<tr>
<td></td>
<td>Kamahi</td>
<td>+62 (27)</td>
</tr>
<tr>
<td>Granville 200–300 mm</td>
<td>Beech</td>
<td>+88 (24)</td>
</tr>
<tr>
<td></td>
<td>Kamahi</td>
<td>–34 (9)</td>
</tr>
</tbody>
</table>

* \( n \) varied from 6–10 due to seedling mortality; standard error of the mean (SEM) is given in parentheses, calculated from the SEM associated with both initial and final nutrient stocks.

**Non-zero \( \Delta \text{Nut} \) values were identified with t-tests (*, **, and *** designate significance at \( P < 0.05, 0.01 \) and 0.001, respectively).
4 Discussion

The various observed increases in coarse soil nutrient stocks and the numerous positive $\Delta Nut$ values prove that the majority of the increased nutrient uptake in the presence of coarse soil, as reported by Smaill et al. (2014), were not directly derived from the coarse soil. The zero and negative $\Delta Nut$ values indicated that nutrient release from coarse soil matched or exceeded the additional plant nutrient uptake associated with the presence of the coarse soil in some cases, but positive $\Delta Nut$ values were much more common (Table 2). Greater amounts of fine soil adhering to the coarse soil could have driven the positive $\Delta Nut$ values, but microscopic examination showed that the fine soil was present in similar quantities after the first and second extractions. Therefore, the positive $\Delta Nut$ values suggest that the coarse soil was stimulating nutrient availability from another source, also increasing nutrient content in the coarse soil in some cases (Table 1). Excluding substantial differences in the extent of fraction separation, this alternate source could only be the fine soil. The mechanism driving this stimulatory effect is unknown; unfortunately the time elapsed between sample archiving and re-examination precluded any investigation of biological mechanisms involved in nutrient release from fine soil.

This stimulatory effect varied with both soil origin and plant species. The enhanced nutrient availability may have been greater for the coarse soil collected from Balmoral and the shallower depth as these soils initially contained more nutrients (Smaill et al., 2014). Previous research regarding interactions between coarse and fine soil (Grewal et al., 1984; Corti et al., 2002; Johnson et al., 2012) does not clearly address this issue, so this observation cannot be satisfactorily explained at this time. The greater number of positive $\Delta Nut$ values for mountain beech compared to kamahi in the Granville soils may be due to the inherent physiological differences between the species which can affect interactions with coarse soil (Augusto et al., 2001; Bakker et al., 2004), but as plant species did not influence changes in coarse soil nutrient stocks, no clear conclusion can be made. It was also not known why the variation in $\Delta Nut$ values was greater for Ca than any other nutrient. There was substantial variation in both the changes in the stock of Ca in the coarse soil and plant Ca uptake in the presence of the coarse soil, so the overall variation was not driven by one component.

This analysis demonstrates that the additional plant nutrient uptake associated with the presence of the coarse soil fraction was predominantly not sourced from the coarse soil itself, but otherwise raises more questions than answers. These results clearly support the need for more research about the role of the coarse soil fraction, as it appears to be vital to understanding the functioning of soil as a whole.

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References