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NORWAY SPRUCE MONOCULTURES AND THEIR TRANSFORMATION TO CLOSE-TO-NATURE FORESTS FROM THE POINT OF VIEW OF SOIL CHANGES IN THE CZECH REPUBLIC

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Abstract

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At present, the proportion of Norway spruce stands in the Czech Republic amounts to about 54%. Natural composition should amount to 11% and recommended proportion is 36.5%. Today, research is particularly focussed on defining the properties of forest sites unsuitable for growing spruce monocultures, changes in the cycle of elements (particularly nitrogen), processes of the organic residue decomposition and relationships between the condition of nutrition, soil properties and climatic conditions. A network of demonstration areas has been established for comparative studies of forest stands in the various degree of transformation. The meaning of transformation does not generally consist in the replacement of spruce monocultures by stands of other species but in assigning such a position to spruce where a multi-purpose forest will be in accordance with the forest site capacity. In experimental plots Hetlin, the process was studied of the accumulation of organic matter in the surface humus in spruce monocultures and in the course of their transformation to a mixed forest. Moreover, nutrient concentration was compared in L, F, H and A layers. In addition to this, condition of spruce nutrition was compared in a monoculture in relation to the amount of accumulated humus with optimum and deficit concentrations of main bioelements. Effects of spruce monocultures on the acidification of soil surface layers were compared with neutralization effects of beech stands.

Key words: spruce monoculture, conversion, soil changes

Introduction

Before the marked change in tree distribution caused by man, the original range of Norway spruce in Europe occurred besides a boreal zone also separately in mountain massifs of Alpine, Hercynian, Carpathian, Rhodopian and Illyrian regions. The problem of spruce origin is important also for Czech forestry and, therefore, proper attention was paid to it. Through various comparative and archive studies it has been proved that spruce occurred frequently even at lower altitudes on sites with permanent high air humidity and on soils with the high degree of waterlogging or even on peat soils (Mráz, 1959). Mráz (1959) tends towards the opinion of Reinhold (1944) (in Mráz, 1959) that 'relict' spruce stands of lower locations are relics of the Atlantic period vegetation which has been preserved at certain sites up to the present day. Also Málek (1958) came to a conclusion that, in the Bohemian-Moravian upland connecting the Bohemian basin with SW Moravia with fading out Pannonian climate, spruce was distributed far more than we assumed. Spruce was scattered as a mixture or even as a predominating species all over the upland in districts which did not exceed the area of several hectares. It was not limited on the highest altitudes of about 800 m only but it occurred also at lower altitudes on waterlogged plateaus, in wide ravines and gorges along streams as well as in deeper valleys of rivers.

In addition to usually pure stands spruce formed mixtures with silver fir, alder or with beech and other species as mentioned by Samek, Plíva (1957) on the example of the Brdy Mts. The fact can be supposed also in other regions.

Extensive introduction of spruce falls particularly into the second half of the 19th century when natural forests were converted to Norway spruce monocultures in order to increase the volume of wood production. These brought both increase in wood and growth of negative phenomena (Nožička, 1972).

Long-time discussions were caused mainly by a thesis on the rapid degradation of forest soils related to the formation of podzols as mentioned particularly by Pelíšek (1955). In characterizing marked podzolization he states that the process "occurs under spruce and pine monocultures in forest regions of lowland up to piedmont locations with the shortage of precipitation and with higher temperature conditions". This statement was based on the involvement of the process of illimerization (lesivage) to the process of podzolization (particularly on loess sediments at lower locations) and also on discounting a fact that the occurrence of podzols on sandstones at lower locations (Bohemian Cretaceous Table) is not related to the present occurrence of spruce monocultures, i.e. podzols originated far earlier than in the period of growing spruce in the region. This opinion is, however, in contradiction with the opinion of e.g. Šály (1978) who states that under a forest stand various soil-forming processes related to the combination of soil-forming factors occur and it is not possible to stress one factor only from the whole context and to attribute absolute effects to it.

Besides the fact, e.g. Bublinec (1994) emphasizes 'economic' exploitation of nutrients for the production of wood in spruce as compared with beech. In a beech stand, 152 kg woody biomass is produced from 1 kg N but in a spruce stand as many as 393 kg. He also notes that it is not possible to speak about the evident deterioration of soil properties under coniferous stands although he admits marked changes in the forest floor.

Nilgård (1971) summarizes his studies carried out under spruce monocultures planted after beech stands in southern Scandinavia as follows: changes from mull humus to mor occur (with the possibility of podzolization processes), deterioration of the water regime, decrease in exchangeable nutrients in upper horizons, increase in C/N ratio, increased accumulation of litter on the soil surface, decrease in the percentage of ammoniacal nitrogen transferred to nitrates.

Also Klimo (2000) supports some conclusions of Nilgård and moreover, he emphasizes acidification effects of the surface humus H layer under spruce monocultures.

In connection with the potential transformation of spruce monocultures to mixed particularly spruce/beech stands a number of problems appears.

As for the problem of the potential deficit of Ca in the upper soil layer, Glatzel et al. (2000) conclude that in a mixed spruce/beech stand a two-storey root system is formed. Spruce spreads in the upper soil layer and beech takes water and Ca contained in it from deeper layers. Thus, Ca is included in the element cycling and reduces acidification effects of spruce litter. On the other hand, Schmidt, Kazda (2000) mention that marked reduction of the spruce root system on soil surface layers in a mixed stand with beech can condition its higher sensitivity to water deficit. The different character of stemflow in spruce and beech is also important because large amounts of precipitation water reach the zone of the root system of beech.

At present, orientation of forestry in the Czech Republic is, on the one hand, conditioned by catastrophic damage to spruce stands by biotic and abiotic factors and, on the other hand, by accepting objectives of sustainable forest management which is related to the preservation of the production function of forests, maintaining and increasing biodiversity and the use of gene sources of autochthonous quality trees in forest regeneration (Zezula, 1997). A view of the reconstructed natural and recommended composition of forests in some tree species fully supports the trend.

T a b l e 1. Species composition of stands in the Czech Republic – 1999

Forest composition	% of trees in the stand					
	spruce	fir	pine	larch	oak	beech
Natural	11.0	18.0	5.4	0.0	17.2	37.9
Present	54.2	0.9	17.6	3.7	6.3	5.9
Recommended	36.5	4.4	16.8	4.5	9.0	18.0

With an objective to support ideas of sustainable forest management the project "Objectives and ways of the reconstruction of a monocultural spruce forest: evaluation of exemplary areas of 'close-to-nature' forest management in the Czech Republic" has been accepted. The project is funded by the CR Ministry of Agriculture. The project should respond to the following questions: what are risks of growing spruce in monocultures on unsuitable sites, time period necessary to achieve the transformation, what kind of the new structure of stands contributes to increasing biodiversity and ecological stability, changes in the value of wood production during the processes. It is useful to reconstruct even-aged spruce stands threatening the nature of an ecosystem. The sense is not to replace spruce monocultures by stands of other species but to assign such a position to spruce as a hardly replaceable commercial species where the multifunctional role of a forest will be in agreement with the carrying capacity of a site.

The paper presents results in soil changes during the transformation of spruce monocultures in the second generation by means of beech and fir at a locality of Urban Forests of Kutná Hora, Forest District Hetlín.

Experimental plots and methods

Trial plots are situated in urban forests of Kutná Hora at an altitude of 400–500 m. According to neighbouring meteorological stations, mean annual precipitation amounts to about 650 mm. This factor is modified to a great extent by rather uneven distribution of precipitation during the year and by spring south-east wind circulation. Mean annual temperature amounts to about 7.1°C. Soils in the experimental area represent an important factor. Local pseudogleys or podzol- pseudogleys on Pleistocene sediments (Fig. 1) are characterized by alternating the surface waterlogging and draining. Also physical properties are markedly affected by particle-size distribution and compacted central part of the soil profile forms a mechanical barrier for the root system of trees. Therefore, spruce stands rooting only in the upper soil layer are not stable and suffer from windfalls. These soils are acid. pH values of the most acid H horizon – surface humus (consequences of growing spruce monocultures) are 3.1–3.2. In the lower part, pH values increase to about 5.1–5.3.

In total, 5 plots were established in mature 80 to 100-year-old Norway spruce stands. Simultaneously, plots with 40-year-old beech were studied, two plots with beech aged 20 years and one plot with the stand of silver fir aged 20 years. Criteria for the evaluation of conditions and soil changes in spruce monocultures and transformed stands were as follows:

- accumulation of organic matter and nutrients in the surface humus
- chemistry of A horizon where particularly the root system of trees is distributed
- leaf analysis – nutrition conditions
- acidification effects of spruce stands on the upper mineral horizon of soil and possible neutralization effects of beech litter.

Fig. 1. Soil type: pseudogley.

In each of the plots, soil type and conditions of the surface humus L, F, H (3 repetitions) and A horizon (3 repetitions) were assessed. Needles of spruce and fir were sampled in the upper part of crowns in November, in each of the plots 5 trees. Leaves of beech were sampled in summer months (5 trees).

Results and discussion

Considering a fact that soil changes are supposed particularly in upper soil horizons we paid attention especially to these soil layers.

Accumulation and chemistry of surface humus

Accumulation of surface humus was determined for particular layers L, F and H. Results are given in Table 2. The table shows following facts: in all the plots, marked accumulation of organic matter occurred ranging between 50 and 140 t.ha^{-1}. This relatively broad range divides the plots into two groups:

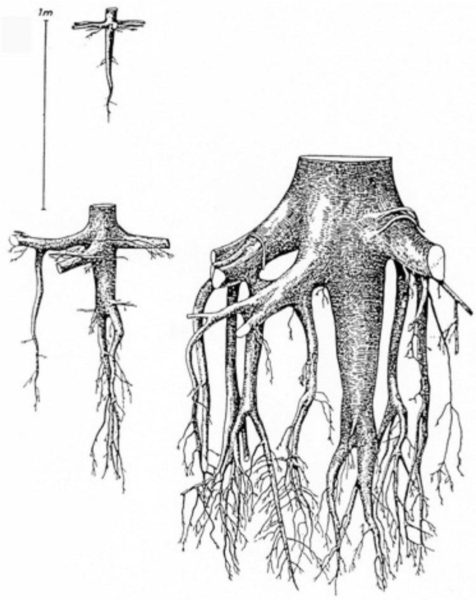
T a b l e 2. Weight of the surface humus [t . ha^{-1}]

Plot No.	L	F	H	Σ L, F, H
1	4.5	23.4	25.1	53.0
2	4.4	9.7	49.9	58.0
3	7.5	30.1	52.3	89.9
4	13.2	7.6	105.7	126.5
5	14.9	38.6	84.6	138.1
3a beech 40 years old	4.4	6.1	44.3	54.8
4a beech 20 years old	5.0	4.6	67.5	77.1
4b fir 20 years old	4.0	9.6	41.2	54.8
5a beech – gap	3.9	510	40.5	49.4

1 plots 1, 2 and 3 where the accumulation of organic matter ranges between 50 and 85 t.ha^{-1}
2 plots 4 and 5 where the accumulation of surface humus is considerably higher, viz 120 to 140 t.ha^{-1}.

In all the plots, the highest accumulation occurs in H layer. In the layer, nutrient cycling (particularly of nitrogen) is markedly decreased and the root system of spruce stands is developed being then shallow which results in the more frequent occurrence of windfalls.

In comparing the surface humus accumulation on basic plots in spruce stands with parallel plots where stands of beech and silver fir were established we can notice the marked decrease of surface humus in L, F and H layers although the H layer shows a relatively slow trend towards decreasing. It means that the cycle of elements was accelerated between the forest stand and upper soil horizons (Table 2). The fact is evident in comparing the condition of parallel plots with the basic plot. The highest decrease of the surface humus matter can be noticed in a gap with silver fir aged about 20 years. An importance of the repeated use of silver fir into the stand species composition can be related to the character of a root system. As shown in Fig. 2 (Kőstler et al., 1968), roots of fir penetrate deep to the soil profile thus aerating the soil environment, use water and nutrients from deeper soil horizons anchoring the stand against the effect of wind. The potential of fir to penetrate by its roots into depth was already noticed in our young silver fir stand. In Fig. 3, the



density is depicted of fine roots on the interface between the surface horizon and A horizon in a young spruce/fir stand thus clearly indicating the different development of the root system of both species.

Accumulation of organic matter on the soil surface is closely connected with the accumulation of particular nutrients. We are mostly interested in reserves of nitrogen (Table 3) which is bound in organic material and, thus, to a great extent

Fig. 2. Root system of fir (Kőstler et al., 1968).

Fig. 3. Root system in H layer (a – spruce, b – fir).

a b

excluded from the nutrition of a forest stand. Although decreasing the nitrogen deficit is often related to the increased input of nitrogen in the form of anthropogenic air pollutants nitrogen management within biogeochemical cycles and their modification by a forest manager remain dominant.

T a b l e 3. Weight of nitrogen in the surface humus [kg . ha^{-1}]

Plot No.	L	F	H	Σ L, F, H
1	53.1	353.3	353.9	760.3
2	61.6	136.7	490.0	688.3
3	105.7	496.6	732.6	1334.9
4	182.1	95.8	1384.7	1662.6
5	219.0	613.7	1252.0	2084.7
3a beech 40 years old	61.6	96.4	527.2	683.2
4a beech 20 years old	59.0	67.2	702.0	828.2
4b fir 20 years old	58.0	125.8	412.0	595.8
5a beech – gap	46.4	79.5	437.4	563.3

Based on data given in Table 3 we can find several phenomena: the highest accumulation of N occurs in H layer. Also in this case, studied plots are divided into groups. In Plots 1, 2 and 3, on average about 500 kg nitrogen per hectare are accumulated in the H layer and in Plots 4 and 5, the average is substantially higher, viz about 1300 kg.ha^{-1}. It is not changed even in N accumulation within the whole horizon of surface humus where the highest values were noticed again in Plots 4 (1662.6 kg.ha^{-1}) and 5 (2084.7 kg.ha^{-1}). In parallel plots regenerated by beech and fir, nitrogen accumulation was significantly decreased in L and F layers while in H layer, it remains in the range of 400–700 kg.ha^{-1} and the total accumulation ranges from 550 to 830 kg. ha^{-1}. This fact is related to the different value of surface humus reserves (Fig. 4).

The process of increased decomposition of organic matter in regeneration elements started the more intensive transport of nitrogen into mineral parts of the soil profile in a mineral form available for the forest stand nutrition.

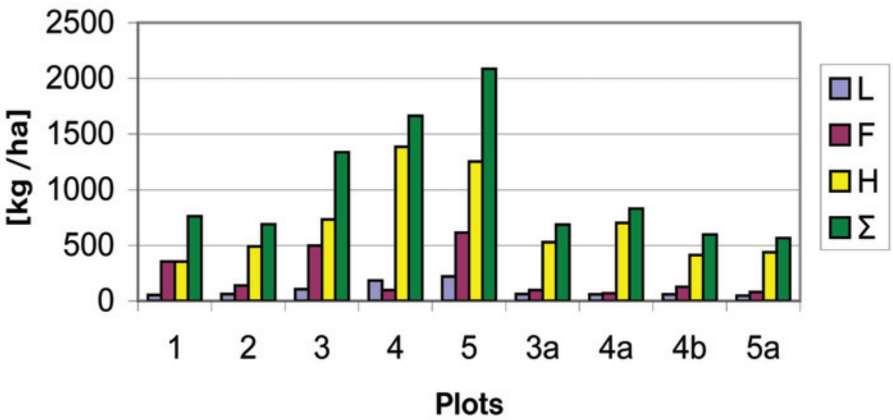


Fig. 4. Nitrogen reserves in the surface humus; 1–5 spruce aged 100 years, 3a, 4a, 5a gaps of beach and fir 4b.

T a b l e 4. Element concentration in the surface humus in spruce monocultures [Plots 1–5]

Plot	Layer	N	C	S	P	K	Mg	Ca	Fe	Mn	Zn	Cu	B
	L	1.18	46.7	1.07	930	1030	567	4172	339	835	35.0	5.66	9.23
1	F	1.51	43.2	1.47	1230	1360	580	2484	2386	440	34.2	8.16	11.5
	H	1.41	36.1	1.47	1410	2960	789	1286	6305	145	40.8	11.7	19.3
	L	1.37	45.2	1.16	1120	1390	762	6211	889	5342	46.9	7.66	14
2	F	1.41	42.5	1.35	1150	1620	730	3578	2396	3227	40.8	7.62	12.7
	H	1.00	22.9	1.30	1570	3690	931	827	10093	367	37.2	7.58	23.9
	L	1.41	46.4	1.35	1320	920	665	4918	517	3053	56.7	7.50	11.8
3	F	1.65	42.7	1.66	2190	1180	604	2979	2723	2162	38.5	10.8	13.6
	H	1.40	32.3	1.37	2100	2720	753	1555	7315	421	37.5	13.1	23.8
	L	1.38	43.6	1.37	1400	1040	670	4687	2188	1119	43.1	8.63	11.9
4	F	1.26	47.1	1.05	1250	980	625	6235	408	1766	56.8	7.48	9.05
	H	1.31	39.9	1.35	2010	1800	580	1694	4948	196	33.7	11.6	17.9
	L	1.47	46.8	1.33	1080	700	462	4359	610	1653	45.7	7.99	11.1
5	F	1.59	43.8	1.75	2040	920	537	3739	2339	1045	50.4	12.6	14.3
	H	1.48	38.6	1.67	2190	1600	525	1901	5648	306	49.1	12.9	19.4

T a b l e 4a. Amount of elements in the surface humus [kg . ha^{-1}]

Plot	Layer	N	C	S	P	K	Mg	Ca	Fe	Mn	Zn	Cu	B
	L	53.1	2101	4.8	4.2	4.6	2.6	18.8	1.5	3.7	0.15	0.02	0.04
	F	353.3	10108	34.4	28.8	31.8	13.6	58.1	55.8	10.3	0.80	0.19	0.26
1	H	353.9	9061	36.9	35.4	67.5	19.8	32.3	158.2	3.6	1.00	0.29	0.48
	Σ	**760.3**	**21270**	**76.1**	**68.4**	**103.9**	**36.0**	**109.2**	**215.5**	**17.6**	**1.96**	**0.50**	**0.78**
	L	61.6	1989	5.1	4.9	6.1	3.3	27.3	3.9	23.5	0.21	0.03	0.06
	F	136.7	4122	13.1	11.1	15.7	7.1	34.7	23.2	18.9	0.40	0.07	0.12
2	H	490.0	11427	64.9	78.3	184.1	46.5	41.3	503.6	18.3	1.86	0.40	1.20
	Σ	**688.3**	**17538**	**83.1**	**94.3**	**205.9**	**56.9**	**103.3**	**530.7**	**60.7**	**2.47**	**0.50**	**1.38**
	L	105.7	3480	10.1	9.9	6.9	5.0	36.9	3.9	22.9	0.43	0.06	0.09
	F	496.6	12853	50.0	65.9	35.5	18.2	89.7	82.0	65.1	1.16	0.33	0.41
3	H	732.6	16893	71.6	109.8	142.2	39.4	81.3	382.6	22.0	1.96	0.68	1.24
	Σ	**1334.9**	**33226**	**131.7**	**185.6**	**184.6**	**62.6**	**207.9**	**468.5**	**110.0**	**3.55**	**1.07**	**1.74**
	L	182.1	5755	18.1	18.5	13.7	8.8	61.9	28.9	14.8	0.60	0.11	0.16
	F	95.8	3580	8.0	9.5	7.4	4.8	47.4	3.1	13.4	0.43	0.06	0.07
4	H	1384.7	42174	142.7	212.5	190.3	61.3	179.1	523.0	20.7	3.56	1.23	1.89
	Σ	**1662.6**	**51509**	**168.8**	**240.5**	**211.4**	**74.9**	**288.4**	**555.0**	**48.9**	**4.59**	**1.40**	**2.12**
	L	219.0	6973	19.8	16.1	10.4	6.9	64.9	9.1	24.6	0.68	0.11	0.16
	F	613.7	16906	67.5	78.7	35.5	20.7	144.3	90.3	40.3	1.94	0.49	0.55
5	H	1252.0	32656	141.3	135.4	135.6	44.4	160.8	477.8	25.9	4.15	1.09	1.64
	Σ	**2084.7**	**56535**	**228.6**	**230.2**	**181.5**	**72.0**	**370.0**	**577.2**	**90.8**	**6.77**	**1.69**	**2.35**

T a b l e 5. Element concentration in the surface humus on comparative regenerated plots 3a, 4a, 4b, 5a

Plot	Layer	N	C	S	P	K	Mg	Ca	Fe	Mn	Zn	Cu	B
3a	L	1.46	44.6	1.18	1150	1890	1006	8420	676	6832	57.4	9.24	13.9
Beech	F	1.58	42.0	1.59	1260	1640	821	5683	1947	8824	53.5	12.1	15.0
40 years	H	1.19	24.6	1.32	1900	3780	962	1717	9648	1913	40.5	13.5	29.4
4a	L	1.18	46.4	0.96	1070	1360	648	5867	384	3404	45.5	7.24	11.0
Beech	F	1.46	43.7	1.29	1200	1320	703	3626	1975	2984	43.2	10.7	11.9
20 years	H	1.04	26.1	1.26	1920	2910	784	1073	8581	441	40.4	9.15	23.0
4b	L	1.45	43.4	1.22	1480	1800	585	4299	2036	1906	52.0	9.18	12.3
Fir	F	1.31	31.5	1.38	1920	3000	913	2156	7124	651	55.9	10.3	20.7
20 years	H	1.00	23.2	0.93	2010	3440	713	925	9740	247	50.0	9.85	26.2
5a	L	1.19	46.2	1.05	910	860	859	7641	347	2999	41.6	7.49	13.3
Beech	F	1.59	44.2	1.41	1240	1690	761	4547	1750	2676	39.2	9.59	13.7
20 years	H	1.08	21.7	1.09	1880	3455	897	1197	8279	397	49.6	9.90	24.7

T a b l e 5a. Amount of elements in the surface humus on comparative regenerated plots [kg . ha^{-1}]

Plot	Layer	N	C	S	P	K	Mg	Ca	Fe	Mn	Zn	Cu	B
3a	L	61.6	1962	5.2	5.1	8.3	4.4	36.3	3.0	30.1	0.25	0.04	0.06
Beech	F	96.4	2562	9.7	7.7	10.0	5.0	34.7	11.9	53.8	0.32	0.07	0.09
40 years	H	527.2	10898	58.5	84.2	167.5	42.6	76.1	427.4	84.7	1.79	0.60	1.30
	Σ	**683.2**	**15422**	**73.4**	**97.0**	**185.8**	**52.0**	**147.1**	**442.3**	**168.6**	**2.36**	**0.71**	**1.45**
4a	L	59.0	2320	4.8	5.4	6.8	3.2	29.3	1.92	17.0	0.22	0.03	0.05
Beech	F	67.2	2010	5.9	5.5	6.1	3.2	16.7	9.1	13.7	0.20	0.04	0.05
20 years	H	702.0	17617	85.1	129.6	196.4	52.9	72.4	579.2	29.8	2.72	0.62	1.55
	Σ	**828.2**	**21947**	**95.8**	**140.5**	**209.3**	**59.3**	**118.4**	**590.2**	**60.5**	**3.14**	**0.69**	**1.65**
4b	L	58.0	1736	4.9	5.9	7.2	2.3	17.2	8.1	7.6	0.21	0.04	0.05
Fir	F	125.8	3024	13.2	18.4	28.8	8.8	20.7	68.4	6.2	0.53	0.10	0.20
20 years	H	412.0	9558	38.3	82.8	141.7	29.4	38.1	401.3	10.2	2.06	0.41	1.08
	Σ	**595.8**	**14318**	**56.4**	**107.1**	**177.7**	**40.5**	**76.0**	**477.8**	**24.0**	**2.80**	**0.55**	**1.33**
5a	L	46.4	1802	4.1	3.5	3.4	3.4	29.8	1.3	11.7	0.16	0.03	0.05
Beech	F	79.5	2210	7.1	6.2	8.5	3.8	22.7	8.8	13.4	0.20	0.05	0.07
20 years	H	437.4	8788	44.1	76.1	139.9	36.3	48.5	335.3	16.1	2.00	0.40	1.00
	Σ	**563.3**	**12800**	**55.3**	**85.8**	**151.8**	**43.5**	**101.0**	**345.4**	**41.2**	**2.36**	**0.48**	**1.12**

In Tables 4, 4a, 5 and 5a, data are given on the concentration and amount of elements in particular layers of the surface humus. Lower concentrations are remarkable of nitrogen in H layers in regeneration elements with beech and fir. Faster mineralization and increased uptake by young stands are an evident reason. Another picture is given by Ca concentration in Plot 3a where owing to a beech stand aged 32 years the concentration is substantially higher as compared with the spruce stand.

Spruce stand –	L layer	4918 $mg.kg^{-1}$	Beech stand –	L layer	8420 $mg.kg^{-1}$
	F	2979 $mg.kg^{-1}$		F	5683 $mg.kg^{-1}$
	H	1555 $mg.kg^{-1}$		H	1717 $mg.kg^{-1}$

Thus, the smallest difference in Ca concentration is in H layer because this layer is partly "conserved" being formed in the previous spruce stand.

Similar situation occurred in the stand with beech (Table 4a) as for Mg concentration.

In the "regeneration gap" of beech aged 20 years (Table 4), increased Ca concentration also occurred particularly in L layer. In this case, the process of surface humus transformation is in an initial stage. However, the situation occurs also in a beech stand aged 40 years (Table 4a). Generally, we can state that beech functions as a soil-improving species there. However, it was not noticed in a gap with silver fir aged 23 years where the concentration of Ca in particular layers of surface humus was lower than in a mature spruce stand.

Changes in A horizon caused by the transformation of spruce monocultures

The surface humus H layer (Fig. 5) not exceeding a value of pH 3.5 is the most acid soil layers in the studied area. Based on the fact it is possible to conclude acidification effects of spruce monocultures. However, it is not possible to corroborate the origin of podzol soil in the course of one or two generations of a spruce monoculture. The origin of pseudogley soils is predominantly related to the soil profile texture, water regime character and alternation of reduction and oxidation processes. However, when we compare pH values of A horizons with those of A horizons on regeneration plots with beech and fir we can notice positive effects of a beech stand in particular. This effect was manifested most markedly in a 37-year-old beech stand where pH values of A horizon exceeded a value of 4. Of course, such a change was not marked in a fir stand (aged 20 years). In characterizing A horizons of basic plots in spruce monocultures (Plots 1, 2, 3, 4 and 5) we can note again differences between Plots 1, 2, 3 and Plots 4, 5. Plots 4 and 5 in spruce stands show lower concentrations of the majority of studied elements such as N, S, P, K, Mg, Ca Fe, Mn, Zn and Cu in A horizons. Higher concentrations shows only B (Table 6).

In assessing the effect of spruce monoculture transformations in the studied area it is possible to consider particularly increased N concentrations in A horizons under young stands of beech and fir to be positive. The same trend can be also noticed in Ca concentration (Fig. 7). Its higher shift was found under a beech stand aged 37 years (Plot 4a). This event also shows significant effects on decreasing the pH values (Table 7, 8).

The given concise overview of the condition and changes in the soil environment affected by spruce monocultures out of their natural range and of changes affected by trans-

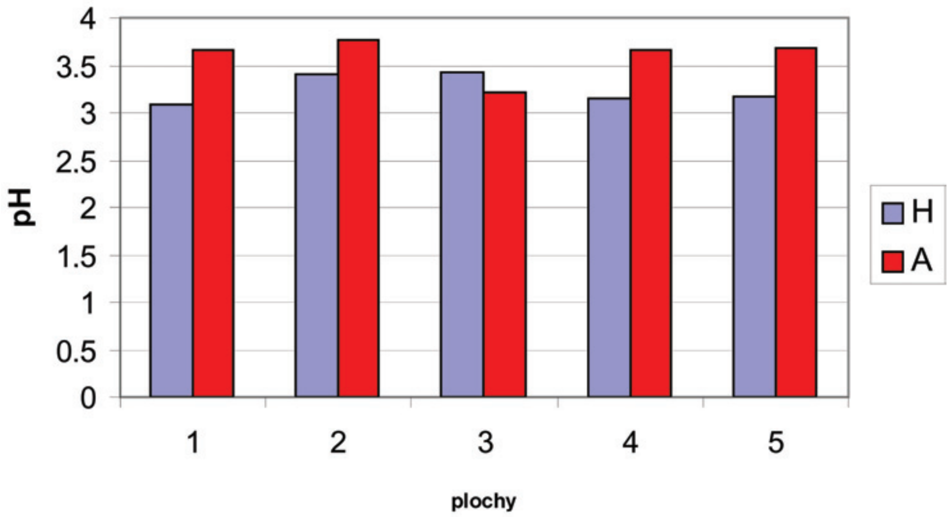


Fig. 5. pH values of H and A horizons in spruce stands.

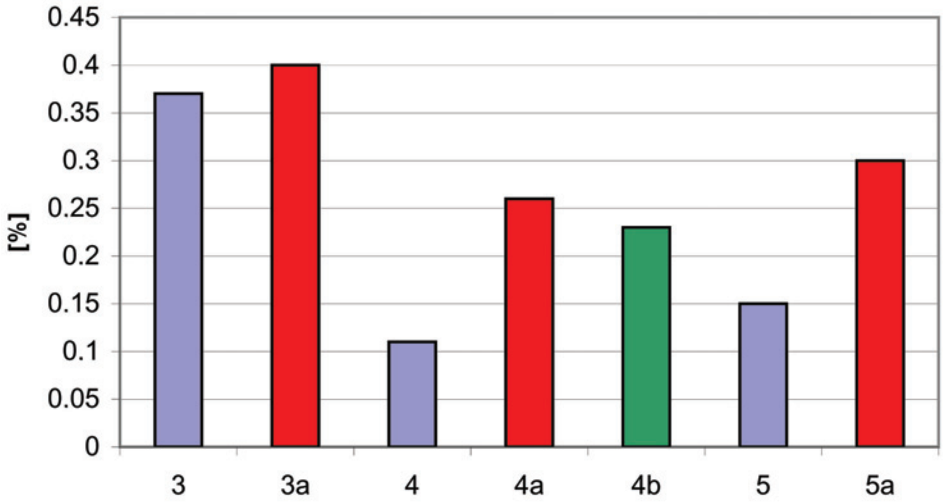


Fig. 6 N concentration in A horizon under spruce stands aged 100 years (3, 4, 5), gaps of beech (3a, 4a, 5a) and fir (4b).

formation processes can provide rational orientation for the creation of ecologically stable productive forest ecosystems.

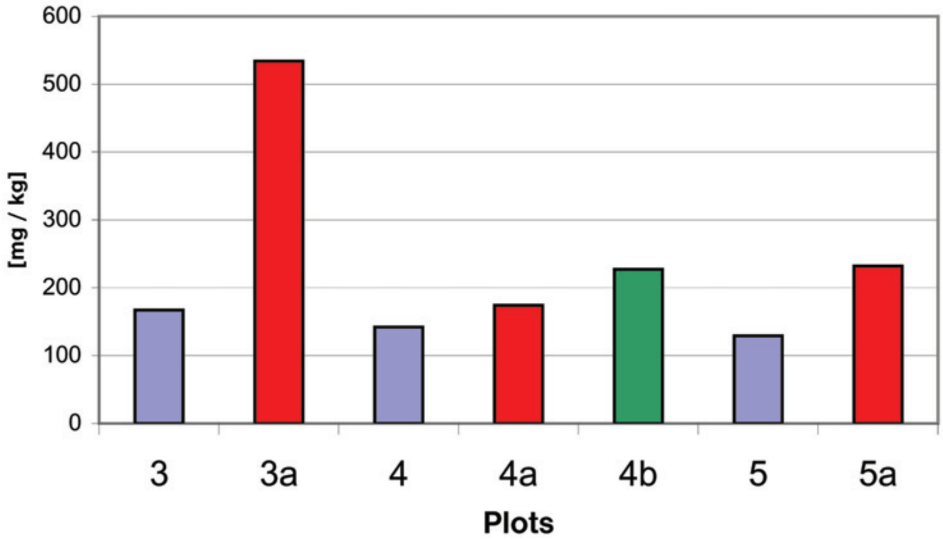


Fig. 7. Ca concentration in A horizon under spruce stands aged 100 years (3, 4, 5),), gaps of beech (3a, 4a, 5a) and fir (4b).

T a b l e 6. Element concentration in A horizon in spruce monocultures

Plot	Depth [cm]	[%]	[%]	[g/kg]	[mg / kg] – total content								
		N	C	S	P	K	Mg	Ca	Fe	Mn	Zn	Cu	B
1	5–8	0.18	3.98	0.85	1060	6310	2017	145	16874	287	43.9	6.78	1.26
2	5–10	0.21	3.20	0.39	770	4630	1902	161	13365	163	35.7	6.17	2.32
3	4–6	0.37	7.58	0.77	1100	4630	1398	167	12029	81.9	28.7	7.08	3.06
4	8–12	0.11	3.10	0.47	790	4100	1448	142	12647	124	24.4	3.74	2.98
5	10–15	0.15	4.01	0.30	910	4270	1259	129	10262	211	30.3	4.48	2.06
Mean 1–5		0.20	4.37	0.56	926	4788	1605	149	13035	173	32.6	5.65	2.34
Mean 1–3		0.25	4.92	0.67	977	5190	1772	158	14089	177	36.1	6.67	2.21
Mean 4–5		0.13	3.55	0.38	800	4185	1353	135	11454	167	27.3	4.11	2.52

Nutrition of trees

In the research area Hetlín, as mentioned above, the amount of accumulation was divided into two groups, viz Plots 1–3 ranging from 50 to 85 t.ha^{-1} and Plots 4–5 ranging from 120 to 140 t.ha^{-1}.

Our hypothesis supposed that differences found in the accumulation of organic matter and thus in “blocking” nitrogen in the element cycling would also show in the condition of nutrition of spruce stands. Results of leaf analyses, however, have not prove this hypothesis. It means that requirements of spruce for the condition of soil (as for nutrients) show a rather broad range. Of course, ecological impacts of this increased accumulation in next generations of spruce monocultures remain a problem.

T a b l e 7. pH values of H layer and A horizon of parallel plots with beech and fir

Plot No.	Layer depth [cm]	pH	
		H_2O	KCl
3a beech 40 years	H A	3.62 4.13	3.16 3.19
4a beech 20 years	H A	3.31 3.86	2.69 3.05
4b fir 20 years	F H A	3.51 3.34 3.79	2.91 2.65 2.97
5a beech 20 years	H A	3.66 3.77	2.94 2.97

Comparisons of the condition of nutrition of spruce with other research areas (Rájec, Rudice, Křtiny, Pokojná hora) also concerning the increased accumulation of organic matter in the surface humus on the level 50–70 $t.ha^{-1}$ do not indicate marked differences eg in nitrogen and calcium. Only in the Rudice area where soils poor in minerals occur low concentrations were noticed of N and in the Pokojná hora area, increased concentrations of Ca were found. The fact can be conditioned by the vicinity of the Moravian Karst limestone region.

Assessing the condition of spruce stands in the Hetlín area after comparison with the "optimum" concentration of main bioelements according to Bavarian directives for the fertilization of forest stands shows that concentrations of these elements occur in ranges corresponding to the optimum condition. No nutrient occurs at the limit of critical conditions. Only the content of Zn is lower than an optimum concentration. This condition can be also corroborated according to Bavarian directives for the fertilization of forest stands where the limit of main bioelement deficit is determined as follows:

T a b l e 8. Element concentration in A horizon on comparative regenerated plots 3a, 4a, 4b, 5a

Plot	[%]	[%]	[g/kg]	[mg / kg] – total content							
	N	C	S	P	K	Mg	Ca	Fe	Mn	Zn	Cu
3a beech 40 years	0.40	9.06	0.47	1390	4520	1583	534	14408	370	33.6	9.57
4a beech 20 years	0.26	7.53	0.24	1040	1230	1459	174	12855	258	27.7	6.24
4b fir 20 years	0.23	7.40	0.55	1120	4510	1527	227	14645	292	30.9	5.48
5a beech 20 years	0.30	7.59	0.65	1170	3670	1224	232	8712	98.5	26.4	5.96

T a b l e 9. Comparison of the condition of nutrition in spruce in the Hetlín area with the “optimum” concentration of nutrients*

Nutrient	Optimum concentration of nutrients	Nutrient concentration Hetlín 2003 (n–25)
N	1.5–2.0%	1.47%
P	0.15–0.20%	0.18%
K	0.45–0.80%	0.50%
Ca	0.30–1.3%	0.40%
Mg	0.09–0.2%	0.12%
Fe	30–180 mg/kg	63.3 mg/kg
Mn	30–600 mg/kg	1630.1 mg/kg
Zn	30–60 mg/kg	20.73 mg/kg
Cu	2–7 mg/kg	2.99 mg/kg

*Grundsätze für die düngung in Wald Bayerisches Staatsministerium, 1987

N – < 1.3 %
P – < 0.13 $g.kg^{-1}$
K – < 0.35 $g.kg^{-1}$
Ca – < 0.10-0.20 $g.kg^{-1}$
Mg – < 0.06-0.07 $g.kg^{-1}$

Leaf analyses of beech in parallel plots show markedly increased nutrient concentrations (Table 9). Thus, we can conclude:

1. nutrient uptake during the year is substantially higher than in spruce
2. beech accelerates element cycling showing improving effects on soil chemistry and deceleration of acidification effects of spruce monocultures which is documented by the higher content of Ca in leaves. N cycle is also markedly changed.

As compared with the effect of beech on soil surface layers the fir needle analysis doe not markedly differ from the analysis of spruce needles particularly as for N concentration where its concentration ranges between 1.19 and 1.54% (mean of 10 samples = 1.35%) in the first needle-year. Ca concentration in the silver fir stand approaches more to the Ca concentration in leaves of beech in a range of 4.83–7.66% with a mean 0.58%. Marked concentration of Ca in fir needles was found in the second needle-year. It means that generally known storage of Ca in older tissues occurs also in fir (Table 10, 11, 12).

Based on the data we can notice that increased accumulation of organic matter and thus also of N in the organic material did not cause worsening the condition of N nutrition of a mature spruce stand. Explanation of the event can be based on other potential sources of N for nutrition such as the shift of N from older tissues (biological cycle of N), using the input of mineral NO_3 and NH_4 from the atmosphere conditioned by anthropogenic effects and, last but not least, possibilities of the uptake of amino-acids as mentioned by Näholm et al. (1998), Zhong, Makeshin (2002), Kozlowski, Pallardy (1997).

T a b l e 10. Element concentration in leaves of beech in Plots 3a, 4a and 5a

Plot	[%]			[g . kg^{-1}]				[mg . kg^{-1}]				
	C	N	S	P	Mg	Ca	K	Fe	Mn	Zn	Cu	B
3a	46.80	2.40	0.14	1.30	1.72	6.88	8.25	169	3165	22.8	5.90	30.8
4a	47.00	2.44	0.13	1.22	2.14	6.94	7.25	148	3714	25.8	5.63	23.4
5a	46.80	2.00	0.11	1.18	1.50	6.72	7.25	133	4697	15.5	4.06	27.5
Mean 3a, 4a, 5a	46.90	2.28	0.13	1.23	1.79	6.85	7.58	150	3858	21.4	5.20	27.2

T a b l e 11. Element concentration in spruce and fir needles in Plots 3a, 4a and 5a

Plot	Needle-year	[%]		[g . kg^{-1}]			
		S	N	P	Mg	Ca	K
Spruce 100 years old	1 2	0.10 0.10	1.47 1.29	1.85 1.37	1.16 1.09	4.02 6.27	4.99 4.52
Fir 20 years old	1 2	0.96 1.17	1.36 1.36	1.29 1.25	1.62 1.65	5.80 8.43	6.52 5.14

T a b l e 12. Relationships between the accumulation of organic matter and N in the surface humus and the condition of nutrition in spruce stands (age 100 years)

Plot No.	Accumulation of organic matter	Accumulation of N in organic matter on the soil surface	Concentration of N in 1-year-old needles of spruce
	[t / ha]	[kg /ha]	[%]
1	53	760	1.36
2	58	688	1.39
3	89	1335	1.47
4	126	1663	1.49
5	138	2085	1.60

Conclusions

Based on the analysis of the condition and changes in organic horizons and organo-mineral horizons A of pseudogleys under secondary spruce monocultures and under stands of beech and silver fir in the transformation stage we can state:

- Spruce monocultures markedly slow the cycle of nutrients particularly of nitrogen affecting acidification of upper soil horizons.
- In the course of the first and second generations of spruce monocultures, the occurrence of the origin of podzol soils has not been proved.
- Newly established beech stands markedly affected the condition of surface humus although the high accumulation of organic matter in H layer can persist for a long time. They also markedly decreased soil acidity and increased the content of Ca in A horizon.
- The admixture of silver fir into transformed stands will markedly affect particularly the distribution of a root system in deeper soil layers.
- Increased accumulation of organic matter in the surface humus did not substantially affected the nutrition of spruce stands by nitrogen.

Translated by B. Horák

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Klimo E., Kulhavý J.: **Transformace smrkových monokultur na lesy blízké přírodě z hlediska půdních změn v České republice.**

V České republice došlo v posledních dvou stoletích k výrazné druhové změně lesních porostů ve prospěch jehličnatých dřevin, převážně smrku. Na základě studia změn půdních vlastností byly zhodnoceny ekologické dopady smrkových monokultur i transformačních procesů pomocí buku a jedle. Na příkladu lokality Hetlín

(Městské lesy města Kutné Hory) bylo poukázáno, že smrkové monokultury výrazně zpomalují koloběh živin, zejména dusíku a zvyšují aciditu svrchních půdních horizontů. Nově založené bukové porosty podmínily rychlejší dekompozici zejména vrstev L a F povrchového humusu, snížily půdní kyselost a zvýšily obsah Ca v horizontu A. Jedle se výrazně projevuje zejména rozložením kořenového systému do větší hloubky půdních substrátů. Rovněž bylo konstatováno, že zvýšená akumulace povrchového humusu se neodrazila ve výživě dospělého smrkového porostu.