Changes in Soil Profile Development and Nutrient Status due to the Afforestation of Agricultural Land

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In the middle of the last century, the recultivation of western Jutland began, and much of the former heathland was converted into agricultural land. Some of this land was too poor to guarantee stable plant production and satisfactory yields. Such land could be defined as marginal land. Consequently, it was abandoned at the beginning of this century and afforested with the conifer species Picea abies. In order to investigate the resultant changes in soil morphology and soil nutrients, a comparison was made of soils that had developed on land afforested with Picea abies at different times during this century, as well as those that had developed on adjacent agricultural land.

Keywords: *Marginal land, afforestation, soil morphology, soil nutrient status.*

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During the Middle Ages, the sandy areas of western Jutland became overgrown by heathland vegetation (particularly heather) due to agricultural mismanagement. In the middle of the last century, a start was made to recultivate much of this heathland, during which time some areas were also converted to conifer plantations. Recultivation commenced in central Jutland, in the area of the Main Terminal Moraine, and progressed westwards. Much of this land was very poor, and some of it was indeed found to be too infertile to ensure stable plant production. It could therefore be defined as marginal land. Consequently, some of this newly-won marginal land was once again abandoned at the start of this century and afforested, mainly with the conifer species Picea abies. Jensen (1976) showed that the initial afforestation of the former farmland took place near the Main Terminal Moraine of central Jutland for several reasons. Similar conclusions and results were obtained by Barrensø (1987). Today, topographical maps clearly reveal that this afforestation took place on earlier farmland as the former field boundaries appear very distinct. However, in some areas, the abandoned fields were amalgamated to allow the establishment of bigger plantations.

The cultivation of heathland changes the physical and chemical properties of the soil dramatically. Removing the natural heathland vegetation, ploughing, manuring, liming and draining eventually change the mor layer to mull, increasing the pH value, base saturation and amount of nutrients. On the other hand, afforestation reverses this trend. Traditionally, abandoned fields have been afforested by the conifer species Picea abies. Several investigations show that Picea abies acidifies the soil (Holmsgaard et al., 1961, Herbauts et al., 1981, Bergkvist, 1987, Fiedler et al., 1987, Sohet et al., 1988). This may lead to podzolization. Larsen (1971) studied the beginning of podzolization occurring in a soil beneath a 66-year old forest of Picea abies that had been planted in a formerly non-podzolized soil once covered by oakwood. Raulund-Rasmussen et al. (1987) described the soil development process that is set off once existing farmland has been afforested. It was estimated that it would take 80 years before a tract of abandoned farmland afforested with Picea abies reached the same low base status as a natural Picea abies forest.

In Denmark, the total forest area is expected to double within the next 50-100 years due to the EC long-term agricultural policy for marginal land. It will probably be the sandiest soils, disfavoured due to their high irrigation needs for stable crop cultivation, which will be the first to be afforested. These soils lie beneath approximately 20% of the farmland area, and are mainly situated in central and western Jutland (Madsen et al. 1990). In order to investigate the changes in soil profile morphology and nutrient status due to the afforestation of farmland, a comparison of soil data from former farmlands afforested with Picea abies at different times in the past with those of existing agricultural land has been carried out.

INVESTIGATION AREA

Geilvang Plantation and Lille Guldbergsminde Plantation are both situated on an outwash plain just west of the Main Terminal Moraine that was formed during the Weichsel glaciation (see fig. 1). The area contains much marginal land. Cultivation has frequently been abandoned at different times in the past, and today the area is a mosaic of mainly first and second generation of Picea abies and a few agricultural fields.

Physical data for the area are as follows. The mean annual temperature is 7,8°C, ranging from 16°C in July to 0°C in February (DMI, 1961). The mean annual precipitation is about 800 mm. Actual evapotranspiration is about 350 mm, whilst leaching is about 450 mm (Aslyng, 1978). The soil has developed mainly on sandy or gravelly meltwater deposits or aeolian sand derived from these types of deposits. The water retention capacity is low, being approximately 60 mm in the uppermost half meter of the soil (Madsen et al., 1990).

Six areas were chosen for the investigation. Three of

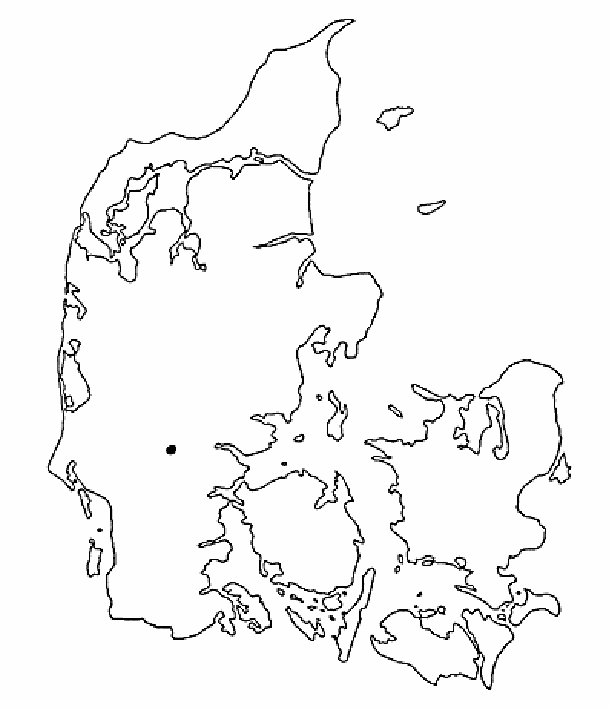

Fig. 1. The location of the investigation area.

these were farmland areas earlier this century, but have now been planted with first generation Picea abies. One area is still farmland. Of the two remaining areas, one has been heathland for centuries, whilst the other was heathland before being afforested in 1914.

The first four areas mentioned will be discussed in detail in this paper:

Area A : 76-year old Picea abies forest (planted 1914)
Area B : 41-year old Picea abies forest (planted 1949)
Area C : 14-year old Picea abies forest (planted 1976)
Area D : Agricultural land

SOIL SAMPLING AND ANALYSIS

In each of the different fields, one test site, measuring 100 metres by 100 metres, was set up. In the centre of each site, a soil profile was excavated and described according to the guidelines laid down by Madsen & Jensen (1988). From each horizon, soil samples were collected for physical and chemical analysis, and tubes were sampled to determine bulk density.

At each test site, 16 augerings to a depth of one metre were carried out. The augerings were evenly distributed within a 25 meter grid. Samples from 3 depths were taken. The uppermost layer to be sampled was the overlying mor layer. The second depth lay between 0-50 cm depth and the third between 50-100 cm. The samples were collected in three separate boxes, according to depths. In each box the content was mixed.

The fine earth samples from the different soil profile horizons and the augerings were then analyzed according to the following methods. Firstly, the particle size distribution was determined using sieve and pipette methods, while the amount of organic carbon was determined by combustion in a LECO apparatus. The pH level was measured in 0.01 M $CaCl_2$, at a soil to liquid ratio of 1:2,5. The amount of total nitrogen was determined by the Kjeldahl digestion method. Total and inorganic phosphorous were determined spectrophotometrically after extracting heated (550°C) and unheated samples, respectively, of the fine earth fraction with 6 M sulphuric acid. Exchangeable Na^+ and K^+ were extracted with 1M NH_4^+-acetat and exchangeable Mg^{2+} and Ca^{2+} with 1 M Na^+-acetat. All four bases were determined by atomic adsorption spectrometry (AAS). The CEC-value (meq/100 g soil) was determined by extracting the Na^+-saturated soil samples (cf. above) with 1 M NH_4^+-acetat and determining the amount of Na^+ in the extract. Iron and aluminium bound in spodic material were extracted by 0.1 M $Na_4P_2O_7$. The total content of 'free' (not silicate-bound) iron and aluminium were extracted using the dithionite-citrat-bicarbonate method (Mehra and Jackson, 1958). All the analyses undertaken are described by Møberg et al. (1987).

OBSERVATIONS AND RESULTS

Table 1 shows the physical and chemical properties of the different horizons making up the four soil profiles. Table 2 shows the thickness of the mor layer at the four sites, measured as a mean of 16 observations evenly distributed within the test field. Furthermore, the distinctness of the (former) Ap-horizon and the degree of cementation of the B-horizon are indicated.

The profiles examined had developed in well-sorted, coarse, sandy material, typical of outwash plains and inland sand dune areas. The afforested areas had been strongly leached, and consequently the pH level and base saturation were very low. Due to nutrient circulation, the base saturation was found to be relatively high in the uppermost horizon, which was also the case in the agricultural field sample as a result of liming. Because of the low clay content in the soil, the variation in the CEC-value closely followed the variation in the organic matter content. The CEC-value was highest in the mor layer and lowest in the C-horizon, characterized by a low content of clay and humus. All four profiles showed various degrees of podzolization due to their different contents of carbon, dithionite-citrate, and pyrophosphate-soluble iron and aluminium. According to Soil Taxonomy, the four soils may be classified as spodosols, but this is based on field

Profile	cm	Horizon	Colour moist	C %	<2μ %	2-20μ %	20- %	>200 μ %	pH $CaCl_2$	CEC meq/100g	BS %	Fe DCB ‰	Fe P ‰	Al DCB ‰	Al P ‰
A	8- 0	O_{1fh}	-	48.38	-	-	-	-	2.7	132.7	4.7	-	-	-	-
	0-32	A_1+A_2	7.5YR 2/0 + 7.5YR 5/2	2.62	3.9	3.2	14.4	78.5	2.7	15.6	2.3	0.9	0.5	0.4	0.3
	32-40	B_{21h}	5YR 2.5/1	6.11	9.0	6.1	19.2	65.7	2.7	37.9	1.3	1.2	0.8	2.0	1.9
	40-65	B_{22ek}	7.5YR 4/6	0.88	4.2	0.9	9.8	85.1	3.8	10.1	3.3	2.5	0.6	1.8	1.5
	65-	C_1	10YR 6/4	0.09	-	1.0	9.3	89.7	4.3	7.7	3.5	0.9	0.3	0.4	0.4
B	5- 0	O_{1fh}	-	20.86	-	-	-	-	3.2	53.8	17.4	-	-	-	-
	0-16	$A_{1(p)}$	10YR 3/1	1.61	5.2	0.1	23.6	71.1	2.9	12.3	3.6	1.7	0.5	0.5	0.4
	16-26	A_2	10YR 3/2	0.74	1.1	2.6	16.2	80.1	3.2	12.8	2.8	1.5	0.5	0.4	0.4
	26-32	B_{21h}	5YR 2.5/1	2.29	4.2	5.5	27.9	62.4	3.5	19.5	2.7	8.7	3.6	2.8	2.2
	32-48	B_{22e}	5YR 3/2	1.62	4.7	5.6	35.1	54.6	3.7	8.1	6.3	9.7	3.8	2.9	2.2
	48-61	B_{23e}	7.5YR 4/4	1.00	2.4	2.9	43.8	50.9	4.0	13.9	3.4	2.2	0.9	3.0	2.6
	61-80	B_{24e}	7.5YR 5/6	0.28	-	2.5	9.9	87.6	4.2	7.6	4.6	3.9	0.8	1.5	1.2
	80-	C_1	10YR 7/4	0.11	-	1.2	17.2	81.6	4.4	4.5	6.0	1.3	0.5	0.7	0.7
C	0-19	$A_{1(p)}$	10YR 3/1	1.07	2.9	3.2	18.0	75.9	3.1	8.0	4.9	2.1	0.7	0.5	0.5
	19-24	B_{21h}	5YR 2.5/1	1.11	3.8	1.9	13.7	80.6	3.8	11.0	7.0	4.2	1.3	1.5	1.2
	24-34	B_{22ev}	7.5YR 3/2	0.85	-	4.3	8.2	87.5	3.9	14.6	4.7	2.9	0.8	2.0	1.6
	34-67	B_{23ev}	10YR 5/8	0.32	-	3.6	15.4	81.0	4.4	9.6	5.5	1.8	0.4	1.2	1.0
	67-105	C_1	10YR 6/6	0.11	-	1.2	6.8	92.0	4.1	9.0	3.1	1.5	0.1	0.5	0.5
	105-	C_2	10YR 6/6	0.10	-	1.1	28.4	70.5	4.3	5.5	5.1	1.5	0.2	0.5	0.5
D	0-25	A_p	10YR 2/1	2.27	4.7	4.8	19.2	71.3	5.0	10.4	40.7	3.0	1.0	0.9	0.9
	25-31	B_{21h}	7.5YR 2/0	1.95	4.3	4.5	18.6	72.6	4.9	16.1	29.4	5.6	1.7	2.1	1.7
	31-67	B_{22e}	5YR 3/3	0.58	-	4.5	5.2	90.3	4.4	18.2	4.6	3.0	0.8	1.8	1.6
	67-93	B_{23e}	7.5YR 4/6	0.26	-	2.0	12.1	85.9	4.1	11.6	3.5	2.2	0.6	1.2	1.1
	93-	C_1	10YR 6/6	0.12	-	1.2	4.7	94.1	4.3	3.1	9.5	1.8	0.3	0.7	0.7

Table 1. Properties of the four soil profiles.

properties (colour, cementation etc.) only, and not on the required chemical properties, which not all the profiles fulfil.

The change in soil morphology due to afforestation was mainly observed in the uppermost horizons, and was particularly evident in the development of a mor layer and the degradation of the former plough layer. The thickness of the mor layer could be closely correlated with the age of Picea abies. In the 76-year old forest, a 9 cm thick mor layer had developed, while it was only 5 cm thick in the 41-year old forest, and less than 1 cm thick in the 14-year old forest. The old Ap-horizon was still very clear, in the 14-year old forest, although it had already lost most of its bases. In the 41-year old forest, it was still possible to recognize the former Ap-horizon, although it was very weak. It was not possible to see the former Ap-horizon in the soil profile of the 76-year old forest. Here, this horizon

	A	B	C	D
O-horizon thickness	9 cm	5 cm	-	-
A_p-horizon distinctness	0	+	++	+++
Cementation	weak + placic horizon	strong	non	weak

Distinctness of the former and present A_p-horizons :
+++ present A_p-horizon
++ distinct, former A_p-horizon
+ weakly recognizable, former A_p-horizon
0 the former A_p-horizon cannot be recognized

Table 2. The morphological characteristics of the present and former Ap-horizons.

Test site	pH 0-50 cm	pH 50-100 cm	BS %	CEC meq/m²	Na meq/m²	K meq/m²	Mg meq/m²	Ca meq/m²	C g/m²	N g/m²	Pt g/m²	Po g/m²	Pu g/m²
Mor													
A	2.8	-	7.5	9572	181.8	102.6	154.8	280.8	3780	153	-	-	-
B	3.4	-	22.8	3149	46.0	42.0	61.0	568.0	1370	57	-	-	-
Mineral													
A	3.2	3.9	3.7	1726	18.3	6.1	11.6	28.3	26656	1322	171	76	95
B	3.5	4.2	8.4	1491	11.1	6.5	9.5	93.8	14780	872	158	51	107
C	3.9	4.2	10.6	1099	8.3	11.2	8.3	89.2	9886	298	206	44	162
D	4.8	4.5	24.8	1379	8.7	12.3	10.8	337.3	15291	866	233	64	169

Table 3. The chemical properties of the uppermost metre of the mineral soil at each of the four test sites and of the mor layer at test sites A and B (the bulk density is assumed to be 0.2 g/cm³).

had become a mixture of bleached A_2 material and black patches originating from former tree roots.

The soil profile descriptions did not show a clear correlation between the age of afforestation and the degree af cementation in the B-horizon. Profile C did not show any sign of cementation. Profile A had weak cementations in the B-horizon apart from a thin, well-developed, placic horizon upon which temporary groundwater had formed. Profile D had weak cementations but no placic horizon, while profile B had strong cementations in the B-horizon. On the other hand, there seemed to be some correlation between the distinctness of the Bh-horizon and the age of afforestation. The oldest afforested area showed very clear Bh-horizons, rich in organic matter, while the youngest afforested area possessed a less distinct Bh-horizon with a low organic matter content.

Table 3 shows the chemical properties of the uppermost one metre of both the mineral soil and the mor layer of test sites A and B, based on the mixed samples stemming from the 16 augerings made at each sampling site. The CEC value is much higher in the mor layer than in the mineral soil below due to the high content of organic matter. The base saturation in the two mor layers is also significantly higher compared to that of the mineral soil below due to root activity, which transports nutrients from the subsoil to the organic top layer. Although the base saturation is relatively high, the pH-value is lower than in the mineral soil below. The pH level and base saturation in the mineral soil of the four test sites revealed an increasing acidification of the soil with increasing forest age. The decrease in the pH level and base saturation was observed to be most pronounced during the first years of afforestation. Assuming that the base saturation was similar to that of the agricultural field when afforestation took place (BS = 25%), the data confirmed the estimation by Raulund-Rasmussen et al. (1987) that in this region it takes about 80 years before the soil of afforested, former farmland falls to the same base saturation as that lying beneath previously uncultivated, natural forest areas of Picea abies. However, the degree of reduction in base saturation was observed to be very small during the second half of the 80 year period. In the soils of the neighbouring heathland, which was afforested with Picea abies in 1916, the base saturation was found to be 7%. When comparing this with the base saturation in the soil in area A, this would seem to indicate that a shorter period than 80 years may elapse before abandoned farmland is leached to the same degree as non-farmland.

The cation exchange capacity was found to be highest for the old forest soil, due to a high content of organic matter, and lowest for that of the 14-year old forest, where the organic matter content was lowest. The sum of exchangeable bases was lowest for the soil of the oldest forest, whilst it was similar for those of the two younger forest, and highest for that of the agricultural land. The amount of exchangeable sodium increased with forest age, being therefore lowest in the soils of the agricultural land. The amount of exchangeable magnesium in the soil was observed to be similar at each site, whilst there was a slight tendency for exchangeable potassium to decrease with increasing forest age. This tendency was even more pronounced for calcium. The percentage share of Na, K, Mg and Ca in relation to the total amount of exchangeable bases differed greatly between the oldest forest soils and the agricultural land soils. In the oldest forest soil, Na and Ca made up 28% and 44% of the bases respectively, compared to 2% and 92% respectively in the agricultural land soils. For the two other forest areas, sodium and calcium accounted for approximately 8% and 77% of the exchangeable bases. These differences were mainly due to the liming of the agricultural land, which had given these soils a very high, and unnatural, calcium content. Where liming activities had ceased due to afforestation, the accumulated calcium was being leached while not being fully replaced by weathering processes. This was changing the base ratio of the soil.

The total phosphorous content in the uppermost metre of the soil was highest for the agricultural land. Organic phosphorous content is closely related to organic matter content and was therefore found to be highest in the soil of the oldest forest. The content of inorganic phosphorous is highest in agricultural soil and will decrease with increasing forest age. This may be the result of using phosphoric manures and fertilizers for different lengths of time and the immobilization of phosphorus by iron and aluminum (hydr)oxides in the soil.

CONCLUSIONS

As in the case of the coarse sandy soils of Jutland, the conversion of cultivated marginal land to forest plantations of Picea abies may give rise to the following changes in pedological development and the chemical properties of soils:

- A mor layer will develop 20-30 years after the start of afforestation and may reach a thickness of 10 cm after 80 years.
- The former Ap horizon will degradate. 40 years after afforestation, it may still be recognizable, but will have disappeared after 80 years.
- During the early years following afforestation, there will be a rapid decrease in base saturation. After 40-80 years, the base saturation will fall to the same level as that found in the soils of forest areas that have never been cultivated.
- The composition of exchangeable bases will change because the soils do not more receive Ca^{2+} through liming.

References

Aslyng, H. C. (1978). Miljø og Jordbrug. DSR, København.

Barrensø, B. (1987). En foreløbig kortlægning af tilplantede landbrugsarealer i dette århundrede. Marginaljorde og miljøinteresser. Miljøministeriet, Skov- og Naturstyrelsen, København.

Bergkvist, B. (1987). Leaching of metals from forest as influenced by tree species and management. Forest Ecology and Management 22:29-56.

Dansk Meteorologisk Institut (DMI) (1961). Danmarks klima 1931-61. DMI meddelelser nr. 19.

Fiedler, H. J. & Hunger, W. (1989). Charactersierung von Braunerden unter Laub- und Nadelwald im Czornebohgebiet. Arch. Nat. Schutz. Landsch. Forsch., Berlin.

Herbauts, J. & de Buyl, E. (1981). The relation between spruce monoculture and incipient podzolisation in ochreous brown earths of the Belgian Ardennes.

Holmsgaard, E., Holstener-Jørgensen, H. & Yde-Andersen, A. (1961). Jordbundsdannelse, tilvækst og sundhedstilstand i rødgranbevoksninger af første og anden generation. Det Forstlige Forsøgsvæsen 27:145-149.

Jensen, Kr. M. (1976). Opgivne og tilplantede landbrugsarealer i Jylland (English and German Summary). Atlas over Danmark, serie II, bd. 1, C. A. Reitzel, København.

Larsen, J. B. (1971). Podsoludviklingshastigheden. Kgl. Vet.- og Landbohøjskole, København.

Madsen, H. B. & Jensen, N. H. (1988). Vejledning til beskrivelse af jordbundsprofiler. Landbrugsministeriets Arealkontor, Vejle.

Madsen, H. B., Reenberg A. & Holst, K. A. (1990). Mapping potentially marginal land in Denmark. Soil use and management 6:114-120

Mehra, O. P. and Jackson, M. L. (1958). Iron oxide removal from soils and clays by a dithionite citrate system buffered with sodium bicarbonate. Clays and Clay Minerals. Monograph No. 5. Earth Science Series. Proc. 7th Nat. Conf. Clays and Clay Min., p.317-327. Pergamon Press, New York, 1960.

Møberg, J. D., Petersen, L. & Borggaard, O. K. (1987). Geologi og Jordbundslære - Pedologiske analyser. Kgl. Vet.- og Landbohøjskole, DSR København.

Raulund-Rasmussen, K. & Petersen, L. (1987). Arealanvendelse og jordbundsudvikling. Marginaljorde og Miljøinteresser. Miljøministeriet, Skov- og Naturstyrelsen, København.

Sohet, K., Herbauts, J. & Gruber, W. (1988). Changes caused by Norway Spruce in ochreous brown earth, assessed by iso quartz method.Journal of Soil Science 39:549-561.

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References

Aslyng, H. C. (1978). Miljø og Jordbrug. DSR, København.

Barrensø, B. (1987). En foreløbig kortlægning af tilplantede landbrugsarealer i dette århundrede. Marginaljorde og miljøinteresser. Miljøministeriet, Skov- og Naturstyrelsen, København.

Bergkvist, B. (1987). Leaching of metals from forest as influenced by tree species and management. Forest Ecology and Management 22:29-56.

Dansk Meteorologisk Institut (DMI) (1961). Danmarks klima 1931-61. DMI meddelelser nr. 19.

Fiedler, H. J. & Hunger, W. (1989). Charactersierung von Braunerden unter Laub- und Nadelwald im Czornebohgebiet. Arch. Nat. Schutz. Landsch. Forsch., Berlin.

Herbauts, J. & de Buyl, E. (1981). The relation between spruce monoculture and incipient podzolisation in ochreous brown earths of the Belgian Ardennes.

Holmsgaard, E., Holstener-Jørgensen, H. & Yde-Andersen, A. (1961). Jordbundsdannelse, tilvækst og sundhedstilstand i rødgranbevoksninger af første og anden generation. Det Forstlige Forsøgsvæsen 27:145-149.

Jensen, Kr. M. (1976). Opgivne og tilplantede landbrugsarealer i Jylland (English and German Summary). Atlas over Danmark, serie II, bd. 1, C. A. Reitzel, København.

Larsen, J. B. (1971). Podsoludviklingshastigheden. Kgl. Vet.- og Landbohøjskole, København.

Madsen, H. B. & Jensen, N. H. (1988). Vejledning til beskrivelse af jordbundsprofiler. Landbrugsministeriets Arealkontor, Vejle.

Madsen, H. B., Reenberg A. & Holst, K. A. (1990). Mapping potentially marginal land in Denmark. Soil use and management 6:114-120

Mehra, O. P. and Jackson, M. L. (1958). Iron oxide removal from soils and clays by a dithionite citrate system buffered with sodium bicarbonate. Clays and Clay Minerals. Monograph No. 5. Earth Science Series. Proc. 7th Nat. Conf. Clays and Clay Min., p.317-327. Pergamon Press, New York, 1960.

Møberg, J. D., Petersen, L. & Borggaard, O. K. (1987). Geologi og Jordbundslære - Pedologiske analyser. Kgl. Vet.- og Landbohøjskole, DSR København.

Raulund-Rasmussen, K. & Petersen, L. (1987). Arealanvendelse og jordbundsudvikling. Marginaljorde og Miljøinteresser. Miljøministeriet, Skov- og Naturstyrelsen, København.

Sohet, K., Herbauts, J. & Gruber, W. (1988). Changes caused by Norway Spruce in ochreous brown earth, assessed by iso quartz method.Journal of Soil Science 39:549-561.