Acidification of forest soils in Slovakia – causes and consequences

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ABSTRACT: In Slovakia, soil acidification remains an environmental and forestry related issue despite a sharp decrease in the $S0_2$. Recent monitoring of critical acid loads of Slovak forests show that around one third of Slovak forests are directly affected by acidification. In this situation, an increased biomass extraction from forests for energy generation purposes, considered by some decision-makers, poses a serious threat to geobiochemical cycles and may further aggravate the effect of the emissions on soils. In other parts of the country however, the drop in pH value means a soil degradation in sense of soil forming processes rather than in reference to forest production. This fact is also confirmed with the values of growing stock in Slovak forests, continually increasing since 1920.

Keywords: soil acidification; forest ecosystem; critical stress; utilization biomass

Processes leading to the acidification of forest soils take place within a complex landscape framework determined by its geomorphology. Important determining factors are: composition and development of vegetation, soil-forming parent material, woody species composition, air pollution and variability of soil properties (Kočík 1995; Kočík, Kulich 2003). We cannot omit the proper forest management method that is presents another factor of a paramount importance (Kobza et al. 2002). This is mainly the question of growing coniferous monocultures and phytomass extraction through harvesting (Machava 2002). At present, tendencies exist to remove from the forest not only logs but also branches and subsurface biomass (roots). However, the biggest amount of basic cations is accumulated particularly in these wood biomass components. Their removal from the stand by whole tree logging is connected with extraction of several tens or even hundreds kilograms of calcium, magnesium, potassium and other cations from the stand (Machava 2001, 2003). These alkaline constituents are locked out of the nutrient cycling; instead, they are exported together with the logged wood. In such a way, the steady-state biochemical cycles are impaired. The final result is acidification of the forest environment – together with all the consequences for the forest health condition.

Airborne pollutants – the cause of soil acidification

In the introduction we have shortly summarized three principal causes of soil acidification in Slovakia: coniferous monocultures, removal of basic cations connected with wood logging and input of acid components from the polluted air into the forest soil. In the following text, we will focus at airborne pollutants as the decisive factor causing soil acidification.

Situated in the centre of Europe, Slovakia has an unfavourable position, being heavy influenced with the long-range air pollution transport. Prevailing western and northwestern winds displace progressively increasing amounts of gaseous airborne pollutants with concentrations cumulated from the west coastal regions towards the Central Europe. Therefore, inputs of sulphates, nitrates and other acid components into forest ecosystems remain high, despite a considerable drop in domestic emissions: SO_2 from 550,000 t/year to 120,000 t/year (21% compared to 1990 levels) and NO_x from

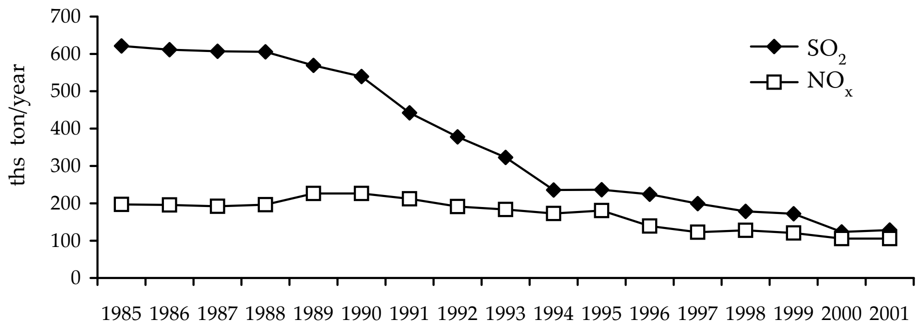

Fig. 1. Emissions of main pollutants in the Slovak Republic

245,000 t/year to 105,000 t/year (42% compared to 1990). The efforts meeting the UNECE Convention on long-range air pollution have resulted in the following reductions in the air pollution levels in Europe: sulphuric emissions by 60% compared to the year 1980, nitrogen oxides by 25% compared to 1990. Also in several other pollutants, the trend has turned to decreasing (Fig. 1).

However, it is very important that the SO_2 fraction keeps on being the most significant component of the air pollution in Slovakia – in spite of existing prognoses about a possible overtopping with NO_x-based pollutants in the forthcoming years. According to these predictions, NO_x-based pollutants are expected to become the main acidification agent – as it is at present the case of industrial lands of Europe. There is also the high important fact that the national sources of pollution with SO_2 and NO_x are overlapping in their territorial impacts (synergic and acidification effects of SO_2 and NO_x). In such a way, it is not difficult to specify, distinctly and easy, the heaviest affected territories in the Slovak Republic. Mean values of pH and elements concentrations in the precipitation are in Table 1.

It is remarkable that the lowest acidity of precipitation (the highest pH values) has been found in the lowlands and hilly lands (pH = 4.8–5.8), in spite of their heaviest pollution in comparison with other land types. This is caused by massive fallout of alkaline dust – with origin either in carbonate eolic sediments (loess) or released in alkaline flying ash. The lowland regions in Slovakia have also characteristic seasonal dynamics of sulphur concentration in precipitation, with a typical maximum in winter (Table 2).

In the mountain areas is the maximum of sulphate concentrations in precipitation shifted to the spring months (beech and spruce ecosystems). In beech ecosystems, also a secondary summer maximum is possible.

Deposition to broadleaved and coniferous ecosystems

The basic regularities in concentrations of the particular chemical components and in their deposition both to broadleaved, mainly beech, and coniferous (spruce) ecosystems are conspicuous. The situation in the Slovak Carpathians is summarized in Table 3.

There is an evident change in the ratio between acid and alkaline components in precipitation water fallen through the crown canopy. The situation is different in the broadleaved and coniferous ecosystems. For example, in the beech ecosystems is the mean annual value of the ratio between acid and alkaline components in open area 170:100, in the throughfall we can see some increase in the alkaline component to 185:100. On the other hand, in the spruce regions was the alkaline/acid ratio in precipitation water collected in open area much more equilibrated (115:100), but the increase in alkaline component in the throughfall was dramatic

Table 1. Mean annual values of pH and concentrations of chemical elements in precipitation (mg/l) in open area

Characteristics	pH	NH_4-N	NO_3-N	K^+	Ca^{2+}	Mg^{2+}	SO_4-S
Area: Lowlands and hilly lands	4.8–5.8	1.0–1.8	0.7–0.8	0.2–0.4	0.6–3.7	0.1–0.5	1.8–2.6
Mountain areas	4.3–4.6	0.9–1.5	0.5–2.0	0.2–0.6	0.4–4.1	0.1–0.9	1.8–5.2

Table 2. Seasonal dynamics of concentration of sulphates in precipitation (mg/l) in the mixed oak-hornbeam forest ecosystem

Month	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	X.	XI.	XII.
SO_4 (mg/l)	6.4	5.6	4.0	2.9	1.2	0.8	1.0	1.1	2.3	3.9	5.2	5.8

Table 3. Annual input of selected elements to broadleaved and coniferous ecosystems

	Input to open area		Input to deciduous stand
H^+	0.2		0.2
N-NO_3^-	16.2		13.3
N-NH_4	6.9		7.6
P-PO_4^{3-}	0.3		1.3
K^+	**9.7**	fall of precipitation	**52.0**
Ca^{2+}	15.5	through canopy – throughfall	17.0
Mg^{2+}	2.6		5.2
S-SO_4^{2-}	**33.5**	kg/ha/year	**31.4**
Na^+	3.3		2.7
170 Acid components **85**			
100 Alkaline components **100**			

	Input to open area		Input to coniferous stand
H^+	0.1		0.6
N-NO_3^-	12.3		16.5
N-NH_4	19.8		6.3
P-PO_4^{3-}	4.5		0.3
K^+	**14.9**	fall of precipitation	**16.8**
Ca^{2+}	4.7	trough canopy – throughfall	11.0
Mg^{2+}	3.8		5.2
S-SO_4^{2-}	**49.4**	kg/ha/year	**78.0**
Na^+	4.2		2.4
115 Acid components **280**			
100 Alkaline components **100**			

(280:100). This fact reveals an immense infiltration effect of the crown layer in coniferous species, which, bearing the assimilation organs all over the year, trap from the atmosphere enormous amounts of acid aerosols. These aerosols are washed with precipitation, flushed into the soil, lower the alkalinity of the soil sorption complex and cause chemical degradation of the forest soils.

Vertical zonation of acid components of deposition

There is distinct vertical zonation in acid component deposition. In Slovakia, the maximum input was observed at altitudes 700–1,200 m (Mišíková, Šubová 2003). This is also true for agro-ecosystems, primarily mountain meadows and pastures but also for arable land. However, forests, namely coniferous ecosystems, with their large assimilatory area index, enhance this acidification effect considerably (Table 4).

Recent monitoring of critical acid load to Slovak forests allows us to conclude about a drop in deposition inputs; however, still around one third of Slovak forests are directly affected by acidification (Pišút, Šubová 2001).

From the table it is evident that the input of acid components in the deposition (NO_3^-, SO_4^{2-}, F^-, H^+) in kg/ha reaches its maximum in the zone of spruce forest stands. This is evidently true for the wider area of the Western Carpathians, which was confirmed with SO_2 concentrations in the atmosphere changing with altitude, having the maximum in the just mentioned altitudinal zone (Šubová 2003).

Table 4. Constituents of bulk deposition with maximum in zone of spruce forest stands

Vegetation tier	Altitude (m a.s.l.)	n	pH		N-NO_3^-		S-SO_4^{2-}		F^-		H^+	
			VP	P	VP	P	VP	P	VP	P	VP	P
Oak	under 400	1	6.6	6.2	33	40	140	154	–	–	0	0
Beech	700–400	5	4.8	4.7	6	6	14	18	1.9	0.9	0.1	0.1
Spruce	1,200–700	4	4.8	4.0	10	13	33	59	2.5	1.9	0.1	0.7
Upper forest line	over 1,300	2	5.5	4.6	8	12	24	34	1.9	1.4	0.1	0.4

The observed amounts of the particular components on the open plots (kg/ha/year) are: sulphate sulphur 33, nitrate nitrogen 10, fluorine 2.5, hydrogen protons 0.1, with pH approximately 4.8. In the spruce forests stands, were found the following corresponding amounts: 59, 13, 1.9 and 0.7, entering the forest soils in drip and throughfall. The average pH value of precipitation is 4.0. In this zone occurs the most severe acidification of soils – which was already detected in the 1980's. The pH values of cambisols in this zone, originally between 4.0–5.0, are at present decreasing up to 3.5 in the range of genetic depth (± 50 cm). The corresponding soil profiles maintain their cambisol-specific morphology, however, with features of a rather podzol-like dynamics. On localities that have a catena character is formed a distinct altitudinal gradient reflecting the increasing precipitation acidity. The average change in pH values over this gradient is 0.32 per 100 m (Machava 2002).

The pH values of stem-flow water on spruce reach 2.1–4.5, with an annual mean of 2.9. In the beech stands, where the stem-flow amount represents about 10% of the precipitation in open area, the acid zone develops on the high-stem-flow side of trees growing in soil with low pH values (about 3.5). However, the excessive acidification connected with the stem-flow decrease with increasing distance from the stem; in general, at a 3m distance no impact can be identified.

Effects of deposition input on soils

Acid components in deposition of airborne pollutants to soil cause the well-known soil acidification. The soils at altitudes 700–1,200 m a.s.l. manifest podzol-like dynamics in their chemistry, in spite of the fact that the morphology of their profile corresponds to brown forest soils (cambisols). These processes are especially conspicuous in the neighbourhood of tree stems where pH values in the stemflow decrease below pH = 3, in conditions of our mountains and spruce stands, not rarely even to 2.6. However, it is necessary to notice that this drop in pH values means the soil degradation more understood from the viewpoint of soil forming processes that from the viewpoint of production. This fact is also confirmed with the values of growing stock in Slovak forests, continually increasing since 1920. There is the steepest increase beginning with the year 1960, connected with manifestation of the first results of intensive industrialization running in the Slovak Republic and neighbouring lands after World War II. In this period, that means from 1960 to 2000, was in our country recorded an increase in the growing stock without bark by 150 mil./m^3, i.e. from 260 to 410 mil./m^3 that is 158% compared to the state in 1960.

CONCLUSIONS

Situated in the centre of Europe, Slovakia has a very unfavourable position, due to permanent heavy load with air pollutants. Prevailing western and north-western winds bring from the industrial centres in west Europe towards the eastern parts of the continent masses of air with increasing concentrations of pollutants, primarily SO_2 and NO_x, cumulated from other pollution sources during the transport. This cumulative effect has a considerable impact on chemical degradation of soils that become, in such a way, the "final station" of various airborne pollutants. Consequently, in spite of a significant drop in production of inland airborne pollutants by 2000, with the values of SO_2 lowered by 21% and NO_x lowered by 42% compared to 1990, the degradation of soil-forming processes in our forest soils is still in progress. Nevertheless, this fact is not reflected on the forest ecosystems production showing a continual increasing tendency since 1920, i.e. since the time of the first accessible data.

The amount of acid components in the bulk deposition is evidently dependent on the altitude. The biggest inputs of acid materials into forest ecosystems are between 700–1,200 m a.s.l., that means over the range in which spruce reaches the highest share in the tree species composition. Recent monitoring of critical acid load to Slovak forests showed that around one third of Slovak forests are directly affected by acidification.

References

KOČÍK K., 1995. Zhodnotenie vplyvu niektorých rizikových prvkov vo výžive rastlín. Nitra, VŠP, AF: 181.

KOČÍK K., KULICH J., 2003. Metódy sledovania a hodnotenia rizikových prvkov v agroekosystémoch. Zvolen, TU: 121.

KOBZA J. et al., 2002. Monitoring pôd Slovenskej republiky – 2. cyklus. Bratislava, VÚPOP: 178.

MACHAVA J., 2001. Occurence and effect Pb in forest ecosystem. Folia Oecologica, *28*: 125–137.

MACHAVA J., 2002. Transferové koeficienty Cu a Pb v systéme kambizem – sadenice smreka. Phytopedon, *1*, Supplement: 136–142.

MACHAVA J., 2003. Vzťah medzi pôdou a porastom smreka pri dlhodobej imisnej záťaži lesných ekosystémov. Druhé pôdoznalecké dni v SR, vedecká konferencia. Stará Lesná, 16.–18. jún 2003. Bratislava, VÚPOP: 217–225.

MIŠÍKOVÁ K., ŠUBOVÁ D., 2003. Príspevok k rozšíreniu machorastov v Národných parkoch Vysoké Tatry, Nízke Tatry a Slovenský raj. Naturae tutela, *4*: 7–10.

PIŠÚT I., ŠUBOVÁ D., 2001. Príspevok k poznaniu lišajníkov Tatranského národného parku Nízke Tatry. Naturae tutela, *2*: 7–14.

ŠUBOVÁ D., 2003. Výskyt lišajníkov a machorastov v horskej oblasti Jánskej doliny. Konferencia s medzinárodnou účasťou prírodovedných pracovníkov múzeí a pracovníkov múzeí v prírode, 26.–28. 5. 2003, Liptovský Mikuláš, Slovenské múzeum ochrany prírody a jaskyniarstva: 35–38.

Príčiny a dôsledky acidifikácie lesných pôd Slovenska

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ABSTRAKT: Napriek masívnemu poklesu emisií SO_2 acidifikácia pôdy zostáva v Slovenskej republike vážnym lesníckym a environmentálnym problémom. Aktuálne výsledky monitoringu kritických záťaží ukázali, že približne jedna tretina lesných ekosystémov SR je priamo zasiahnutá acidifikáciou. V tejto situácii predstavuje extrakcia biomasy z lesných ekosystémov za účelom výroby energie ďalšie ohrozenie biogeochemických cyklov a zvýšenie účinku imisií na lesné pôdy. Na ostatnom území SR však pokles pH znamená viac degradáciu pôd v zmysle pôdotvorných procesov ako vo vzťahu k produkcii lesných ekosystémov. Potvrdzujú to najmä údaje o nepretržite narastajúcej zásobe dendromasy v lesných ekosystémoch Slovenska od r. 1920.

Kľúčové slová: acidifikácia pôdy; lesné ekosystémy; kritické záťaže; využitie biomasy

Slovensko v dôsledku lokalizácie v strede Európy má veľmi nepriaznivú imisnú situáciu. Západné a severozápadné vetry prinášajú zo západoeurópskych priemyselných centier vzdušné masy, v ktorých sa postupne zvyšujú koncentrácie škodlivín, predovšetkým SO_2 a NO_x. Tento kumulatívny efekt výrazne pôsobí na chemickú degradáciu pôd, ktoré sa stávajú konečnou stanicou rozličných imisií. Preto napriek ich výraznému poklesu doma (SO_2 napr. na 21 % a NO_x na úroveň 42 % v porovnaní s rokom1990) chemická degradácia našich – najmä lesných – pôd naďalej pokračuje.

Kyslé zložky depozície silne závisia od nadmorskej výšky. Ich najvyšší objem v lesných ekosystémoch sa nachádza medzi 700–1 200 m n. m., t. j. v pásme, v ktorom má smrek svoj najväčší podiel na drevinovom zastúpení. Pomer kyslých zložiek k alkalickým sa pritom po prechode zrážok korunovou vrstvou výrazne mení. V bukových ekosystémoch pomer kyslých komponentov k alkalickým dosahuje na voľnej ploche hodnotu v ročnom priemere 170/100, po prechode korunami prevažujú alkalické zložky v pomere 185/100. V smrekových oblastiach sa pomer kyslých zložiek k alkalickým zvyšuje po prechode korunovou vrstvou zo 115/100 na 280/100. Svedčí to o enormnom filtračnom efekte korunovej etáže, ktorá pri existencii asimilačných orgánov ihličnatých drevín počas celého roka vyčesáva z ovzdušia veľké množstvá kyslých aerosolov. Tieto sa zrážkami zmývajú a splachujú do pôdy, debazifikujú sorpčný komplex a vyvolávajú chemickú degradáciu lesných pôd. Spôsobujú tak ich acidifikáciu, pôdy získavajú podzolovú chemickú reakciu napriek tomu, že morfológia pôdneho profilu má ráz hnedých lesných pôd (kambizeme).

Doba hodnotenia prísunu imisných uložením založená na monitoringu vo vzťahu ku kritickým kyslým záťažiam ukazuje, že približne jedna tretina lesov Slovenska je priamo postihnutá acidifikáciou.

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