Restoration of forest soils on reforested abandoned agricultural lands

V. V. PODRÁZSKÝ, I. ULBRICHOVÁ

Faculty of Forestry and Environment, Czech University of Agriculture, Prague, Czech Republic

ABSTRACT: Restoration of forest soil character after the change of agricultural land use has not been studied yet despite the large areas reforested since the late 40ies of the last century. This process takes place throughout Europe to an increasing extent at present. The reformation of forest soils was studied in the area of Český Rudolec town: Natural Forest Area 16 – Czech-Moravian Uplands, altitude 600–630 m a.s.l., bedrock is built of granites and gneisses, soil type is Cambisol, forest site type 5K1. The process of restoration of a new humus form was analysed in plantations of American red oak (*Quercus rubra*), Swedish birch (*Betula pendula*), European larch (*Larix europea*) and Norway spruce (*Picea abies*), the site was homogeneous. The particular tree species accumulated 12.81, 13.81, 46.57 and 44.76 t/ha of surface organic matter during the last 30–40 years, these values are typical of forest sites at lower and middle altitudes and corresponding tree species composition. The effect of broadleaved species and conifers was markedly different, in the first case pH in KCl ranged 3.8–3.9 (mineral soil) and 3.5–5.2 (holorganic horizons), being 3.5–3.8 (mineral soil) and 3.1–5.1 (holorganic layers) for the conifers. Visible effects of the particular tree species were also evident in the soil adsorption complex and in the contents of plant available and total nutrients. The results can be summarised and generalised: – the forest soil character is reformed at lower and middle altitudes in a relatively short time from the aspect of surface humus accumulation and basic soil chemistry (30–40 years), – birch exhibited the best revitalisation effect among the studied species, – American red oak and Norway spruce humus accumulation potentials were different although the soil chemistry was comparable, – Norway spruce did not show a remarkable degradation effect until now, – on the contrary, European larch appeared as a site degrading species.

Keywords: afforestation; agricultural land; soil restoration; species composition; humus forms; litter formation

Reforestation of abandoned agricultural lands is an urgent issue of landscape management in marginal areas. A decrease in agricultural production as well as the loss of agriculture profitability called for projects concerning the change in land use. Large plantation programs for landscape forming and conserving functions are funded throughout Europe in some cases, as an alternative to the non-profitable and expensive conservation of agricultural land use. Intensive forestry use is considered economically and environmentally more desirable because of the more natural character of forest ecosystems compared to the agro-ecosystems. Forests represent the climax vegetation formation on almost 90% of the Czech territory (MÍCHAL 1994). In the Czech Republic, the area suitable for afforestation projects is estimated between 50,000 to 500,000 ha. The area of abandoned agricultural land has increased by 25,000–30,000 ha per year since 1990, according to Ministry of Agriculture it reaches 300,000 ha at present (7% of agricultural land – WEGER 2003). The associated problems are also the carbon dioxide fixation from the atmosphere as well as the use and elimination of nitrogen deposition (BURSCHELL, WEBER 1992; PODRÁZSKÝ 1998).

Restoring the forest ecosystem, forest soil reformation and restoration including the typical energy flow and matter turnover is a relatively unknown problem. The origin of humus forms as for their quality and quantity has not been described. The aim of the presented study is the documentation of forest soil re-creation dynamics in concrete conditions of the Český Rudolec area using different tree species and description of the process by quantitative as well as qualitative parameters.

MATERIAL AND METHODS

Site. The studied plots are located in the territory of Český Rudolec Forest District, in Forest Natural Area 16 Českomoravská vrchovina (Czech-Moravian Uplands). The climate is of upland character, but the terrain is flat, the altitude ranges between 600 to 630 m above sea level. The geological bedrock is built of volcanic (granite) and metamorphic acid (gneiss, para-gneiss) rocks, poor in

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Table 1. Surface humus accumulation in stands of particular tree species (t/ha)

Tree species	Red oak	Swedish birch	Norway spruce	European larch
L + F_1	1.49	1.65	6.52	8.92
F_2	4.36	4.12	16.84	13.49
H	6.96	8.04	21.40	24.16
Total	**12.81**	**13.81**	**44.76**	**46.57**

nutrients. As a result of pedogenesis, oligotrophic and oligo-mesotrophic Cambisols developed. These plots – forest stands were studied: of American red oak (*Quercus rubra*), Swedish birch (*Betula pendula*), European larch (*Larix europea*) and Norway spruce (*Picea abies*). Site character was the same – forest site type was determined as 5K1 (acid fir-beech or *Abieto-Fagetum* sites), age of 28–37 years.

Sampling and analyses. Samples of humus forms were collected using a square iron frame 25 × 25 cm in 4 replications. Particular holorganic layers of surface humus and Ah horizons were sampled (GREEN et al. 1993): L, F, H, Ah, and also B horizon. The mineral horizons were not sampled quantitatively. Two layers were distinguished in the F horizon according to their transformation stage and character: F_1 was sampled together with the L layer and F_2 together with H, when more detailed separation was not possible due to the low layer thickness. Bulk samples were taken directly in the field from particular horizons for sample processing, which was carried out in a laboratory in the Forest and Game Management Research Institute, Opočno Research Station (Tomáš Co. Laboratory), using standard (for decades) analytical procedures. These characteristics were determined and analysed: amount of dry mass of holorganic horizons, texture of mineral soil samples with Kopecký's apparatus, pH in water and 1 N KCl, soil adsorption complex according to Kappen (S – base content, T – cation exchange capacity, H – hydrolytical acidity, V – base saturation), total nitrogen according to Kjeldahl, total humus content according to Springer-Klee, total exchange acidity and its components (exchangeable Al and

Table 2. Soil reaction and adsorption complex characteristics in stands of particular tree species

Horizon	pH H_2O	pH KCl	S	H	T	V
			(mval/100 g)			(%)
American red oak						
L + F_1	5.6	4.9	43.3	17.3	60.6	71.5
F_2	5.7	4.8	51.7	22.9	74.6	69.3
H	5.3	4.5	30.2	18.0	48.2	62.6
Ah	5.4	3.5	4.1	9.2	13.3	30.9
B	5.8	3.9	2.2	5.7	7.9	28.1
Swedish birch						
L + F_1	6.0	5.2	57.2	13.3	70.5	81.2
F_2	6.1	5.2	59.2	17.0	76.3	77.7
H	5.8	4.8	44.9	17.0	62.0	72.5
Ah	5.2	3.7	6.8	9.8	16.6	41.1
B	5.9	3.8	1.1	5.8	6.9	15.7
Norway spruce						
L + F_1	6.3	5.1	41.8	13.3	55.1	75.9
F_2	5.5	4.3	29.4	24.4	53.7	54.7
H	5.4	3.9	19.0	23.3	42.3	44.8
Ah	5.3	3.6	6.4	13.6	20.1	32.1
B	5.7	3.8	2.9	7.3	10.2	28.3
European larch						
L + F_1	4.9	3.8	37.1	36.5	73.6	50.4
F_2	4.9	3.2	30.4	57.0	87.3	34.8
H	5.0	3.1	13.2	47.7	60.9	21.7
Ah	5.0	3.2	3.2	11.1	14.3	22.6
B	5.5	3.5	3.5	7.3	10.8	32.2

Table 3. Total humus, nitrogen and exchangeable acidity content in soil horizons of particular stands of different tree species

Horizon	Humus (%)	$Acidity_{ex}$	H_{ex}	Al_{ex}	Nitrogen (%)
		(mval/1,000 g of fine earth)			
American red oak					
$L + F_1$	55.8	35.7	17.4	18.3	1.34
F_2	53.5	18.0	11.0	7.0	1.86
H	39.7	13.6	6.5	7.1	1.08
Ah	6.2	38.3	1.5	36.8	0.29
B	2.9	40.9	1.5	39.4	0.13
Swedish birch					
$L + F_1$	52.8	21.0	12.7	8.3	1.49
F_2	59.6	19.0	14.7	4.3	1.82
H	48.7	11.3	7.8	3.5	1.51
Ah	8.4	29.0	1.7	27.3	0.39
B	2.8	39.6	1.3	38.3	0.14
Norway spruce					
$L + F_1$	53.8	17.0	14.1	2.9	1.57
F_2	46.8	13.0	4.2	8.8	1.44
H	34.9	31.0	3.2	27.8	1.18
Ah	13.9	51.6	1.5	50.2	0.57
B	5.6	37.1	1.3	35.8	0.27
European larch					
$L + F_1$	56.3	12.7	6.1	6.6	1.71
F_2	74.2	18.7	9.1	9.6	1.62
H	42.7	35.4	6.3	29.1	1.12
Ah	6.1	50.0	1.5	48.5	0.29
B	4.3	40.0	1.4	38.7	0.18

H), plant available nutrients in 1% citric acid solution, total nutrients using AAS after mineralisation in sulphuric acid and selenium. Analytical methods used for a long time were applied to enable comparison with older results from other plots.

Statistical analysis was not possible due to the used method of bulk samples. The number of four replications for sampling is on the lowest limit of statistical representativeness (Podrázský 1993).

RESULTS AND DISCUSSION

Research results are summarised in Tables 1 to 6. The first of them documents humus accumulation in the stands of particular tree species. Higher accumulation was observed in coniferous stands (ca. 3.5 times), the values for the particular broad-leaved species did not differ substantially nor for both coniferous species (Table 1). Accumulation reached the level typical of forest ecosystems of lower and middle altitudes (Podrázský et al. 2001a, 2002), including the characteristic differences between stands of variable species composition. The amount of surface humus, representative of stands in the given natural conditions, was formed in a relatively very short period (30–40 years). The basic characteristics of soil chemistry also showed the values and soil profile dynamics that are characteristic of forest soils in similar site conditions and with similar species composition (Table 2). On the other hand, the humus accumulation was considerably lower and the pedochemical characteristics more favourable compared to forest stands at higher altitudes (Podrázský, Souček 1995; Podrázský 1998). No data on reforestation of agricultural lands presented by other authors are available.

Dynamics of soil chemical characteristics showed the changes and trends typical of forest soils, i.e. a decrease in pH in horizons of surface humus with increasing depth, further decrease in mineral A horizons, values corresponding to meso- to oligotrophic Cambisols. All sites showed the trends of pH value increase in B horizons. An exception was observed on the larch plot, where the values of mineral horizons were higher compared to surface humus. At the same time, pH was much lower compared to other species including the Norway spruce. Particular horizons in the birch stand showed the most favourable level of the soil pH.

In the birch stand the state of the soil adsorption complex (values S, H, T, V) was best, stands of red oak, spruce and larch followed. Differences are marked especially in

Table 4. Content of plant available nutrients (1% citric acid) in soils of particular tree species stands (mg/1,000 g of fine earth)

Horizon	P_2O_5	K_2O	CaO	MgO	Fe_2O_5
American red oak					
L + F_1	1,421	2,267	6,720	1,637	43
F_2	840	1,253	9,387	1,085	48
H	629	613	6,667	685	219
Ah	111	190	387	75	619
B	107	90	173	29	535
Swedish birch					
L + F_1	1,684	3,293	7,467	2,267	24
F_2	1,057	2,200	9,067	1,672	40
H	764	1,053	8,507	1,173	309
Ah	192	208	407	113	927
B	138	82	60	26	753
Norway spruce					
L + F_1	541	933	9,787	747	77
F_2	417	347	5,733	413	285
H	367	280	3,227	277	488
Ah	126	87	267	80	773
B	85	57	173	59	561
European larch					
L + F_1	569	700	5,627	589	35
F_2	295	260	4,587	437	117
H	267	120	2,667	272	475
Ah	266	75	87	44	851
B	236	53	53	30	725

the holorganic horizons, mostly determined by the tree species litter quality.

Humus content (correspondingly total carbon content) in holorganic horizons did not show any significant differences between particular stands, a little higher humus content was observed in the corresponding horizons in the larch stand, indicating probably the slower transformation process. No differences were observed in the mineral horizons.

Table 5. Total nutrient content in holorganic horizons of stands of particular tree species (%)

Horizon	N	P	K	Ca
American red oak				
L + F_1	1.17	0.29	0.32	1.16
F_2	1.79	0.42	0.22	1.16
H	0.97	0.25	0.30	0.44
Swedish birch				
L + F_1	1.48	0.21	0.38	1.08
F_2	1.69	0.25	0.28	1.06
H	1.53	0.29	0.34	0.60
Norway spruce				
L + F_1	1.43	0.15	0.12	1.36
F_2	1.50	0.15	0.18	0.56
H	1.14	0.13	0.36	0.14
European larch				
L + F_1	1.54	0.24	0.12	0.48
F_2	1.46	1.14	0.08	0.34
H	1.01	0.13	0.36	0.14

Table 6. Granulometric composition of mineral horizons in stands of particular tree species (grain size in mm/content in %)

Horizon	2–0.25	0.25–0.05	0.05–0.01	0.01–0.001	Below 0.001
American red rak					
Ah	39.88	17.22	23.99	12.05	6.86
B	33.02	14.56	23.92	17.57	10.94
Swedish birch					
Ah	34.46	11.05	28.67	15.70	10.13
B	30.86	14.05	25.12	17.40	12.58
Norway spruce					
Ah	32.81	12.73	35.00	12.52	6.94
B	26.28	14.28	33.06	19.32	7.06
European larch					
Ah	41.44	20.88	14.66	14.66	8.36
B	41.42	19.23	15.91	15.72	7.72

The lowest total nitrogen content was documented in the American red oak stand, being a result of intensive uptake and high nitrogen requirement of this species. An opposite situation was observed in the birch stand (Table 3), which means lower relative requirements of the pioneer species and extensive use of the environment (BURTON et al. 2003).

Exchangeable acidity characteristics (total ex. acidity, ex. H and Al) were lower in the uppermost holorganic layers of the broadleaved species (Table 3). In the H horizon, and in the mineral horizon A, the situation was opposite – lower transformation degree in the surface horizon and higher acidity in more transformed layers of the conifers is a reason for this. The status is similar in the B horizons of all sites.

Very marked were differences in the content of plant available nutrients in 1% citric acid solution (Table 4). In the holorganic horizons, contents of all studied macroelements were highest under the birch stand, documenting ameliorative effects of this pioneer species at similar sites (PODRÁZSKÝ 2001), as well as its pioneer character and soil-conservation function (BURTON et al. 2003). Available phosphorus content of mineral horizons was the highest in the larch stand, indicating both lower requirements of this species and acidifying, P extricating environment (lowest pH – ŠÁLY 1978). As for bases, the contents were highest in the birch stand again, the lowest on the larch plot. A very similar situation in stands of different species composition was also documented in other evaluated localities/experiments (PODRÁZSKÝ et al. 2001b, 2002).

Total nutrient content was analysed only in the holorganic horizons (Table 5). As for nitrogen, the highest values were documented for birch again, no differences were observed between the other species. Surprising was the situation in the Norway spruce stand, showing relatively high contents. On the contrary, the total P-content was the lowest there, but with similar value like for other species. High total as well as available P contents were documented in the soil of larch stand again. This trend is probably species-specific and it was also documented on other plots (PODRÁZSKÝ et al. 2001b, 2002).

In the less transformed horizons, higher potassium contents were observed in the soil horizons of broad-leaved stands, the situation did not differ much between the H horizons. Total calcium content was lower in the case of conifers, especially of the larch.

There were not any significant differences in the granulometric composition (texture) of mineral horizons between stands/sites of particular tree species, plots can be considered as homogeneous sites (Table 6). The results possess a high level of representativeness as for the site homogeneity. There are not any comparable results in the Czech literature and our results can be considered as the first preliminary data.

CONCLUSIONS

The results of this research documented the process of forest soil restoration on the abandoned agricultural land. This knowledge is considerably missing at present. The following conclusions can be generalised from our research results:

- Amount and morphology of surface humus (holorganic horizons) were formed as corresponding to forest soils in local conditions during the last 28–37 (30–40) years.
- The soil chemistry is also typical of forest soils in comparable site conditions, as well as the dynamics of pedochemical characteristics in the studied profile.
- Birch was demonstrated as a species with most marked ameliorative effects, the soil in birch stand showed the character considered as the most favourable.
- American red oak at the relatively rich site showed rather a soil conserving than soil amelioration effect, effects of high nutrient uptake by this species were visible.
- Soil degradation effect of the Norway spruce was not demonstrated, nutrient and organic matter cycling did not result in high soil degradation.

– European larch in the studied conditions, on the contrary, affected the soil chemistry and organic matter cycles negatively.

Several recommendations could be derived from these results for the forestry practice and landscape management:
– on reforested agricultural lands, relatively rich in nutrients, more demanding tree species prevent larger nutrient losses, forming efficient nutrient cycles,
– mixed stands should be established, more effectively using the soil profile and nutrient spectrum,
– the tree species with demonstrated soil degradation effects also have to be cultivated in mixtures,
– in this case the more effective use of nutrient pool is assured and soil degradation is prevented. Productive but environmentally effective forest stands would be established and managed.

References

BURSCHELL P., WEBER M., 1992. Der Wald als CO_2-Senke. Energiewissenschaftliche Tagesfragen, *42*: 273–286.

BURTON P. et al. (eds.), 2003. Towards sustainable management of the boreal forest. National Research Council of Research Press. Ottawa, Ontario, Canada: 1039.

GREEN R., TROWBRIDGE R.L., KLINKA K., 1993. Towards a Taxonomic Classification of Humus Forms. Forest Sci., *39*, Monograph 29: 1–49.

MÍCHAL I., 1994. Ekologická stabilita. Brno, Veronica: 275.

PODRÁZSKÝ V., 1993. Zhodnocení půdní reakce (pH) jako ukazatele stavu lesních půd z hlediska statistické analýzy. [Práce PGS.] Praha, FF UK: 43.

PODRÁZSKÝ V., 1998. Akumulace uhlíku v lesních ekosystémech – příklad smrkových a bukových stanovišť ve vyšších polohách. Lesnictví-Forestry, *44*: 392–397.

PODRÁZSKÝ V., 2001. Půdotvorná funkce porostů náhradních dřevin. In: Krajina, les a lesní hospodářství. I. Konf. 22.–23. 1. 2001, Kostelec n. Černými lesy. Praha, ČZU: 129–145.

PODRÁZSKÝ V., SOUČEK J., 1995. Akumulace humusu a jeho kvalita na bukových stanovištích v oblasti Rýchor (Krkonoše). Commun. Inst. For. Bohem., *18*: 47–58.

PODRÁZSKÝ V., POLENO Z., REMEŠ J., 2001a. Vliv porostů listnatých dřevin na stav humusových forem v podmínkách nižších poloh. In: Krajina, les a lesní hospodářství. I. Konf. 22.–23. 1. 2001, Kostelec n. Černými lesy. Praha, ČZU: 18–23.

PODRÁZSKÝ V., REMEŠ J., LIAO C.Y., 2001b. Vliv douglasky tisolisté (*Pseudotsuga menziesii* /Mirb./ Franco) na stav humusových forem lesních půd – srovnání se smrkem ztepilým. Zpr. Lesn. Výzk., *46*: 86–89.

ŠÁLY R., 1978. Pôda – základ lesnej produkcie. Bratislava, Akademia: 235.

WEGER J., 2003. Biomasa pro energetické využití. Lesn. Práce, *82*: 34–36.

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Obnova charakteristik lesních půd na zalesněných opuštěných zemědělských půdách

V. V. Podrázský, I. Ulbrichová

Fakulta lesnická a environmentální, Česká zemědělská univerzita v Praze, Praha, Česká republika

ABSTRAKT: Práce dokumentuje rychlost obnovy lesních půd na zalesněné zemědělské půdě v oblasti Českého Rudolce (přírodní lesní oblast 16, Českomoravská vrchovina, 600–630 m n. m., podloží žuly a ruly, půdní typ kambizem, lesní typ 5K1). Byl studován proces vytváření humusové formy a stav půdního chemismu v porostech: dubu červeného (*Quercus rubra*), břízy bradavičnaté (*Betula pendula*), modřínu evropského (*Larix europea*) a smrku ztepilého (*Picea abies*). Stáří porostů se pohybovalo v rozmezí 30–40 let, za toto období akumulovaly odpovídající množství nadložního humusu (pro nižší polohy), také půdní chemismus vykazoval dynamiku typickou již pro lesní půdy. Výrazně rozdílně se projevil vliv listnáčů a jehličnanů, bříza vykazovala meliorační vliv, dub červený spíše konzervační působení. Smrk na rozdíl od modřínu dosud nepůsobil výraznou degradaci půdy.

Klíčová slova: zalesňování; zemědělské půdy; obnova půd; druhové složení; humusové formy; tvorba opadu

Rychlost obnovy charakteru lesních půd po zalesnění zemědělsky využívaných ploch byla sledována minimálně – příspěvek představuje jedno z prvních sdělení. Plochy byly studovány v oblasti Českého Rudolce: přírodní lesní oblast 16, Českomoravská vrchovina, nadmořská výška 600–630 m, podloží žuly a ruly, půdní typ kambizem, lesní typ 5K1. Byl studován proces vytváření humusové formy a stavu půdního chemismu v porostech: dubu červeného (*Quercus rubra*), břízy bradavičnaté (*Betula pendula*), modřínu evropského (*Larix europea*) a smrku ztepilého

(*Picea abies*). Stanoviště bylo pro všechny porosty velice homogenní. Jednotlivé dřeviny akumulovaly v období 30–40 let 12,81, 13,81, 46,57 a 44,76 t/ha povrchového humusu, hodnoty již byly typické pro lesní půdy nižších poloh, výrazně se odlišovalo působení listnáčů a konifer. Půdní reakce potenciální se pohybovala pro listnáče v rozmezí 3,8–3,9 (minerální půda) a 3,5–5,2 (organické horizonty) a pro jehličnany v rozsahu 3,5–3,8 a 3,1–5,1. Patrný vliv jednotlivých dřevin se objevil i v charakteru sorpčního komplexu a v obsazích přístupných i celkových živin. Výsledky šetření lze obecně uzavřít: z hlediska sledované akumulace nadložního humusu a pedochemických charakteristik se vytváří charakter lesní půdy v nižších a středních polohách do 30–40 let, bříza má nejpříznivější vliv na stav půd, rozdíly mezi smrkem a dubem červeným byly spíše v množství akumulace než v melioračním (půdotvorném) efektu, smrk dosud nepůsobil výrazně degradačně na rozdíl od modřínu evropského.

Corresponding author:

Prof. Ing. VILÉM V. PODRÁZSKÝ, CSc., Česká zemědělská univerzita v Praze, Fakulta lesnická a environmentální,
165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 383 403, fax: + 420 220 923 132, e-mail: podrazsky@lf.czu.cz