JOURNAL OF FOREST SCIENCE, *52*, 2006 (1): 1–12

Soil aspects of forest site revitalization after windrow cultivation by heavy mechanization on the Krušné hory Mts. Plateau

D. Vavříček, P. Šimková, P. Samec, P. Formánek

Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry Brno, Brno, Czech Republic

ABSTRACT: The reflection of soil properties in the health condition of forest stands is connected with synergy of stressors that influence the forest existence. In the Krušné hory Mts. (Czech Republic, Europe) methods of full-area site mechanized preparation before reforestation were applied on existing ecotopes of the air polluted clear-cut area and the uniform relief of windrows was established. The hypothesis whether the soil in the windrows could be directly used for local cultivations as a substrate suitable for forest tree species growth was examined. The influence of three machines (digger, bulldozer and cultivator) used for the windrow cultivation was monitored in relation to soil properties. The state of the properties of prepared sites was compared with retained windrows and control plots with scarification. The effects of mechanized soil preparation before reforestation were different according to the concrete ecological factors of the given sites. The influences of individual means of mechanization on concrete soil properties were determined as locally differentiated. The windrow cultivation led to an increase in cation exchange capacity (*CEC*) especially due to an increase in Ca^{2+} and Mg^{2+} content. Locally it led to the stabilization of $N\text{-}NH_4^+$ content. The optimization of soil physical properties was connected with the state of C_{ox}. The mechanized windrow cultivation did not optimize either C/N ratio or maximum capillary capacity (Θ_{MCC}) or porosity (p). The mechanized windrow cultivation in the conditions of decreased air pollution load generally appears as a good technology for revitalization of degraded sites because it provided more optimal trophic conditions for the forest tree species growth than windrows or sites with completed scarification.

Keywords: Krušné hory Mts.; topsoil horizon; site preparation; bulk density; humus

Trophic factors of forest soils indicate spatial and temporal differentiation. Their reflection in the health condition of forest stands is connected with synergy of stressors that influence the forest existence. The most important changes in the forest tree nutrition were observed especially in regions heavily affected by air pollution depositions (Purdon et al. 2004). The Krušné hory Mts. (338–1,244 m a.s.l.; +5.5 to +2.7°C, 900–1,200 mm) (Culek 1996) are a region where in 1970–1977 air pollution caused a fast decrease of forest cover percentage (23.9%). In 1975–1977 forest stand damage was also initiated on a large area in the territory of the Czech Republic (Vacek 1996; Schwarz 1997). Temperature fluctuations during the winter 1978/1979 were the starting event for subsequent long-term forest decline and forest stand dieback on large areas in many European regions. The last extensive direct forest stand damage by SO_2 was observed in the Krušné hory Mts. on an area larger than 10,000 ha in 1996 (Bridges et al. 2002). This situation was also influenced by unfavourable meteorological impacts that led to a long-term accumulation of air pollution in the ridge part of the mountain range. The last period of significant forest damage in the Czech Republic was from 1991 to 1994 characterized by dry climatic episode.

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6215648902.

The forest dieback was followed by efforts aimed at forest reconstruction. The Krušné hory Mts. plateau provided ideal conditions for the application of forest site mechanized preparation. Soil scarification was done by diggers and bulldozers for the preparation of sites for forest regeneration, soil horizons relatively unaffected by air pollution were denuded and the uniform relief of windrows was created. The environment of windrows enabled to make a fast progress of reforestation (and also repetitively) and to apply chemical amelioration (Podrázský et al. 2001). Mechanized devastation of the natural ecotope led to topsoil horizon degradation and risky humus losses (Jirgle 1983; Kubelka 1992; Vavříček, Šimková 2004). Changes in the substance fluxes resulting from chemical amelioration led to temporary progressive degradation of forest types (cf. Smolander et al. 2000; Olsson, Kellner 2002; Vavříček, Šimková 2004). The mixed material of windrows (Table 1) became an important source of available mineral nutrients and N_t on these sites and an environment with optimal values of C/N ratio. Organic matter fermentation in windrows became a process ensuring the creation of optimal conditions for plant nutrition with only minimal immobilization of nitrogen (Vavříček 2003).

MATERIAL AND METHODS

The Krušné hory Mts. are a marked fault elevation of the Saxothuringian Zone of Bohemian Massif. They are mainly built of parametamorphites (phyllites) and migmatites. Three sites were selected in the territory of Klášterec nad Ohří forest district: Špičák working-plan area (185A 2); Nádraží working-plan area (418B 2) and Suchdol working-plan area (403E 2). On these sites individual field plots (FPs) were specified after windrow cultivation. For the specification of elementary FP, the concrete technological method of cultivation of previous windrow by heavy machinery was essential (Vavříček et al. 2005). The state of soil physical properties, sorption complex, available mineral nutrients and humus substances were observed on plots after windrow preparation by digger, bulldozer or cultivator. The state of properties of the cultivated sites was compared with original retained windrows (W) and control plots (CP) with completed scarification. The selected sites are situated on the Krušné hory Mts. plateau at the elevation of 880–890 m a.s.l. where zonal soils are represented especially by Haplic Podzols (Šimková, Vavříček 2004a,b; Vavříček 2003). The potential vegetation on these sites generally corresponds to the associations *Calamagrostio-villosae Piceetum* and *Sphagno-Piceetum* (Culek 1996; Neuhäuslová et al. 1998). Site 185A 2 is characterized by northern exposition and forest type group (FTG) 7K (*Fageto-Piceetum acidophilum*). Site 418B 2 is characterized by southern exposition and FTG 7K. Site 403E 2 is characterized by its southern exposition and FTG 6S (*Piceeto-Fagetum mesotrophicum*) (LHP 1999–2008, unpubl.).

Nine sampling places were regularly established on each FP, left W and CP. Chemical and physicochemical soil properties were determined on the basis of composite samples. The soil samples were situated into topsoil horizons. Terrain research was conducted during the growing season 2004. The determination of soil physical properties involved only those characteristics that could be determined from metal core sampling cylinders of standardized volume 100 cm^3 (Rejšek 1999; Samec et al. 2005; Vavříček et al. 2005): bulk density (ρ_d), particle density (ρ_s), porosity (p), maximum capillary capacity (Θ_{MCC}), water retention capacity (Θ_{RC}) and minimum soil aeration ($A_{min} = p - \Theta_{MCC}$) (Vavříček et al. 2005). These basic physicochemical soil properties were determined: soil acidity (pH/H_2O and pH/KCl) with a combination glass electrode (soil/H_2O or 1M KCl = 1/2.5) and cation exchange capacity (*CEC*) by the Kappen method (Klečkovskij, Peterburskij 1964) and Mehlich method (Zbíral 2002) with consideration of Al^{3+} presence determined by the Sokolov method (Sokolov 1939).

Available mineral nutrients (Ca^{2+}, Mg^{2+}, K^+) were determined from Mehlich II extract (Mehlich 1978) by the method of atomic absorption spectrophotometry. The content of phosphorus was determined by the spectrophotometry in a solution of ascorbic acid, H_2SO_4 and Sb^{3+}. Humus substances (Ugolini, Spaltenstein 1992) were determined spectrophotometrically from absorbances of humus substances in pyrophosphate. Using this method carbon was quantified from humic acids (C-HA) and from fulvic acids (C-FA) and the C-HA/FA ratio was calculated. The content of oxidizable organic carbon (C_{ox}) was determined by oxidation of $H_2Cr_2O_7 + H_2SO_4$ when unconsumed chrome acid was determined by titration of Mohr salt solution. Total nitrogen (N_t) was determined by Kjeldahl method (Zbíral et al. 1997). Mineralized non-sorbed nitrogen (NH_4^+ and NO_3^-) from the soil solution was determined by desorption in 10% NaCl and by spectrophotometry (ČSN ISO 7150-1; ČSN ISO 7890-3). The amount of a compound sorbed on the area of an ion exchanger installed at a depth of 15 cm on FP under selected seedlings from June

Table 1. List of genetic components of windrow basic material (according to Vavříček et al. 2005)

Genetic component fraction	Working-plan area					
	185A 2 – Špičák		418B 2 – Nádraží		403E 2 – Suchdol	
	(%)	(m^3)	(%)	(m^3)	(%)	(m^3)
H	5	375	–	–	–	–
A/H	36	2,705	19	932	31	1,781
H/A	33	2,495	29	1,414	14	807
A	4	300	–	–	–	–
A/B	12	982	6	273	1	47
B	6	450	5	225	–	–
H+A+B	4	300	9	450	12	950
B/A	–	–	32	1,526	32	2,114

to October was obtained in this way. As a result ammonia nitrogen ($N\text{-}NH_4^+$) and nitrate nitrogen ($N\text{-}NO_3^-$) were computed separately. Differences in the values of determined soil properties between individual sites and FPs were statistically evaluated by global linear models (Zar 1994) and non-parametric Kruskal-Wallis (*K-W*) and Wilcoxon (*W*) test at $P < 0.05$ and $P < 0.01$.

RESULTS

Statistically significant differences were proved in the whole set of monitored properties when different techniques of FP mechanized preparation and different localization of sites were considered. ρ_s, *CEC*, C_{ox}, N_t, NH_4^+ and Ca^{2+} were generally found to be influenced only by different site conditions. Especially

Table 2. Soil analysis ($\bar{x} \pm \rho$) of selected research plots on Špičák site (185A 2). FP – field plot, R – windrow, CP – control plot

Soil property		FP preparation			R	CP
Quantity	unit	bulldozer	digger	cultivator		
ρ_d	g/cm^3	0.56 ± 0.18	0.55 ± 0.04	0.78 ± 0.14	0.48 ± 0.11	1.03 ± 0.16
ρ_s		1.22 ± 0.41	1.36 ± 0.28	1.54 ± 0.29	1.30 ± 0.30	2.20 ± 0.21
ρ	%	52.93 ± 6.07	57.68 ± 8.32	48.79 ± 6.13	62.79 ± 4.67	53.24 ± 5.06
Θ_{MCC}		60.45 ± 5.65	50.73 ± 7.36	56.70 ± 3.99	43.11 ± 7.82	51.58 ± 6.09
Θ_{RC}		57.98 ± 6.36	48.00 ± 7.33	56.20 ± 3.80	39.52 ± 6.42	49.87 ± 6.18
A_{min}		2.48 ± 1.26	9.82 ± 9.91	0.99 ± 0.51	19.68 ± 7.83	3.31 ± 2.74
pH/H_2O	$-\log c(H^+)$	3.92 ± 0.14	3.60 ± 0.06	4.19 ± 0.12	3.47 ± 0.16	5.09 ± 0.66
pH/KCl		3.16 ± 0.08	2.99 ± 0.07	3.40 ± 0.18	2.90 ± 0.04	4.14 ± 0.62
	mmol/kg	449.50 ± 17.68	461.00 ± 11.31	403.00 ± 19.80	–	–
CEC_{Kappen}		496.00 ± 19.80	518.50 ± 41.72	433.00 ± 76.37	361.00	231.50 ± 34.65
P	mg/kg	4.00 ± 0.00	5.50 ± 2.12	4.50 ± 0.71	3.00	2.50 ± 2.12
Mg		137.50 ± 21.92	94.50 ± 19.09	272.00 ± 82.02	68.00	75.50 ± 14.85
Ca		712.00 ± 353.55	447.50 ± 34.65	655.00 ± 256.90	413.00	270.00 ± 45.25
K		65.50 ± 2.12	60.00 ± 11.31	75.00 ± 5.66	70.00	56.00 ± 8.49
C_{ox}	%	18.77 ± 8.28	15.61 ± 3.30	13.22 ± 6.00	16.13 ± 5.36	6.07 ± 1.76
C-HA		3.47 ± 0.11	4.69 ± 0.05	3.35 ± 0.00	3.33	0.74
C-FA		1.38 ± 0.08	1.36 ± 0.00	1.53 ± 0.08	1.27	0.28
N_t		0.76 ± 0.34	0.56 ± 0.14	0.40 ± 0.05	0.65 ± 0.23	0.23 ± 0.09
$N\text{-}NH_4^+$	$mg/100\ cm^2$	1.44 ± 0.30	1.90 ± 0.87	0.88 ± 0.67	–	–
$N\text{-}NO_3^-$		0.12 ± 0.09	0.07 ± 0.05	0.03 ± 0.03	–	–
C-HA/FA	1	2.52 ± 0.23	3.46 ± 0.05	2.20 ± 0.12	2.62	2.64
C/N		28.32 ± 4.05	25.19 ± 3.77	32.43 ± 9.46	24.67	26.56 ± 0.18

Table 3. Soil analysis ($\bar{x} \pm \rho$) of selected research plots on Nádraží site (418B 2). FP – field plot, R – windrow, CP – control plot

Soil property		FP preparation CP			R	CP
Quantity	unit	bulldozer	digger	cultivator		
ρ_d	g/cm^3	0.77 ± 0.19	0.85 ± 0.16	0.92 ± 0.21	0.72 ± 0.16	1.17 ± 0.18
ρ_s		1.73 ± 0.39	1.86 ± 0.33	1.90 ± 0.33	1.81 ± 0.38	2.45 ± 0.18
ρ	%	55.55 ± 8.99	53.99 ± 5.48	51.55 ± 5.35	59.74 ± 8.13	52.44 ± 5.26
Θ_{MCC}		52.16 ± 8.21	41.07 ± 4.10	53.43 ± 7.24	38.85 ± 6.21	46.83 ± 5.83
Θ_{RC}		47.93 ± 9.05	36.44 ± 3.79	50.18 ± 6.95	31.76 ± 5.09	42.12 ± 7.00
A_{min}		8.12 ± 7.43	12.92 ± 5.82	2.70 ± 1.80	21.66 ± 11.44	5.61 ± 4.34
pH/H$_2$O	–log c(H$^+$)	4.00 ± 0.01	3.83 ± 0.03	4.18 ± 0.01	3.93 ± 0.13	4.43 ± 0.19
pH/KCl		3.29 ± 0.23	3.42 ± 0.06	3.44 ± 0.01	3.32 ± 0.29	3.85 ± 0.21
	mmol/kg	324.00 ± 16.97	346.00 ± 29.70	313.00 ± 11.31	–	340.00
CEC_{Kappen}		275.00 ± 12.73	294.00 ± 35.35	240.00 ± 8.49	286.50 ± 102.53	147.67 ± 23.76
P	mg/kg	5.50 ± 0.71	6.50 ± 0.71	4.50 ± 0.71	5.00 ± 1.41	4.00 ± 1.73
Mg		59.00 ± 22.63	49.00 ± 18.39	44.00 ± 14.14	52.00 ± 39.60	40.00 ± 9.00
Ca		276.00 ± 65.05	223.00 ± 74.95	257.00 ± 120.21	219.50 ± 150.61	191.67 ± 69.12
K		63.00 ± 1.41	62.50 ± 10.61	68.50 ± 6.36	54.50 ± 0.71	59.33 ± 5.13
C$_{ox}$	%	9.32 ± 3.64	8.66 ± 3.36	8.26 ± 4.32	10.07 ± 4.57	3.10 ± 1.17
C-HA		1.81 ± 0.08	1.32 ± 0.06	1.49 ± 0.25	3.07	0.42 ± 0.06
C-FA		0.80 ± 0.01	0.82 ± 0.10	0.83 ± 0.01	1.08	0.37 ± 0.24
N$_t$		0.35 ± 0.17	0.30 ± 0.11	0.34 ± 0.21	0.39 ± 0.16	0.13 ± 0.04
N-NH$_4^+$	mg/100 cm^2	–	–	–	–	–
N-NO$_3^-$		–	–	–	–	–
C-HA/FA	1	2.27 ± 0.01	1.62 ± 0.13	1.64 ± 0.11	2.84	1.35 ± 0.71
C/N		27.12 ± 6.98	29.10 ± 4.61	24.58 ± 4.21	25.06 ± 4.94	23.25 ± 5.77

p, A_{min} and phosphorus content were determined as soil properties strictly influenced by mechanized windrow cultivation. Statistically significant differences were computed for the values pH, ρ_d, Θ_{RC}, Θ_{MCC} and C-HA, C-FA and Mg^{2+} content that could be the result of differentiated impacts of windrow cultivation by different means of mechanization on the different sites (Tables 5–7). Regardless of the current anthropogenic interventions available K$^+$ content, NO$_3^-$ flux and usually also C/N ratio from

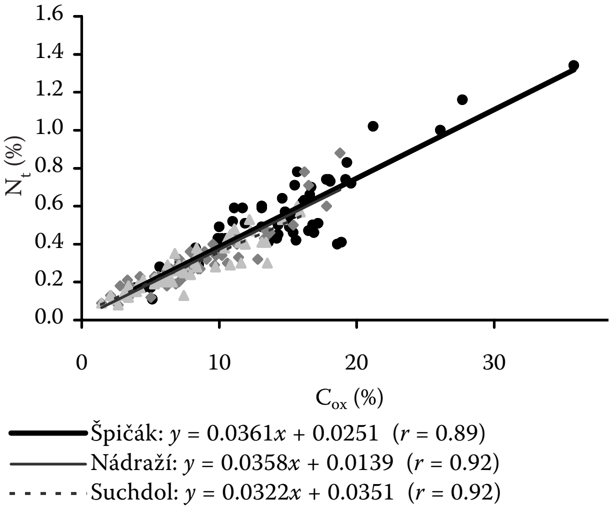

Fig. 1. Linear regression of C$_{ox}$ and N$_t$

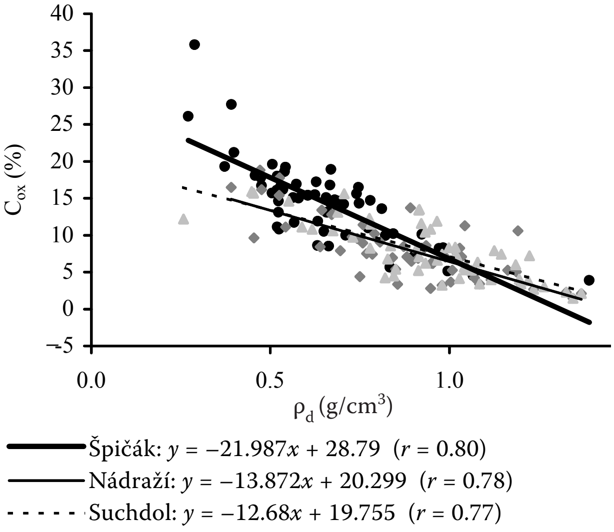

Fig. 2. Linear regression of ρ$_d$ and C$_{ox}$

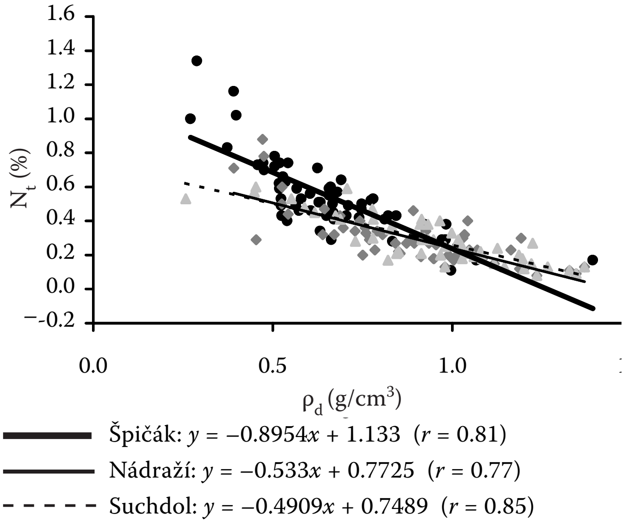

Fig. 3. Linear regression of ρ_d and N_t

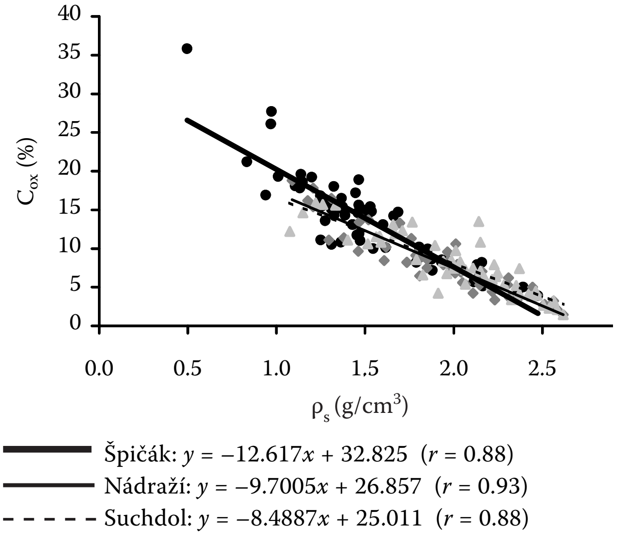

Fig. 4. Linear regression of ρ_s and C_{ox}

the topsoil horizons were determined as stable (not influenced by mechanization). Windrow cultivation was reflected positively in the optimization of available Ca^{2+} and Mg^{2+} supply.

The detection of statistical differences was found to depend on sufficiently specified conditions of this significance. These conditions are given by the fact that on individual sites different impacts of the mechanized windrow cultivation were recorded for some soil quantities. Especially FPs on the site 185A 2 differed in these effects in relation to other sites (Table 2). Statistically significant changes in the flux of

Table 4. Soil analysis ($\bar{x} \pm \rho$) of selected research plots on Suchdol site (403E 2). FP – field plot, R – windrow, CP – control plot

Soil property		FP preparation			R	CP
Quantity	unit	bulldozer	digger	cultivator		
ρ_d	g/cm³	0.96 ± 0.12	0.80 ± 0.33	0.99 ± 0.12	0.72 ± 0.22	1.18 ± 0.09
ρ_s		2.10 ± 0.29	1.80 ± 0.52	1.93 ± 0.24	1.75 ± 0.48	2.43 ± 0.26
ρ	%	54.01 ± 2.68	56.93 ± 9.16	48.38 ± 5.58	58.74 ± 5.37	52.44 ± 3.67
Θ_{MCC}		48.35 ± 4.44	42.84 ± 7.80	49.19 ± 4.97	33.95 ± 13.59	47.02 ± 9.74
Θ_{RC}		44.63 ± 4.62	39.28 ± 7.20	44.01 ± 5.41	29.14 ± 9.98	43.05 ± 6.98
A_{min}		7.04 ± 4.32	14.75 ± 15.64	4.02 ± 3.24	424.79 ± 13.91	5.61 ± 3.96
pH/H_2O	−log c(H^+)	4.11 ± 0.11	4.10 ± 0.22	4.09 ± 0.03	4.15 ± 0.03	4.15 ± 0.14
pH/KCl		3.46 ± 0.04	3.56 ± 0.33	3.51 ± 0.11	3.48 ± 0.18	3.97 ± 0.08
$CEC_{Mehlich}$	mmol/kg	364.50 ± 7.78	322.00 ± 96.17	349.50 ± 41.72	199.00	337.00
CEC_{Kappen}		298.00 ± 2.83	251.50 ± 101.12	296.00 ± 26.87	306.50 ± 53.03	163.00 ± 19.80
P	mg/kg	3.50 ± 0.71	7.00 ± 0.00	6.50 ± 0.71	2.00 ± 0.00	3.50 ± 0.71
Mg		55.00 ± 15.56	41.00 ± 26.87	56.00 ± 24.04	35.50 ± 2.12	65.50 ± 4.95
Ca		276.00 ± 65.05	223.00 ± 74.95	257.00 ± 120.21	105.50 ± 2.12	292.00 ± 1.41
K		64.00 ± 7.07	53.50 ± 2.12	61.50 ± 19.09	52.50 ± 10.61	71.00 ± 2.83
C_{ox}	%	8.39 ± 3.30	9.29 ± 5.07	9.72 ± 2.52	9.96 ± 2.48	3.85 ± 1.46
C-HA		2.52 ± 0.08	0.95 ± 0.03	1.36 ± 0.08	1.49	0.44
C-FA		1.01 ± 0.13	0.78 ± 0.06	1.01 ± 0.06	0.92	0.34
N_t		0.28 ± 0.11	0.35 ± 0.18	0.32 ± 0.07	0.39 ± 0.14	0.17 ± 0.04
N-NH_4^+	mg/100 cm²	2.39 ± 1.17	2.97 ± 2.64	3.21 ± 2.95	–	–
N-NO_3^-		0.07 ± 0.05	0.15 ± 0.16	0.15 ± 0.12	–	–
C-HA/FA	1	2.51 ± 0.23	1.22 ± 0.05	2.11 ± 0.70	1.62	1.29
C/N		31.11 ± 11.91	26.23 ± 2.73	30.76 ± 4.96	24.83 ± 4.47	22.91 ± 3.92

Table 5. Two-way ANOVA results showing statistical differences (at $P < 0.05$) in soil physical properties of windrows according to the used type of site preparation and according to the placement

Quantity	Variable	SS	MS	F
ρ_d	locality	1.17	0.59	16.07
	preparation type	0.40	0.20	5.53
	interactions	0.19	0.05	1.27
ρ_s	locality	4.91	2.45	19.67
	preparation type	0.23	0.11	0.92
	interactions	0.79	0.20	1.58
Θ_{MCC}	locality	1,246.72	623.36	16.31
	preparation type	1,304.36	652.18	17.07
	interactions	174.21	43.55	1.14
Θ_{RC}	locality	1,981.39	990.70	25.09
	preparation type	1,429.38	714.69	18.10
	interactions	210.85	52.71	1.33
p	locality	5.89	2.95	0.07
	preparation type	622.46	311.23	6.91
	interactions	147.15	36.79	0.82
A_{min}	locality	270.68	135.34	2.61
	preparation type	1,379.44	689.72	13.32
	interactions	44.44	11.11	0.21

soil NH_4^+ mineralization were determined in dependence on the means of mechanization used for the site preparation. The intensity of NH_4^+ flux in soil on this site was significantly lower (Tables 2–4 and 7). The values of soil phosphorus in FPs of the site 185A 2 were evaluated as coincident at the limit of acceptance of statistically significant differences. The possibility of influencing the C/N ratio after the cultivation of windrows was found minimal at the limit of acceptance of statistically significant differences. The values of ρ_s, C-HA, C-FA and pH from original solid W corresponded with the values of the specific gravity from all FPs. Compared to CP all FPs on the site 185A 2 differed in parameters ρ_d, ρ_s and N_t. On FPs an increase in *CEC* values and in concentrations of available mineral nutrients was registered.

Correspondingly on the site 418B 2 the mechanized windrow cultivation by different machines was not reflected in the changes of ρ_d, ρ_s, C_{ox} or N_t compared to the left referential windrow (Table 3). The content of C-HA and C-FA was determined as normalized only insignificantly. On the contrary, these quantities were determined as significantly different from their values on the local CP. Specifically on the local cultivated windrows evident normalization of pH, *p*, Θ_{RC} and Θ_{MCC} values was recorded.

On the site 403E 2, compared to the original windrow, the most marked changes in the soil properties after cultivation were detected for *CEC*, mineral nutrient content, ρ_s, Θ_{MCC}, Θ_{RC}, *p* and A_{min}. On the individual FPs the values of *p*, A_{min}, Θ_{MCC} and mostly also the C/N ratio were modified by windrow cultivation to the state that corresponded with CP. The individual types of preparation did not influence the values of ρ_d, ρ_s, C_{ox} and N_t on FPs. Sporadic unfavourable impacts of mechanical preparation on the C/N ratio were recorded there (Table 4).

Highly significant correlations between the selected soil properties were computed for all sites. Regression relations are represented on the basis

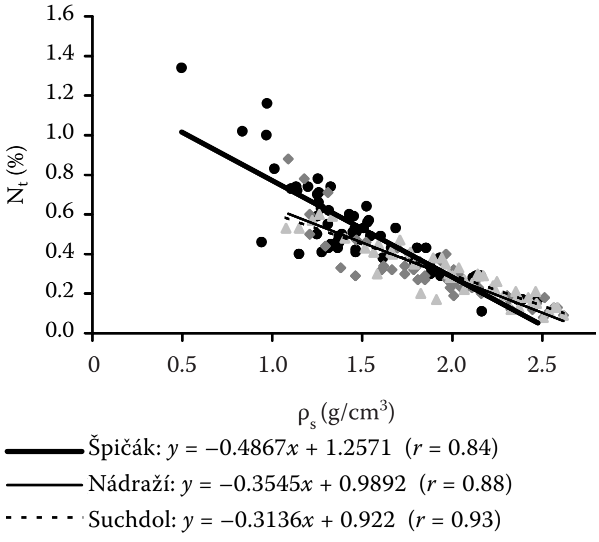

Fig. 5. Linear regression of ρ_s and N_t

Table 6. Two-way ANOVA results showing statistical differences (at $P < 0.05$) in chemical soil properties of windrows according to the used type of site preparation and according to the placement

Quantity	Variable	SS	MS	*F*
P	locality	3.44	1.72	2.07
	preparation type	12.11	6.06	7.27
	interactions	8.56	2.14	2.57
Mg	locality	55,068.44	27,534.22	24.38
	preparation type	12,036.78	6,018.39	5.33
	interactions	22,774.89	5,693.72	5.04
Ca	locality	644,043.00	322,021.50	12.51
	preparation type	60,872.33	30,436.17	1.18
	interactions	81,189.67	20,297.42	0.79
K	locality	162.11	81.06	0.99
	preparation type	282.11	141.06	1.72
	interactions	112.89	28.22	0.34
C_{ox}	locality	865.27	432.64	20.96
	preparation type	41.97	20.98	1.02
	interactions	110.76	27.69	1.34
N_t	locality	1.12	0.56	18.56
	preparation type	0.17	0.08	2.79
	interactions	0.44	0.11	3.65
C/N	locality	84.34	42.17	0.99
	preparation type	35.83	17.92	0.42
	interactions	427.82	106.96	2.52
C-HA	locality	18.04	9.02	2,100.10
	preparation type	0.23	0.12	27.33
	interactions	5.72	1.43	332.95
C-FA	locality	1.24	0.62	119.71
	preparation type	0.05	0.03	5.18
	interactions	0.05	0.01	2.41
C-HA/FA	locality	2.45	1.23	68.53
	preparation type	0.40	0.20	11.06
	interactions	4.23	1.06	59.18
$N\text{-}NH_4^+$	locality	18.93	18.93	6.32
	preparation type	1.76	0.88	0.29
	interactions	3.51	1.75	0.59
$N\text{-}NO_3^-$	locality	0.02	0.02	2.34
	preparation type	0.00	0.00	0.11
	interactions	0.05	0.02	2.59

of comparison of C_{ox} and N_t (Fig. 1) and they were also determined on the basis of comparison of the relation of ρ_d or ρ_s with these parameters (Figs. 2–5). Only for data from the site 185A 2 influenced by variance load correlations for the values of Θ_{MCC} and C_{ox} ($r = 0.29$) or N_t ($r = 0.29$) were found at $P < 0.05$. For these data the regression correlation between N_t and C/N ($r = 0.32$) was found at $P < 0.01$. However for data from sites 418B 2 and 403E 2 regression correlations between the C/N ratio and C_{ox} were identically determined at $P < 0.05–0.001$ ($r = 0.31–0.35$).

DISCUSSION

The effects of the soil mechanized preparation before reforestations were different according to the concrete ecological factors of the sites. The analysis of the set of mechanically cultivated FPs on three

Table 7. Two-way ANOVA results showing statistical differences (at $P < 0.05$) in pH and *CEC* of windrows according to the used type of site preparation and according to the placement

Quantity	Variable	SS	MS	*F*
pH/H_2O	locality	0.11	0.06	4.33
	preparation type	0.29	0.14	10.95
	interactions	0.18	0.04	3.36
pH/KCl	locality	0.33	0.16	6.84
	preparation type	0.07	0.04	1.55
	interactions	0.13	0.03	1.33
CEC_{Mehlich}	locality	42,010.11	21,005.06	14.34
	preparation type	2,082.11	1,041.06	0.71
	interactions	4,677.89	1,169.47	0.80
CEC_{Kappen}	locality	171,426.33	85,713.17	37.81
	preparation type	4,233.33	2,116.67	0.93
	interactions	9,389.33	2,347.33	1.04

sites in the Krušné hory Mts. and comparison of the results of this preparation technology with original Ws and CPs showed that those soil properties remained permanently influenced, the values of which continued to correspond with Ws also after cultivation. These properties were usually significantly different compared to their values on CPs. The soil properties that differentiated on FPs in relation to Ws and at the same time did not significantly differ from the values on CPs could be considered as normalized after the cultivation of windrows. The cultivation of windrows led to the increase in *CEC* in the topsoil horizons. The soil acidity increase was recorded as well as the increase in Ca^{2+} and Mg^{2+} concentrations. Mechanization significantly influenced ρ_d. Humus substance contents were also changed according to the changes on individual FPs. The changes in the flux of mineralized $N\text{-}NH_4^+$ were determined in dependence on the value of C-HA/FA ratio and *CEC*. Generally low values of non-sorbed $N\text{-}NH_4^+$ indicated that its significant portion was bound either in the soil microbial biomass (Stamsevich 1972) or in the soil sorption complex (Vavříček et al. 2005). The recorded high values of non-sorbed mineral $N\text{-}NH_4^+$ could potentially mean that it was released simply into runoff waters and atmosphere. Unfavourable values of Θ_{MCC}, porosity and A_{min} could appear as limiting factors for reforestation on cultivated windrows.

The basic prerequisite for successful forest regeneration is still sufficient minimization of air pollution deposition in Central European mountain regions. The principles of complex revitalization of anthropogenically degraded forest sites were examined in the form of chemical and biological amelioration (Kubelka 1992; Podrázský et al. 2001, 2003; Podrázský, Ulbrichová 2005). The effects of chemical amelioration in the degraded territories of the Krušné hory Mts. proved a positive reaction in increased soil pH-value, base cation content and also base saturation. The biological amelioration proved as efficient in the case of cultivated substitute tree stands; they were able to provide ecological cover and contributed to humification stimulation (Ulbrichová et al. 2004b).

Especially providing for the genesis of soil surface humus is the basic presumption for ecological stability of forest stands on degraded sites (Podrázský et al. 2003; Ulbrichová et al. 2004a). In the case of scarification, the absence of genetically fully developed surface humus layers could be a potential cause for the non-optimal state of some topsoil properties. In the case of CPs potential influences of previous scarification were still reflected in the lower values of concentrations of available nutrients, N_t and C-HA.

The windrows of mixed organic and mineral material were monitored as an alternative potential source of deficient soil components. The fermentation processes stimulated the release of mineral nutrients in the decomposition processes and influenced nitrogen mobilization and C/N ratio stabilization (Vavříček 2003). The cultivation of windrows led to an increase in the C/N ratio up to critical values (cf. Wittich 1953). At the same time the material from windrows after cultivation provided the substrate with optimal amount of mineral nutrients and *CEC*. The soil scarification in connection with the devastation of surface humus layer and often also with dolomitic limestone application led to progressive degradation of forest types to the level of less fertile trophic units (cf. Šach 1992; Vavříček, Šimková 2004).

Nevertheless, the success of forest stand establishment on anthropogenic substrates depends not only on the intensity of human impacts during ameliorations but also on the configuration of climatic factors and meteorological conditions in the growing season (Cunningham, Wittwer 1984; Mauer, Palátová 2000). Weather conditions, temperature and precipitation fluctuations are displayed as primary stresses. In extreme cases of synergic influence the series of primary, secondary (water deficiency in the plant in consequence of damage to conducting pathways of the stem) and tertiary stresses (i.e. fungal pathogens) is responsible for the decline of young plantations and young stands (Martínková et al. 2000). The important symptoms of substitute stand decline are defoliation, fungal infections, loss of fine roots and the change of ectomycorrhiza into endoectomycorrhiza (Mauer, Palátová 2003). Besides a decrease in the air pollution load the precondition for reducing the limiting factors and stress factors influencing forest stands cultivated on clear cuts induced by air pollution and on degraded sites is to grow forest tree species in substrates enabling the development of sufficient root systems.

References

BRIDGES K.S., JICKELLS T.D., DAVIES T.D., ZEMAN Z., HUNOVÁ I., 2002. Aerosol, precipitation and cloud water chemistry observations on the Czech Krusne hory plateau adjacent to a heavily industrialised valley. Atmospheric Environment, *36*: 353–360.

CULEK M. (ed.), 1996. Biogeografické členění České republiky. Praha, Enigma: 347.

CUNNINGHAM T.R., WITTWER R.F., 1984. Direct seeding oaks and black walnut on mine soils in eastern Kentucky. Reclamation and Revegetation Research, *3*: 173–184.

ČSN ISO 7150-1., 1994. Jakost vod. Stanovení amonných iontů. Část 1: Manuální spektrometrická metoda. Praha, Český normalizační institut: 3–11.

ČSN ISO 7890-3., 1994. Jakost vod. Stanovení dusičnanů. Část 3: Spektrometrická metoda s kyselinou sulfosalicylovou. Praha, Český normalizační institut: 2–7.

JIRGLE J., 1983. Komplexní stanovisko k tzv. buldozerové (a bagrové) přípravě půdy v imisních oblastech. [Závěrečná zpráva.] Ústí nad Labem, VÚLHM: 76.

KLEČKOVSKIJ V.M., PETERBURSKIJ A.V., 1964. Agrochimija. Moskva, Kolos: 527.

KUBELKA L., 1992. Zhodnocení vlivu chemické meliorace půd degradovaných imisemi v lesní oblasti Krušné hory za období 1973–1991 [Závěrečná zpráva.] Teplice, Severočeské státní lesy: 69.

MARTÍNKOVÁ M., MADĚRA P., ÚRADNÍČEK L., 2000. Příčiny zhoršené vitality porostů břízy (*Betula* L.) v Krušných horách. In: SLODIČÁK M., NOVÁK J. (eds.), Výsledky a postupy výzkumu v imisní oblasti SV Krušnohoří. VÚLHM Jíloviště-Strnady, VS Opočno: 21–24.

MAUER O., PALÁTOVÁ E., 2000. Root system response to stress in artificially established Norway spruce stands. Ekológia (Bratislava), *19*, Supplement: 151–161.

MAUER O., PALÁTOVÁ E., 2003. The role of root system in silver birch (*Betula pendula* Roth) dieback in the air-polluted area of Krušné hory Mts. Journal of Forest Science, *49*: 119–129.

MEHLICH A., 1978. New extractant for soil test evaluation of phosphorus, potassium, magnesium, calcium, sodium, manganese and zinc. Communications in Soil Science and Plant Analysis, *9*: 477–492.

NEUHÄUSLOVÁ Z., BLAŽKOVÁ D., GRULICH V., HUSOVÁ M., CHYTRÝ M., JENÍK J., JIRÁSEK J., KOLBEK J., KROPÁČ Z., LOŽEK V., MORAVEC J., PRACH K., RYBNÍČEK K., RYBNÍČKOVÁ E., SÁDLO J., 1998. Mapa potenciální přirozené vegetace České republiky. Praha, Academia: 450.

OLSSON B.A., KELLNER O., 2002. Effects of soil acidification and liming on ground flora establishment after clear-felling of Norway spruce in Sweden. Forest Ecology and Management, *158*: 127–139.

PODRÁZSKÝ V., REMEŠ J., ULBRICHOVÁ I., 2003. Biological and chemical amelioration effects on the localities degraded by bulldozer site preparation in the Ore Mts. – Czech Republic. Journal of Forest Science, *49*: 141–147.

PODRÁZSKÝ V., ULBRICHOVÁ I., 2005. Obnova povrchového humusu při zalesňování zemědělských ploch a stanovišť po buldozerové přípravě v Krušných horách. In: NEUHÖFEROVÁ P. (ed.), Místo biologické meliorace v obnově lesních stanovišť. Kostelec nad Černými lesy, ČZU: 77–82.

PODRÁZSKÝ V., ULBRICHOVÁ I., MOSER W.K., 2001. Ecological impact analysis of mechanised site preparation techniques. Journal of Forest Science, *47*: 146–149.

PURDON M., CIENCIALA E., METELKA V., BERANOVÁ J., HUNOVÁ I., ČERNÝ M., 2004. Regional variation in forest health under long-term air pollution mitigated by lithological conditions. Forest Ecology and Management, *195*: 355–371.

REJŠEK K., 1999. Lesnická pedologie – cvičení. Brno, MZLU: 154.

SAMEC P., URBAN J., KISZA L., 2005. Vybrané efekty biologické meliorace ve vztahu k půdním fyzikálním vlastnostem. In: NEUHÖFEROVÁ P. (ed.), Místo biologické meliorace v obnově lesních stanovišť. Kostelec nad Černými lesy, ČZU: 67–76.

SCHWARZ O., 1997. Management of the Forest Ecosystems in the Krkonoše National Park, Black Triangle Region, Czech Republic. In: GUTKOWSKI R.M., WINNICKI T. (eds.), Restoration of Forests. Salzburg, Amsterdam, Kluwer Academic Publishers: 215–226.

SMOLANDER A., PAAVOLAINEN L., MALKONEN E., 2000. C and N transformations in forest soil after mounding for regeneration. Forest Ecology and Management, *134*: 17–28.

SOKOLOV A.V., 1939. Determinacia izmenenia glinozema v podach. Chimizacija socialističeskogo zemledelija, *7*: 30–35.

STAMSEVICH S.A., 1972. Effect of plant cover and soil cultivation on the number of microorganisms and content of organic substances in the soil. In: SZEGI J. (ed.), Proceedings of the Symposium on Soil Microbiology. Budapest, Akadémiai Kiadó, *11*: 41–48.

ŠACH F., 1992. Degradace lesních pozemků při mechanické přípravě pro zalesňování: ohrožení půdoochranné, vodohospodářské a produkční funkce lesů. Lesnictví-Forestry, *38*: 65–80.

ŠIMKOVÁ P., VAVŘÍČEK D., 2004a. The pedogenesis and physical-chemical characteristics changes based on anthropic factors (The west Ore Mountains). In: BUCHTA I., KAŇOVÁ D., STEJSKAL R., ŠIMKOVÁ P. (eds.), Contemporary state and development trends of forests in cultural landscape. Brno, MZLU: 120–124.

ŠIMKOVÁ P., VAVŘÍČEK D., 2004b. Změny geneze a fyzikálně chemických charakteristik diagnostických horizontů na základě antropogenních vlivů (Krušné hory – západ). In: NOVÁK J., SLODIČÁK M. (eds.), Výsledky lesnického výzkumu v Krušných horách v roce 2003. Jíloviště-Strnady, VÚLHM: 45–60.

UGOLINI F.C., SPALTENSTEIN H., 1992. Pedosphere. In: BUTCHER S.S., CHARLSON R.J., ORIANS G.H., WOLFE G.V. (eds.), Global Biogeochemical Cycles. San Diego, Academic Press: 123–153.

ULBRICHOVÁ I., PODRÁZSKÝ V., MOSER W.K., 2004a. Půdotvorná role břízy na intaktních plochách. In: NOVÁK J., SLODIČÁK M. (eds.), Výsledky lesnického výzkumu v Krušných horách v roce 2003. Jíloviště-Strnady, VÚLHM: 61–66.

ULBRICHOVÁ I., REMEŠ J., PODRÁZSKÝ V., 2004b. Hlavní náhradní listnaté dřeviny v Krušných horách a jejich půdotvorná a půdoochranná funkce. In: REMEŠ J., PODRÁZSKÝ V., NEUHÖFEROVÁ P. (eds.), Dřeviny a lesní půda. Biologická meliorace a její využití. Kostelec nad Černými lesy, ČZU: 124–129.

VACEK S., 1996. Vývoj zdravotního stavu porostů na TVP v Krkonoších. In: VACEK S. (ed.), Monitoring, výzkum a management ekosystémů na území KRNAP. VÚLHM Jíloviště-Strnady, VS Opočno: 28–43.

VAVŘÍČEK D., 2003. Současný stav na stanovištích s celoplošnou dozerovou a bagrovou přípravou půdy z aspektu jejich revitalizace v 7. LVS Krušných hor. In: SLODIČÁK M., NOVÁK J. (eds.), Výsledky lesnického výzkumu v Krušných horách v roce 2002. Jíloviště-Strnady, VÚLHM: 9–24.

VAVŘÍČEK D., ŠIMKOVÁ P., 2004. Komparace skarifikovaných ploch mezi valy a přirozeným edatopem 7. LVS Krušných hor. In: NOVÁK J., SLODIČÁK M. (eds.), Výsledky lesnického výzkumu v Krušných horách v roce 2003. Jíloviště-Strnady, VÚLHM: 29–44.

VAVŘÍČEK D., ŠIMKOVÁ P., FORMÁNEK P., SAMEC P., 2005. Revitalizace půdního prostředí valů v 7. LVS Krušných hor s návrhem dalších opatření pro obnovu lesa – II. díl. [Parciální realizační výstup Grantové služby LČR – 1/2003.] Brno, MZLU: 188.

WITTICH W., 1953. Untersuchunger über den Verlauf der Streuzersetzung. Schriftenreihe der forstlichen Fakultät Göttingen, *9*: 7–33.

ZAR J., 1994. Biostatistical Analysis. New Jersey, Prentice Hall Int.: 584.

ZBÍRAL J., 2002. Analýza půd I. Jednotné pracovní postupy. Brno, ÚKZÚZ: 197.

ZBÍRAL J., HONSA I., MALÝ S., 1997. Analýza půd III. Jednotné pracovní postupy. Brno, ÚKZÚZ: 150.

Received for publication June 17, 2005
Accepted after corrections August 1, 2005

Půdní aspekty revitalizace lesních stanovišť po rozpracování valů těžkou mechanizací na náhorní plošině Krušných hor

D. Vavříček, P. Šimková, P. Samec, P. Formánek

Lesnická a dřevařská fakulta, Mendelova zemědělská a lesnická univerzita v Brně, Brno, Česká republika

ABSTRAKT: Odraz půdních vlastností ve zdravotním stavu lesních porostů souvisí se synergickým působením stresorů, které existenci lesa ovlivňují. V imisní oblasti Krušných hor vznikly ekotopy imisních holin, na nichž byly aplikovány metody celoplošné mechanizované přípravy stanoviště a vznikly uniformní reliéfy valů. Byla ověřována hypotéza, zda zemina valů může být přímo využita při rozpracování pro vznik substrátu vhodného pro růst lesních dřevin. Efekty mechanizované přípravy půdy před zalesněním jsou různé v závislosti na konkrétních stanovištních ekologických faktorech. Vliv jednotlivých mechanizačních prostředků na konkrétní půdní vlastnosti byl zjištěn jako lokálně diferencovaný. Rozpracováním valů došlo k nárůstu kationtové výměnné kapacity (KVK) především díky zvýšení obsahu Ca^{2+} a Mg^{2+}. Lokálně došlo ke stabilizaci obsahu N-NH_4^+. Optimalizace fyzikálních vlastností souvisela se stavem C_{ox}. Mechanizované rozpracování valů nedokázalo optimalizovat C/N ani maximální kapilární kapacitu (MKK) nebo pórovitost (*p*). Mechanizované rozpracování valů se za podmínek snížené imisní zátěže obecně jeví jako využitelná technologie revitalizace degradovaných stanovišť, protože pro růst lesních dřevin poskytuje troficky optimálnější podmínky než valy nebo skarifikované plochy.

Klíčová slova: Krušné hory; svrchní půdní horizonty; příprava stanoviště; objemová hmotnost; humus

Trofické faktory lesních půd vykazují prostorovou i časovou diferenciaci. Jejich odraz ve zdravotním stavu lesních porostů souvisí se synergickým působením stresorů, které existenci lesa ovlivňují. Nejvýznamnější změny ve výživě lesních dřevin byly zaznamenány především v regionech silně zasažených imisní depozicí (Purdon et al. 2004). Krušné hory (338–1 244 m n. m., +5,5 až +2,7 °C, 900 až 1 200 mm) (Culek 1996) představují region, kde v letech 1970–1977 v důsledku imisních škod došlo k rychlému snížení lesnatosti o 23,9 %. Poslední rozsáhlé přímé poškození lesních porostů SO_2 bylo v Krušných horách pozorováno v roce 1996 na ploše více než 10 000 ha (Bridges et al. 2002). Tato situace byla ovlivněna i nepříznivými meteorologickými vlivy, za kterých docházelo k dlouhodobé kumulaci znečištění v hřebenové části hor. Jako poslední období výrazného celorepublikového poškození lesů lze vymezit roky 1991–1994 provázené suchou klimatickou epizodou.

Odumírání lesa bylo následováno snahami o jeho rekonstrukci. Náhorní plošina Krušných hor poskytovala ideální podmínky pro aplikaci mechanizované přípravy lesních stanovišť. Při používání bagrů a buldozerů při přípravě stanovišť pro obnovu lesa byla půda skarifikována, byly obnaženy imisemi relativně nezasažené půdní horizonty a byly vytvořeny uniformní reliéfy valů. Prostředí valů umožňovalo i opakovaný rychlý postup zalesnění a aplikaci chemické meliorace (Podrázský et al. 2001). Směsný materiál valů (tab. 1) se na těchto stanovištích stal důležitým zdrojem přístupných minerálních živin, N_t a prostředím s optimální hodnotou C/N (Vavříček 2003).

Na území Lesní správy Kláštěrec nad Ohří byly vybrány tři lokality [revír Špičák (185A 2); Nádraží (418B 2) a Suchdol (403E 2)], kde byly po předešlém rozpracování valů vymezeny jednotlivé pracovní plochy (PP). Pro vymezení elementární PP vždy byl důležitý konkrétní technický postup rozpracování předešlého valu těžkou mechanizací (Vavříček et al. 2005). V průběhu vegetačního období 2004 zde byl sledován stav půdních fyzikálních vlastností, sorpčního komplexu, přístupných minerálních živin humusových látek na plochách po rozpracování předešlých valů bagrem, buldozerem nebo frézováním. Stav vlastností takto připravených ploch byl srovnán s ponechanými valy i skarifikovanými kontrolními plochami (KP).

Efekty mechanizované přípravy půdy před zalesněním jsou různé v závislosti na konkrétních stanovištních ekologických faktorech. V celé množině sledovaných půdních vlastností byly prokázány statisticky významné rozdíly při zohlednění aspektu různé techniky mechanizované přípravy FPs i v aspektech různé lokalizace ploch. Jako ovlivnitelné pouze v závislosti na různých stanovištních poměrech byly obecně zjištěny měrná hmotnost, kationtová výměnná kapacita (KVK), C_{ox}, N_t, NH_4^+ a Ca^{2+}. Jako půdní veličiny striktně ovlivněné mechanizovaným rozpracováním valů byly zjištěny především pórovitost (*p*), minimální vzdušná kapacita (A_{min}) a obsah fosforu. Byly zjištěny statisticky významné rozdíly pro hodnoty pH, objemové hmotnosti, retenční vodní kapacity (RVK), maximální kapilární kapacity (MKK) a obsahu humusových látek a Mg^{2+}, které mohou být výsledkem diferencovaných dopadů rozpracování valů různými mechanizačními prostředky na různých lokalitách (tab. 5–7).

Rozpracováním valů došlo v rámci svrchních půdních horizontů k nárůstu KVK. Byl zjištěn růst půdní reakce i růst koncentrací Ca^{2+} a Mg^{2+}. Mechanizace se výrazně projevila ve vlivu na měrnou hmotnost. V souvislosti s jejími změnami byly na jednotlivých PP změněny i obsahy humusových látek. V závislosti na jejich hodnotě a na stavu KVK byly zjištěny i změny v toku mineralizovaného N-NH_4^+. Obecně nízké hodnoty nesorbovaného N-NH_4^+ znamenají, že jeho významná část je naopak vázána buď v půdní mikrobiální biomase (Stamsevich 1972), nebo v půdním sorpčním komplexu (Vavříček et al. 2005). Zaznamenané vysoké hodnoty nesorbovaného minerálního N-NH_4^+ mohou potenciálně znamenat jeho snadnou uvolnitelnost do odtokových vod nebo atmosféry. Jako limitní faktory pro zalesnění rozpracovaných valů se mohou jevit nepříznivé hodnoty MKK, p a A_{min}.

Corresponding author:

Dr. Ing. Dušan Vavříček, Mendelova zemědělská a lesnická univerzita v Brně, Lesnická a dřevařská fakulta,
Lesnická 37, 613 00 Brno, Česká republika
tel.: + 420 545 134 187, fax: + 420 545 211 422, e-mail: dusvav@mendelu.cz