EFFECT OF THINNING ON THE FORMATION OF HUMUS FORMS ON THE AFFORESTED AGRICULTURAL LANDS*

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Presentation documents the surface humus accumulation process, the dynamics of forest soil restoration and the effect of different forest stand density on the soil revitalization. The plantation of Norway spruce was established in 1965 on the former agricultural land, the thinning experiment following IURFO methods was established in 1971. The accumulation of surface humus and basic soil chemistry characteristics development are described in the period 1993–2002. The control variants are compared with the heavy thinning effects. Surface humus accumulation of 35.52 t/ha (1993) and 48.56 t/ha (2002) was documented on the control variant, for the variants with lower density it varied in the ranges 24.00–25.68 (1993) and 42.66–35.43 t/ha. The forest stand established on the agricultural land accumulates considerable amounts of surface matter (carbon) in holorganic horizons in a relatively very short time. The soils show visible acidification in the period 1993–2002, accelerated in the more dense stands. This is reflected by the pH, base content and base saturation decrease. Also the contents of divalent bases decrease. These processes are caused by higher surface humus accumulation, more intense nutrient uptake and higher acid deposition in the more dense stands.

humus forms; forest soils; afforestation of agricultural lands; accumulation; soil chemistry; thinning; Norway spruce

INTRODUCTION

Afforestation of low production agricultural lands is an important topic in the last years. Forests represent the climax vegetation formation on almost 90% of the Czech territory (Míchal, 1994). In the Czech Republic, the area suitable for reforestation projects is estimated between 50,000 to 500,000 ha. According to the last official estimation, there are 307,202 ha of marginal agricultural land suitable for reforestation, and further 974,980 ha for transformation in the permanent grassland, and 182,075 ha for fishponds establishment (Novák et al., 2003). The abandoned agricultural land extent increases by 25,000–30,000 ha per year since 1990, according to the Ministry of Agriculture it reached 300,000 ha at present (7% of agricultural land – Weger, 2003). The associated topics are also the carbon dioxide fixation from the atmosphere, as well as the use and elimination of nitrogen immissions (Burschell, Weber, 1992; Podrázský, 1998).

The process of forest soils re-formation, organic matter accumulation, soil characteristics development and carbon fixation on reforested agricultural lands are totally not described in the modern literature. Exceptionally, the restoration of forest humus forms is documented on the abandoned agricultural lands (Podrázský, Ulbrichová, 2004), or the surface humus reformation is described on bulldozed plots – in immission areas (Remeš, Podrázský, 2003; Ulbrichová, Podrázský, 2003). Establishing the forest stand under such conditions, soil ecosystem compartment is usually fully neglected. Aim of the presented study is the documentation of the soil status, regeneration of the humus form character and quantification on a typical re-forested site in the Czech conditions.

MATERIAL AND METHODS

The Machov research plot is located on the Forest District Broumov territory, on the former Broumov Enterprise, district Hvězda, stand 403 I. It is Mesosoic part of the Sudetské mezihoří Mts. The research plot is located at the altitude 700 m a.s.l. and it is characterized by the mean year temperature 6 °C, mean year precipitation 800 mm, immission zone 3 and with snow-danger zone 1–2. The Norway spruce stand was established by the planting 2/2 spruce plants on the abandoned agricultural land, of the Cambisol character originally. The forest type group was reconstructed as 5K, acid fir-beech stand and the management group 53 – spruce stands of acid sites of higher elevations (Chroust, 1990). Climatic district was determined as B10, moderately warm, very wet, highland character.

Research plot Machov was established in 6-year old plantation in 1971. Six variants were defined, of size 40 x 24 m in two replications (A, B), three of them were selected for research. The original plantation was established in the spacing 1 x 1 m, the number of trees per 1 ha was approximately 7000 individuals and the height was 1.2 m at the time of experiment beginning, using the

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Table 1. Stand characteristics of particular variants on the plot Machov at the age 15 and 23 years (C h r o u s t, 1990)

Age / Plot	15					23				
Characteristics	N	K	D	H	V	N	K	D	H	V
	inds	m^2/ha	cm	m	m^3	inds	m^2/ha	cm	m	m^3
1 A B	251	1.3	8.1	5.6	4.24	242	3.4	13.3	11.0	19.3
4 A B	251	1.14	7.6	5.5	3.7	122	2.03	15.5	11.6	11.7
6 A B	685	2.29	6.5	5.0	10.7	600	4.41	9.6	9.4	24.3

Data related to the plot

IUFRO methods for a series of experiment throughout Europe (C h r o u s t, 1990).

According to this method, the density was reduced to 2,500 inds/ha on variants 1 to 5, being left for natural mortality and spontaneous development only on variant 6. Thinning programs for variants 1, 4 and 6, selected for our research, are as follows:

1) after reduction to 2,500 inds/ha, the spontaneous development is allowed,
2) first reduction to 1,200 at upper height reached 10 m, second at 20 m (to 900 ids/ha) and third at 22.5 m, reducing the number of ids/ha to 700, simulation of the mechanized treatment,
3) spontaneous dynamics since plantation.

Table 1 documents the taxation characteristics of studied stands at the age 15 and 23 years (C h r o u s t, 1990).

Humus horizon and mineral soil samples were taken on variants 1, 4 and 6, as well as in the neighboring larch stand of the same age in autumn 1993 and 2002 in four replications, in horizons L + F1, F2, H and Ah (G r e e n et al., 1993). Due to formation of new humus form on the surface of agricultural land, the particular horizons were hardly to distinguish (1993). The soil samples were processed in the laboratory of the Research Station Opočno by standard methods: the dry mass of holorganic layers at 105 °C, pH in water and 1 N KCl, soil adsorption complex characteristics by Kappen (S – bases content, H – hydrolytical acidity, T – cation adsorption capacity, V – bases content), plant available nutrients (P, K, Ca, Mg, Fe sesquioxides) contents using AAS in 1% citric acid solution, total nutrients content in holorganic layers using mineralisation by selene and sulphuric acid and AAS and spectrophotometry. Statistical evaluation was applied using analysis of variance at 95% confidence level.

RESULTS AND DICUSSION

The research plot Machov documents the development of humus forms on the re-forested agricultural land, homogenized in the upper part during cultivation. The enrichment in nutrients can be supposed in the same period. The surface humus was totally missing, originating *de novo* since reforestation. Its accumulation in the first decades is documented in Table 2.

In both years, the highest accumulation, statistically significant, was documented on the plot with maximum density (6), in all horizons. In the first year of the sampling (1993), the highest surface humus accumulation was measured on the most dense stand (6A), in both studied horizons. Other two plots did not differ much. After 10 years, the trend was similar among plots: the lowest amount of holorganic horizons was observed on the plot 4A (intensively thinned), higher on the plot 1A (left without treatment after first thinning) and the highest amount on the plot 6A (control plot). The differences reached the extent 13 t/ha, i.e. 25–30%. During the studied period, the further accumulation of the surface organic matter was measured on the afforested agricultural land, reaching 13.14 t/ha (6A), 18.66 t/ha (1A – closing the canopy and creating good conditions for the litter accumulation), and 9.75 (4A – the mostly open with rapid OM /organic matter/ decomposition). The differentiation of the particular holorganic horizons was more visible in the second sampling period. All the stands were without ground vegetation. The density effect was reflected by the statistically significant differences in the surface OM accumulation, the forest stand growing on the reforested agricultural land accumulates considerable amounts of the surface humus in a relatively short time. The neigh-

Table 2. Accumulation of surface humus on particular variants of the Machov experiment

Horizon		$L + F_1$	F_2	$(F_2) + H$	Total
Plot	Year				
6 A	1993	13.38		22.14	35.52
	2002	9.41 a	13.26 a	26.11 b	48.56
1 A	1993	7.98		16.02	24.00
	2002	7.47 ab	10.61 a	24.58 ab	42.66
4 A	1993	10.61		15.07	25.68
	2002	7.22 ab	10.26 a	17.95 a	35.43
Larch	1993				
MD	2002	4.93 a		10.00 a	14.93

Table 3. Soil reaction of humus form layers on particular variants of the Machov experiment

Horizon Plot	Year	L + F_1		F_2		(F_2) + H		Ah	
		pH H_2O	pHKCl	pH H_2O	pHKCl	pH H_2O	pHKCl	pH H_2O	pHKCl
6A	1993	4.42	3.84			3.93	3.36	4.17	3.44
	2002	4.55	3.98 b	3.90 a	3.28 a	3.65 a	2.98 a	3.78 a	3.08 a
1A	1993	4.81	4.01			4.39	3.60	4.30	3.44
	2002	4.88	4.38 c	4.22 ab	3.65 bc	3.85 ab	3.18 b	4.02 b	3.30 b
4A	1993	4.57	3.82			4.29	3.53	3.91	3.37
	2002	4.88	4.28 c	4.38 b	3.72 c	3.88 b	3.25 b	4.00 b	3.08 a
Larch	1993								
MD	2002	4.60	3.55 a			4.15 ab	3.30 ab	3.80 ab	3.25 ab

Table 4. Bases content (S) and hydrolytical acidity (H) of horizons of humus forms on particular variants of the Machov experiment (meqv/100 of fine dry earth)

Horizon Plot	Year	L + F_1		F_2		(F_2) + H		Ah	
		S	H	S	H	S	H	S	H
6A	1993	33.7	21.18			26.5	35.3	7.0	8.9
	2002	32.4 bc	18.3 a	23.5 b	43.2 b	11.5 a	39.4 a	1.8 ab	11.3 bc
1A	1993	35.3	19.0			26.5	29.7	6.4	11.1
	2002	39.2 c	14.4 a	30.2 b	33.8 ab	11.5 a	28.0 b	2.0 ab	9.9 a
4A	1993	27.1	28.9			27.2	31.9	4.3	13.1
	2002	26.6 ab	18.1 a	30.2 b	30.4 a	20.3 b	32.6 b	2.8 b	12.8 d
Larch	1993								
MD	2002	20.2 a	35.6 b			11.2 a	36.2 ab	1.8 ab	12.2 cd

boring European larch stand accumulated ca 1/3 of this amount in a comparable period only.

The differences in the values of the soil reaction were not visible in 1993 (Table 3), only the densest stand showed the highest acidity of the holorganic layers (not significantly). The differences were not obvious in the mineral layers. These tendencies were more prominent in the year 2002 – the pH values of both studied types being significantly lower in the most dense stand. There was trend of pH decrease with increasing stand density (increasing bases uptake, surface organic matter accumulation) in the whole studied profile. The larch litter showed significantly higher acidity, the differences decreasing in lower horizons. In the last decade, the soil reaction decreased by 0.1 to 0.4 pH degree and there is obvious the trend of forest soil acidification continuing to recent years.

The bases content (Table 4) was relatively comparable among variants in 1993, a little lower in the less dense stand. Similar trend was documented only in the uppermost layer in 2002, lower, the S values decreased with increased stand density statistically significantly. The reason could be the same as in the case of the soil reaction, i.e. the increased uptake of bases and higher accumulation of humus necromass. Similar tendency was observed at replacing the less demanding broad-leaves by conifers in different site conditions. The hydrolytical acidity showed opposite trend. The considerable losses of bases can be supposed in the period 1993–2002, as well as the acidification of the observed horizons. From this point of view, the larch plot did not exceed the documented range much, the bases contents were lower and the H values usually slightly higher.

Also the values of the cation exchange capacity were similar among variants in 1993. Also the tendency was not visibly different in 2002, only the slight decrease in the CEC is observed in the period 1993–2002. The bases content was so connected with hydrolytical acidity increase, which was joint with a significant decrease of the base saturation (Table 5). The humus form originated due to transformation of the larch litter showed lower values of the CEC as well as BS in general.

The soils of studied stands, established on the agricultural land, are acidified in the time interval 1993–2002, this trend is intensified by the cultivation of denser stands. This is caused by:

- more prominent accumulation of nutrients fixing litter in the denser stands,
- more intense nutrient uptake by stands with higher density,
- higher acid deposition in stands with higher above-ground biomass (Hruška, Cienciala, 2001).

Table 5. Cation exchange capacity (T – meqv/100 of fine dry earth) and base saturation (V – %) of horizons of humus forms on particular variants of the Machov experiment

Horizon		L + F_1		F_2		(F_2) + H		Ah	
Plot	Year								
		T	V	T	V	T	V	T	V
6A	1993	55.5	60.7			61.8	42.8	16.0	44.0
	2002	50.8 ab	64.0 bc	66.8 b	35.7 ab	51.0 b	22.8 a	13.1 ab	13.8 ab
1A	1993	54.3	65.0			56.2	47.1	17.5	36.6
	2002	53.6 b	73.1 c	64.0 b	47.3 bc	39.4 a	28.0 ab	11.9 ab	16.8 ab
4A	1993	56.0	48.4			59.1	46.0	17.4	24.8
	2002	44.8 ab	59.5 b	60.6 b	50.1 c	52.9 b	17.6 b	15.7 c	17.6 b
MD	1993								
	2002	55.8 b	35.8 c			47.2 a	23.4 a	13.8 bc	12.6 ab

Table 6. Plant available nutrients content in oxidic forms (P_2O_5, K_2O – mg/kg) in substrates of horizons of humus forms on particular variants of the Machov experiment

Horizon		L + F_1		F_2		(F_2) + H		Ah	
Plot	Year								
		P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
6A	1993							93	37
	2002	1243 b	958	463	248 a	165 a	126	137	68
1A	1993							107	37
	2002	1023 ab	1304	334	316 a	189 a	141	124	53
4A	1993							137	31
	2002	888 a	1053	548	383 ab	302 b	182	186	55
MD	1993								
	2002	999 ab	1353			550	766 b	241 c	63

Table 7. Plant available nutrients content in oxidic forms (CaO, MgO – mg/kg) in substrates of horizons of humus forms on particular variants of the Machov experiment

Horizon		L + F_1		F_2		(F_2) + H		Ah	
Plot	Year								
		CaO	MgO	CaO	MgO	CaO	MgO	CaO	MgO
6A	1993							733	97
	2002	10 667a	798	6733 a	342 a	3467 b	196	562 a	96 a
1A	1993							633	87
	2002	11 093 a	899	6533 a	373 ab	2734 a	192 a	393 b	82 a
4A	1993							400	63
	2002	10 933 a	779	7800 a	454 b	3900 b	244 c	468 ab	84
MD	1993								
	2002	7 787 b	738			4266 b	415 ab	430 ab	

The plant available nutrients content was determined for mineral horizons only in 1993. There was not evident difference in the available phosphorus content in the first year of sampling. During the next 10 years, the slight increase of the plant available P content was observed, significantly higher increase was documented in the larch stand and a little lower in the less dense stand (variant 4A). The highest content of this nutrient form was determined in the humus forms (H layer) in the same experiment variants in 2002. The contents were not significantly different in the F2 horizon. In the litter layer, the P content increased with the growing stand density – probably due to slower litter transformation and decomposition. The plant available potassium content was very similar among variants. Considerable increase was observed during the studied period, probably due to transi-

Table 8. Plant available nutrients content in oxidic forms (Fe_2O_3 – mg/kg) in substrates of horizons of humus forms on particular variants of the Machov experiment

Horizon		L + F_1	F_2	(F_2) + H	Ah
Plot	Year				
		Fe_2O_3	Fe_2O_3	Fe_2O_3	Fe_2O_3
6A	2002	200 a	462	924 a	2589 a
1A	2002	151 a	566	1431 c	2142 b
4A	2002	133 a	346	1037 ab	1863 b
MD	2002	659 b	430		1762 b

Table 9. Total nutrients content (P, K – %) in substrates of horizons of humus forms on particular variants of the Machov experiment

Horizon		L + F_1		F_2		(F_2) + H	
Plot	Year						
		P_2O_5	K_2O	P_2O_5	K_2O	P_2O_5	K_2O
6A	1993	0.100	0.064			0.086	0.140
	2002	0.115	0.100 ab	0.092 ab	0.100 a	0.088	0.220 a
1A	1993	0.089	0.099			0.094	0.105
	2002	0.120	0.115 ab	0.102 b	0.015 a	0.105	0.340 b
4A	1993	0.101	0.118			0.086	0.060
	2002	0.110	0.085 a	0.082 a	0.096 a	0.098	0.195 a
MD	1993						
	2002	0.125	0.210 c	0.105 ab	0.220 ab		

Table 10. Total nutrients content (Ca, Mg – %) in substrates of horizons of humus forms on particular variants of the Machov experiment

Horizon		L + F_1		F_2		(F_2) + H	
Plot	Year						
		CaO	MgO	CaO	MgO	CaO	MgO
6A	1993	0.830	0.100			0.420	0.200
	2002	1.315 bc	0.064	0.185 ab	0.054	0.012 a	0.064 ab
1A	1993	0.880	0.113			0.450	0.231
	2002	1.330 bc	0.067	0.330 ab	0.062	0.020 b	0.076 b
4A	1993	0.450	0.177			0.400	0.187
	2002	1.550 c	0.065	0.550 bc	0.064	0.020 b	0.056 a
MD	1993						
	2002	0.210 a	0.073	0.020 a	0.068 b		

tion of the stands from the intensively growing thickets to more mature stands with equilibrium between decomposition, release and uptake of nutrients.

The plant available calcium and magnesium contents were growing with increasing stand density in 1993 in the mineral Ah horizons, in the less dense stands, the decrease was faster. Similar tendencies were documented in 2002, despite the differences between variants 1A and 4A were minor. The larch was not leaving the limits marked by spruce stands. The situation was different in the holorganic horizons. In the larch stand, the contents were higher with the exception of the litter (but F2 horizon was split between L and H layers, so H-contents were affected by this sampling difference. In the spruce stands, the statistically significant difference did not correlate with the stand density.

The Fe-sesquioxide content in the citric acid solution was determined in 2002 only. It increased with the depth of particular horizons. In the litter and fermentation layers, it was the highest in the larch stand, not significantly it was higher also in the densest variant (6A). In lower holorganic horizons, the differences were not clearly ordinated. In the mineral soil, the iron contents increased with the spruce stand density, the soil from the larch stand showing the lowest content.

The total phosphorus content was very similar among variants in 1993, no trend was visible owing to particular variants. Any profound changes were not observed until

2002, the values were slightly higher in general, the same was documented in the larch stand. The total potassium contents showed different tendency (increase with the density decrease) in the upper studied holorganic horizon (L + F1) comparing to the lower one (F2 + H – content decrease with the density decrease). An increase in the period 1993–2002, despite statistically significant differences without clear trend among variants was documented. Under larch, the total K contents were higher in general.

The total calcium content showed clear trend of decrease on the less dense plot which was heavily thinned. This tendency was just opposite to the situation in 2002. The contents were very high in the litter layers this year, this may be caused by liming of neighbouring agricultural lands. Much higher decrease was documented in lower horizons.

Also in the case of the total magnesium content, the increase with lower density was observed in 1993, no clear trends were described in 2002. Considerable decrease was obvious between both sampling years. The humus quality under larch did not differ much from the situation in the Norway spruce stands.

CONCLUSIONS

The effects of the thinning treatments were much more visible on the afforested agricultural lands compared to the continually forested sites. The density effect was reflected statistically significantly by the amount of the surface humus. The forest stand, which is established on the former pasture, accumulates considerable amounts of the organic matter (carbon) in the holorganic horizons during relatively short time. The studied soils of coniferous tree species show obvious tendency to the acidification in the period 1993–2002, which trend is intensified by the cultivation of denser stands. This is reflected by the pH values decrease, bases content decrease and the base saturation decreases as well. Also the content of divalent cations in the soils is lowered. This can be caused by:

- higher accumulation of litter in denser stands, its slower transformation and mineralization,
- more intense nutrient uptake by more dense stands,
- higher values of acid litter in those stands.

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Vliv výchovných zásahů na vznik humusových forem na zalesněné zemědělské půdě.
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Předkládaná práce dokumentuje proces akumulace nové vrstvy nadložního humusu na zalesněné zemědělské půdě, vlastní proces tvorby lesní půdy a vliv různé hustoty porostu na tuto půdní revitalizaci. Kultura smrku ztepilého byla založena v roce 1965. V roce 1971 byly podle metodiky IUFRO založeny různé varianty výchovy porostů. Srovnáván je proces akumulace nadložního humusu a vývoj základních charakteristik půdního chemismu v letech 1993 a 2002 na variantách kontrolních a na silně probírané ploše. Na kontrolní variantě byla doložena akumulace 35,52 t/ha (1993) a 48,56 t/ha, na variantách s nižší hustotou bylo dokumentováno 24,00–25,68 t/ha (1993) a 42,66–35,43 t/ha. Porost založený na zemědělské půdě akumuluje značná množství organické hmoty (uhlíku) v holorganických horizontech během dosti krátké doby. Půdy sledovaných porostů konifer ukazují v období 1993 až 2002 vesměs patrnou tendenci acidifikace, která je zesilována pěstováním hustších porostů. Projevuje se to poklesem hodnot pH, obsahu bází a nasycení sorpčního komplexu bázemi. Rovněž obsah dvoumocných kationtů v půdách klesá. To je zapříčiněno větší akumulací opadu v hustších porostech, intenzivnějším odběrem bází hustšími porosty a vyšším kyselým spadem v hustších porostech.

humusové formy; lesní půdy; zalesněné zemědělské půdy; akumulace; půdní chemismus; výchova porostů; smrk ztepilý

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