EVALUATION OF CONVERSION OF TREE SPECIES AND LIMING AS MEASURES TO DECREASE SOIL COMPACTION IN A BEECH FOREST ON LOAMY SOIL[1]

B. Muys
Laboratory of Forestry, State University of Ghent
Belgium

Summary

A comparative study in the forest of Zoniën (Belgium) found that conversion of tree species and liming can be worthwhile operations in order to decrease soil compaction in beech monocultures on loamy soil. The soil restoration after introducing oak and maple can be explained to an important extent by an amelioration of the soil biological activity and the humus quality. The restoration after liming is clearly due to an increased earthworm activity. Since this action is limited by the species available at the site, it is proposed to experiment in the future with liming combined with the introduction of deep-burrowing earthworm species.

Résumé

(Evaluation de la conversion d'essences forestières et du chaulage comme mesures diminuants le tassement du sol dans une hêtraie sur sol limoneux.)
Une étude comparative établie en forêt de Soignes (Belgique) a pu montrer que la conversion d'essence et le chaulage peuvent être des opérations valables afin de diminuer le tassement du sol sous hêtraie en région limoneuse. La restauration du sol après l'introduction du chêne et de l'érable peuvent être attribué en grande partie à l'amélioration de l'activité biologique du sol et la qualité d'humus. La restauration après chaulage est clairement dûe à une activité lombricienne augmentée. Puisque cette action est gravement limitée par les espèces disponibles dans le site, il est proposé d'expérimenter avec la combination du chaulage avec l'introduction des vers de terre anéciques.

---

[1]Paper presented at the FAO/ILO/ECE Seminar on the impact of mechanization of forest operations on the soil, held at Louvain-la-Neuve, Belgium (sept. 1989).

TABLE OF CONTENTS

1. INTRODUCTION

The Zoniën forest, situated only 15 km from the center of Brussels, is well known for its spectacular so called "cathedral" stands of beech.
However, soil compaction and soil degradation are severe restrictions in the Zoniën forest management. Winddamage is unusually high and threatens the forest stability.
MANIL (1951) and GALOUX (1953) considered two centuries of beech monocultures as the main soil degrading factor. More recently, others noticed a compaction of the deeper soil layers due to paleo-periglacial phenomena. (LANGOHR & VERMEIRE 1982, LANGOHR & CUYKENS 1985). Anyway, such naturally sensitive soils degrade as a consequence of employment of heavy logging machinery (FROEHLICH 1976) and in this particular case also by uncontrolled horseriding (VAN MIEGROET 1974).
This phenomenon is clearly illustrated by the appearance of pseudogley spots in the superficial soil layers and plant species typical for wet, poorly oxygenated soils (Carex remota Jusl. ex L., Polygonum hydropiper L., Juncus effusus L. and Impatiens L. spp.) and by lack of natural regeneration (LE TACON 1981).
It is clear that for the conservation of forest stability, it is necessary, next to prophylactic measures concerning the construction and use of logging equipment (ABEELS 1983, BREDBERG & WASTERLUND 1983), to search for adequate curative techniques to decrease superficial soil compaction.
Techniques have been worked out to solve the problem of soil compaction, but they mostly neglected the role of soil biological activity, especially of the earthworms. However, their beneficial activity on soil fertility and soil structure was prooved manyfold (BOUCHE & al. 1987, DELL'AGNOLA & NARDI 1987, SHAW & PAWLUK 1986). According to HILDEBRAND (1983, 1987), only biological means can re-establish soil physical conditions, favourable to natural beech regeneration on compacted loess loam sites.

Therefore, two classical ameliorating techniques in sylviculture (HUSS-DANELL & LUNDMARK 1988, VAN DEN BURG 1986) are tested in this paper on their effect on soil compaction and evaluated on the importance of soil biological activity in general and earthworm activity in particular : changing of tree species and liming.

2. SITE DESCRIPTION

The Zoniën forest covers about 4380 ha. Altitude above sea-level varies from 60 to 120 metres. Annual temperature averages 9,5 °C ; yearly precipitation totals 750 mm (MUYS & al. 1988).
On the plateaus, the loamy soil of niveo-eolic loess origin is severely lessivated and is classified as a grey brown podzolic. 80 % of the surface is covered with beech monocultures. Plant association belongs to the Milio-Fagetum and has been recorded in the investigated stands by ROGISTER (1975 & 1978a). On site 1, a part of an about 140 years old beech stand was limed in 1957 with 4 tonnes CaO (between 76,5 and 86,5 % CaO) per ha. On this site, we compared a limed parcel with a blank one. On site 2, called Zevenster, a tree species trial was set up in 1906/1907 with homogeneous blocs of 50 x 50 m. On this site, nowadays incorporated in the normal forest management, 3 blocks were selected to compare

soil compaction : maple (Acer pseudoplatanus L. slightly mixed with Acer platanoides L.), oak (Quercus robur L.) and beech (Fagus sylvatica L.).

3. MATERIALS AND METHODS

In each of the 5 selected stands (site 1 : limed beech, beech; site 2 : maple, oak, beech), 5 permanent plots were established. In each of these plots, 8 soil compaction measurements were executed in summer period, using the STIBOKA penetrograph with a cone of 1 cm^2 having a top angle of 60˜. The values obtained at depths of 2.5, 5, 7.5, 10, 15, 20 and 25 cm were taken into account, as well as the depth of the first impenetrable soil layer (cone resistance > 450 N/cm^2). Inaccesible layers below this first compact soil layer were given the arbitrary value of 500 N/cm^2.
In addition, a number of soil ecological variables were egally measured in this permanent plots. Earthworm communities were sampled with the handsorting method on a soil volume of 30 x 30 x 20 cm, decomposition rate of the local leaf litter was determined by means of litterbags and expressed as procentual mass loss. Decomposition was evaluated 1, 2.5, 6 and 12 months after incubation in autumn. Soil chemical analysis was performed on the Ah-horizon between 0 and 3 cm. Soil samples were dried (75 ˜C)and pH H_2O was determined. C was analysed with the method of Walkley & Black, total N with the modified method of Kjehldahl, exchangeable cations by percolation with 1 N ammonium acetate (pH 7) followed by flame photometry for Ca, K and Na and by atomic absorption spectrometry in a Sr extract for Mg; and finally the cation exchange capacity by percolation of ammonium ions with KCl, followed by steam destillation and titration. Plant communities were estimated with the method of Braun-Blanquet and processed with the method of ROGISTER (1978b) to obtain indicator values for soil reaction, nitrification and humidity.

4. RESULTS AND DISCUSSION

4.1. Cone resistance measurements

The penetrograph cone resistance can be used as a valid parameter to evaluate soil compaction. IDE & al (1982) found that cone resistance values greater than 200 N/cm^2 are harmful for fine roots of agricultural crops. VAN MIDDELEM (1984) found a good relation between cone resistance and bulk density of the soil. Since tree roots are mainly concentrated in the superficial layers as a consequence of the periglacial soil compaction starting from about 30 à 40 cm and since anthropogenous compaction through logging operations, horse-riding, etc. disturbs mainly the superficial layers, this research concentrates on the first 25 cm. In all stands, compaction increases with the depth (Figure 1). An analysis of variance with the forest stand as origin of variation was executed for the compaction measured at depths of 2.5, 5, 7.5, 10, 15 an 25 cm and for the depth of the first impenetrable layer met (resistance > 450 N/cm^2) (mean values table 1).
As illustrated in table 2, all analyses detected extremely significant differences in compaction between the stands.

Prospecting the results and the additional tests more in detail, following assessment were done :

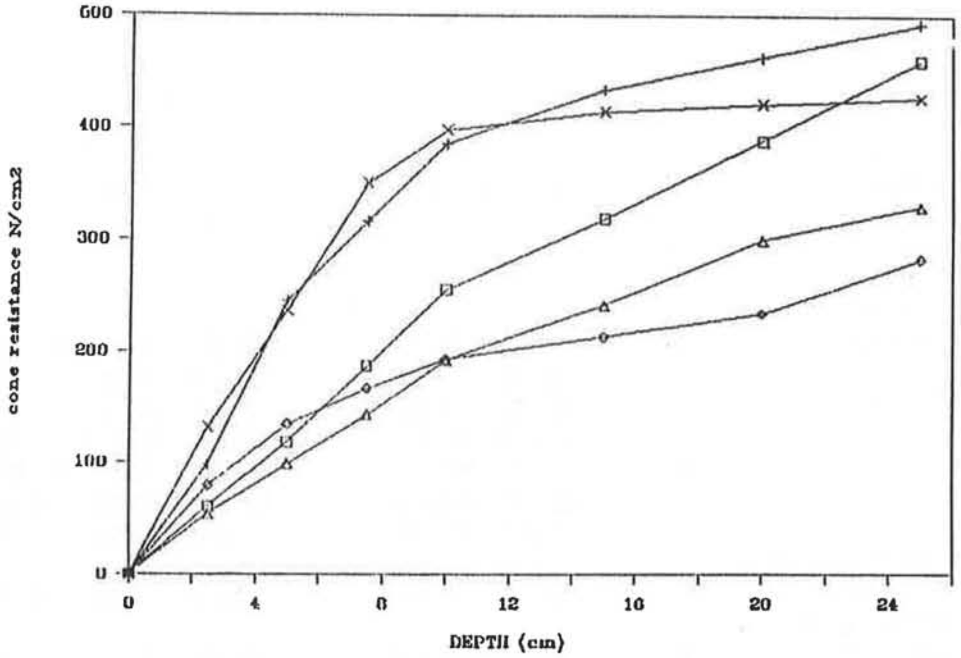


Figure 1. : Mean penetrograph cone resistance ($N.cm^{-2}$) as a function of depth (cm) for the investigated forest stands (Plot 1: □ limed beech, + beech; Plot 2 : ◊ maple, △ oak and x beech).

- On site 1, the limed stand is significantly less compacted than the blank one, until a depth of 20 cm. Already diminuating at 20 cm, the difference at 25 cm has become very small : practically all cone introductions, limed or not, couldn't penetrate until this depth. It signifies that the liming effect is restricted to a superficial soil layer with a thickness of about 20 cm (see further). This is affirmed by the mean depth of the first layer with a cone resistance > 450 N/cm^2 : 11 cm in the blank, 22 cm in the limed stand.

- The second site, being the species trial, shows significant differences between beech as compaction sensitive stand on the one hand and maple and oak as almost compaction-less stands on the other hand for the whole profile between 0 and 25 cm. Difference, although not significant, has been assessed between oak and maple : the soil under oak is more loose above 10 cm depth, same loose at 10 cm and more compacted at deeper layers than under maple. This is slightly reflected in the comparison between depths of the first compacted layer : 33 cm under maple, 29 under oak and 16 under beech.
  When comparing the untreated beech stands of both sites, one can only observe significant differences for a depth of 25 cm : the beech stand of the species trial is somewhat less compacted ; its first compacted layer is situated at 16 cm on an average against 11 cm for the beech stand of site 1.

Table 1 : Variable means for the 5 compared forest stands

SITE		1		2		
FOREST STAND		1	2	3	4	5
specification		limed beech	beech	maple	oak	beech
VARIABLE	CODE					
CONE RESISTANCE (N/cm2)						
2.5cm depth	A	60.000	97.500	78.875	53.399	130.750
5 "	B	117.750	245.500	133.750	98.141	236.750
7.5 "	C	186.250	316.250	166.375	142.153	350.250
10 "	D	255.402	385.125	192.375	191.540	397.250
15 "	E	318.768	432.750	212.625	241.244	413.875
20 "	F	388.196	461.750	234.000	299.984	420.250
25 "	G	458.625	492.500	283.125	329.401	425.750
DEPTH OF FIRST COMPACT LAYER (>450N/cm2) (cm)	H	21.213	11.050	32.838	29.005	15.788
EARTHWORM COMMUNITIES						
density (m-2)	I	92.400	8.600	47.800	33.000	5.600
fresh biomass (g.m-2)	J	15.316	0.901	5.269	4.042	0.115
SOIL ANALYSIS (0-3 cm)						
pH(H2O)	K	4.353	3.777	4.033	3.762	3.778
C(%)	L	2.382	3.060	2.322	2.728	3.156
N(%)	M	0.251	0.302	0.249	0.304	0.300
C/N	N	9.587	10.154	9.052	9.022	10.963
exchangeable cations (meq/100g)						
Mg	O	0.331	0.259	0.275	0.248	0.267
Ca	P	2.252	0.748	0.952	0.652	0.808
K	Q	0.065	0.061	0.119	0.066	0.055
total	R	2.649	1.068	1.346	0.966	1.131
CEC(meq/100g)	S	17.000	20.400	17.400	18.480	20.680
base cation saturation (%)	T	15.582	5.235	7.736	5.227	5.490
LITTER DECOMPOSITION (% mass loss)						
after 1 month	U	30.000	27.500	17.800	0.000	10.200
" 2.5 "	V	40.800	30.000	21.600	24.400	12.800
" 6 "	W	43.800	33.100	50.100	45.200	23.000
" 12 "	X	78.200	47.700	76.000	58.100	51.800
VEGETATION INDICES						
mN(nitrification index)	Y	6.264	5.231	5.638	3.932	5.673
mR(reaction index)	Z	3.341	2.461	3.140	2.282	3.176
mF(humidity index)	a	5.912	5.723	5.516	5.553	6.567
mN x mR (humus quality index)	b	20.926	12.873	17.020	8.974	18.015
THICKNESS OF Ah-HORIZON (cm)	c	10.000	5.250			

Table 2 : Analysis of variance comparing penetrograph cone resistance ($N.cm^{-2}$) and depth of the first compact layer > 450 $N.cm^{-2}$ between the 5 investigated forest stands.

VARIABLE	TOTAL NUMBER OF OBSERVATIONS	GLOBAL AVERAGE	F-RATIO	SIGNIFICANCE LEVEL
CONE RESISTANCE (N/cm2)				
2.5cm depth	200	84	11.067	***
5 "	200	166	19.067	***
7.5 "	199	231	26.512	***
10 "	199	283	27.039	***
15 "	199	323	26.69	***
20 "	199	359	27.36	***
25 "	199	396	26.713	***
DEPTH OF FIRST COMPACT LAYER (>450N/cm2)	199	22.1	17.65	***

4.2. Global Multivariate analysis

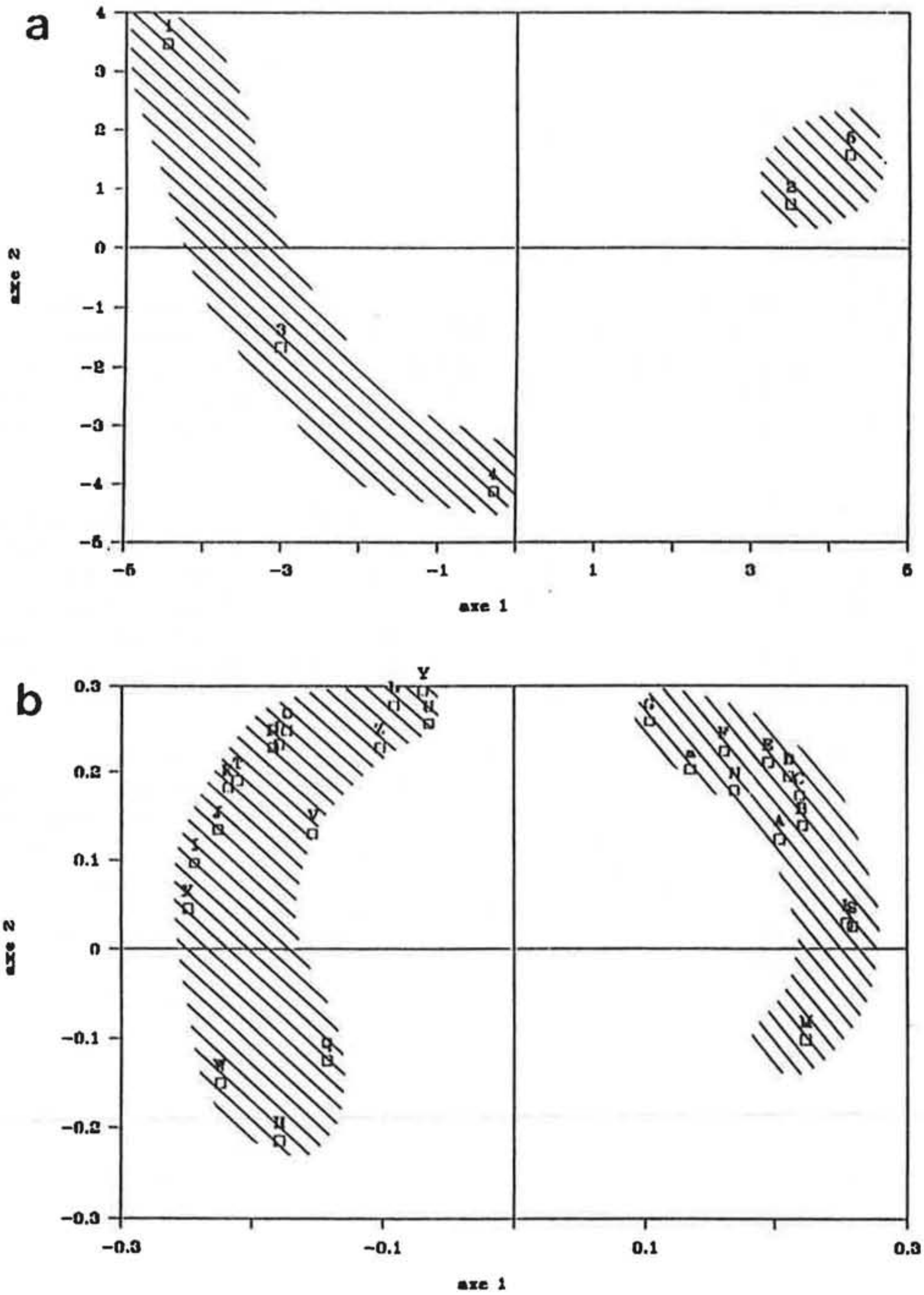
Because this paper's objectives are to evaluate the role of biological soil processes on the degree of compaction, the cone resistance measurements are confronted with a lot of ecological variables, thought to be relevant in describing soil fertility, humus quality and soil biological activity, especially earthworm activity (table 1).

The analysis is performed using the method of principal components. Principal components are calculated using the matrix of correlations. When observing the situation of the 5 forest stands in the plane of the first and second principal axe, two groups can be clearly distinguished : the untreated beech stands (2 and 5) at the positive side of the first axe and the maple (3), oak (4) and limed beech (1) stand at the negative side (figure 2a).

The first axe explains 53 % of total variation. The meaning of this axe is illustrated in the plot of the component weights (figure 2b) : the first axe is mainly formed by the variables (codes see table 1) carbon content of the Ah-horizon (0-3 cm) (L) and cation exchange capacity (S) at the positive side of the axe ; earthworm density (I and J), litter decomposition (W and X), pH-value (K) and base cation saturation (0-3 cm) (T) at the negative side of the axe. All the foregoing variables are significantly correlated among each other, except carbon content in relation with the negative variables.
The first axe consequently consists in a synthesis of humus quality, earthworm activity and soil fertility : at the positive side of the axe, high carbon contents in the upper horizon characterize bad litter decomposition and lack of mixing between organic matter and mineral soil. Also a higher C.E.C. in the layer 0-3 cm was to be exspected at this side of the axe, because of the high humus content of this superficial layer. The absence of

earthworms and other soil biological activity, which are able to loosen and mix up the soil, cause or at least conserve soil compaction. As a matter of fact, the compaction variables (A,B,C,D,E,F,G) are all together concentrated at the positive side of the first axe. The situation of the humidity index of vegetation (a) in this same area of the plot is explained by the gleyfication of the upper soil layers, due to superficial compaction.

Figure 2. : Global principal components analysis of the data.
a. situation of the stands (legend table 1) in the plane of the first and second principal axe with indication of 2 clusters.
b. situation of the variables (legend table 1) in the plane of the first and second principal axe.



The opposite side of the axe, on the contrary, shows that the earthworm activity is closely related with soil pH and base cation saturation being the main indicators for soil chemical fertility. Litter decomposition becomes very earthworm related after 6 months of breakdown processes (before, leaching and microbial incubation are important and are less litter-selective (MUYS 1989)).The depth of the first compact horizon (H) is also situated at this side of the axis.

All this indicates that increasing soil fertility and soil biological activity decrease soil compaction and it affirms the statement of HILDEBRAND (1987) that long-term solutions against soil-compaction can only be reached by biological means.

Between the stands with negative values on the 1st axe, a big difference in humus quality does occur, varying from a value of -4.5 on the first axe for limed beech (an earthworm-rich mull humus) to -0.3 for oak (a moder humus). Maple is intermediate. Altough humus quality differs between these stands, cone resistance values differ hardly (see 4.1.). Indeed, as can be noticed in figure 1a, the pool of compaction variables lays on the diagonal between 1st and 2nd axe, in a way that the distance between them and the stands 1, 3 and 4 is about the same or even slightly advantageous for oak. Here we arrive at the interpretation of the second axe, that still accounts for 31 % of variance. Although cone resistance measurements are situated on the diagonal between 1st and 2nd axe, compaction in the superficial layers (A, B) is more attracted to the 1st axe and compaction in the deeper layers more to the 2nd axe ; variable G, cone resistance at 25 cm depth, even being one of the most explicative factors of the 2nd axe. At the negative side of the second axe, we observe the depth of the first compacted layer (H). Therefore, it is supposed that the 2nd axe explains the compaction of the deeper soil layers.

This hypothesis explains the enormous elongation between stands 1, 3 and 4 along the 2nd axe : limed beech is very loose and aerated in the upper layers but still compacted in the deeper horizons. Oak, on the contrary, is loose over the whole profile. Maple is intermediate but anyway at the negative side of the 2nd axe and thus having more affinity with oak.

The low compaction under oak can not be sufficiently explained by the measured variables concerning litter decompostion, earthworm activity, humus quality, etc. : most of these variables are situated at the positive side of the 2nd axe. Under oak, the pH value is as low as under beech, earthworms are rather abundant but not enough to create a mull and it concerns moreover only litter-dwelling so called epigeic species. On figure 1b, the amount of exchangeable potassium (Q) and the state of litter decomposition after 6 months (W) seem to be correlated with the favourable soil structure under oak. Besides, it is known that the microbial activity under oak can be very high (VOETS & al 1975) and that the root structure, being horizontal and soil compacting for beech, is vertical and soil-structuring for oak (VAN MIEGROET 1974). More research will be needed to precise these findings.

4.3. Multivariate analysis of site 1

Since we found in the foregoing that the variables measured are able to explain soil compaction succesfully in site 1 (the liming

Table 3 : Variables of the separate plots in site 1 (liming experiment).

FOREST STAND		1					2				
specification		LIMED DEECH					BEECH				
PLOT		1	2	3	4	5	1	2	3	4	5
VARIABLE	CODE										
CONE RESISTANCE (N/cm2)											
2.5cm depth	A	17.500	160.000	8.125	15.000	99.375	63.125	122.500	81.250	119.375	101.250
5 "	B	51.075	221.875	22.500	73.750	210.750	108.125	249.375	163.750	312.500	313.750
7.5 "	C	97.500	360.000	44.375	145.000	284.375	265.000	362.500	262.500	288.750	402.500
10 "	D	168.125	404.286	75.625	288.750	340.625	269.375	436.875	379.375	392.500	447.500
15 "	E	293.125	395.714	141.250	385.000	378.750	332.500	500.000	378.750	480.000	472.500
20 "	F	346.075	467.857	277.500	441.875	406.875	465.000	500.000	398.750	485.000	460.000
25 "	G	473.125	500.000	401.875	462.500	455.625	500.000	500.000	477.500	500.000	485.000
DEPTH OF FIRST COMPACT LAYER (>450N/cm2) (cm)	H	23.625	15.000	34.313	19.313	13.813	13.125	8.313	15.500	9.813	8.500
EARTHWORM COMMUNITIES											
density (m-2)	I	87.000	7.000	220.000	102.000	46.000	18.000	0.000	5.000	5.000	15.000
fresh biomass (g.m-2)	J	12.941	0.703	39.016	16.414	7.508	1.905	0.000	0.185	0.025	2.390
SOIL ANALYSIS (0-3 cm)											
pH(H2O)	K	4.170	3.835	4.750	4.805	4.205	3.800	3.815	3.775	3.700	3.795
C(%)	L	1.960	2.760	2.590	2.630	1.970	2.600	3.290	3.580	3.170	2.660
N(%)	M	0.209	0.208	0.202	0.292	0.183	0.245	0.324	0.344	0.324	0.272
C/N	N	9.397	9.507	9.176	8.998	10.779	10.607	10.154	10.422	9.793	9.794
exchangeable cations (meq/100g)											
Mg	O	0.261	0.207	0.438	0.406	0.261	0.125	0.239	0.293	0.363	0.273
Ca	P	1.280	0.520	3.920	4.640	0.900	0.440	0.380	1.420	0.780	0.720
K	Q	0.062	0.051	0.072	0.103	0.041	0.041	0.062	0.082	0.072	0.051
total	R	1.603	0.779	4.430	5.229	1.202	0.606	0.681	1.795	1.215	1.045
CEC(meq/100g)	S	17.600	19.000	15.800	16.000	16.600	18.600	21.600	25.400	18.800	17.600
base cation saturation (%)	T	9.108	4.098	28.038	32.680	7.242	3.256	3.152	7.068	6.461	5.936
THICKNESS OF Ah-HORIZON (cm)		9.000	5.000	16.000	13.000	7.000	3.500	7.250	7.000	5.500	3.000
	C										

experiment), we decided to recalculate the principal components analysis for this site only, now however considering each plot (1 stand contains 5 plots) separately (data table 3).

The first principal axe accounts for 66 % of total variance. Figure 3a illustrates the situation of the plots in the plane of the 1st and the 2nd axe. All plots of the untreated beech stand 2 are well-clustered at the positive side of the 1st axe. The limed plots, however, show an enormous variation from an extreme negative position for plot 1.3, to a positive position for 1.2. within the cluster of untreated plots of stand 2. Trying to explain this positioning, following assessments can be made (figure 3b) :

- As in the global analysis (see 4.2.), the negative side of the first axe is formed by variables, describing soil fertility and humus quality. It are : earthworm biomass (J) and density (I), pH-value (K), base cation saturation (T), exchangeable Ca-content (P) and total amount of exchangeable cations (R). Data of litter decomposition are not available for the separate plots. Also the depth of the first compacted layer and the thickness of the Ah-horizon are strongly contributing to the construction of the negative side of the axe.

- As opposed to the global analysis, the cone resistance measurements strongly contribute to the construction of the first axe. C/N value and C.E.C. of the upper 3 cm appear also at this side of the axe being indicators for soils with humus accumulation. The 2nd and 3th axe, explaining respectively 17 and 8 % of total variance have an indistinct significance, moreover, they don't have any significant influence on the compaction level, where we are interested in.

Figure 3. : Principal components analysis for site 1 (liming experiment).
a. situation of the plots (legend table 3) in the plane of the first and second principal axe.
b. situation of the variables (legend table 3) in the plane of the first and second principal axe.

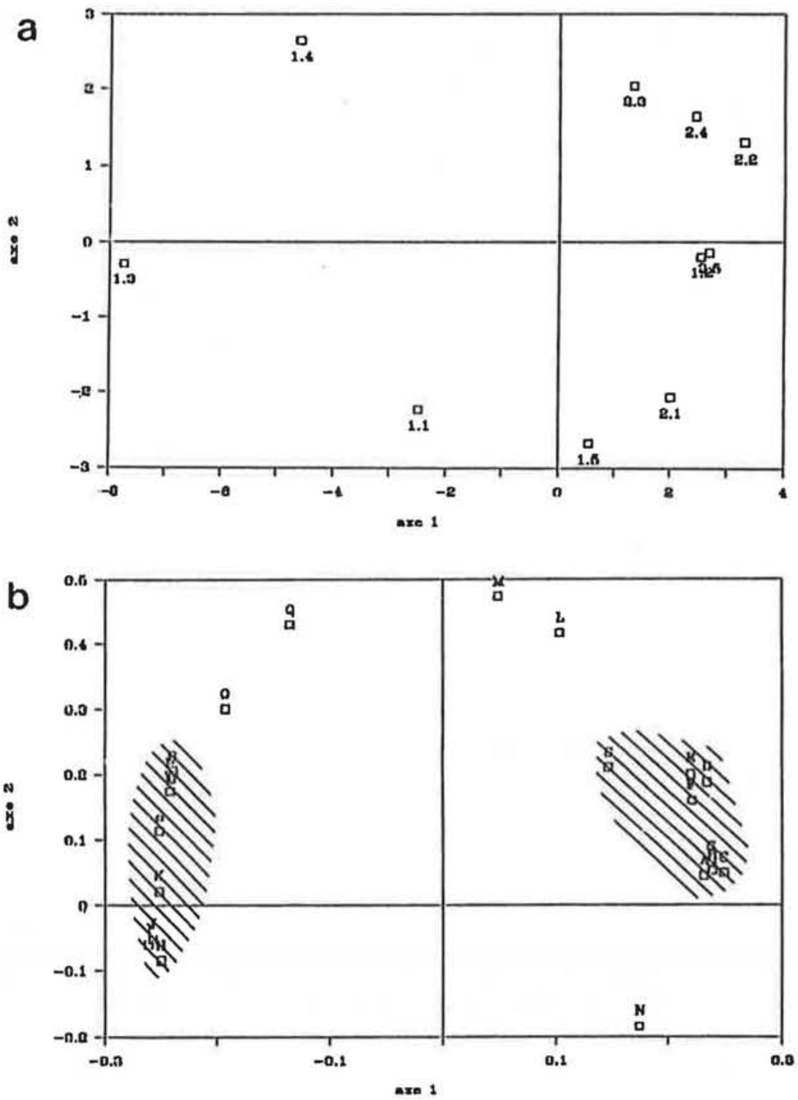
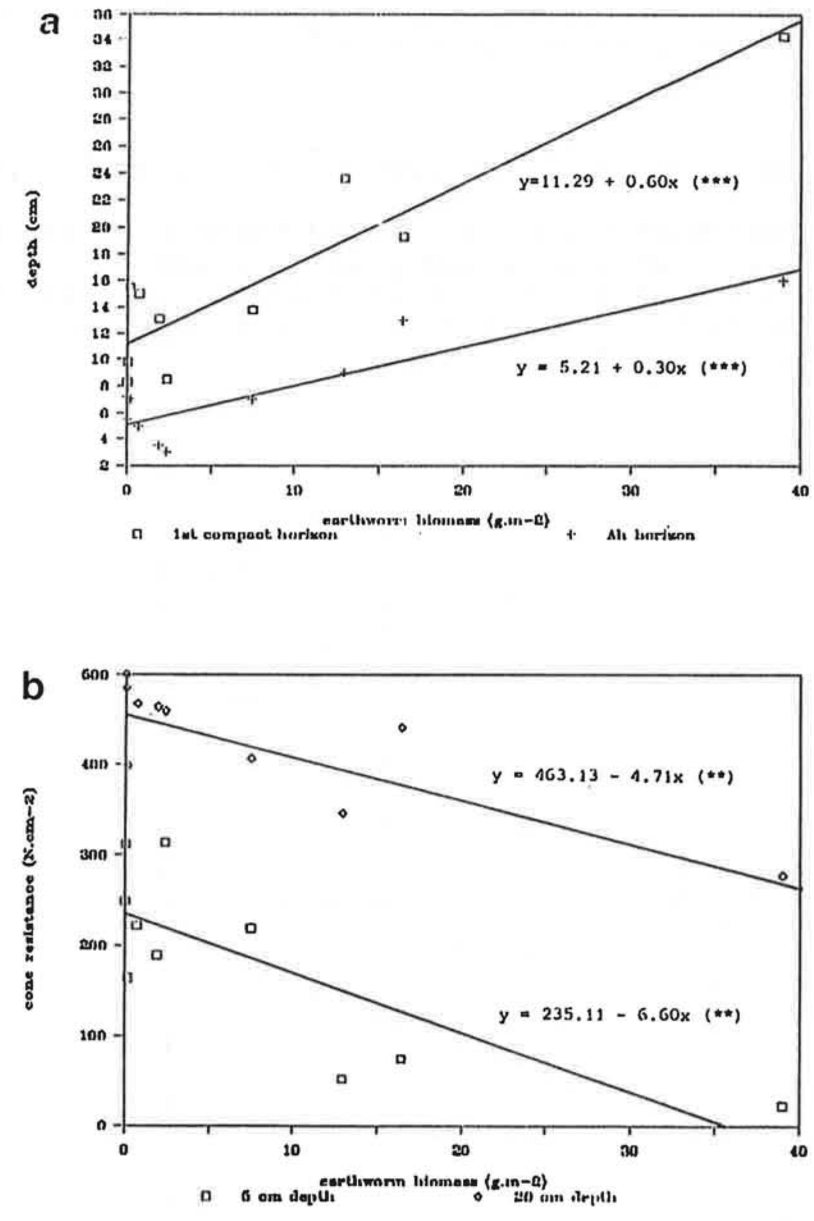


Figure 4. : Regression lines for different variables as a fuction of earthworm biomass.
a. thickness of the Ah-horizon (r=0.8939***) and depth of the first compact layer > 450 $N.cm^{-2}$ (r=0.9225***).
b. cone resistance measurements at 5 (r=-0.7861**) and 20 (r=-0.9344***) cm depth.



For site 1, the foregoing allows to make some preliminary conclusions, affirmed by several publications (GASPAR & al. 1982, TOUTAIN & al. 1988, VAN DEN BURG 1986) : liming increases litter quality and as a consequence, earthworm density. Earthworms mix up organic matter and mineral soil, making the Ah-horizon thicker. The lower limit of earthworm activity is obviously clear as it coincides with the lower limit of the black Ah-layer, which is characterised by earthworm galleries and a crumby structure. As a matter of fact, the compaction of the superficial soil layers decreases spectacularly through this action of worms. As illustrated in figure 3a, it is very important to notice the big variation between the plots of the limed stand. It means that liming is not an entire succes in the struggle against soil compaction. Another variable is possibly as important as the presence of Ca. According to the information available on the liming operation of 1957, it is believed that the liming happened quite homogeneously. The variation in earthworm density, compation, etc., however, follows an irregular spotted pattern, which is reliably predicted by the vegetation : earthworm-dense uncompacted spots are characterised by a vegetation with Urtica dioica L., Circaea lutetiana L. and Milium effusum L. Slightly compacted zones are mainly covered with Rubus L. spp. and compacted zones, where almost no earthworms occur, with Athyrium filix-femina (L.) Roth., or even worser, with Holcus mollis L. (As a reference, in the untreated beech stand, vegetation types are found with Rubus L., Holcus mollis L., Pteridium aquilinum (L.) Kuhn. and on the most compacted places with Deschampsia flexuosa (L.) Trin. as dominant species). We suppose that on the most favourable places, the higher concentration of exchangeable Ca and the higher pH-value are not explained by a higher original dose of CaO compared to the other places, but by smaller losses afterwards, through more efficient mineral cycling as a consequence of higher earthworm activity. This opinion is illustrated in the regression lines of Ah-thickness, depth of the first compacted layer and cone resistance as functions of the independent variable earthworm biomass (figure 4). These differences in earthworm density and activity could be due to differences in earthworm communities already before the liming operations.

This hypothesis could explain why not only the quantity of earthworms differs between the plots, but also the species composition. The plots 1,3 and 4 of the limed stand are the only plots of the 5 stands investigated, that contain endogeic species (BOUCHE 1977), being Allolobophora limicola Michaelsen and Octolasium cyaneum Savigny. These are humus-eating worms with a considerable burrowing activity. All other plots contain only epigeic species, i.e. litter-dwellers, namely Lumbricus rubellus Hoffmeister, Lumbricus castaneus Savigny, Dendrobaena octaedra Savigny, Dendrobaena rubida Savigny and Dendrobaena attemsi Michaelsen. In the totality of plots, no single anecic earthworm could be found, i.e. very active deep-burrowing and litter-decomposing species.

5. CONCLUSIONS

The evaluation of changing tree species and liming as valuable operations restoring compacted soils in the beech forest of Zoniën has lead to following conclusions :

- Highly significant decrease in compaction was found under oak, maple and limed beech, compared to the untreated beech stand.

Under oak and maple however, the soil is loosened until 30 cm or deeper. Under limed beech, the loose layer is restricted to a depth of 20 cm.

- The restoration can be globally explained by an increased earthworm density and biomass, a faster litter decomposition expressed as procentual mass loss after 6 and 12 months, higher base cation saturation, lower C/N-ratio and by other parameters describing humus quality.
- For oak and - to a lesser extent - for maple, the foregoing variables couldn't explain everything, especially not the loose structure below 20 cm. Microbial activity, root structure and other variables not measured in this research, play presumably an important role. More research will be needed to explain.
- In the liming experiment, restoration can be fully explained by earthworm activity and humus quality parameters. The loosened layer, restricted to a depth of about 20 cm coincides with the lower limit of earthworm activity.
- Liming was not entirely effective in relation to soil restoration but following a spotted pattern. The earthworm-inoculum at the moment of liming is probably of big importance. Anyway, in order to increase effectiveness in horizontal and vertical direction, it seems to be necessary to combine the liming operation with earthworm introduction (HUHTA 1979). Research is absolutely needed to develop this techniques.

Acknowledgements

This research was subsidized with a grant of the IWONL. Thanks also to M. VERLOO for the extended laboratory accomodations.

6. REFERENCES

ABEELS, P.F.J., (1983). Uberlegungen zur Herstellung von Reifen für forstwirtschaftliche Fahrzeuge. Forstw. Cbl. 102, p. 80-86.

BREDBERG G., von C.J. & WASTERLUND, I., (1983). Wurzel- und Bodenschäden durch Fahrzeuge. Forstw. Cbl. 102, p. 86-98.

BOUCHE, M.B., (1987). Stratégies lombriciennes. In : Soil organisms as components of ecosystems. Ecological bulletin 25, p. 122-132.

BOUCHE, M.B., FERRIERE, G. & SOTO, P., (1987). The role of earthworms in the decomposition and nitrogen nutrition of plants in a grass land. In : PAGLAI & OMODEO (eds.). On earthworms. Modena, p. 113-129.

BOUDRU, M., (1947). Influence des essences sur le pouvoir tampon de la couverture morte et du sol. Essai préliminaire en forêt de Soignes. B.S.R.F.B., 54 (8), p. 298-307.

DELL'AGNOLA G. & NARDI S., (1987). An overview of earthworm activity in the soil. In : PAGLAI A. & OMODEO P.(eds.) On earthworms. Modena, p. 103-112.

FROEHLICH, H.A., (1976). The influence of different thinning systems on damage to soil and trees. In : HAMILTON, G.J. (ed.). Aspects of thinning. Forestry Commission Bulletin 55, p. 102-105.

GALOUX, A., (1953). Le hêtre et la dégradation des sols forestiers loessiques. B.S.R.F.B., 60 (3), p. 225-235.

GASPAR Ch. & al., (1982). Recherches sur l'écosystème forêt : effet d'une fertilisation en forêt sur les populations de Lombrics. Annls.Soc.r.zool.Belg. 112 (1), p. 45-48.

HILDEBRAND, E.E., (1983). Der Einfluss der Bodenverdichtung auf die Bodenfunktionen im forstlichen Standort. Forstw. Cbl. 102, p. 111-125.

HILDEBRAND, E.E., (1987). Die Struktur von Waldböden - ein gefährdetes Fliessgleichgewicht. AFZ 16/17, p. 424-426.

HUHTA, V., (1979). Effects of liming and deciduous litter on earthworm populations of spruce forest, with an inoculation experiment on A. Caliginosa - Pedobiologia 19, p. 340-345.

HUSS - DANELL, K. & LUNDMARK, J.E., (1988). Growth of nitrogen - fixing Alnus incana and Lupinus spp. for restoration of degenerated forest soils in northern Sweden. Studia forestalia Suecica 187, 20 pp.

IDE, G., et Al., (1982). Influence of subsoiling on the growth of cereals. Pedologie, 32 (2), p. 193-207.

LANGOHR, R. & VERMEIRE, R., (1982). Well drained soils with a "degraded" Bt horizon in loess deposits in Belgium ; relationship with paleo-periglacial processes. Biuletyn peryglacjalny 29 (14), p. 203-212.

LANGOHR, R. & CUYKENS, G., (1985). Een bos op lemen voeten. Bodem en reliëf in het Zoniënbos : unieke getuigen. Natuurreservaten 7 (5), 132-139.

LE TACON, F., (1981). (Régénération naturelle du hêtre). Influence des conditions du sol et de sa préparation. In : TEISSIER DU CROS, E. (ed.). Le hêtre. INRA Paris 613 pp., p. 229-230.

MANIL, G., (1951). Considérations sur la pédologie forestière à propos de récentes excursions. B.S.R.F.B., 58 (4), p. 164-174.

MUYS, B., VAN DEN BERGE, K., ROSKAMS, P., MADDELEIN, D. & MEYEN, S., (1988). Analysis of natural regeneration in a 200 year old beech stand. Silva Gandavensis 53, p. 61-81.

MUYS, B., (1989). Earthworms and litter decomposition in the forests of the flemish region. In : Invertebraten. Symp. KBIN Brussel 1988. In press.

ROGISTER, J.E., (1975). Invloed van de boomsoortenkeuze op ontwikkeling en samenstelling van de kruidlaag. Proefstation van Waters en Bossen, Groenendaal Werken Reeks A, n° 15, 28 pp.

ROGISTER, J.E., (1978a). Invloed van bekalking op de samenstelling en evolutie van de kruidlaag in oude beukenbestanden. Proefstation van Waters en Bossen, Groenendaal. Werken, Reeks F, n˚ 18, 33 pp.

ROGISTER, J.E., (1978b). Bijdrage tot de ekologische klassering van bosplantengezelschappen. Proefstation van Waters en Bossen, Groenendaal. Werken Reeks A, n˚ 16, 157 pp.

SHAW C. & PAWLUK S., (1986). The development of soil structure by Octolasion tyrtaeum, Aporrectodea turgida and Lumbricus terrestris in parent materials belonging to different textural classes. Pedobiologia 29, p. 327-339.

TOUTAIN F. & al., (1988). Possibilités de modification du type d'humus et d'amélioration de la fertilité des sols à moyen terme en hêtraie par apport d'éléments minéraux. R.F.F. 40 (2), p. 99-107.

VAN DEN BURG, J., (1986). Bekalking van bossen. 2. Een overzicht van de buitenlandse literatuur. De Dorschkamp Wageningen rapport n˚ 424, 545 pp.

VAN MIDDELEM, Y., (1984). De bodemverdichtingsproblematiek in het Zoniënbos, meer bepaald in verband met de bosexploitatie. Thesis R.U.Gent, 113 pp.

VAN MIEGROET, M., (1974). Het Zoniënbos en zijn toekomst. Groene band 13, p. 122-132.

VOETS, J.P., AGRIANTO, G. & VERSTRAETE, W., (1975). Etude écologique des activités microbiologiques et enzymatiques des sols dans une forêt de feuillus. Rev.écol.Biol.Sol 12 (3), p. 543-555.