GROWTH PATTERNS, PHLOEM NUTRIENT CONTENTS AND ROOT CHARACTERISTICS OF BEECH (FAGUS SYLV.L.) ON SOILS OF DIFFERENT REACTION

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ABSTRACT

A pilot study was run in 6 older beech stands in Lower Franconia growing either on Terrae fuscae and Parabraunerde soils of high pH and rich in bases (A) or on acid to podzolic brown forest soils (B). Intensive growth analyses of 2-4 representative trees per stand revealed different levels, but similar time patterns of diameter and volume increment. The extremely dry early summer season of 1976 depressed growth on both acid and highly buffered soils. Beech phloem sampled at breastheight contained more K, Mn, Zn and Al, but less Ca on (B) than on (A), whereas contents of N, P, Mg and Cu were similar. Density of living roots of selected trees in the topsoil (0-50 cm) attained the same order of magnitude on both groups of substrata; but less roots were detected in the subsoil of acid sites. Living fine roots of trees on (A) showed evidence of containing more Ca and less Mn than trees on (B); N, P, K, Mg, Fe, Cu, Zn and Al however varied on similar levels.

2 selected trees growing on a podzolic soil and suffering from bark necrosis exhibited, as compared with unaffected neighbours, similar development of diameters from 1940-75 and the same abrupt decrease of radial increment in 1976, but no subsequent regeneration. They had exceptionally high N, P and Zn, but very low K contents in the phloem. The root system of one of those trees was strikingly shallow and covered by Armillaria mellea rhizoids. The fine roots didn't differ in element contents from those of adjoining healthy trees.

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1. INTRODUCTION

Beech (Fagus sylv.L.) occurs in Germany both on acid and alcaline substrata. Under comparable moisture and temperature conditions it grows better on soils well provided with bases and ranging in pH from 5 to 8 than on soils with an acid reaction. On acid sites, liming seems to improve the growth of beech more efficiently than that of Norway spruce (Picea abies L.; 3). This superiority of growth on soils with a high pH level is generally attributed to an optimal supply of N, P, Ca and Mg. The absence of toxic levels of Al and Mn may also be a main factor contributing to this phenomenon.

According to a theory forwarded by B. Ulrich and coworkers (4), vast areas of forest land in Central Europe suffer nowadays from a rapid decrease of pH due to interactions between acid precipitation and the production of mineral acids within the soils themselves (e.g. HNO_3 via mineralization and nitrification). This acid formation, they suggest, is promoted by warm and dry weather conditions. Ulrich and coworkers (4) expect this rapid acidification to reduce the vitality and growth of forests mainly by releasing toxic amounts of Al and Mn into the soil solution, by enhancing the leaching of bases and by inducing the accumulation of nutrients in an inactive organic floor. They fear, that this complex of damaging events is already causing premature shedding of leaves and dieback in stands of different species and should finally lead to a degradation of forests into acid heathlands (4, 5).

If this fast reduction of soil pH together with its suggested negative effects is already taking place, one would expect, that beech stands on acid sandy soils exhibit a decline in growth and Al- or Mn- induced damages within the root system, whereas comparable trees on highly buffered loamy or clayey sites with high pH are not yet affected.

These considerations and similar research approaches in Scandinavia initiated the following pilot study which compares growth, nutritional status and root characteristics of selected beech trees on soils of different textural and chemical properties. The study was undertaken in order to detect, if possible, site-specific deviations in behaviour of those trees indicating a rapid deterioration of soil fertility as suggested by B. Ulrich.

2. MATERIAL AND METHODS

Six older beech stands were chosen in Lower Franconia at 5-60 km distance from Würzburg in a NNE direction. Their soils were derived either from triassic limestones (Muschelkalk, in one case mixed with basalt) or from triassic old red sandstone (Buntsandstein). Both types of sedimentary rock are partly covered by loess deposits. Table 1 describes in detail the sampling sites and soils. Climatic conditions within the study area are rather similar with the only exception being site "Kalkofen" (2).

The area under investigation is situated rather far away from big urban or industrial agglomerations, but nevertheless seems to have been affected by soil acidification during the past two decades (Wittmann 1981, personal comm.).

On each sampling site a homogenous plot of 900 or 1600 m^2 was established. The diameters at breastheight were recorded for all living trees. After computation of the total basal area per hectare, 2-4 beech trees per plot, showing the mean diameter and the average height of the 100 largest stems per hectare (top height trees), were cut. For these trees, characterized in Table 2, we measured total height, crown width and length and determined age. Afterwards the stems were divided into ten sections. For each section one representative stem slice was sampled. An additional cut was made at breastheight. With the help of a special program (Kawabata a. Schiibajashi 1977, Kennel 1977, Flurl 1981) we were able to compute and to plot complete stem analyses and the alteration with time of diameter, height, basal area and volume increments for the whole life span of each individual tree.

Due to technical circumstances, the study had to be started in March 1980, when no foliage was present. Therefore we used the phloem analysis (1) for an evaluation of the nutritional status of sample trees, analysing the fresh inner bark sampled at breastheight.

At 1 m distance from the stumps of 4 additional beech trees on different soils, pits were dug out 3 m wide and 1 m deep. After careful preparation of the front wall, all living and dead roots were identified and classified with regard to diameter and then counted. Afterwards representative samples of living roots of the diameter classes "finest roots" ($<$ 1 mm) and "fine roots" (1-2 mm) were cut, carefully cleaned with distilled water, dried and ground (woody and bark material together) for chemical analysis. From the rooting space, soil was sampled at 10 cm intervals.

Plant tissue analyses for N, P, K, Ca, Mg, Fe, Mn, Cu, Zn and Al and soil pH determinations were performed using standard laboratory procedures (2).

Table 1: Description of sampling sites
Br = Braunerde, Tf = Terra fusca, Pb = Parabraunerde, Ps = Pseudogley, Pd = Podsol

	Sampling area					
Characteristic	Kalkofen	Dachsbau	Dianenlust	Reuterlein	Brückengraben	Kleinhahn
Forest District	Steinach	Bad Neustadt	Münnerstadt	Würzburg	Steinach	Steinach
Compartment	V 3b	III 3b	XIX 2a	II 1b	XII 3f	I 2b
Growth district	Hohe Rhön	Nördl.Fränk. Platte	Nördl.Fränk. Platte	Südl.Fränk. Platte	Vorrhön	Vorrhön
Mean elevation (m)	800	370	380	320	350	350
Aspect	NW	SW	-	-	-	SE
Inclination	steep	gentle	-	-	-	steep
Mean annual temp. (°C)	5,7	7,5	8,0	8,0	8,0	8,0
Mean annual precipitation (mm)	1050	620	600	600	650	650
Parent rock	mixed slope deposits of Basalt and Muschelkalk	Muschelkalk	Loess covering Muschelkalk	Loess covering Muschelkalk	Loess covering old Red Sandstone	old Red Sandstone
Soil type	Br.-Tf	Tf	Pb.-Tf	Pb.-Tf	Ps.-Pb	Pd.-Br.
Texture	clayey loam	loamy clay	silty loam/ loamy clay	silty loam/ loamy clay	silty loam/ clayey sand	loamy sand
Range of pH (H_2O)	6,1-7,8	5,5-7,6	5,1-7,1	4,8-7,1	4,0-6,5	3,3-4,7
Plant association	Asperulo-Fagetum	Galio-Carpinetum	Galio-Carpinetum	Melico-Fagetum	Luzulo-Fagetum	Luzulo-Fagetum

Table 2: Characteristics of healthy sample trees

Characteristic	Sampling area					
	Kalkofen	Dachsbau	Dianenlust	Reuterlein	Brückengaben	Kleinhahn
n	3	4	3	1	3	2
age	87-102	77-82	71-76	120	104-111	109-111
DBH (cm)	28,8-33,2	33,0-35,3	38,0-42,2	50,0	32,9-35,4	32,4-33,5
height (m)	25,5-28,8	24,6-26,5	26,3-27,6	28,7	26,3-28,0	24,2-27,2
Top height site class (according to yield table SCHOBER 1967; moderate thinning)	I,3-II,7	I,3-II,1	0,8-I,3	II,4	II,5-II,9	II,7-III,5

3. RESULTS AND DISCUSSION

3.1 Growth characteristics

Figure 1 demonstrates the time patterns of annual radial increment

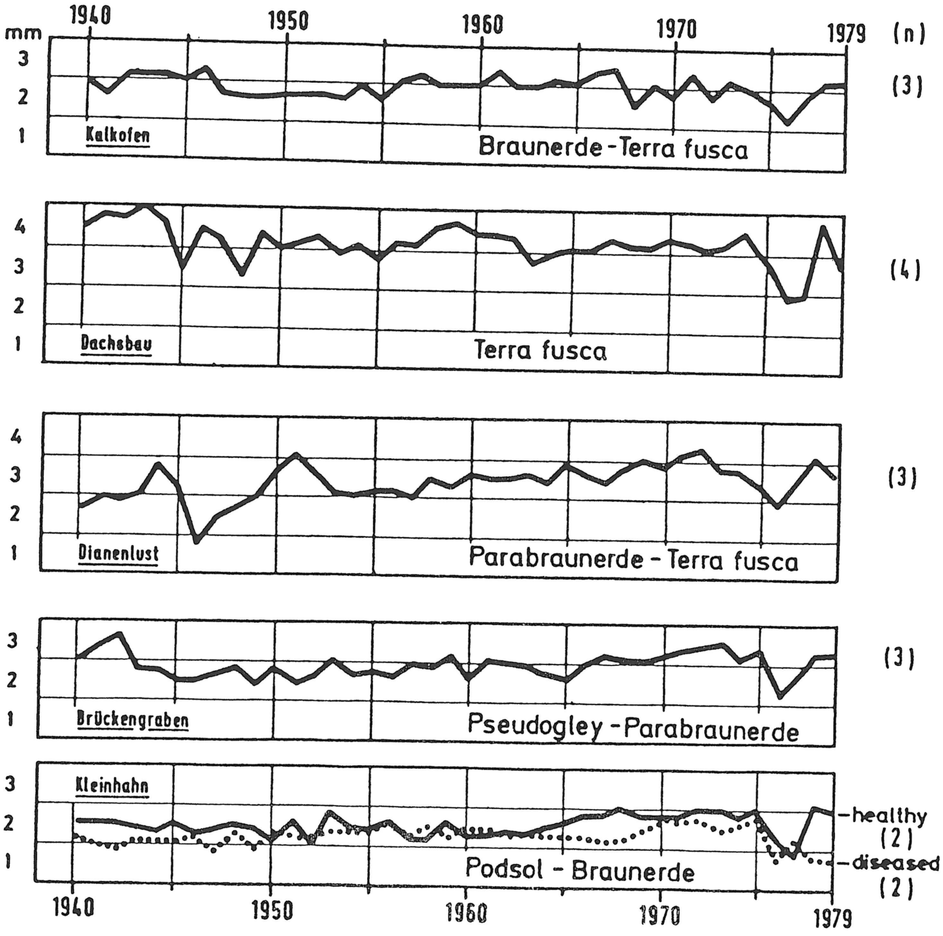

Figure 1. Mean year ring width at breastheight of 2-4 sample trees at five locations differing in soil reaction

at breastheight during the past 40 years. In correspondance with the differences in site classes (Table 2) its level is generally lower on acid substratum than on soils well provided with bases. After a pronounced reduction of year ring width in the late forties, the majority of sample trees exhibited a slight, but steady increase of radial growth until 1973/74. This tendency was even more obvious for stands on acid soils (Brückengraben, Kleinhahn) as compared with beech trees growing on base-rich substratum (Kalkofen, Dachsbau), although the former stands were older. Another sharp decline of radial growth occured in 1975/76, followed in most cases by rapid recovery. This depression, coinciding with extremely low precipitation mainly in 1976 (Figure 2) was observed

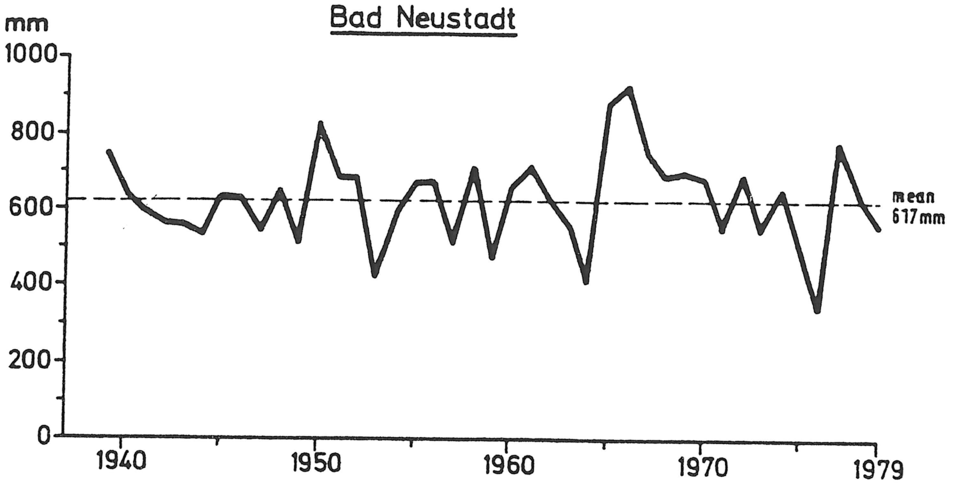

Figure 2. Annual precipitation during the period 1939-1979. Forest District Bad Neustadt/Saale

both on acid sandy sites and on well buffered Braunerde-Terra fusca at higher elevation. These observations indicate that Al or Mn toxicity was not a major factor in causing this chronosequence. Two sample trees at the site "Kleinhahn" suffering from bark necrosis revealed, as compared with unaffected neighbours, after similar development of diameter increment from 1940-75, the same significant decline in 1976, but no subsequent rise.

Table 3, which summarizes the mean current annual diameter increment data of healthy sample trees during three subsequent periods, prevailingly exhibits a growth increase on sandy acid soils as well as on substrata high in pH in 1970-74. This phase was followed by a remarkable decline of diameter increments from 1975 onwards. The mean annual current volume increment (Table 4) rised even more pronouncedly during 1970-74 on all sites under study and was generally depressed in the following period including unusually dry years.

3.2 Element contents of beech phloem

Phloem sampled at breastheight from healthy trees generally contained less Ca, but more K, Mn, Zn and Al on acid than on base-rich

Table 3: Comparison of current annual diameter increment of healthy sample trees during three subsequent periods

		mean current annual diameter increment (mm)			Difference (mm)	
Sampling site	tree number	(a) 1965-69	(b) 1970-74	(c) 1975-79	(b)-(a)	(c)-(b)
Muschelkalk						
Kalkofen	1	5,8	4,6	3,9	-1,2	-0,7
	2	4,3	4,0	3,1	-0,3	-0,9
	3	3,3	3,1	2,7	-0,2	-0,4
Dachsbau	12	6,3	6,5	5,8	+0,2	-0,7
	13	6,3	5,1	4,1	-1,2	-1,0
	14	4,5	5,4	5,0	+0,9	-0,4
	15	5,9	6,1	4,4	+0,2	-1,7
Dianenlust	9	7,0	6,5	5,2	-0,5	-1,3
	10	6,1	6,7	11,6	+0,6	+4,9
	11	5,2	5,8	6,8	+0,6	+1,0
Buntsandstein						
Brückengraben	6	2,5	2,9	3,0	+0,4	+0,1
	7	4,1	4,4	4,4	+0,3	-
	8	5,4	6,8	4,0	+1,4	-2,8
Kleinhahn	4	3,4	3,5	3,4	+0,1	-0,1
	5	4,0	4,1	3,4	+0,1	-0,7

Table 4: Comparison of current annual volume increment of healthy sample trees during three subsequent periods

		mean current annual volume increment (dm^3)			Difference (dm^3)	
Sampling site	tree number	(a) 1965-69	(b) 1970-74	(c) 1975-79	(b)-(a)	(c)-(b)
Muschelkalk						
Kalkofen	1	27,4	30,2	30,0	+2,8	-0,2
	2	29,9	33,4	30,4	+3,5	-3,0
	3	21,1	26,9	26,6	+5,8	-0,3
Dachsbau	12	27,7	36,9	38,6	+9,2	+1,7
	13	31,6	31,9	31,0	+0,3	-0,9
	14	27,0	35,1	32,9	+8,1	-2,2
	15	33,2	44,4	41,0	+11,2	-3,4
Dianenlust	9	45,2	55,2	39,6	+10,0	-15,6
	10	46,0	53,2	41,9	+7,2	-11,3
	11	43,8	48,5	43,9	+4,7	-4,6
Buntsandstein						
Brückengraben	6	23,6	28,1	33,3	+4,5	+5,2
	7	27,4	35,1	34,0	+7,7	-1,1
	8	24,3	37,3	29,4	+13,0	-7,9
Kleinhahn	4	26,7	24,4	23,6	-2,3	-0,8
	5	26,5	31,8	27,8	+5,3	-4,0

soils, whereas contents of N, P, Mg and Cu varied on similar levels (Tables 5 and 6). Annual diameter and volume increments were positively correlated with Fe contents in phloem, but inversely related to K. The first relationship mainly originates from superior Fe supply of the most vital stand "Dianenlust" on Parabraunerde-Terra fusca. The negative correlation of both growth parameters to K is due to the fact, that slowly growing stands on acid sandy soils are well provided with this element, whereas the most vigorous trees on Pb.-Terra fusca had only moderate K contents in phloem. The phloem levels of Al and Zn reflected increased solubility of these elements in acid soils derived from old red sandstone. The best growing trees on Pb.-Terra fusca, however, had only slightly less Al in phloem. The Ca/Al ratios (on an equivalent basis) of all trees far exceeded the value of 1. Trees affected by bark necrosis didn't differ significantly in phloem contents of Al and Mn from neighbouring healthy trees, but contained more N and Zn and much less K.

3.3 Root densities

For 4 selected beech trees the densities of living roots were determined as root numbers per area unit (Table 7). In the top soil these densities attained the same order of magnitude for all trees which were comparable in age and diameter irrespective of soil chemical status and health conditions.

On the other hand there is evidence that less living roots were present in the subsoil of acid substrata. The root system of one diseased tree growing on the most acid site covered by this study was remarkably shallow and contained many Armillaria mellea rhizoids and dead tissues.

3.4 Nutrient contents of roots

The same four trees used for studies on root distribution were analyzed for the nutrient and aluminum contents of living finest and fine roots (Tables 8 and 9). Healthy trees on base-rich soils contained more Ca, but less P and Mn in both root fractions as compared with beech trees on soils derived from old red sandstone. N, K, Mg, Fe, Zn, Cu and Al contents, however, varied on similar levels. The Ca/Al ratios of fine and of finest roots on acid soils varied from 0,9 to 4,4 and from 0,9 - 2,2 respectively. Roots of the diseased tree did not differ significantly in element contents from those of its healthy neighbour and generally exhibited higher Ca/Al ratios.

Table 5: Macronutrient contents of beech phloem at breastheight. Ranges and means.

Sampling area	number of trees	N	P	K mg/g dry matter	Ca	Mg
Muschelkalk						
1.Kalkofen	3	7,5-7,7/7,6	0,33-0,34/0,33	2,1-2,5/2,3	64-100/78	0,41-0,46/0,42
2.Dachsbau	4	5,2-6,4/5,9	0,27-0,35/0,32	2,0-2,6/2,3	70-82 /77	0,34-0,42/0,39
3.Dianenlust	3	6,5-6,7/6,6	0,29-0,35/0,32	1,8-2,0/1,9	33-50 /44	0,37-0,43/0,39
Buntsandstein						
5.Brückengraben	3	5,4-6,4/5,8	0,24-0,25/0,24	2,3-2,6/2,4	26-28 /28	0,42-0,42/0,42
6.Kleinhahn						
-healthy trees	2	4,1-6,9/5,5	0,34-0,34/0,34	2,3-3,0/2,7	29-35 /32	0,36-0,45/0,41
-diseased trees	2	6,1-10,6/8,4	0,29-0,68/0,49	0,3-0,8/0,5	31-39 /35	0,44-0,44/0,44

Table 6: Micronutrient and aluminum contents of beech phloem at breastheight. Ranges and means.

Sampling area	number of trees	Fe	Mn	Zn	Cu	Al
				µg/g dry matter		
Muschelkalk						
1.Kalkofen	3	16-17 /17	640-1230 /907	3-4 /3	2-3 /3	Tr*)
2.Dachsbau	4	15-18 /17	350- 450 /418	3-3 /3	3-4 /4	Tr*) -15 /7
3.Dianen-lust	3	18-24 /22	640-1170 /887	3-4 /3	3-4 /3	25-29 /27
Buntsandstein						
5.Brückengraben	3	12-17 /15	1660-2620 /2063	5-7 /6	2-3 /3	29-37 /33
6.Kleinhahn						
-healthy trees	2	15-19 /18	1390-1650 /1520	4-4 /4	2-3 /3	27-35 /31
-diseased trees	2	19-20 /20	1450-2740 /2095	9-10 /10	3-5 /4	33-38 /36

*) Traces only

Table 7: Mean number of living roots per dm² rootable area (a) and percentage of dead roots (b). Rootable area = total area of the vertical cross-section of a particular soil layer minus area occupied by stones > 5 cm diameter

Feature	Sampling site							
	Kalkofen		Reuterlein		Kleinhahn			
					healthy tree		diseased tree	
Soil type	Br.-Terra fusca		Parabraunerde		Pods.-Braunerde		Pods.-Braunerde	
Range of $pH(H_2O)$	6,1-7,8		5,2-7,1		3,9-4,7		3,3-3,9	
Sample tree:								
age	87		120		100		80	
DBH(cm)	29,5		50,0		25,0		29,0	
height(m)	20,1		27,2		18,7		19,4	
Roots per dm²								
0-50 cm	a	b	a	b	a	b	a	b
< 2 mm	13,4	<5	8,6	<5	13,2	<5	13,8	11
2-5 mm	0,7	<5	1,3	6	1,4	<5	0,8	34
> 5 mm	0,5	<5	0,9	<5	0,7	<5	0,4	10
50-100 cm								
< 2 mm	5,2	<5	3,6	<5	2,6	<5	1,4	59
2-5 mm	0,3	<5	1,0	<5	0,2	<5	-	86
> 5 mm	0,2	<5	0,5	<5	0,1	<5	-	0
0-100 cm								
< 2 mm	10,2	<5	6,1	<5	7,9	<5	7,6	11
2-5 mm	0,5	<5	1,1	<5	0,8	<5	0,4	43
> 5 mm	0,4	<5	0,7	<5	0,4	<5	0,2	9

Table 8: Nutrient and aluminum contents of living finest roots (diameter < 1 mm). Ranges of values in topsoil (ts) and subsoil (ss)

Element		Sampling site			
		Kalkofen	Reuterlein	Kleinhahn healthy tree	Kleinhahn diseased tree
		ts ss			ts ss
N	mg/g	10 - 6	11 -5	7 -9	8 -5
P	mg/g	0,8- 1,0	0,9-0,7	1,5-1,3	0,7-1,0
K	mg/g	2 - 2	2 -2	3 -3	2 -1
Ca	mg/g	6 -16	2 -4	1 -1	2 -1
Mg	mg/g	0,6-0,7	0,8-1,2	0,7-0,6	0,8-0,7
Fe	mg/g	3- 2	1- 1	2- 2	1- 2
Mn	µg/g	100-64	93-84	374-227	455-309
Cu	µg/g	9- 8	8- 7	6- 5	6- 5
Zn	µg/g	41-28	90-20	59-50	66- 90
Al	µg/g	190-512	334-395	504-523	410-519

———— no clear depth function

Table 9: Nutrient and aluminum contents of living fine roots (1-2 mm). Ranges of values in topsoil (ts) and subsoil (ss)

Element	Sampling site			
	Kalkofen	Reuterlein	Kleinhahn healthy tree	Kleinhahn diseased tree
	ts ss			ts ss
N mg/g	7 - 5	8 -5	5 -5	8 -3
P mg/g	1,0- 0,7	0,9-0,8	1,5-1,2	1,7-1,0
K mg/g	2 - 2	2 -2	2 -3	2 -3
Ca mg/g	8 -16	5 -1	2 -1	3 -1
Mg mg/g	0,6- 0,5	0,8-1,5	0,8-0,7	1,2-0,8
Fe mg/g	2- 1	1- 2	1- 2	1- 1
Mn µg/g	76- 39	288-47	453-150	490-131
Cu µg/g	1- 6	7- 5	4- 4	6- 3
Zn µg/g	31- 17	100-11	64- 42	90- 43
Al µg/g	$\overline{139-512}$*)	$\overline{399-527}$*)	$\overline{370-508}$*)	$\overline{489-297}$*)

*) maximum always in A_l or B_{vl}

$\overline{\qquad\qquad}$ no clear tendency within the profile

4. CONCLUSIONS

We were not able to detect any recent growth decline specific for beech trees on acid soils.

The obviously long-lasting differences in site class between beech stands on acid soils and those on base-rich substrata could not be explained satisfactorily by our analyses. Differences in stand age, in availability of water and in climatic site conditions to some extent may have obscured the relations between element supply and growth. The Ca nutrition should be taken into special consideration during further investigations.

Phloem as well as root analysis partly reflected the increased solubility and uptake of Al, Zn and Mn on acid soils. The differences in tissue levels between the most vital trees and slowly growing beeches however were generally small. Therefore these elements are assumed not to exert any toxic effects in the stands investigated. It is not probable, that Al or Mn toxicity were responsible for the decline in growth observed in dry periods.

All trees which were sampled and were comparable in age, exhibited similar root density in the topsoil (0-50 cm), but there was evidence of less roots being present in the subsoil (50-100 cm) on acid sites. This shallower root system, the reasons of which are not yet clear, is an important disadvantage during dry periods.

Bark necrosis of selected sample trees coincided with an unusually high percentage of dead roots, with shallow root system and with the occurence of Armillaria mellea. The extremely low contents of K and the very high levels of Zn in the phloem of those trees need further attention.

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