METHODS FOR SAMPLING COARSE ROOTS OF AN INDIVIDUAL TREE IN THE FIELD

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ABSTRACT

We review briefly the coarse-root-sampling methods in forest ecosystems. The root system of an individual tree often has large bulk, and therefore it requires laborious field work for root-weight survey. Past studies have developed hand-digging, pull-out, and washing methods for sampling individual roots. Following these methods of sampling, the obtained data can be used to establish allometric relationships for root biomass. In the field, appropriate combination of root-sampling methods makes the root-survey process more practical. Here, we describe our root-sampling methods used in the experimental forest of Gifu University and present a dataset on the root weight of 17 cool-temperate-forest tree individuals belonging to 12 species. We believe that this dataset will be of use to researchers who study allometric relationships of tree roots.

Keywords: Cool-temperate forest, dataset of root weight, individual-tree roots, pull-out method, root density and biomass, soil-block sampling, trench sampling, washing method

Introduction

Information on an individual tree weight is crucial for estimating forest biomass. As a tree has substantial aboveground organs and corresponding underground roots, laborious efforts are necessary, especially to study root systems buried in soil. Therefore, forest ecologists are often concerned about the balance between accuracy of estimation and labour/time in the field.

Forty years ago, Santantonio \textit{et al.} (1977) reviewed root biomass studies of forest ecosystems and published allometric equations for various tree species. Comprehensive studies of Karizumi (1974a, 1974b, 1976) analysed biomass distribution and absorptive structure of tree roots. These studies have largely helped the development of basic principles on root biomass studies.

Based on such methods, root-biomass studies in various kinds of forests were accumulated after 1980s. Cairns \textit{et al.} (1997) introduced 165 of root biomass studies from tropical rain forests to subalpine forests and analysed biomass allocation pattern, excluding the data of wet forests, such as mangroves. Root biomass data was used for the estimation of forest productivities (Reichle, 1981) and of the net ecosystem production (Luyssaet \textit{et al.} 2008). Our group (Komiyama \textit{et al.}, 2008) also estimated the productivities of mangrove forests by using root biomass data. Subsequently, we (Poungparn and Komiyama 2013; Komiyama 2014) had reviewed the estimation of forest productivities and net ecosystem production of mangrove forests providing the root biomass data.

Recently, a new method using ground-penetrating radar has been introduced to detect coarse roots and estimate biomass (Hirano \textit{et al.} 2009, 2012; Butnor \textit{et al.} 2011; Tanikawa \textit{et al.} 2013, 2016). Also, for fine-root dynamics, minirhizotron technique and optical scanner method have been developed (Noguchi \textit{et al.} 2005; Dannoura \textit{et al.} 2008). If these methods become completely practical, non-destructive method for tree-root study will be largely promoted and tree-root studies can be done without any excavation.

However, many field researchers study tree roots based on ordinary methods and do desire to know further concrete methods for assessing root biomass in the fields. Recently, Addo-Danso \textit{et al.} (2016) had reviewed and assessed the efficiency of various root-sampling methods, such as root excavation, and soil cores, soil pits.

This review summarises and describes concrete processes for excavating the root system of an individual tree. Here, we provide an effective method for collecting the coarse roots of a single tree and present an example dataset generated using this method. This dataset is not included in the dataset of Falster \textit{et al.} (2015) and Komiyama \textit{et al.} (2017).

Two principles of root biomass estimation in forests

First, we briefly describe the principles of root biomass estimation on either an individual tree or area basis. Estimations of
for an individual tree are nearly synonymous with the allometric method. The allometric relationships are constructed using field data on tree weight. For example, Kajimoto et al. (1999) harvested six *Larix gmelinii* trees in Siberia and determined an allometric relationship of root weight using the square of stem diameter at breast height (DBH) for an independent variable. In this method, the labour required to survey root weights is a substantial limitation, as allometric relationships can differ among tree species and forest stands. Moreover, the assumption that the survey data includes the maximum size of the focal trees must be followed.

To reduce laborious field-work, common allometric equations have been developed for various types of forest (e.g. Chave et al. 2005, Ishihara et al. 2015, Komiyama et al. 2005, 2011). These equations obey either statistical or biological laws. For an example, Komiyama et al. (2005) used the pipe model and the static model of plant form (Oohata and Shinozaki 1979; Shinozaki et al. 1964ab) to establish a set of allometric equations on mangroves. Recently, databases such as Falster et al. (2015) and Komiyama et al. (2017) have supplied tree weight data obtained from around the world.

Apart from allometry, another method for estimating biomass based on area is sampling roots from a quadratic area or cubic volume of soil. Soil blocks (“trench” if an aggregation of soil blocks is used; Fig. 1) are established in forests to obtain root density measurements for conversion to root biomass. When using this method, researchers should take into account the skewed distribution of the coarse-root density of a tree. Root density is extremely high in the vicinity of root stock and decreases with increased distance from the base; thus, root sampling in forests must cover either a large number of soil blocks or blocks that are large in size. However, statistically adequate sampling is rarely achieved in the field due to the limitation of labour and time. Therefore, area-based methods are primarily used to estimate fine roots that are uniformly distributed over forest areas (e.g., Persson 1980).

Nevertheless, individual root weights can be estimated using the trench sampling method by modelling the root density distribution (Komiyama et al. 2000, 2003). This model assumes that the root density of a tree decreases exponentially from its base, \( M = M_0 e^{-aL} \), where \( M \) is root density at distance \( L \), and \( M_0 \) is the initial root density at the tree base. Herein, the value of \( M_0 \) is analytically proportional to DBH\(^2\). The parameter “\( a \)” is the decreasing rate that differs by root size but is constant within species. Assuming that the shape of root area is circular and contains no roots from adjacent trees, the root weight \( W_R \) is calculated using the formula:

\[
W_R = 2\pi \int_0^L (LM) dL = 2\pi M_0 a^{-2} (1-e^{-a(L+1)}).
\]

If \( L \) is long enough, \( W_R \) becomes \( 2\pi M_0 a^{-2} \). Given the parameters \( a \), \( L \), and \( M_0 \), the individual root weights of a tree can be arbitrarily calculated from the formula. The units of variables and parameters were \( W_R \) in [kg], \( L \) in [m], \( M \) in [kg m\(^{-2}\)], \( M_0 \) in [kg m\(^{-2}\)], and \( a \) in [m\(^{-1}\)], respectively.

Three methods for collecting roots from an individual tree

In the era of International Biological Programs (IBP), Karizumi (1974b) presented a method to dig out and collect roots from a solitary tree (Fig. 2). A concentric circle of 4.0-m radius is established for analysing the horizontal distribution of roots. From the centre of tree base, eight areas are established at 50-cm intervals. To analyse the vertical distribution of roots down to 1.2 m, horizons are divided into sections 0–15, 15–30, 30–60, 60–90, and 90–120-cm deep. Karizumi (1974b) categorised root sizes as fine (0–2 mm), small (2–5 mm), medium (5–20 mm), large (20–50 mm), and very large (larger than 50 mm).

However, collection of roots from a single tree is rather difficult in the field, because roots of other individual trees coexist within any given area. Three methods have been used to deal with this complication: hand-digging, pull-out, and washing methods.

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**Fig.1. Example of trench excavation of roots.** A trench consists of five horizontal soil blocks and ten vertical blocks. Using this design, the three-dimensional distribution of the root density of a tree can be estimated.
Hand-digging method faithfully traces a root system and digs it up by hand, similar to an archaeological survey. Given sufficient labour and time, researchers can achieve a high accuracy of root weight using this method. However, hand-digging method requires considerable labour, especially for large trees.

Pull-out method uses a winch to collect roots from underground. Using the strong tension of the winch, researchers can extract a part of or an entire root system of target trees. However, root loss is common during this process. In a 24-year-old Cryptomeria japonica stand, Yamada and Shidei (1968) estimated root loss to be 11.6% of total root weight, as roots smaller than 5 mm in diameter were cut. Such root loss will occur in hand digging too. In a large dipterocarp forest of Malaysia, Niiyama et al. (2010) estimated the loss to be 23% for coarse roots (roots ≥ 5 mm in diameter) when roots were excavated manually with assist of a power shovel. They suggested that the relative proportion of lost roots was not constant but tended to increase considerably with increases in tree size.

Washing method uses water pumps connected to a hose and nozzle to wash out a single root system in the field. Some pumps can generate strong water currents (e.g., fire pumps: Baskerville, 1966; Yamada and Shidei, 1968). Use of this method is restricted to locations near water reservoirs. In addition, researchers must minimise land erosion and the efflux of muddy water. Komiyama et al. (2005) used this method for mangroves with high efficiency, although sloughed small roots were always collected during the process.

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Root-sampling example and accompanying dataset

As each of the three methods described above has its merits and demerits, an appropriate combination of all three (i.e., hand-digging, pulling, and washing) is necessary for thorough coarse-root collection. During 2008–2011, we conducted a root biomass study in the experimental forest of Gifu University (137°13' E, 36°00' N), Gifu Prefecture, Japan.

Prior to excavation, the trunk diameter at the tree base (D₀), DBH, and the extension of the branches of target trees, were measured using measuring tapes. Subsequently, the root stock was cut off from the tree stem using chainsaws. The horizontal extension of root system was visually assessed by tracing large roots. The species identification of roots was then possible by careful discrimination of surface colour and texture of respective root fractions.

From the outer circumference of the root extension, surface soil was dug by hand or occasionally using power shovels. Finally, the entire root system was lifted from the ground using winches. Throughout this process, supplemental collection of sloughed roots was also required. Furthermore, skilled manipulators were needed to operate the equipment and machinery.

After this procedure, roots were washed and weighed. The whole root system was transported by trucks to a location near an office. The root system was washed using pumped river water (Fig. 3). For cypress trees (Chamaecyparis obtusa), we kept most of fine roots attached to the root system when the water pressure was moderated. After separating live roots from the soil and other material, fresh weights of live roots were measured using electronic balances. Approximately 500 g of root samples were collected from each size class to calculate the dry weight/fresh weight ratio.

Table 1 presents a dataset for 17 individuals belonging to 12 species. Among the 17 samples, 11 were deciduous broad-leaved trees (nine species) and the remaining six were evergreen conifers (three species). Root weight (W₁) of 17 individual trees ranged from 4.9 – 957.2 kg, among which W₁ was in triple digits for 8 individuals. DBH ranged from 8.1–72.3 cm. The stem or the entire above-ground portion was weighed for nine individual trees. Remaining eight sample trees were felled by sudden soil erosion; as such, their aboveground segments became damaged, resulting in a lack of data.

Table 1: Root weight and DBH for the 17 sample trees.

<table>
<thead>
<tr>
<th>Species</th>
<th>17 Trees</th>
<th>11 Deciduous Trees</th>
<th>6 Conifers</th>
<th>DBH (cm)</th>
<th>Root Weight (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cypress</td>
<td>3</td>
<td></td>
<td>3</td>
<td></td>
<td>500–1000</td>
</tr>
<tr>
<td>Oak</td>
<td>1</td>
<td></td>
<td>1</td>
<td>10</td>
<td>200</td>
</tr>
<tr>
<td>Maple</td>
<td>1</td>
<td></td>
<td>1</td>
<td>15</td>
<td>150</td>
</tr>
<tr>
<td>Other broad-leaved trees</td>
<td>6</td>
<td>5</td>
<td>1</td>
<td>8–20</td>
<td>50–500</td>
</tr>
<tr>
<td>Pine</td>
<td>2</td>
<td></td>
<td>2</td>
<td>15–30</td>
<td>200–1000</td>
</tr>
</tbody>
</table>

Root weight was calculated as a ratio of the specific gravity of the root system and the dry weight/fresh weight ratio.
in lack of data. This dataset will be of use to researchers who study allometric relationships of tree roots. Also, the data on tree weights of temperate forests are available in Falster et al. (2015).

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**REFERENCES**


