Fertilization of spruce monocultures in the territory of Training Forest Enterprise in Kostelec nad Černými lesy

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ABSTRACT: Long-term fertilization effects were evaluated including NPK, Ca and N applications at the lower altitudes. The studied localities are in the territory of Training Forest Enterprise in Kostelec nad Černými lesy, at an altitude of 300–500 m a.s.l., sites of beech-oak-fir types. Fertilizers were used in 1965–1967, the evaluation of soil condition was done in 1967 (before fertilization) and 2002. After 25–35 years, only low effects of fertilization are detectable in the humus forms and complex soil profile – surface humus accumulation, soil chemistry, as well as nutrient contents. Complex fertilization was reflected in higher site fertility in general, N-fertilization only in the progress of acidification. During the period 1967–2002, a strong general trend of acidification is obvious caused by both acid deposition and Norway spruce monoculture-based forestry.

Keywords: fertilization; Norway spruce; forest soils; humus forms; acidification; amelioration

Temporary lack of timber in the last centuries and decades led to the study of opportunities for increasing timber production. The trends of solution to this economic problem were different: introduction of close-to-nature principles in some cases (restoration of degraded sites), introduction of exotic species, tree breeding technologies and forest land extension (reforestation of marginal agriculture lands). Among them, the increase of site fertility and production also played an important role – by improving the soil condition and nutrient supply. Other arguments for the fertilization use are nutrient losses by soil acidification and biomass removal and healthy status improvement of declining forest stands (Podrázský et al. 2003).

Fertilization in forestry can be effectively used in different site conditions and at different forest stages: in forest nurseries, at reforestation, in plantations, at medium age of stands and also in older stands with the harvest perspective. In forest nurseries, it is *conditio sine qua non* for soil fertility conservation. Fertilization of young plantations should accelerate their increase and improve vitality to shorten the time necessary for intensive care (weeding, fencing, re-planting), to reduce mortality at unfavourable sites (Remeš et al. 2004). In the medium and older age, it has production purposes: volume growth increase, assortment changes, and soil improvement for forest regeneration (Binkley 1986). A lot of data is available for fertilization of young plantations, but in Czech conditions, the information on older stand treatments is missing.

Fertilization influences not only the growth of forest trees but also the soil condition and chemistry, then it affects the tree vitality and resistance to particular damage factors. On the other hand, frequent changes in forest policy led to abandonment of many research plots, established in the past. In the territory of the Training Forest Enterprise in Kostelec nad Černými lesy research plots with fertilization testing were also established in 1965–1967. The aim of the study was to quantify increment ef-

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fects of particular fertilization methods in maturing spruce stands at different sites. The plots were not studied between the years 1967 and 2002. The aim of the present study is to document research results on one re-constructed plot set in this area: effects of fertilization on the forest soil in 1967–2002 and soil changes on the control plot in this period.

MATERIAL AND METHODS

Several systems of permanent research plots (PRP) were established in the territory of Training Forest Enterprise Kostelec nad Černými lesy. This area is located 25–50 km SE of Prague. The climate is moderately warm and arid, mean annual temperature is 7.6°C, average annual precipitation is 655 mm (Ondřejov Station). The soils are of Luvisol type, the established research plots are especially at the fir-beech sites. The set of three studied plot is in Jevany District in the stand 442D11, at the altitude 400 m a.s.l., on a very moderate SE slope, in the forest type *Luzulo-Quercetum luzuletosum pilosae*, in modern classification 3S1 (fresh oak-beech site). The soil is sand-loamy, on perm-carbonian sediments, the locality is called Aldašín (the name of the village extinct in Thirty Years' War).

The plots were established in the period 1965–1967, in total 39 plots, 0.20–0.25 ha each, the position and dendrometric parameters were determined for individual trees. Three basic variants were defined:

– control one, without fertilizer application,
– full fertilization, NPKCa,
– nitrogen application, N.

NPKCa: commercial fertilizer, 150–200 kg of pure N/ha, 50–100 kg pure P/ha, 100 kg pure K/ha, 100–400 kg pure Ca/ha.

N: 180–200 kg pure N/ha in the ammonium nitrate form. All applications were done manually to ensure even fertilizer distribution. The experiment was stopped in 1970, renewed in 2002. Only a part of plots was conserved.

Sampling of holorganic layers was done using a steel frame 25 × 25 cm in 4 replications, particular horizons were sampled separately. Moreover, the topmost mineral horizon was sampled too – not quantitatively (Green et al. 1993). Bulk samples were formed directly in the field by particular horizons, analyses were performed by standard pedochemical methods at Opočno Research Station – fa Tomáš – laboratory. There characteristics were determined: amount of DM in holorganic horizons, their content of total nutrients (N, P, K, Ca, Mg – mineralization by sulphuric acid and selenium, AAS), content of plant available nutrients in the 1% citric acid solution, pH (H_2O, 1 N KCl), soil adsorption complex characteristics according to Kappen (S – base content, H – hydrolytic acidity, T – cation exchange capacity, V – base saturation), exchangeable acidity, total humus content and total nitrogen content according to Kjeldahl. Number 4 of replications is on the significance limit (Podrázský 1993).

Mineral horizons were sampled using the soil borer, by particular pedogenetic horizons, comparable with 1967 sampling layers. On the first sampling date, only a limited set of characteristics was determined, so the comparison possibilities are restricted.

Table 1. Surface humus amount and total nutrient content in holorganic horizons on the Aldašín plot

Plot	Horizon	Dry matter (t/ha)	N	P	K	Ca	Mg
			(%)				
26 Control	L + F_1	6.848	1.29	0.07	0.08	0.70	0.034
	F_2	19.000	1.46	0.07	0.10	0.10	0.042
	H	45.960	1.44	0.08	0.16	0.02	0.040
Total		71.808					
25 NPKCa	L + F_1	4.920	1.30	0.08	0.08	0.62	0.034
	F_2	12.020	1.38	0.08	0.08	0.24	0.032
	H	48.820	1.43	0.08	0.16	0.02	0.040
Total		65.760					
27 N	L + F_1	4.316	1.50	0.07	0.06	0.40	0.032
	F_2	19.012	1.52	0.08	0.10	0.04	0.044
	H	58.032	1.84	0.09	0.14	0.02	0.032
Total		81.360					

Table 2. Soil pH and soil adsorption complex characteristics on the Aldašín plot

Plot	Horizon	pH H_2O	pH KCl	S	H	T	V (%)
				(mval/kg)			
26 Control	L + F_1	4.60	3.90	13.7	21.4	35.1	39.1
	F_2	4.00	3.70	26.2	39.9	66.1	39.6
	H	4.40	3.20	16.0	50.5	66.6	24.1
	Ah	4.10	3.00	3.8	15.0	18.8	20.3
	B1	4.30	3.50	0.8	4.9	5.7	13.5
25 NPKCa	L + F_1	4.50	3.40	15.5	19.3	34.8	44.7
	F_2	4.20	3.70	23.9	25.9	49.9	48.0
	H	4.10	3.10	18.3	56.5	74.8	24.4
	Ah	4.50	3.0	5.0	25.9	30.8	16.1
	B1	4.70	3.50	0.3	8.1	8.4	3.5
27 N	L + F_1	4.30	3.50	13.1	22.8	35.8	36.5
	F_2	4.90	3.30	22.2	37.2	59.4	37.4
	H	4.00	3.00	14.8	59.6	74.5	19.9
	Ah	4.30	3.10	4.1	26.9	31.0	13.2
	B1	4.70	3.60	0.5	9.4	9.9	4.7

RESULTS

Tables 1 to 4 document the experimental results. Changes in the surface humus amount showed a possible decrease on the plot with full fertilization and an increased amount in the N-variant (Table 1). This could indicate the more rapid organic matter cycling on the former plot (liming effect, high nutri-

Table 3. Exchangeable acidity and plant available nutrient content on the Aldašín plot

Plot	Horizon	Exchangeable acidity	Exchangeable hydrogen	Exchangeable aluminium	P_2O_5	K_2O	CaO	MgO	Fe_2O_3
		(mval/kg)			(mg/kg)				
26 Control	L + F_1	22.6	9.8	12.8	464	607	5,867	432	77
	F_2	14.4	7.2	7.3	245	225	3,812	229	224
	H	47.1	5.2	41.9	150	115	1,947	148	547
	Ah	58.3	2.4	55.9	87	47	367	55	940
	B1	32.1	1.8	30.3	117	39	67	21	376
25 NPKCa	L + F_1	17.0	10.2	6.8	605	816	5,547	403	104
	F_2	14.5	8.8	5.7	435	197	4,453	261	200
	H	39.1	6.3	32.9	155	99	2,187	155	452
	Ah	49.1	3.7	45.4	131	50	507	63	711
	B1	44.4	1.6	42.8	242	58	140	59	835
27 N	L + F_1	20.7	10.4	10.3	412	381	4,320	323	83
	F_2	20.8	7.4	13.4	368	192	3,467	267	224
	H	68.3	6.8	61.6	81	123	1,160	135	413
	Ah	75.0	4.0	71.0	91	99	480	75	881
	B1	55.3	1.7	53.6	39	21	80	43	1,109

Plant available nutrients – oxide form: P_2O_5, K_2O, CaO, MgO, Fe_2O_3

Table 4. Dynamics of the soil chemistry in the period 1967–2002 in the Aldašín locality (control plot)

Year	1967					2002				
Horizon	Ah	B1	B2	B3	C	Ah	B1	B2	B3	C
Depth (cm)	0–4	4–34	34–52	52–73	73 +	0–4	4–34	34–52	52–73	73 +
pH H_2O	3.80	4.50	4.80	4.70	4.80	4.10	4.30	4.40	4.70	4.60
pH KCl	3.60	4.30	4.25	4.20	4.30	3.00	3.50	3.70	3.40	3.50
P_2O_5 (mg/kg)	40	40	30	23	30	87	117	38	53	57
K_2O (mg/kg)	32	17	41	54	42	47	39	24	41	44
CaO (mg/kg)	75	90	313	821	582	367	67	240	700	860
MgO (mg/kg)	22	43	97	97	97	55	21	78	169	188
Fe_2O_3 (mg/kg)	1,263	620	524	477	381	940	376	550	679	622

Plant available nutrients in oxide form

ent – P, Ca – content) and acidification effect in the nitrogen variant. In the N-variant, higher contents of total N were documented as well as the decrease in total K, Ca, Mg contents. P-content was slightly increased in both fertilized variants.

Soil pH determined in H_2O was highly variable, without visible trends in the holorganic horizons. In the mineral horizons, the values were slightly higher in both fertilized variants. With the exception of the uppermost holorganic layer (L + F_1), the values were comparable on the control and fully fertilized plot, being lower on the nitrogen fertilized plot, in the humus horizons again. The content of exchangeable bases was comparable on all plots, both types of fertilization increased the hydrolytical acidity. As a consequence, the cation exchange capacity increased on fertilized plots with the exception of the uppermost horizons. Base saturation was also influenced by fertilization – the variant with complex fertilization showed lower values in the mineral horizons compared to control, the nitrogen-fertilized variant in the whole profile. So the complex fertilization showed minimum effects on the basic soil chemistry, the nitrogen fertilization was reflected in the trend of lowering of the pH and base contents, the acidification effect is obvious.

The values of exchangeable acidity were lowered by the complex fertilization compared to the control plot, N-fertilization contributed a general increase of this parameter. This was caused especially by the increase in the exchangeable Al content and this is another evidence for the acidification effects of the nitrogen application. The P-content was increased in the complex variant and decreased by the N-fertilization again. This was caused probably by the dilution effect (Binkley 1986) in the increased biomass of the forest stand. The available potassium content, in the holorganic horizons also the calcium content, shows a similar tendency. Plant available magnesium contents increased in mineral horizons in both fertilized variants, in the holorganic ones its tendency differed: an increase on NPKCa-plot and a general decrease on the N-plot. The changes in the plant available iron content also show the acidification effects of nitrogen fertilization.

Large differences were demonstrated by the results of analyses between the years 1967 and 2002, despite the restricted set of performed analyses. The pH (H_2O) values were slightly higher in 2002 and comparable in the B_3 layer compared with the 60s, in other horizons a general decrease by 0.2–0.4 pH units was observed, which is over the analytical error. Moreover, the pH determined in KCl demonstrated a general marked decrease by 0.4–0.8 pH units, enabling to consider the important soil acidification in the last 4 decades.

The contents of plant available nutrients did not show such simple trends. The P-content increased in general, the K-content shows the tendencies of movement into the uppermost (biological mobilization) and the lowest (leaching) horizons. The divalent bases also migrate into the surface and underground horizons, the translocation by uptake and leaching being very probable. This trend is also confirmed by the iron contents, lowered in the upper and increased in middle and lower horizons. We can evaluate the general tendency as acidification with considerable nutrient (base) losses in the near future.

CONCLUSIONS

The object of the studies was a unique set of established research plots to investigate fertilization effects in the territory of the Training Forest Enterprise in Kostelec nad Černými lesy. The effects of complex fertilization and only nitrogen fertilization were studied in the period 1967–2002. The preliminary results concerning the forest soils documented:

– Even after 35 years, the effects of fertilization are obvious although the soil changes are not profound;

– In the surface humus accumulation, no clear tendencies were visible, the total nutrient content was affected by their artificial input (complex variant), N-fertilization led to a decrease in the base content;

– In the basic soil chemistry parameters, the effect of nutrient supply including bases in the complex variant and the acidification effect of nitrogen fertilization were obvious;

– Acidification took place in the 1960–2002 period.

In the studied stands, besides the acid deposition and fertilization effects there is a very high probability of acidification effects of the Norway spruce monocultures and of the limitation of the root systems only to the uppermost soil (especially holorganic) horizons. One of the most important conclusions is that fertilization with higher N-amount can endanger the soil condition and stand stability and increase the soil acidification and considerable soil acidification took place also at medium and lower altitudes.

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Hnojení smrkových monokultur na území Školního lesního podniku Kostelec nad Černými lesy

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ABSTRAKT: Příspěvek uvádí hodnocení pokusů s aplikací hnojení NPKCa a N v nižších polohách a vliv těchto opatření na stav lesních půd. Studované lokality jsou na území Školního lesního podniku v Kostelci nad Černými lesy, v nadmořské výšce 300–500 m, ve 3. LVS. Hnojiva byla aplikována v letech 1965–1967, hodnocení základního půdního chemismu bylo provedeno v r. 1967 (před hnojením) a v r. 2002. Po 25–35 letech byly doloženy pouze slabé vlivy vápnění a hnojení v humusových formách a v celém půdním profilu – akumulace nadložního humusu, půdní chemismus a obsah živin. Komplexní hnojení se odrazilo ve zvýšení půdní úrodnosti, aplikace dusíkatého hnojení v acidifikaci půd. V období 1967–2002 byl doložen silný obecný trend acidifikace způsobený kyselou depozicí a kultivací smrkových monokultur.

Klíčová slova: hnojení; smrk ztepilý; lesní půdy; humusové formy; acidifikace; meliorace

Příspěvek uvádí hodnocení pokusů s aplikací hnojení NPKCa a N v nižších polohách, vliv těchto opatření na stav lesních půd. Studované lokality jsou na území Školního lesního podniku v Kostelci nad Černými lesy, v nadmořské výšce 300–500 m, ve 3. LVS. Hnojiva byla aplikována v letech 1965–1967, hodnocení základního půdního chemismu bylo provedeno v r. 1967 (před hnojením) a v r. 2002.

Po 25–35 letech byly doloženy pouze slabé vlivy vápnění a hnojení v humusových formách a v celém půdním profilu – akumulace nadložního humusu, půdní chemismus a obsah živin. Změny byly patrné ve zvýšení hydrolytické acidity a snížení nasycení bázemi na hnojených variantách. Komplexní hnojení se odrazilo ve zvýšení půdní úrodnosti, zatímco aplikace dusíkatého hnojení se projevila acidifikací půd, což se odrazilo ve zvýšení hodnot výměnného hliníku (tab. 1–3).

V období 1967–2002 byl doložen silný obecný trend acidifikace způsobený kyselou depozicí a kultivací smrkových monokultur s kyselým opadem (hodnoty aktivní půdní reakce poklesly o 0,2–0,4, půdní reakce výměnné o 0,4–0,8, tab. 4). Vzhledem k této tendenci a získaným výsledkům je možné očekávat ztráty bazických živin na stanovišti a jejich vyplavování do hlubších horizontů, což může ovlivnit pěstované kultury vzhledem k rozložení kořenů především v povrchových vrstvách.

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