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Roots - the hidden key players in estimating the potential of Swiss forests to act as carbon sinks.

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Introduction

The role of root systems in the CO_2 budget of forests is still largely unknown. One of the reasons is doubtlessly the extraordinary effort involved in gathering information about the size and spread of a complete root system of a tree.

In recent years, multifaceted modeling approaches have been developed based on existing data to assess the root spread of different tree species (Adiku *et al.* 1996; Brown *et al.* 1997; Lynch 1997). More recently, models have been developed to estimate root biomass (Cairns *et al.* 1997; Laclau 2002; Vogt *et al.* 1998). The results are ambiguous: they show widely differing percentages of calculated root biomass vs. above-ground biomass. These differences also apply to existing conversion factors that include root biomass into the computation of total biomass.

Possible reasons for these differences are the difficult accessibility of the roots and, more importantly, the varying environmental factors affecting root growth. According to Schmid-Haas & Bachofen (1991), who investigated root systems of uprooted Norway spruce saplings, the radii of these roots depend basically on:

(i) Tree size (positive correlation to breast-height diameter)
(ii) Soil type (negative correlation to soil porosity)
(iii) Stand density (negative correlation to stand density)

According to this investigation, the variability of the size of root systems (of for example Norway spruce) is very high. However, it should be noted that this investigation did not take into account the coarse roots which remained in the soil. Furthermore, the pH-value of the soil influences the longitudinal growth of roots. The root growth of *Pinus pinaster* showed a reduced longitudinal growth at a pH-value of 3.5 (higher values at pH 6.5), whereas biomass values according to an increased secondary growth are high (Arduini et al. 1996).

The ROOKEY-project (Roots – the hidden key players) at the Swiss Federal Research Institute WSL aims to analyze root systems of wind-thrown European beech (*Fagus sylvatica L.*) and Norway spruce (*Picea abies (L.) Karst.*) saplings, to enable the computation of site-dependant correlations between above-ground and below-ground biomass. There are two main questions to be answered in this project: (i) which role do roots play related to above ground biomass; (ii) is the presently increased growth of trees based on a shift in the relation between above-ground and below-ground biomass? This report concentrates on the role of roots related to above ground biomass.

Material and methods

In the first phase of the project, existing data (root-ball dimensions) of 128 European beech and 129 Norway spruce saplings thrown by the “Lothar” storm-event in the winter of 1999 were analyzed. Next, correlations were calculated between the different root-ball parameters (radius, diameter, depth) and the respective breast-height diameter (dbh) of the stem. In order to enable accurate calculations, all above ground parameters of the trees (height of stem and crown, dbh, age and growth rates) were taken into account.

The disadvantage of this approach is that root-ball data represent the volume of the whole root ball, instead of the volume of the real root system (figure 1). Consequently, the soil has to be removed to analyze the real biomass of the root system. For this reason, the root system of a 120 year old Norway spruce, also thrown in 1999, was exposed to get an impression of the real amount of roots. Unfortunately, all fine roots were decayed and bigger parts of the coarse roots were rotten. The coarse roots could nevertheless be sampled for analysis of the relationship between longitudinal and radial growth of the vertical and horizontal roots.

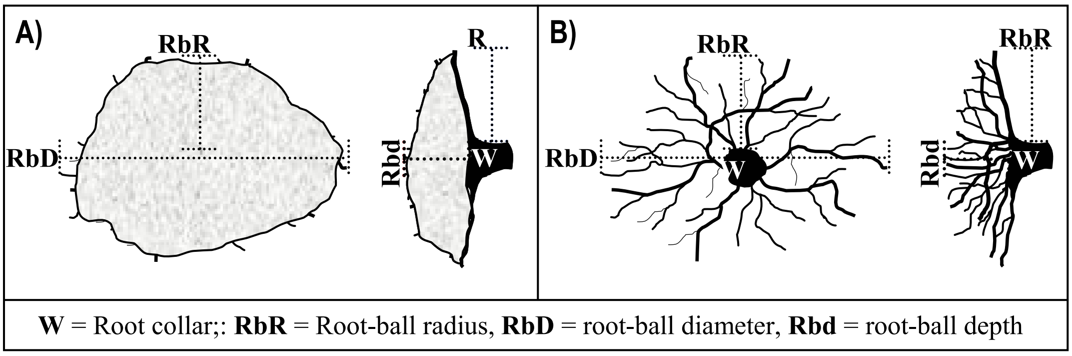

*Figure 1: **A)** Measured root-ball data. Root distribution and biomass can only be estimated. **B)** Real biomass determination can only be done after the removal of the soil*

Additionally, the root systems of 15 naturally-grown European beech and 28 Norway spruce saplings (age: 5 – 10 years) were excavated, and their spread, volume and weight were measured.

In August 2002, a thunderstorm threw a 150-year old European beech in the area of Zürich, Switzerland. The fracture points at the coarse roots around the root ball were rather small, so about 95% of the whole root system was covered in the root ball. The topicality of the event ensured the possibility to expose the coarse as well as the fine roots for biomass calculation. After exposing the whole root system it was cut off and transported in peaces to the lab. Further analyses were based on a 3D grid dividing it into sectors of 30cm (see figure 2 and 3). Currently, roots belonging to each sector are being cut out and their volume and weight are being measured.

Figure 2: Root ball of a 150 year-old beech (A) before and (B) after removing the soil. The root system was cut off (C) to analyze distribution and biomass (D & E) in the lab.

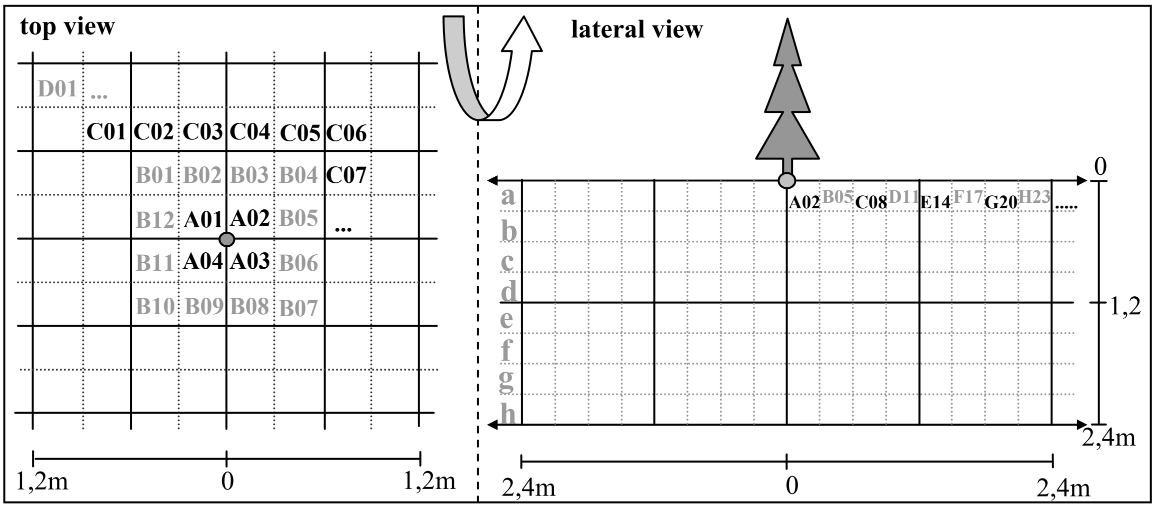

Figure 3: Schematic view of the 3-dimensional grid that is used to document the distribution of the root system in the soil.

Correlations for all trees (no site differentiation) were calculated for the diameter D, the radius R (≠ D/2, compare figure 1) and the depth of the root balls in relation to two values of dbh. These were measured perpendicular to each other (dbh1 and dbh2), due to unevenly shaped stems.

First results and future work

First analysis of root-ball data in relation to dbh showed highest correlations between dbh and root-ball diameter for all trees of all sites. This is valid for both species, although European Beech showed similar correlations between root-ball radius and dbh (table 1). These differences might be caused by the different shape of the root systems of the two species.

Table 1: Correlation coefficients between different values of dbh and the respective root-ball parameters of Norway spruce and European Beech (no site differentiation). Shaded cells: significance level p < 1% (compare significance levels to the right of the table); bold: highest values; dbh1 and dbh2 are two values of diameter at breast height measured perpendicular to each other for each stem; dbh represents the average of dbh1 and dbh2

SPRUCE	***Th***	***RbD***	***Rbd***	***RbR***	***dbh1***	***dbh2***	***dbh***	
Th	1.00							
RbD	0.12	1.00						
Rbd	0.42	0.02	1.00					
RbR	0.12	0.46	0.09	1.00				n=124
dbh1	0.52	**0.46**	0.30	0.38	1.00			r*95=0.17
dbh2	0.52	**0.44**	0.30	0.34	0.95	1.00		r*99=0.23
dbh	0.53	**0.46**	0.30	0.36	0.99	0.99	1.00	r*99.9=0.3

BEECH	***Th***	***RbD***	***Rbd***	***RbR***	***dbh1***	***dbh2***	***dbh***	
Th	1.00							
RbD	0.24	1.00						
Rbd	0.14	0.14	1.00					
RbR	0.16	0.61	0.15	1.00				n=120
dbh1	0.32	**0.61**	0.34	**0.65**	1.00			r*95=0.17
dbh2	0.33	**0.58**	0.32	**0.63**	0.95	1.00		r*99=0.23
dbh	0.33	**0.60**	0.33	**0.65**	0.99	0.99	1.00	r*99.9=0.3

Th: height of tree; **RbD**: root-ball diameter; **Rbd**: root-ball depth; **RbR**: root-ball radius; **dbh**: diameter at breast height

Correlations are in some cases stronger if they are calculated for single sites, but contrary to the analysis of all sites they are highly variable. The correlation values vary between the different parameters RbD, Rbd and RbR. Furthermore the correlation values are even negative at some sites, which is a strong contrast to the analysis of the values of all sites (table 2).

An additional effect occurred for single site analysis - although the differences in the two dbh-values of each stem were in most cases very low (1 – 2 cm), the resulting correlations were highly variable (table 2). The reason for this variation has to be further analyzed. It could be caused by the differences in age and stem size rather than by inter-site conditions.

Table 2: Examples for variable, site-specific correlation coefficients between different values of dbh (five trees) and the respective root-ball parameters. Variation of dbh1-dbh2 represents the max. difference between the two values for each of the five trees of a site. Shaded cells: explained variance r^2 > 25% (r > 0,5); bold values: significance level p < 5%; italic values: negative values

	Diameter	Depth	Radius	Variation dbh1-dbh2	Species	No.of trees	Site
dbh 1	0.59	0.44	0.78	0 – 1 cm	Norway spruce	5	A
dbh 2	0.59	0.38	0.79				
dbh 1	0.56	0.08	*-0.57*	1 – 2 cm		5	C
dbh 2	0.35	*-0.17*	*-0.70*				
dbh 1	*-0.69*	0.46	0.78	< 2 cm		5	E
dbh 2	*-0.28*	0.01	0.39				
dbh 1	0.22	**0.91**	0.88	0 – 1 cm	European beech	5	B
dbh 2	0.09	**0.92**	0.86				
dbh 1	0.82	*-0.19*	0.07	1 – 2 cm		5	D
dbh 2	0.85	*-0.33*	0				
dbh 1	**0.89**	0.05	*-0.52*	< 2 cm		5	F
dbh 2	0.34	0.65	0.18				

Coherence between root-ball parameters and the value of dbh seems to be obvious, but not strong enough to be used for further calculations. As a consequence, more above ground parameters have to be taken into account and, most importantly, the root system has to be exposed and measured.

Age determination of single horizontal and vertical roots of exposed root systems showed clear differences in the longitudinal growth of the roots, independent of site quality. The necessity to stabilize and support the tree with nutrients causes an increased growth of the horizontal roots in the first years of root system development.

The analysis of the exposed root system of the 150 year-old European beech will be finished in December 2003. The resulting data will be compared to the existing data of root balls measured on the basis of trees thrown by the "Lothar"-event of 1999. In addition, root systems of trees aged 20 – 50 years will be analyzed in 2004 to close the gap between trees aged 10 and 100 - 150 years. Besides for pure biomass determination, these data will be used to verify the assumption that the biomass of whole root system is more strongly related to the age and size of a tree than to (differing) site conditions.

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