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Biological activity, nitrogen dynamics, and chemical characteristics of forest soils in the Šumava National Park

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ABSTRACT: This paper deals with large-scale mountain forest decline in the Šumava National Park. The changes in biotic and abiotic properties of forest sites follow the tree layer disintegration. Changed microclimatic conditions such as intensity of irradiance, moisture and temperature of the top holorganic layers together with altered development of ground vegetation could strongly affect the values of microbiological respiration activity and the rates of nitrogen mineralization and nitrification. Soil substrates, built of organic mater, located on stony locations, are endangered by introskeletal erosion. This paper compares these features in pairs of research plots, consisting of dead or cut forest and of living stand. According to the results of this study, higher rates of organic matter decomposition, transformed dynamics of nitrogen and other nutrients and possible nutrient leaching from soil solutions were demonstrated in the forest floor under declined spruce stands. The extent and seriousness of these adverse processes for forest soils are strongly site dependent.

Keywords: Šumava NP; *Picea abies*; soil chemistry; biological activity; nitrogen dynamics

Rapid decline of Norway spruce stands in some areas of the Šumava National Park has been observed during the last decades. The bark beetle outbreak, windthrow disaster together with air pollution and inappropriate management are the most serious problems that endanger the stability and sustainability of these valuable forest ecosystems (PODRÁZSKÝ 1999a; VINŠ 1999).

The changes in biotic and abiotic properties of forest sites follow the decline of the tree layer (VOGT et al. 1986; JURGENSEN et al. 1988; LINHART 1999; VACEK et al. 1999). A larger amount of solar radiation reaches the soil surface and increases its temperature (understorey vegetation and top holorganic layers receive a considerably larger amount of solar radiation under the declined tree layer in comparison with the living forest stand). The moisture status of the soil is changing due to decreased tree transpiration and interception. The surface and ground water runoff shows different dynamics under the declined forest stand compared to the vital forest stand (KUŘÍK et al. 1999). The adverse effects of clear-cut conditions on the state and development of the forest floor were shown in many studies. According to EMMER (1999), changed moisture and temperature conditions of the top organic layers can strongly influence the rate of microbiological activity and consequently the rate of organic matter decomposition and mineralization. Higher rates of microbial activity, increased organic matter decomposition and nutrient availability on the clear-cut sites were also shown by BINKLEY (1984), KLIMO and KULHAVÝ (1994), SVOBODA and PODRÁZSKÝ (2000). JURGENSEN et al. (1988) point where clear-cut conditions could cause an extensive loss of surface organic matter, which can have important implications for soil chemical, biological and physical properties, especially at infertile forest sites. The problem of organic matter loss and introskeletal erosion was also a subject of some studies performed in this country. According to ŠACH and PAŠEK (1996), ŠACH (1999), PODRÁZSKÝ (1999b) the extensive loss of organic matter following the deterioration and cutting of Norway spruce stands at some forest sites in our mountain areas represents a considerable threat to the stability of forest soils. Introskeletal erosion was studied in the Jizerské hory Mts. (ŠACH, PAŠEK 1996), Krkonoše Mts. (ŠACH 1999), and also in the Šumava Mts. (PODRÁZSKÝ 1999a). The latest studies showed that the rate of microbial activity, organic matter decomposition and mineralization and nutrient availability could be strongly affected not only in the conditions of clear-cuts but also during actual forest stand disintegration. SVOBODA and PODRÁZSKÝ (2000) reported a higher rate of microbial activity and organic matter decomposition as well as higher nutrient availability followed by losses of some nutrients at a stony forest site under declined Norway spruce stand in the area of Plechý Mt. (Šumava NP). NOVÁK (1999) found out higher microbial activity together with increased rates of nitrification and nitrogen availability in the forest soil under declined Norway spruce stand in the same area.

The aim of this study was to determine the dynamics of microbial activity regarding nitrogen transformation in holorganic horizons collected in two disintegrated

Table 1. General information on the plots in zone I of Šumava NP – Trojmezná Mt.

Plot	Altitude (m)	Forest type group	Substrate	Soil type
9	1,295	8N	Biotite granite	Leptosol/Podzol
30	1,260	8S	Biotite granite	Dystric Cambisol

Table 2. Description of the humus profile on research plot No. 30. Humus form determined – Humimor (GREEN et al. 1993) or Mull mor (VOKOUN 2000)

Horizon	Thickness (cm)	Description of the humus form
Lv	0–1.5	Forest litter mostly composed of the leaves of *Athyrium distentifolium*, *Luzula sylvatica*, *Calamagrostis villosa* and the needles of *Picea abies*, apparent colour changes, moist, loose, initial fragmentation.
F1m	1.5–3.5	Moist, loose, abundant fibrous fragments of plants, non-compact matted structure, common fungal mycelium.
F2m	3.5–5.5	Moist, compact matted structure, pliable consistence, abundant fungal mycelium and roots.
Hh	5.5–13	Moist, dark black colour, compact matted structure and resilient consistence, greasy, abundant fungal mycelium, abundant fine and medium roots.
Ah	13–15	Relatively bold, it is followed by mineral horizons.

Norway spruce stands at forest sites that are considered relatively safe from direct processes of introskeletal erosion but that can be threatened by the processes associated with introskeletal erosion such as increased rate of organic matter decomposition and nutrient availability followed by leaching of nutrients (especially nitrogen) from the soil solution (PODRÁZSKÝ 1999a).

Description of the site

This study was performed on two permanent plots located in zone I of Šumava NP, No. 124 – Trojmezná Mt. The area concerned is situated in the spruce vegetation zone, its altitude ranges from 1,210 m a.s.l. to 1,350 m a.s.l. The average annual air temperature is about 3.5°C; the average annual rainfall is about 1,200 mm. Table 1 gives an overview of selected plots.

Research plots No. 9 and 30 are situated on the NNE slope of Trojmezná Mt.; plot No. 9 is located in compartment 47a and plot No. 30 in compartment 48a. Both research plots include dead and vital parts of spruce stands. A part of the forest stand on plot No. 30 died due to bark beetle outbreak during summer 1998. At the time of sampling, the remaining part of the plot was covered with vital forest stand. Research plot No. 9 comprised a vital forest stand at the time of sampling and about ten years old cleared area. The occurrence of the windthrows was probably origin in this cleared area.

Plant phytocenosis in the concerned area is composed of Skeletal Spruce, Stony-acidic Spruce, Fresh nutrient-medium Spruce, and Acidic Spruce. The age of the forest community was assessed to be 200–300 years; forest stands represent the most valuable relics of natural mountain forest ecosystem in the Czech Republic (PRŮŠA 1990). The cover of the vegetation layer is close to 100% on a majority of the forest sites. The plant species *Vaccinium myrtillus*, *Calamagrostis villosa*, *Luzula sylvatica*, *Avenella flexulosa*, and *Athyrium distentifolium* are most abundant. Loamy structure with a high content of debris in the soil profile is typical of the soils; Cambisol, Lep-

Table 3. Description of the humus profile on research plot No. 9. Humus form determined – Hemimor (GREEN et al. 1993) or Typical Mor (VOKOUN 2000)

Horizon	Thickness (cm)	Description of the humus form
Lv	0–1.5	Forest litter mostly composed of the leaves of *Vaccinium myrtillus, Calamagrostis villosa, Avenella flexulosa* and the needles of *Picea abies*, small sized fragments of branches, apparent colour changes, moist, no roots, loose.
F1m	1.5–4.5	Moist, loose character, abundant fibrous plant fragments, common fungal mycelium, common roots.
F2mw	4.5–7.5	Dry – moist, moderate non-compact matted structure, abundant fungal mycelium, common roots, and abundant decayed wood, felty character.
Hrw	7.5–10	Dry – moist, dark reddish brown colour, weakly blocky structure, discernible plant fragments, loose, common fungal mycelium, concentrated around the roots, fibrous character, abundant decayed wood.
Ah	10–11	Thin, featureless horizon.

tosol, and Podzol are common soil types found in the area concerned. Tables 2 and 3 give an overview of the general characteristics of holorganic layers and the types of humus forms found on research plots 9 and 30. Additional information concerning the vegetation cover and site characteristics of permanent plots located in this area was published (SVOBODA 2002).

MATERIAL AND METHODS

Soil pits were dug on plot No. 9 in the vital stand and on plot No. 30 in the dead stand. Characters and thickness of holorganic horizons were described in the vital and dead part on each plot. The samples of the individual holorganic and mineral horizons were collected on 12 and 13 September in 2000. Sampling of holorganic horizons was performed in a different way compared to the sampling of mineral horizons. Sampling of holorganic layers (horizons F and H) was performed at randomly selected sites (four replications on each part) in both the vital and dead parts of each plot. A total of sixteen soil samples for horizon F and the same amount of samples from horizon H were gathered on both plots. Mineral horizons were sampled according to the morphogenetic horizons in soil pits on both plots.

A laboratory in Forestry and Game Management Research Institute – Opočno Research Station carried out the analyses that were performed by standard methods (ŠARMAN 1981; ZBÍRAL 1995, 1996). The following chemical and biological characteristics of holorganic and mineral horizons were determined:

A. For the holorganic horizons – content of ammonium and nitrate nitrogen, biological (basal and potential) respiration activity, $pH_{(H_2O)}$, $pH_{(KCl)}$, characteristics of absorbing complex (base-exchange complex) according to Kappen (S – content of bases, H – hydrolytic acidity, T – base-exchange capacity, V – base saturation of absorbing complex, exchange acidity and its components (exchange hydrogen and aluminum), content of litter (aggregate carbon) and nitrogen according to Kjeldahl.

B. For the mineral horizons the same chemical characteristics were determined except for nitrogen transformation and biological respiration activity. Granulometric composition was further determined for mineral horizons.

Biological respiration activity

Actual biological activity – weighed portion (25 g of organic matter) was put into a sealable one-liter glass container; this material was outspread around the wall and a glass vial with 25 ml of 0.1N NaOH was put in the middle. The container was sealed and incubated for 24 hours at a temperature 25°C. This process was repeated for the following five days with original sample, the solution of 0.1N was changed every 24 hours.

Potential biological activity – weighed portion (12.5 g of organic matter) was put into a sealable glass container, this material was outspread around the wall and a glass vial with 25 ml of 0.1N NaOH was put in the middle. In this case, the sample was sprayed with 12.5% solution of glucose (2 ml of glucose per 12.5 g sample). The container was sealed and incubated for 24 hours at a temperature 25°C.

Control determination was made with the same chemicals under the same conditions but without the organic matter sample.

Evaluation – every day when the incubation of the sample was determined, the vial with 0.1N NaOH solution was removed from the container and put into a titration flask. About 2 ml of 25% $BaCl_2$ solution and several droplets of phenolphthalein were added into the titration flask. The solution in the flask was titrated with 0.1N HCl solution until absolute discoloring. The consumption of hydrochloric acid was subtracted from its consumption during the control determination and the difference was multiplied by the constant 2.2. The amount of carbon dioxide in mil-

Table 4. Microbial activity characteristics of holorganic horizons – respiration activity

Plot	Horizon	Biological respiration activity – basal (mg CO_2/100 g of dry matter per 24 hours)					Biological respiration potential	Moisture (%)
		day 1	day 2	day 3	day 4	day 5		
Living	F	103.9 a	106.6 b	71.4 a	63.2 a	59.6 a	292.7 b	51.6
9	H	26.0 a	20.0 a	7.4 a	15.6 a	16.4 a	77.7 a	47.9
Dead	F	109.1 a	87.3 a	73.2 a	70.9 b	66.5 b	378.9 c	51.0
9	H	27.1 a	23.2 a	8.2 b	14.4 a	18.5 a	104.4 a	46.5
Living	F	115.4 a	77.7 a	76.0 a	66.3 ab	56.8 a	250.2 a	59.2
30	H	58.8 b	44.9 b	49.0 b	39.5 b	33.1 b	191.1 b	57.4
Dead	F	176.4 b	110.9 b	121.8 b	92.7 c	74.6 c	589.1 d	75.8
30	H	51.8 b	51.2 c	36.8 b	33.4 ab	22.8 a	183.8 b	60.5

Indexes a, b, c and d express significant differences between the values of biological respiration activity (basal and potential) for horizons F and H. Values with different indexes significantly differ from each other

Table 5. Microbial activity characteristics of holorganic horizons – nitrogen dynamics

Plot	Horizon	Moisture (%)	NH_4-N (mg/kg dry matter)		NO_3-N (mg/kg dry matter)	
			before inc.	after inc.	before inc.	after inc.
Living	F	51.6	54.8	154.2 b	8.1	117.0 b
9	H	47.9	11.3	14.6 a	5.6	48.8 a
Dead	F	51.0	63.9	214.8 d	2.4	53.4 a
9	H	46.5	18.3	24.8 b	6.2	53.1 a
Living	F	59.2	51.7	86.2 a	74.5	211.8 c
30	H	57.4	22.5	45.7 c	23.2	165.8 c
Dead	F	75.8	82.6	155.2 b	125.6	327.1 d
30	H	60.5	23.5	46.6 c	39.0	112.1 b

Indexes a, b, c and d express significant differences between the values of nitrogen dynamics (NH_4-N and NO_3-N) for horizons F and H. Values with different indexes significantly differ from each other

ligrams produced by the weighed portion of the sample is the result of the analyses.

Nitrogen transformation

Weighed portion (25 g of organic matter) was moistened with distilled water and put into a glass container. The glass container was put into an incubator and processed for 14 days at a temperature 25°C. During the incubation period, the same weighed portion of the sample was cryopreserved for the purposes of further evaluation. The amount and forms of soil nitrogen determined in the control and incubated samples were compared.

Preparation of extract – incubated and control samples were embedded with 200 ml of 1% K_2SO_4 solution and macerated over night. The next day, they were processed and filtered. The content of N-NH_4 and N-NO_3 (ammonium and nitrate nitrogen) was determined in the filter liquor.

N-NH_4 – ammonium nitrogen was determined using a photo-electric colorimeter with Nessler's reagent.

N-NO_3 – nitrate nitrogen was determined using an ion-selective nitrate electrode.

Statistical evaluation

The final values of nitrogen dynamics and biological respiration from each part of each plot were used for statistical evaluation (set of sixteen samples for each analyzed biological and chemical characteristic). Single-factor analysis of variance with the significance level 0.05 was used to evaluate the final values of nitrogen dynamics and biological respiration activity (living versus dead forest was used as a factor of statistical analysis). The differential indexes a, b, c, and d (Tables 4 and 5) express significant differences in individual chemical and biological characteristics. The values with different indexes differ from each other significantly.

RESULTS AND DISCUSSION

Biological respiration activity of holorganic horizons

Comparing the results of respiration activity of holorganic horizons collected on plots No. 9 and 30, it is important to consider the site conditions of these plots. Differences in the ground vegetation layer and morphological properties of holorganic horizons (Tables 2 and 3) illustrate distinct site conditions of these two plots that can influence biochemical processes taking place in the soil profile. The moisture of holorganic horizons is also an important property that can strongly influence the rate of biological activity (EMMER 1999). The holorganic horizons collected on research plot No. 30 had higher moisture content compared to the holorganic horizons collected on plot No. 9 (Table 4). The holorganic horizons F and H collected in the dead part of plot No. 30 had the highest moisture content. Another important factor that could possibly influence the rate of biological activity of holorganic horizons is the age of dead forest stand on each plot. While the forest stand on plot No. 30 disintegrated during summer 1998, the age of the clear-cut on plot No. 9 was about 10 year at the time of the sampling.

Table 4 shows the dynamics of basal and potential biological respiration activity of holorganic horizons F and H collected on the research plots. Comparing the rate of respiration activity between the holorganic horizons F and H on both plots, it is obvious that in all cases the rate of respiration activity was higher in horizon F. PODRÁZSKÝ (2001) stated that the higher rate of biological activity of holorganic horizon F compared to H horizon is general. FORMÁNEK and GRUNDA (2000) showed the higher biological respiration activity in the sample of holorganic horizon L compared to the composite sample of holorganic horizons F and H in limed soils of mountain Norway spruce stand.

The rate of (basal and potential) respiration activity on plot No. 30 was significantly higher in horizon F collected in the dead forest stand compared to horizon F collected in the vital forest stand. The rate of respiration activity (basal and potential) in horizons H on this plot was comparable in both parts (vital and dead forest stands). The dynamics of biological activity was different on plot No. 9. On this plot, the rate of the basal respiration activity in horizons F and H collected in both the dead and vital part of forest stand was comparable, while the rate of potential respiration activity was significantly higher in horizon F collected in the dead forest stand. The values of the potential respiration activity in horizon H were comparable in both the vital and dead forest stand. The age of the dead forest stand (the clear-cut was about ten years old at the time of sampling) on plot No. 9 could possibly explain this feature. PODRÁZSKÝ (1992, 1999b) showed that following the changes in site conditions, the rate of basal respiration activity increased. Later on, during the process of mineralization, easily decomposed substances are broken down and the rate of basal respiration activity is decreasing despite of the fact that the rate of potential respiration activity is still relatively high. Significantly higher rates of respiration activity in the holorganic horizons collected in the dead forest stands on both plots indicate higher rates of microbial activity and consequently higher rates of organic matter decomposition. Due to changed sites conditions (temperature, moisture and intensity of irradiance), the rate of the microbially mediated processes such as decomposition and mineralization of organic matter is strongly influenced (PODRÁZSKÝ 1996). BINKLEY (1984) also showed the higher site-specific microbial activity in holorganic layers L, F, and H on the cut areas compared to the uncut areas. NOVÁK (1999) presented that not only clear-cut conditions but also the canopy closure of forest stand could possibly affect the rate of microbial activity. The rate of microbial activity was higher at forest sites with decreased canopy closure of the tree layer and with expanding ground vegetation layer.

Nitrogen dynamics – N mineralization and nitrification

Table 5 shows the content of $NH_4 – N$ and $NO_3 – N$ ions in holorganic horizons F and H collected in the dead and vital forest stand on plots No. 9 and 30. The fifteen days long incubation period that was used to determine the content of nitrate and ammonium ions for the purposes of this study does not allow any thorough analyses of nitrogen transformation. On the other hand, on the basis of these analyses, it is possible to compare the nitrogen dynamics in the holorganic layers of declined forest stand and vital forest stand (SVOBODA, PODRÁZSKÝ 2000).

The content of ammonium nitrogen (before and after incubation) was significantly higher in horizon F collected in the dead forest stands on both plots compared to the vital forest stands (Fig. 2). Nitrogen mineralization in the holorganic horizon H showed slightly different dynamics. On plot No. 9, in horizon H, the content of ammonium nitrogen before and after incubation was higher in the dead forest stand compared to the vital forest stand. On plot No. 30, the content of ammonium nitrogen in horizon H was similar in both the vital and dead forest stand. SVOBODA and PODRÁZSKÝ (2000) found at the stony sites of Norway spruce stand with the large introskeletal potential increased availability of ammonium ions in the holorganic layers collected on the plot with declined tree layers compared to the vital forest stand. Comparing the intensity of nitrification (Fig. 1) on the dead and vital part of plot 9, the content of nitrate ions before incubation in horizons F and H was similar. The content of nitrate ions after incubation was significantly higher only in horizons F collected in dead forest stands; the content of nitrate ions after incubation in horizons H was similar in both the dead and vital part of plot No. 9. The rate of nitrification (before and after incubation) on plot No. 30 was higher in both horizons F and H collected in the dead forest stands compared to the vital forest stands (Fig. 1). The higher content of ammonium and nitrate ions in horizon F compared to horizon H on both plots supports an assumption that horizon F generally shows the higher rate

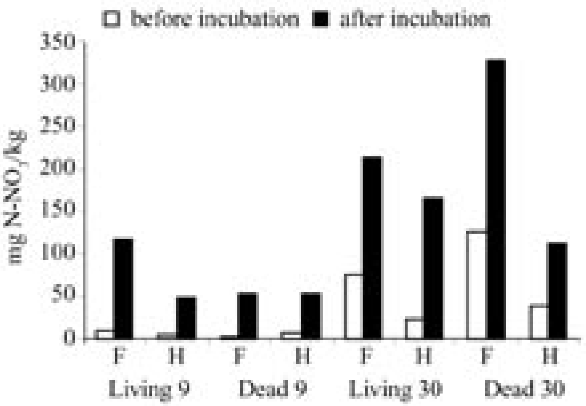

Fig. 1. Content of nitrate ions in holorganic layers F and H collected in the dead and vital forest stand on plots No. 9 and 30

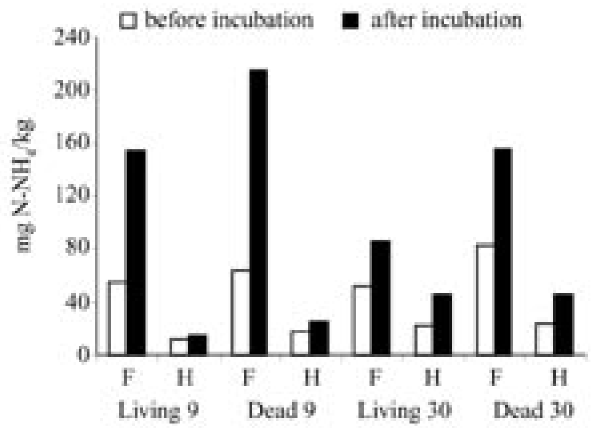

Fig. 2. Content of ammonium ions in holorganic layers F and H collected in the dead and vital forest stand on plots No. 9 and 30

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of microbial activity (TIETEMA 1992). Comparing the rate of N mineralization and nitrification in the holorganic layers of declined forest stand and vital forest stand on the research plots, increased availability of ammonium ions and nitrate ions in the holorganic layers under declined forest stands is obvious. BINKLEY (1984) also found the increased availability of N in holorganic layers L, F, and H on the cut sites compared to the uncut ones. The changed site conditions following the decline or cutting of the tree layer are likely to explain changes in the nitrogen dynamics. The rates of nitrogen mineralization and nitrification depend on the site conditions such as soil temperature and soil moisture (EMMER 1999).

There are obvious differences between the rates of N mineralization and nitrification in holorganic layers on both plots. They could possibly be explained by higher moisture (Table 5), different site conditions (Tables 1–3), different canopy closure of the tree layer, and different cover and vegetation type of the ground layer of plot No. 30 compared to plot No. 9. Ammonium ions were the prevailing form of nitrogen on plot No. 9; this was in accordance with other authors. On the other hand, the content of nitrate ions on plot No. 30 was similar to the content of ammonium ions. FORMÁNEK and KULHAVÝ (2001) and NOVÁK (1999) reported that ammonium nitrogen was a prevailing form of nitrogen available in the forest soils of Norway spruce stands in the temperate zone. On the basis of this study, there is no clear explanation for the relatively high nitrification rates in the holorganic layers on plot No. 30. NOVÁK (1999) stated that the expansion of the ground vegetation layer together with decreased canopy closure could strongly affect the rates of nitrification. TIETEMA et al. (1992) showed that pH differences smaller than one unit in the pH range could affect N transformation rates. Another possible explanation is a high temporal and spatial variability of nitrogen mineralization and nitrification mentioned by EMMER (1999), FORMÁNEK and GRUNDA (2000).

Soil reaction and characteristics of absorbing complex

Table 6 gives an overview of pH values and characteristics of the absorbing complex in holorganic horizons F and H collected in the dead and vital forest stands on plots No. 9 and 30. There are not any large differences in $pH_{(H_2O)}$ between the holorganic layers collected in the dead and vital forest stands on both plots. The values of $pH_{(H_2O)}$ are lowest in the holorganic horizons and gradually increase in the lower mineral horizons. Decreasing values of $pH_{(H_2O)}$ in the holorganic horizons and its increase in the lower mineral horizons is typical of mountain acid forest soils (PODRÁZSKÝ 2000).

The values of exchangeable soil reaction $pH_{(KCl)}$ showed a trend comparable to the values of $pH_{(H_2O)}$. The lowest values of $pH_{(KCl)}$ were in the holorganic horizons and increased in the lower mineral horizons. Comparing the values of active and potential soil reaction, there is a difference of about two units in the pH range between $pH_{(H_2O)}$ and $pH_{(KCl)}$ in a majority of holorganic and mineral horizons. ŠARMAN (1981) reported that the value of $pH_{(KCl)}$ was in a close relationship with the base-exchange

Table 6. The values of soil reaction and characteristics of absorbing complex

Plot	Horizon	Depth (cm)	$pH_{(H_20)}$	$pH_{(KCl)}$	S	T-S	T	V (%)
					(mval/100 g)			
Living 9	F	1.5–7.5	5.2	2.8	7.2	76.6	83.8	8.6
	H	7.5–11	5.1	2.8	2.6	55.8	58.4	4.4
	Ahe	11–30	5.2	3.6	1.7	11.3	13.0	12.9
	Bh	30–40	5.1	3.6	1.6	14.2	15.8	10.4
	Bs	40–55	5.3	3.7	0.1	6.9	7.0	1.1
	B/C	55–65	5.4	4.1	0.2	4.5	4.7	4.1
	Cn	65 +	5.5	4.3	0.1	9.1	9.2	1.1
Dead 9	F	1–7.5	5.1	2.8	21.4	71.3	92.7	23.1
	H	7.5–12	4.8	2.8	5.2	50.9	56.1	9.3
Living 30	F	1.5–5.5	4.9	3.4	15.2	78.0	93.2	16.3
	H	5.5–14	4.9	3.3	6.7	63.1	69.8	9.5
Dead 30	F	1.5–5.5	5.0	3.2	45.3	83.0	128.3	35.3
	H	5.5–15	4.9	3.2	5.5	61.5	67.1	8.2
	Ahe	15–20	5.0	3.7	2.2	7.3	9.5	23.5
	Bh	20–30	5.1	3.6	1.5	9.6	11.1	13.8
	Bs	30–40	5.1	3.6	1.1	8.5	9.6	11.9
	B/C	40–50	5.4	3.8	2.2	8.9	11.1	20.2
	Cn	50 +	5.4	3.9	2.0	6.7	8.7	23.1

Table 7. Total humus and nitrogen content and characteristics of exchangeable acidity

Plot	Horizon	Depth (cm)	Humus (%)	Nitrogen (%)	Ex. acidity	Ex. H	Ex. Al
					(mval/kg)		
Living 9	F	1.5–7.5	62.0	1.92	121.7	9.4	112.3
	H	7.5–11	46.7	1.96	142.0	6.3	135.8
	Ahe	11–30	6.6	0.24	57.6	0.7	56.9
	Bh	30–40	3.3	0.13	65.9	0.4	65.5
	Bs	40–55	4.6	0.12	65.1	0.2	64.9
	B/C	55–65	2.1	0.06	39.8	0.0	39.8
	Cn	65 +	1.1	0.06	28.4	0.2	28.2
Dead 9	F	1–7.5	58.6	1.97	118.0	7.3	110.7
	H	7.5–12	41.2	1.58	105.3	12.5	92.8
Living 30	F	1.5–5.5	56.8	2.64	232.5	12.7	219.8
	H	5.5–14	45.2	2.36	218.0	7.6	210.4
Dead 30	F	1.5–5.5	53.2	2.42	207.8	4.2	203.6
	H	5.5–15	44.7	2.28	175.2	4.0	171.2
	Ahe	15–20	2.3	0.16	56.5	0.0	56.4
	Bh	20–30	2.0	0.13	80.5	0.0	80.5
	Bs	30–40	1.6	0.10	72.0	0.0	72.0
	B/C	40–50	1.4	0.07	64.1	0.0	64.1
	Cn	50 +	1.9	0.10	64.5	0.0	64.5

complex and thus its value was closer to the factual pH in the soil. Comparable low values of $pH_{(KCl)}$ in the holorganic horizons collected in the area of Trojmezná Mt. were found by NOVÁK (1999), PODRÁZSKÝ et al. (2000). Although the values of active soil reaction were comparable on both plots, the values of potential soil reaction in the holorganic horizons on plot No. 30 were about a half of the unit (in the pH range) higher compared to plot No. 9. A possible explanation is different site conditions and different type and character of holorganic horizons (see Tables 2 and 3). Another possible explanation is a high temporal and spatial variability of the soil reaction in the mor layers that was found by NYKVIST and SKYLLBERG (1989).

In the whole soil profile, the content of exchangeable base cations (S) according to the scale – content of bases in the soil profile (REJŠEK 1999) is very low. The content of exchangeable base cations is highest in the holorganic horizons; with increasing depth of the soil profile the amount of base cations decreases. A slightly higher amount of base cations in the bottom mineral horizons (Cn, B/C) is probably connected with the weathering of the parent rock material and subsequent release of minerals into the soil solution. Comparing the content of bases (S) in holorganic horizons F and H collected in the dead and vital forest stands on both research plots, the dynamics that was already demonstrated by analyzing the microbial activity and nitrogen dynamics on both plots is obvious. A higher content of bases is in horizons F collected in the dead forest stands on both research plots compared to horizons F collected in the vital stands. The increased content of bases in horizons F is probably connected with higher microbial activity and consequent increasing decomposition of organic matter followed by a release of nutrients into the soil solution. SVOBODA and PODRÁZSKÝ (2000) showed an increased content of base cations in the holorganic layers following the decline of spruce stands in the area of Trojmezná Mt. The values of cation exchangeable capacity (T) and hydrolytic capacity (T-S) show a similar pattern like the base content (S). The highest values of T and T-S were found in the holorganic horizons, and their values decreased with increasing depth of the soil profile; only on the transition between the eluvial and illuvial (enriched) mineral horizons the values of T and T-S slightly increased. Higher amounts of exchangeable Al (Table 7) in the illuvial mineral horizons can explain this fact. The dynamics of base saturation (V) that strongly depends on the base content and cation exchangeable capacity confirms an assumption about the relative enrichment of holorganic horizons in the dead forest stands with the products of organic matter decomposition. Horizons F (on both research plots) and H (only on plot No. 9) collected in the declined forest stands show higher values of the base saturation compared with horizons F and H collected in the vital stands. In the soil profile, the values of base saturation (V) show a different pattern compared to the base content. A steep fall of T and T-S values on the transition between the holorganic and mineral horizons causes a relative increase in the base saturation values between holorganic horizons and mineral horizons.

Characteristics of exchangeable acidity, total humus and nitrogen

Table 7 gives an overview of exchangeable acidity and its characteristics (exchangeable Al and H), total humus content and total nitrogen content. The dynamics of exchangeable acidity in the soil profile also confirms an assumption about the higher biological activity and enhanced decomposition of organic matter in the holorganic horizons under the declined forest stands. The values of exchangeable acidity and consequently the values of exchangeable Al were higher on both research plots in horizons F and H collected in the vital forest stands compared to horizons F and H collected in the dead forest stands. In the soil profile, exchangeable acidity and its characteristics (exchangeable Al and H) diminished with increasing depth. The increased values of exchangeable Al on the transition between eluvial and illuvial mineral horizons indicate possible podzolisation processes within the soil profile.

The analysis of total humus and nitrogen did not reveal any strong dynamics. There were no differences in the total humus and nitrogen content between holorganic horizons collected in the vital and dead forest stands. The values of total humus and nitrogen were higher in the holorganic horizons and decreased with increasing depth of the soil profile.

CONCLUSIONS

The holorganic horizons of the forest soil collected under declined spruce stand showed different dynamics compared to the holorganic horizons collected under vital forest stand. The values of microbiological respiration activity, the rates of nitrogen mineralization and nitrification were found significantly higher in forest soils under the dead tree layer and on the clear-cut. The characteristics of the absorbing complex – base saturation and base content of the holorganic horizons showed analogous dynamics. Changed microclimatic conditions such as intensity of irradiance, moisture and temperature of the top organic layers together with altered development of the ground vegetation are acceptable explanations of these processes.

Generally, a higher rate of organic matter decomposition, transformed dynamics of nitrogen and other nutrients and their possible leaching from soil solutions in the forest floor under declined Norway spruce stand were demonstrated. The extent and seriousness of these adverse processes for the forest soil is strongly site dependent.

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Biologická aktivita, dynamika dusíku a charakteristiky půdního chemismu lesních půd v Národním parku Šumava

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ABSTRAKT: Příspěvek se zabývá rozsáhlým odumíráním horských lesních ekosystémů v Národním parku Šumava, při kterém dochází po rozpadu stromového patra ke změně biotických a abiotických vlastností lesních stanovišť. Hodnoty mikrobiologické respirační aktivity a dynamiky dusíku (mineralizace a nitrifikace) mohou být výrazně ovlivněny změněnými mikroklimatickými podmínkami stanoviště (teplota, vlhkost, ozáření) a následným rozvojem přízemní vegetace. Půdní substráty na extrémních kamenitých lokalitách, které jsou složené především z organických horizontů, mohou být ohroženy introskeletovou erozí. Příspěvek porovnává uvedené jevy na dvojici výzkumných ploch, zahrnujících odumřelý nebo vykácený lesní porost a vitální lesní porost. Změněná mikrobiologická respirační aktivita, pozměněná dynamika dusíku a ostatních živin spolu s jejich možným vyluhováním byly prokázány v lesních půdách pod odumřelými lesními porosty. Rozsah a nebezpečnost těchto jevů pro lesní půdy je značně závislá na konkrétním typu stanoviště.

Klíčová slova: NP Šumava; *Picea abies*; půdní chemismus; biologická aktivita; dynamika dusíku

Odumírání smrkových porostů na území NP Šumava není problémem pouze posledního desetiletí. Biotické činitele (*Ips typograhpus*), abiotické činitele (vítr, sníh, imise), ale i nevhodný management daného území jsou nejvážnější problémy, které ohrožují stabilitu lesních ekosystémů v dané oblasti (PODRÁZSKÝ 1999a; VINŠ 1999). Odumírání lesních ekosystémů nezpůsobuje pouze škody na stromovém patře, ale také může výrazným způsobem narušit ekologickou stabilitu daného území.

Odumírání stromového patra je provázeno výraznou změnou teplotních, vlhkostních a světelných poměrů na stanovišti (VOGT et al. 1986; JURGENSEN et al. 1988; LINHART 1999; VACEK et al. 1999). Půdní povrch nezastíněný stromovým patrem obdrží vyšší množství slunečního záření, a tím dochází ke změně teplotních poměrů na stanovišti. Vlhkostní režim půdního povrchu se mění vlivem snížené transpirace a intercepce stromového patra. Povrchový a podzemní odtok má odlišný průběh v porostech živého lesa v porovnání s porosty mrtvého lesa nebo holin (KUŘÍK et al. 1999). Nepříznivý vliv klimatických a stanovištních podmínek na vývoj a stav vrchní vrstvy půdy byl prokázán v mnoha studiích. Podle EMMERA (1999) změněné teplotní a vlhkostní poměry vrchních organických vrstev půdy mohou výrazně ovlivnit míru mikrobiologické aktivity, a tím také úroveň mineralizace a rozkladu vrchních organických vrstev. Zvýšená úroveň mikrobiologické aktivity, rozkladu humusu a přístupnosti živin po odumření a rozpadu stromového patra byla prokázána také v dalších studiích (BINKLEY 1984; KLIMO, KULHAVÝ 1994; SVOBODA, PODRÁZSKÝ 2000). JURGENSEN et al. (1988) prokázal, že v podmínkách holin může docházet k výrazným ztrátám povrchového humusu, což má značný dopad na půdní chemické, fyzikální a biologické vlastnosti obzvláště na nepříznivých stanovištích. Problematika degradace povrchového humusu a introskeletové eroze je řešena také v našich podmínkách. ŠACH a PAŠEK (1996), ŠACH (1999) a PODRÁZSKÝ (1999b) prokázali výraznou ztrátu organické hmoty na některých stanovištích v horských polohách, ke které došlo po odumření a těžbě smrkových porostů. Procesy introskeletové eroze představují výrazné ohrožení stability lesních porostů na některých stanovištích a byly dokumentovány v Krkonoších (ŠACH 1999), Jizerských horách (ŠACH, PAŠEK 1996) a na Šumavě (PODRÁZSKÝ 1999a). Poslední studie prokázaly zvýšenou úroveň mikrobiologické aktivity a rozkladu organické hmoty nejen na holinách, ale i v organických horizontech lesních porostů během probíhajícího odumírání stromového patra. NOVÁK (1999) prokázal zvýšenou úroveň mikrobiologické aktivity a nitrifikace spolu se zvýšeným množstvím přístupného dusíku v lesní půdě odumírajícího smrkového porostu v oblasti Trojmezenského pralesa v NP Šumava.

Cílem studie je stanovit mikrobiologickou aktivitu a dynamiku dusíku v holorganických horizontech odebraných v lesní půdě horského smrkového lesa a posoudit, zda ke zvýšení mikrobiologické aktivity, rychlosti rozkladu a mineralizace povrchového humusu může dojít již ve stadiu odumírání a rozpadu lesních porostů.

Studie byla provedena na dvou trvalých výzkumných plochách umístěných v první zóně NP Šumava Trojmezenský prales. Každá z výzkumných ploch zahrnovala odumřelý nebo rozpadající se lesní porost a dosud vitální lesní porost. Zájmová oblast leží ve smrkovém lesním vegetačním stupni v nadmořské výšce od 1 210 do 1 350 m. Průměrná roční teplota je 3,5 °C a průměrné roční srážky 1 200 mm. Rostlinná společenstva v dané oblasti jsou tvořena skeletovou smrčinou, kyselou smrčinou, kamenitou kyselou smrčinou, svěží smrčinou a podmáčenou klenovou smrčinou. SVOBODA (2002) uvádí podrobnou charakteristiku jednotlivých výzkumných ploch.

Vlastní odběr vzorků probíhal ve dvou fázích. Nejprve byly vykopány půdní sondy (jedna půdní sonda na každé ploše), ve kterých byl proveden popis půdního profilu, a následně odebrány vzorky minerálních horizontů podle genetických horizontů. Vzorky humusových horizontů F a H byly odebrány ve čtyřech opakováních na náhodně zvolených místech v odumřelém i živém lesním porostu na každé ploše. Analýzy byly provedeny standardními metodami (ŠARMAN 1981; ZBÍRAL 1995, 1996) v laboratoři Výzkumného ústavu lesního hospodářství a myslivosti – Výzkumná stanice Opočno. Analýzy zahrnovaly: stanovení $pH_{(H_2O)}$ a $pH_{(KCl)}$, charakteristiky sorpčního komplexu (S, H, T, V), výměnnou aciditu a její složky, obsah humusu, obsah celkového dusíku podle Kjeldahla. Pro holorganické horizonty byla dále stanovena biologická respirační aktivita a dynamika dusíku.

Při porovnávání biologické respirační aktivity holorganických horizontů odebraných na ploše 9 a 30 je nutné vzít v úvahu stanovištní podmínky na plochách. Charakter přízemní vegetace, morfologické vlastnosti odebíraných horizontů (tab. 1–3) na jednotlivých plochách odrážejí specifické stanovištní podmínky, které mohou ovlivnit biochemické procesy probíhající v půdním prostředí.

Výsledky biologické respirační aktivity horizontů F a H na výzkumných plochách ukazuje tab. 4. Z výsledků vyplývá, že úroveň respirační aktivity byla ve všech případech vyšší v horizontu F v porovnání s horizontem H. Vzorky horizontů (hodnoty pro horizont F byly statisticky průkazné) odebraných na ploše 30 v odumřelém lese vykazovaly (tab. 4) vyšší hodnoty respirační aktivity v porovnání se vzorky horizontů odebraných v dosud vitálním lese. Na ploše 9 byly hodnoty respirační aktivity bazální srovnatelné pro horizonty odebrané v odumřelém i vitálním lese, lišily se pouze hodnoty respirační aktivity potenciální (rozdíly byly statisticky průkazné) (tab. 4). BINKLEY (1984) a PODRÁZSKÝ (1996) také prokázali vyšší (stanovištně závislou) úroveň mikrobiologické aktivity v horizontech L, F a H na holinách v porovnání s vitálním lesem. NOVÁK (1999) uvádí výsledky, které naznačují vliv zápoje stromového patra a expanze přízemní vegetace na úroveň respirační aktivity.

Výsledky dynamiky dusíku (obsah NH_4-N a NO_3-N iontů v horizontech F a H) ukazuje tab. 5. Pro účel studie byla použita 15denní doba inkubace, která neumožňuje přesnější stanovení transformace dusíku. Na druhé straně je ale dostatečně přesná pro porovnání dynamiky dusíku v holorganických horizontech odebraných v odumřelém a vitálním porostu (SVOBODA, PODRÁZSKÝ 2000). Obsah NH_4-N iontů (před inkubací a po ní) byl vyšší v horizontu F odumřelého lesa v porovnání s vitálním porostem na obou plochách (tab. 5). Mineralizace dusíku v horizontu H byla vyšší v odumřelém lese v porovnání s vitálním porostem na ploše 9, zatímco na ploše 30 vykazovaly hodnoty mineralizace dusíku v horizontu H podobné hodnoty (tab. 5). Obsah NO_3-N iontů v horizontech F a H před inkubací na ploše 9 byl podobný, zatímco po inkubaci byl rozdíl v horizontu F odebraném v živém a mrtvém porostu (tab. 5). Na ploše 30 byl výrazný rozdíl v úrovni nitrifikace po inkubaci mezi horizonty F a H odebranými v odumřelém lese a vitálním porostu. SVOBODA a PODRÁZSKÝ (2000) uvádějí podobné výsledky dynamiky dusíku v holorganických horizontech odebraných v horském smrkovém lese na stanovištích s výrazným obsahem skeletu v půdním profilu. BINKLEY (1984) prokázal zvýšenou přístupnost dusíku v horizontech L, F a H odebraných na holinách v porovnání s vitálním porostem.

Výsledky stanovení pH a charakteristik sorpčního komplexu jsou uvedeny v tab. 6. Hodnoty pH byly nejnižší v horizontech F a H; poté postupně vzrůstaly s hloubkou půdního profilu. Charakteristika sorpčního komplexu podporuje výsledky mikrobiologické aktivity a dynamiky dusíku. Obsah bází (S) a nasycení sorpčního komplexu (V) v horizontech F odebraných v odumřelém lese na obou plochách byl vyšší v porovnání s vitálním porostem (tab. 6). Hodnoty S a V v horizontu H odebraném v odumřelém porostu byly vyšší pouze na ploše 9; na ploše 30 byly tyto hodnoty srovnatelné. Zvýšený obsah bází v horizontu F a částečně také H je pravděpodobně spojen se zvýšenou mikrobiologickou aktivitou, následným rozkladem organické hmoty a uvolňováním živin do půdního roztoku.

Na základě provedených pedochemických a pedobiologických analýz je možné vyvodit tyto závěry:

– humusová vrstva lesních půd v odumřelém lese vykazovala odlišnou dynamiku v porovnání se stále vitálním porostem,

– hodnoty mikrobiologické respirační aktivity, úroveň mineralizace a nitrifikace dusíku a obsahy přístupných bází byly vyšší v humusové vrstvě lesních půd v odumřelém lese v porovnání se stále vitálním porostem.

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