Etude de la distribution et de la dynamique des fines racines combinant les techniques de tranchee et de fenetre d'observation en foret

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Original article

The study of tree fine root distribution and dynamics using a combined trench and observation window method

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Summary — Root distribution and growth were studied in a natural oak-birch coppice, by combining the trench and observation window methods. Root weight was estimated while digging the trench, showing that 90 percent of dry weight is situated in the upper 50 centimetres of soil. Root position was analyzed, using variograms : a cluster effect was observed, around 50 cm for old roots and 20 cm for new roots. Oak and birch appeared to have different seasonal root elongation patterns. The results are discussed in relation to the methods employed.

Tree – root – distribution – profile – spatial distribution – coppice – birch – oak

Résumé — Etude de la distribution et de la dynamique des fines racines combinant les techniques de tranchée et de fenêtre d'observation en forêt. *Différentes méthodes ont été utilisées pour observer* in situ *et caractériser le système racinaire d'arbres forestiers dans un taillis mélangé de chênes et de bouleaux. La biomasse racinaire, estimée au moment du creusement de la tranchée, se trouve localisée en grande partie (90%) dans les 50 centimètres supérieurs. La position des racines, étudiée à l'aide de variogrammes, montre des phénomènes d'agrégation de l'ordre de 50 cm pour les vieilles racines et 20 cm pour les racines jeunes. Chêne et bouleau présentent des vagues de croissance racinaire différentes. Ces résultats sont discutés en fonction des techniques utilisées.*

***Arbre – racine – distribution – profil – distribution spatiale – taillis* – Betula – Quercus**

Introduction

The great majority of studies concerning forest tree root systems has been carried out on artificially cultivated young plants. Only a few studies have dealt with adult forest trees, mainly due to the considerable technical problems involved (Böhm, 1979).

However, young seedlings and plantlets have different growth patterns from adult trees. Isolated plants in pots, or in artificial observation chambers, also differ from those growing in natural conditions, due to differences in biological (competition) and physical (light, water, soil) environment. It is therefore hazardous to make any general conclusion from results obtained in each laboratory experiment.

This may also explain why the amount of experimental data concerning root development of larger trees is rather scarce (Persson, 1983; Santantonio and Hermann, 1985; Ries, 1988). In the present study, various observation methods and techniques are discussed.

A trench and an observation window were tested in order to estimate root distribution and growth in a natural oak-birch stand in central France, with a view to applying this method to a coppicing experiment (Bedeneau and Auclair, in preparation).

Materials and Methods

Site

The experimental site was located at the INRA experimental station 20 km south of Orléans, France (1.54° E, 47.52° N). The natural forest is an ancient coppice containing mostly *Betula pendula* Roth., *Quercus robur* L. with a few scattered *Castanea sativa* Mill. and *Robinia pseudoacacia* L. The root systems are of unknown age; the stems are 25 yrs old.

The soil is acid, of the brown crytopodzolic type with a moderate humus. It has developed in a terrace material consisting of homometric sand, essentially quartzic, unstructured in the upper 40 cm and rapidly becoming gravelly and heterometric. It can be characterized as filtering well, with a very low mineral reserve.

The study plot was situated between *Quercus* and *Betula* stools, at least 1 m away from each stump in order to minimize disturbance of the underground system. A trench 4 m long, 1 m wide and 1 m deep was dug by hand (Fig. 1).

Installation

On each side of the trench 4 (1 x 1) m squares were bordered with a wooden frame. Each of these large squares contained 400 (5 x 5) cm elementary squares which were numbered according to their horizontal and vertical position. Coordinates were marked on the separation boards. Transparent plastic plates were then fixed on the boards, to observe root elongation. Each (1 x 1) m square was covered with an 8-cm thick polystyrene sheet and a black plastic foil. The entire trench was then covered with polystyrene. This assembly maintained an adequate temperature regulation.

Measurements

Several types of data were collected :

1. Root weight was measured while digging the trench. Dead and live roots were carefully and separately sampled in each 25 cm soil horizon. They were then sorted into diameter classes (≤ 1 mm, 1 – 2 mm, ≥ 2 mm), and oven-dried at 105°C.

2. Root position on each side of the trench : in each elementary (5 x 5) cm square, the roots cut during the excavation were counted and sorted according to :

– age : new/old (difference appreciated by the colour);

– species : oak/birch (difference assessed on the basis of general appearance, form, colour).

For each *(x,y)* coordinate the number and quality of roots was thus obtained. This presentation allowed mathematical calculations to be

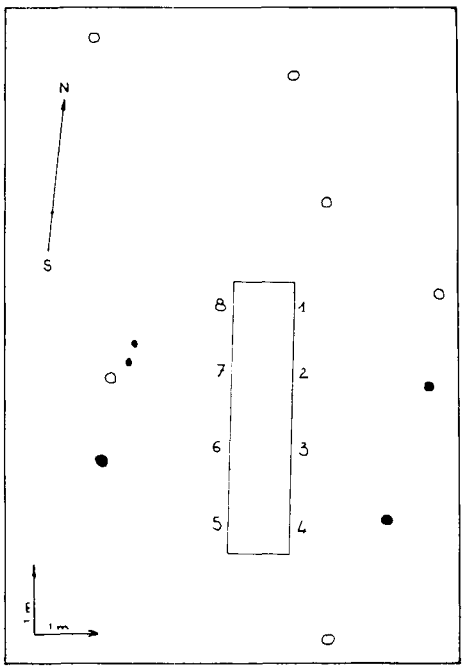

Fig. 1. Diagram of the study plot, showing the position of the trench and the nearest trees. 0 : birch; • : oak.

made on the variable "root density per square centimetre".

3. Elongation : the path followed by the roots during growth was drawn on the transparent plastic plates, using a different colour for each observation date. Total elongation between 2 observations was obtained by following each coloured line with an opisometer. This type of data was recorded at irregular intervals, depending on growth, between March and December on each (1 x 1) m square (4 on the "right" side, numbered 1 – 4, and 4 on "left" side, numbered 5 – 8).

4. Additional data : to simplify tedious elongation measurements, an attempt was made to use infrared photography and video recording. These techniques did not prove satisfactory, mostly due to the outdoor environmental conditions.

Results

Root dry weight

The mean root dry weight excavated per cubic metre was distributed by diameter classes as follows :

- diameter ≤ 1 mm : 41 $g.m^{-3}$
- diameter from 1 to 2 mm : 67 $g.m^{-3}$
- diameter ≥ 2 mm : 395 $g.m^{-3}$
- total root weight : 503 $g.m^{-3}$

Table I shows the distribution by soil horizon. It was observed that the deeper horizons were not explored by the roots, as > 90 percent of the dry weight was found in the upper 50 cm. This result agrees with the soil description : fine roots did not develop below 50 cm, whereas a few coarse roots were observed at a depth of 75 cm.

Root distribution

The root position data collected on each side of the trench was grouped to form two (4 x 1) m grids. Variograms were then computed for each grid in order to analyze the spatial distribution of the roots.

The method used here is that of regionalized variables developed by Matheron (1965) for prospecting and evaluating geological deposits. It consists of the study of variables F(X) whose values depend only on the supporting coordinates *X* : it has been used for studying competition in forest plantations (Bachacou and Decourt, 1976), animal population distribution (Pont, 1987) or soil physical variables (Goulard et al., 1987).

F(X) is considered as a random intrinsic function, thus, for any vector *h*, the mathematical expectancy and variance of the increment F(X + *h*) – F(X) are independant of X and depend only on *h*.

The variogram *g(h)* is half the second-order moment of the random function F(X) :

$$g(h) = 1/2\ E\ [F(X + h) - F(X)]^2$$

The shape of the curve showing *g* as a function of *h*, in particular at its origin, provides a basis for describing the random structure of the variable F :

Table I. Percentage of root weight distribution by soil horizon and by diameter class.

Horizon	*Diameter ≤ 1 mm*	*Diameter 1–2 mm*	*Diameter ≥ 2 mm*	*Total*
0 – 25 cm	5,7	8,3	43,3	57,3
26 – 50 cm	2,8	5,0	28,0	35,8
51 – 75 cm	1,0	0,6	4,7	6,3
76 – 100 cm	0,1	0,1	0,4	0,6
Total	9,6	14,0	76,4	100

– if $g(h)$ is parabolic, it shows a great spatial regularity;

– if $g(h)$ is linear the regularity is poorer;

– if $g(h)$ shows a discontinuity at the origin there is a great irregularity.

In the present study the variable is the number of roots occurring at coordinates (x,y). A variogram can be obtained for each root parameter : old, new, birch, oak, on each side of the trench (left, right). The step of the variogram (h) is 5 cm.

All variograms (Fig. 2) show that the curve starts at approximately half the line determined by the "*a priori* variance". This indicates a cluster effect, varying with root type and side of the trench ≈ 50 cm for old roots and 20 cm for new roots (value read at the starting point of the variogram).

To have a clearer view of this phenomenon, we computed a moving average of each square with the 8 surrounding squares. The smoothed curves obtained (Fig. 3) outline the cluster points. This can be clearly observed at approximately 50-cm intervals, in particular for old oak roots on the left side and at a lesser degree for new roots.

Elongation

Returning to each (1 x 1) m square, we measured the length of all new roots appearing at each observation. During one growing season we thus obtained total root elongation per square, on each side of the trench (Fig. 4).

On the right side, root growth began in March and reached a peak in early July.

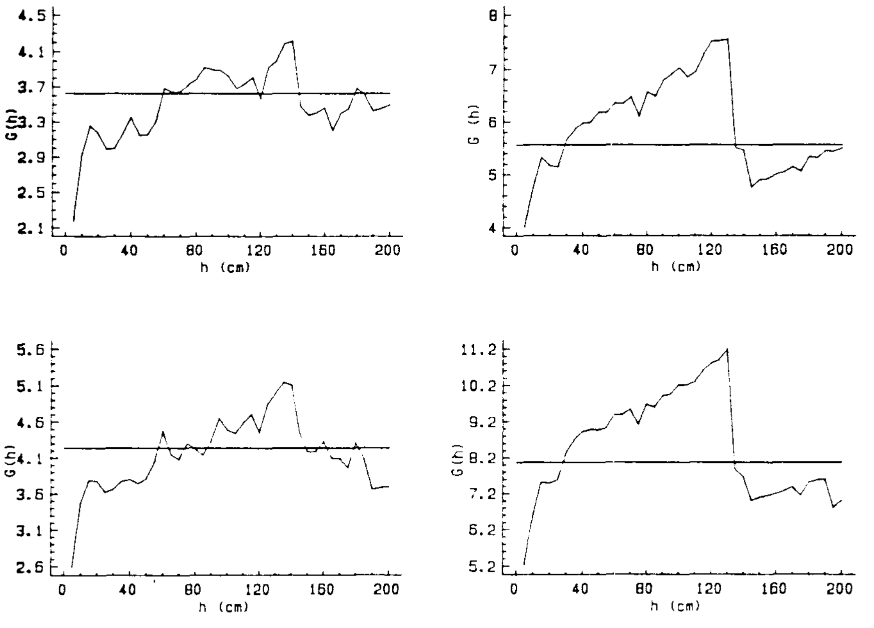

Fig. 2. Examples of variograms obtained, on the left side of the trench. **a** : old oak roots; **b** : new oak roots; **c** : old rots (oak + birch); **d** : new roots (oak + birch). Horizontal lines correspond to the "*a priori* variance".

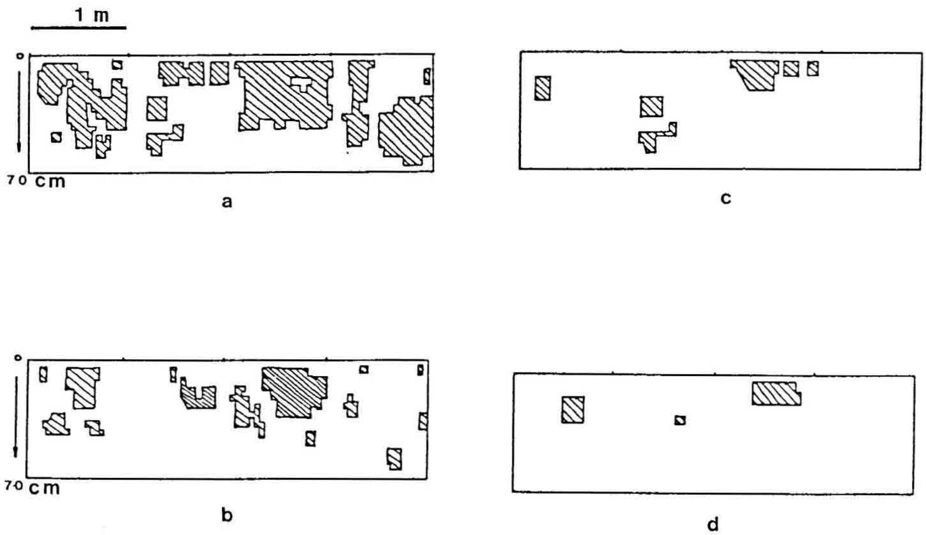

Fig. 3. Diagram showing abundance of roots, on the left side of the trench. **a** : old roots (oak + birch); **b** : new roots (oak + birch); **c** : old birch roots; **d** : new birch roots.

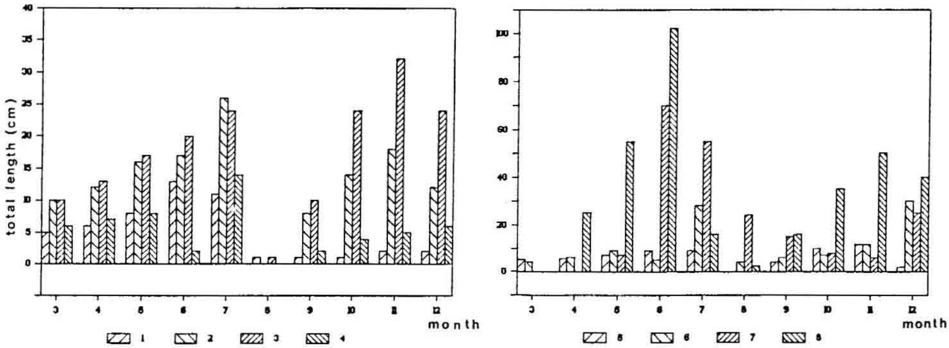

Fig. 4. Total monthly root growth for each 1 x 1 m square. **a** : squares 1 – 4 (right side); **b** : squares 5 – 8 (left side).

Growth ceased in August and a second growth flush appeared from September to December.

On the left side, several elongation flushes were observed :

– square 7 showed intensive growth until June, followed by a gradual growth inhibition until November;

– squares 5 and 6 showed a pattern similar to that observed on the right side;

– square 8 was intermediate.

Square 7 was mostly occupied by birch roots and square 8 by a mixture of birch and oak, whereas the other squares contained only oak roots : this suggests that birch has a different growth pattern from that of oak.

Discussion

Root systems of mature trees can be studied in different ways, but all methods are complex and time-consuming. The study of underground system architecture, by excavation, which has some disadvantages (necessarily destructive, time- and power-consuming; Pages, 1982) can provide some interesting information on growth in different situations (Bedeneau and Pages, 1984). However, the study of coarse roots gives insufficient information about dynamics.

Fine root dynamics may be studied with various techniques, involving core sampling or more costly methods, such as endoscopy (Maertens and Clauzel, 1982) or video recording (Upchurch and Ritchie, 1984). The environmental conditions in the forest would, however, entail additional equipment at an excessive cost.

The trench method used here has its drawbacks (Böhm, 1979) : it causes disturbances in both the soil dynamics (lateral water movements) and the root dynamics (cutting of roots during the digging of the trench). In this study we therefore combined the static description of root distribution with a root observation window technique in order to follow the growth of fine roots *in situ*.

In the dynamic experiment with observation windows, we assumed that :

– damage to soil remains slight because of the careful digging by hand;

– root growth capacity, as described by Sutton (1980) remains unchanged;

– the edaphic factors subject to change are the following : lateral water runoff, and hence mineral runoff (Callot *et al.*, 1982), as well as gas exchange (O_2).

Our assumption that we observed normal growth rather than tree or root system response to the trench is supported by the fact that we observed no major change in above-ground parts of the trees.

Results relative to root weight are similar to those reported by others (Duvigneaud *et al.*, 1977; Gholz *et al.*, 1986). However, our results are somewhat biased, for we collected the roots more than 1 metre away from any stem. Thus we excluded from our estimations the main structural roots accounting for the major part of the underground biomass.

Above-ground biomass amounts here to ≈ 80–100 $t.ha^{-1}$ (Auclair and Metayer, 1980). The underground parts we have measured represent 6 percent of this biomass. This figure is, however, an underestimation of total underground biomass as it does not account for the coarse roots close to the stems and the stumps. We must also be cautious in generalizing on an area basis, as our sampling technique was not intended for that (small sampling area, not random, no replicates, etc.).

The statistical data showed that the roots were not randomly distributed in the soil : in particular, birch roots were intermingled with oak roots. This might be due to different growth behaviour and phenology of the 2 species :

– root elongation in birch began earlier and decreased when oak root elongation was initiated;

– the horizons occupied were different : near the soil surface for birch, deeper in the soil for oak.

The position of the new roots suggested that root growth was derived from older ramifications. The distance between new roots and old roots always remained short. The section of each side of the trench displayed “channels” left by dead roots, and occupied by growing roots, a phenomenon previously described by others (Böhm, 1979). New roots were also found to develop from the sectioned area of cut roots : this ability to form ramifications has been referred to as "root growth capacity" by Sutton (1980).

This suggests that elongation of the primary axes was followed by ramification and elongation of several secondary axes, and that the disturbance induced by the trench did not inhibit root growth.

A strong root growth activity during Spring and Summer was demonstrated (Fig. 4). This agrees with other investigations suggesting a relationship between root growth and accumulation of the previous year's photosynthates (Bonicel and Gagnaire-Michard, 1983). This suggests that cutting during the vegetation period prevents the root system from expanding and new roots from growing, thus hindering the growth of the following coppice cycle.

Conclusions

The present study was aimed at perfecting methods for root observation in natural forest stands, and interpretation techniques.

The excavation method gives static results on root biomass, and its distribution in different diameter classes. It is, however, insufficient for total underground production studies which entail a greater number of observations.

The root observation window gives a dynamic view of root distribution, but its interpretation is most delicate. Root growth has been described by mathematical models (Rose, 1983; Belgrand *et al.*, 1987). The geostatistical approach used here should be considered as an attempt to describe the spatial distribution of root systems. A cluster effect has been shown, but its interpretation in relation to the structure and growth of roots, and to soil heterogeneities would again require a great number of replications.

The limitations underlined here join the general views (Böhm, 1979; Santantonio and Hermann, 1985), stating how time-consuming precise root studies can be. An improvement of the methods described here might be to provide for the possibility of taking samples at various precise developmental stages, giving access to studies on root turnover and productivity, and to the study of nutrient cycles.

The present data only concerns one growing season, and to have a reliable interpretation of the difference between oak and birch growth behaviour, more frequent observations should be undertaken at several important dates in relation to phenology (budbreak, budset, fall).

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