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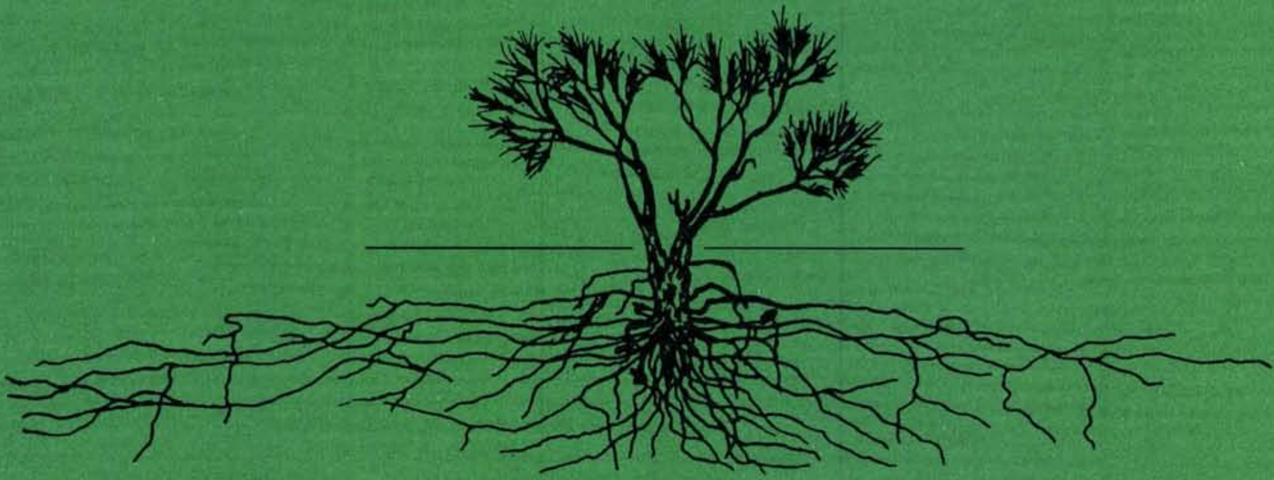

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Growth of tree roots under heavy metal (Pb-) stress

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Abstract
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In oblique root-boxes the development of the root-system of European beech saplings was recorded. The root-boxes were filled with soil distinctly contaminated with heavy metal (Pb). Three layers with differing heavy metal contamination were applied. Root architecture (branching and root laterals development) exhibited distinct changes according to the level of heavy metal stress. Root recovery and root growth pattern is not only influenced by the present stress situation at the root-tip but also by the preceding growth situation of the root.

Keywords: European beech; Rhizotron; Root architecture; Root lateral; Stress recovery.

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Introduction

Trees rarely grow on soils heavily contaminated with toxic heavy metals. Herbs, however, are still found on these soils. Investigations with European beech and Norway spruce have shown that roots of young trees react very specifically to heavy metal stress, and are able to recover in soil horizons with less contamination. This has far-reaching ecological consequences for natural root-systems. It has also consequences for the root systems of trees on polluted sites.

In order to study root development under toxic heavy metal stress two approaches are possible. Almost the only way under field conditions is the mini-rhizotron technique. In some cases entire root systems have been excavated by research-groups. A much easier way is to study root development in the laboratory under controlled conditions in rhizotron boxes, simulating field conditions and varying soil horizons.

Firstly in this report we give some results from experiments, primarily to elucidate changes in root architecture under heavy metal stress, especially with Pb-contamination and secondly we demonstrate the adaptability of the root systems to changing stress conditions.

Material and Methods

In root-boxes (50 cm × 80 cm, see Fig. 1) *Fagus sylvatica* seedlings were grown in Cd or Pb-contaminated soil. The soil was artificially contaminated with known amounts of $Cd(NO_3)_2$ or $Pb(NO_3)_2$ solutions by watering, stirring and drying for several weeks. The plant available heavy metal fraction was determined by 0,1 M NH_4Cl extraction at pH 5. The total amount of heavy metals bound in the soil was about 3 - 5 times higher for Cd, about 8 - 20 times higher for Pb (see Table 1).

Rooting and side root branching was recorded daily. Biomass and heavy metal content of roots and shoots was analysed at the end of the experiments.

Results

The root growth of the primary root of *Fagus sylvatica* differed significantly depending on heavy metal contamination of the substrate. Fig. 2 gives the values of the daily root length increments of the primary roots. Low Pb-contamination of substrate (10 ppm Pb) yielded a slightly higher root growth than in control soil (with 3 ppm Pb), depending on the preceding soil horizon the root had

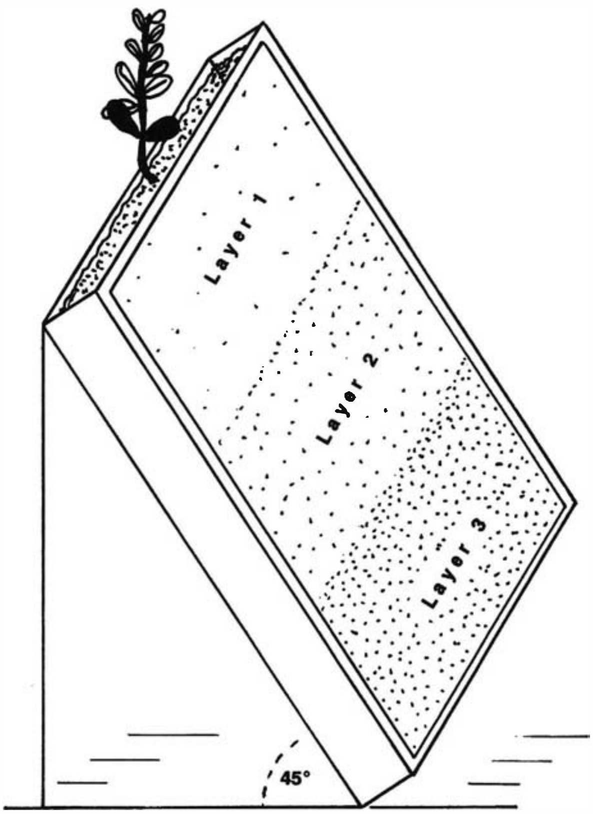

Fig. 1. Sketch of the root-boxes (rhizotron-pots) for observation of root growth in soil horizons that had been artificially contaminated with heavy metals.

grown through. The recovery rate after 50 ppm Pb stress is higher than after 23 ppm Pb stress (Fig. 2).

Not only primary roots show this growth behaviour. Secondary roots of the 1st order (Fig. 3) and 2nd order (Fig. 4) also show a similar growth pattern under varying Pb-stress. High Pb-stress (100 ppm) reduced growth

Table 1. Artificial contamination of soil substrate for experiments with soil horizons in rhizotrons.

Intended concentration of Pb (ppm, plant available fraction)	0	15	30	60	120
Actual concentration of Pb (ppm, plant available fraction: NH_4-Acetate-extract)	3	10	23	50	100
Total concentration of Pb (ppm, HNO_3-extract)	54	155	259	481	820
Percentage of plant-available Pb-fraction, extractable from total Pb-content	5.0	6.3	8.7	10.5	12.1

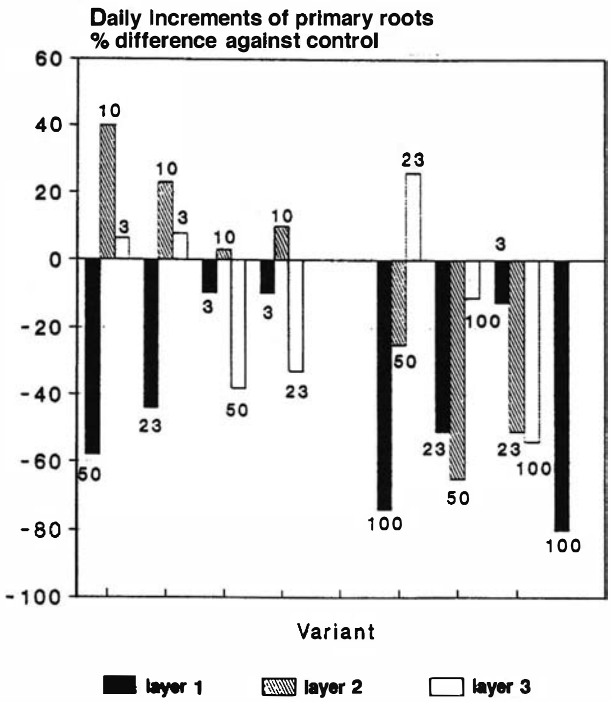

Fig. 2. Daily increment of primary roots of *Fagus sylvatica* seedlings: difference of growth rates in percentages against control plants (3 - 3 - 3).

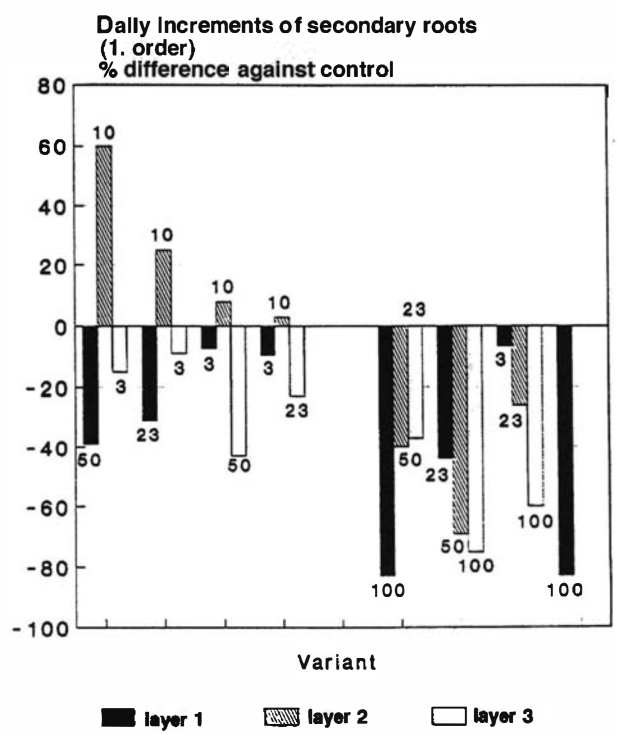

Fig. 3. Daily increment of secondary roots (1st. order) of *Fagus sylvatica* seedlings: difference of growth rates in percentages against control plants (3 - 3 - 3).

Table 2. Shoot length reduction of *Fagus* saplings as a percentage of the control after the experiment.

Pb treatment in the 3 horizons (ppm)	% shoot length reduction in comparison with control [3-3-3]
[50 - 10 - 3]	21
[23 - 10 - 3]	8
[3 - 10 - 50]	13
[3 - 10 - 23]	8
[100 - 50 - 23]	57
[23 - 50 - 100]	20
[3 - 23 - 100]	10
[100 - 23 - 3]	57

drastically and in some cases in resulted very short roots - not reaching the 3rd or even the 2nd soil horizon. Shoots, however, exhibited a significant reduction in length in all treatments, as shown in Table 2.

Roots reaching the 3rd layer exhibit a growth pattern which is partly influenced by the 1st or 2nd horizon.

As shown in Fig. 5, the length of the primary roots in 15 cm (layer 1) is reached by those plants where the roots grow in low heavy metal soil in about 20 to 25 days. At 23 ppm Pb this length is only reached after about 42 days, and at 100 ppm even after 50 days only about 8-9 cm root length is achieved.

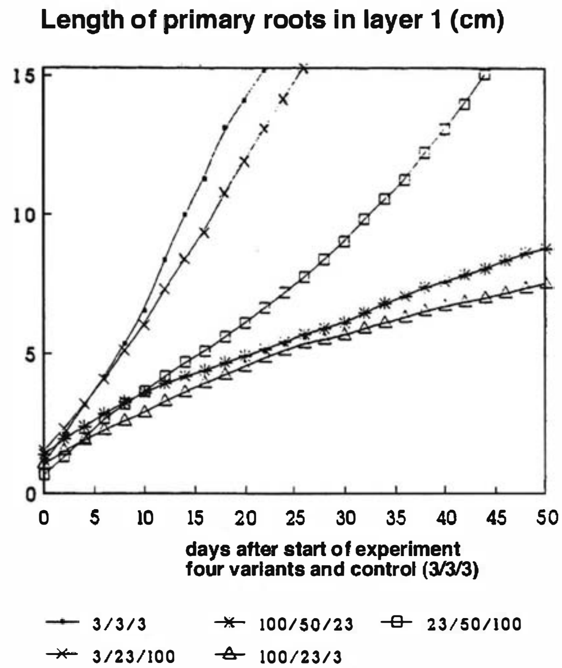

Fig. 5. Length of primary root of *Fagus sylvatica* seedlings within layer 1 (first number giving the concentration of Pb in layer 1); 4 variants and control (3 / 3 / 3) within 50 days.

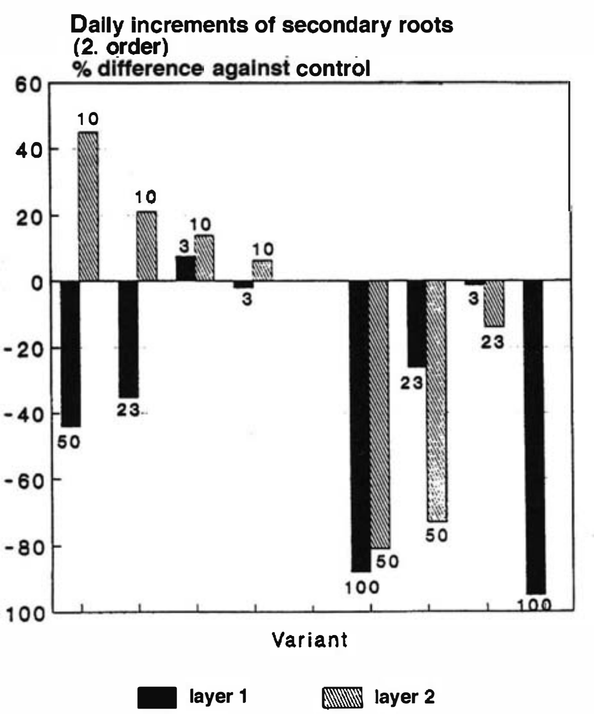

Fig. 4. Daily increment of tertiary roots (secondary roots of 2. order) of *Fagus sylvatica* seedlings: difference of growth rates in percentages against control plants (3 - 3 - 3).

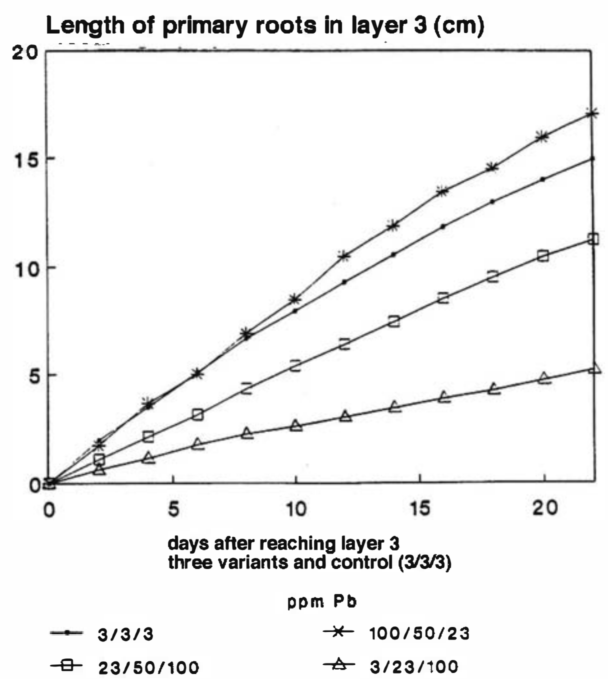

Fig. 6. Length of primary root of *Fagus sylvatica* seedlings within layer 3 (third number giving the concentration of Pb in layer 3); 3 variants and control (3 / 3 / 3) 22 days from the day of reaching layer 3. Day 0 is the point at which the roots reached the top of layer 3.

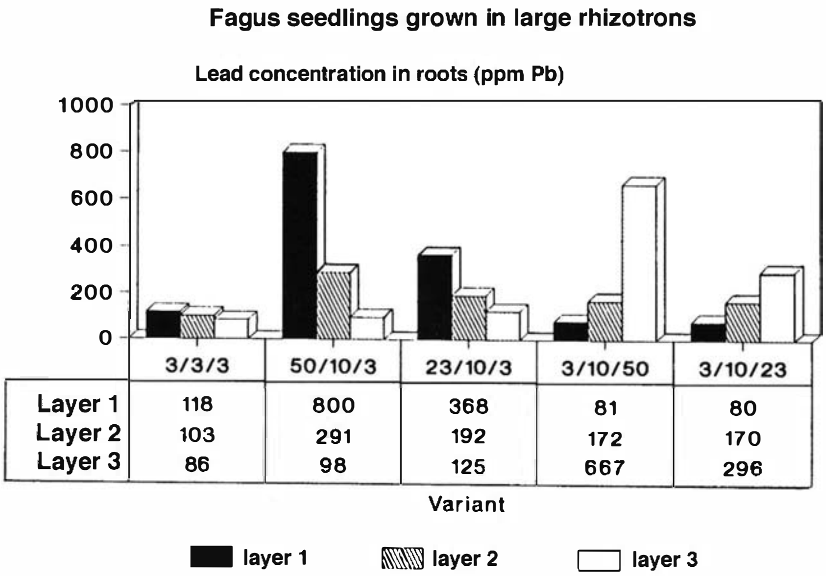

Fig. 7. Pb concentration in roots of *Fagus sylvatica* seedlings growing in three different layers of substrate (with 3 = control, 10, 23 or 50 ppm Pb; four variants and control [3 / 3 / 3]).

When comparing root growth behaviour of the primary root within the third layer (reached after 2-3 months), the 23 ppm Pb roots exhibit slightly better growth than the control roots (3 ppm Pb), as is indicated in Fig. 6. It is also observed that the more stressed roots (23 - 50) show less of a reduction in growth after reaching the 100 layer than the roots coming from the 3 - 23 layers (Fig. 6). Thus growth pattern is not only influenced by the present stress situation but also by the preceding growth situation of the root.

The Pb uptake, expressed as Pb content in the roots of the three horizons, is proportional to that of the corresponding substrate (Fig. 7). A tenfold contamination, however, does not result in a tenfold root content, as is indicated for the three layers (Fig. 7).

In uniformly filled rhizotron boxes the root architecture with Pb and/or Cd soil contamination was tested. The number of laterals and the length of the main root from the tip to initial laterals differs according to Pb-stress. The branching of the root system increases and exhibits a maximal value for third order laterals with relatively high Pb contamination (in this experiment 44 ppm Pb level); 10 ppm was the concentration with the highest total number of laterals (Table 3).

Table 3. Total number of lateral roots per plant of various orders, percentage of short roots (< 2 mm long) among all laterals and length of the unbranched main root of *Fagus* seedlings, grown for 40 days in rhizotron chambers under various plant-available Pb-concentrations (NH_4-acetate-extractable fraction; partly from Noack & Breckle 1987).

Plant-available Pb-concentrations (ppm)	3	10	24	44	238
Number of lateral roots	110	87	70	47	4.1
First order	127	195	189	180	1.2
Second order	1.5	1.0	9.6	14.0	0.3
Total number of lateral roots	238	283	268	241	5.6
Percentage of short roots	36.6	39.4	43.5	46.7	53.8
Length of main root from tip to initial lateral (mm)	35.4	37.6	33.3	24.3	6.0

Discussion

There is a clear indication that branching of the roots is more pronounced under heavy metal stress. In Table 3 the percentages of root types are shown. The increase of secondary roots of the 2nd order is very characteristic. Stunted root systems rather than more branching were the result of Al-stress in *Trifolium pratense* (Fitter et al. 1988).

There is a clear indication that the growth history of the root, (the growth conditions of the preceding days or weeks) play an important role for adaptation of root growth. This is indicated by root growth behaviour shown in Figs. 2 - 6. This behaviour may well contribute to the great plasticity root systems exhibit in adaptation to ecological soil factors. Whether the hormonal balance plays the main role in the internal growth regulation and branching processes remains obscure.

The present day Pb-concentrations in forest soils and leaves close to industrial sites, highways, cities are in the

Table 4. Pb-concentrations (ppm) in soil and *Fagus* leaves from forests and from a pot experiment with contaminated soil showing first symptoms of toxic lead effects (Kahle & Breckle 1985; Ellenberg et al. 1986; Röder & Breckle 1987).

	Total Pb-content in soil (ppm DM)	Plant available fraction of Pb (ppm) (NH4Cl- extracts)	Total Pb-content in leaves of *Fagus* (ppm)
Industrial area (Ruhr)	100-800	10-60	6 - 15
Solling (Lower Saxonia)	300-465	10-30	20
Culture experiment with *Fagus*	388	55	2

same range of those causing the first toxicity symptoms in *Fagus* saplings, as is indicated in Table 4.

It is, however, very difficult to significantly show that present-day forests not only suffer from industrial gaseous emissions but also from chronic heavy metal stress in the soil. Present day concentrations can only be reduced very slowly in natural stands. Individual plant response to heavy metal stress depends not only on dissolved heavy metal concentration but also on background concentrations of other ions in the soil solution (Davies 1991). The responses of roots where complex soil chemistry, metal toxidity and mycorrhizal infection occur in the immediate vicinity of the root are very complex (Davies 1991).

Conclusions

Long-living lifeforms (especially woody plants, trees) have a disadvantage when growing on heavy metal contaminated soils. This might be explained by chronic effects on physiological processes of long-living plants.

Fagus-saplings respond to Pb-stress in the range of actually occurring concentrations, when regarding the plant-available fractions (NH_4-acetate-extracts).

Fagus-saplings respond to Cd-stress in the range of concentrations at least one order of magnitude higher than those of actually occurring soil concentrations (except on specific mining sites; plant available fractions).

Fagus root systems change their architecture in response to Pb and or Cd stress to a more compact and branched root system.

The ecological advantage of increased branching and thus forming a more compact, dense, but less extensive root system can be explained by the fact that cytokinine production as well as water uptake occur in root tips. These are key processes of roots neccessary for the whole plant and plant growth regulation.

Uptake and transport of Pb to the shoot and leaves is very low, although Cd uptake is slightly more enhanced, it is still rather low.

References

Bertels, C., Rüther, P., Kahle, H. & Breckle, S.-W. 1989. Die Entwicklung des Wurzelsystems von Buchenkeimlingen bei Cadmium- und kombinierter Cadmium/Blei-Belastung. - Verh. Gesellsch. Ökologie 18: 376-371.

Davies, M. S. 1991. Effects of toxic concentrations of metals on root growth and development. - In: Atkinson, D. (ed.) Plant Root growth - an ecological perspective, pp. 211-227. Blackwell, Oxford.

Ellenberg, H., Mayer, R. & Schauermann, J. 1986. Ökosystemforschung - Ergebnisse des Solling-Projekts 1966-1986. - Ulmer, Stuttgart, 507 pp.

Fitter, A. H., Nichols, R. & Harvey, M. L. 1988. Root system architecture in relation to life history and nutrient supply. - Funct. Ecol. 2: 345-351.

Kahle, H. & Breckle, S.-W. 1986. Blei- und Cadmiumbelastung von Buchenwäldern. - Verh. Gesellsch. Ökologie 14: 563-566.

Noack, G. & Breckle, S.-W. 1989. Der Einfluß von Blei auf die Wurzelentwicklung von Buchenkeimlingen im Rhizotron.- Verh. Gesellsch. Ökologie 17: 563-566.

Röder, U. & Breckle, S.-W. 1989. Der Einfluß von Blei und Cadmium auf das Wachstum und den Kationengehalt von Buchenkeimlingen auf Waldböden. - Verh. Gesellsch. Ökologie 17: 557-562.