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Effect of deposition substances on the quality of throughfall and soil solution of pedunculate oak and common hornbeam forest

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Abstract

Background and Purpose: *Soil pollution is one of the important stress factors which lead to vitality decrease and forest dieback. For this reason, monitoring of the flux of pollutants into the soil is important activity in forest management and protection. This type of monitoring, comprising quantity and quality of throughfall and soil solution in Croatian lowland forests, was started in 1991 in the Forest Research Institute Jastrebarsko, following the ICP Forest method (International Cooperative Programme on Assessment and Monitoring of Air Pollution on Forests).*

Materials and Methods: *This paper relates to monitoring which was established on 3 sample plots in pedunculate oak and common hornbeam forests (*Carpino betuli-Quercetum roboris, *Anić 1956/emed. Rauš 1969), in the regions of Bjelovarska Česma, Pokupski Basin and Repaš (all in NW Croatia). Rain-gauges and bulks were set up on the plots under tree crowns, as well as in open space without vegetation (for the purpose of control). Modified Ebermayer lysimeters were installed in the soil profile under the humus horizon at 10–20 cm, and in the mineral part of soil at a depth of 100 cm. The field sampling was carried out once a month, and selected ions were analyzed in the water (K^+, Na^+, Ca^{2+}, Mg^{2+}, NH_4^+–N, Cl^-, NO_3^-–N, SO_4^{2-}–S).*

Results: *The results indicate an increase in the amount of deposited substances in forest ecosystems. According to analyses most chloride was found in lysimeters at a depth of 10 and 100 cm in the region of the Pokupski Basin; followed by Česma and then Repaš. Most SO_4^{2-}–S reached lysimeters at a depth of 10 cm in all regions i.e., in Repaš, followed by Česma and Pokupski. An increase in sulfur also occurred in lysimeters at a depth of 100 cm in the region of Pokupski and Česma, with smaller increase recorded at Repaš. Increase of NO_3^-–N was highest at a depth of 10 cm in the regions of Česma and Pokupski. Contents of sodium and chlorine increased most in the region of the Pokupski Basin, in a lysimeter at a depth of 100 cm. Potassium on average was most abundant at Česma in lysimeters at a depth of 10 cm, and somewhat less in the region of Pokupski and Repaš. Calcium on average was most found in the region of Česma, in lysimeters at a depth of 100 cm, which can be explained by the increased amount of $CaCO_3$ in deep layers of soil profile. Magnesium was most registered in Česma at a depth of 100 cm, and then at a depth of 10 cm. A somewhat smaller increase occurred in the Pokupski Basin.*

Conclusions: *All three regions are characterized by significant acidification of forest soils, caused by leaching of air pollutants from tree leaves. Chemical composition of soil solution is disturbed due to increased content of chloride, sulfuric and nitrogenous compounds. The buffer capacity of soils was not the same on all three studied regions (minimum at Pokupski Basin and maximum at Repaš), which was the probable consequence of site-specific differences in soil characteristics.*

INTRODUCTION

Continuous acidification of soil by dry and wet deposition results in a sequence of secondary consequences, such as solubility of heavy toxic metals, nutritious substances and their transition into liquid phase (soil solution) which finds its way into ground water. In this way the capacity of drinking water is decreased, as well as other accompanying phenomena. In such a case it is necessary, in certain climatic conditions and regions, to have knowledge of the quality and amount of water movement through particular forest ecosystems toward ground waters which in the majority of cases are used for water supply. Such problems have been investigated (*1, 2, 3*). This is particularly important in the case of soils which have lower buffer capacity (soils on acid parent material, for example (*4*). Acidification of forest soils, directly connected with the lowering of pH-values and increase in the concentration of Al^{3+} in soil solution, is the most responsible factor in view of damage and dieback of forests in many areas.

Movement of water through soil and throughfall through a certain volume of soil is investigated by lysimeters. By means of lysimeters it is possible to measure the quality of soil solution, as well as the substances which reach the soil by precipitation, and are leached further into ground water, or move laterally along the impermeable soil horizon. The word 'lysimeter' is derived from the Greek words 'lisis', which means dissolving and 'metrom', which means measuring.

This term is applicable to every device used for the study of the amount and quality of water in soil, which passes through 'solum' of the soil and moves laterally along over some inclination. Ebermayer (*5*) was among the first to use lysimeters for measuring water movement through undisturbed soil in the forest. Normal soil solution contains 100–200 various soluble complexes, many of which contain metal cations and organic substances (*6*). In Croatia, lysimetric investigations of the liquid phase of soil occurred later when compared to Europe, and only around ten years ago did a more intensive approach to this field of pedology begin (lysimetric pedology). Only a few investigations have been carried out using lysimetric technique in forest conditions in Croatia. Vranković *et al.* (*7*), Vrbek (*8, 9, 10, 11*), Vrbek and Pilaš (*12*) utilize it in their studies.

Task and aim of investigation

The task was to determine chemical composition of throughfall and soil solution in north-west Croatian forests of Pedunculate oak and Common hornbeam by use of lysimetric method, in specific:

- Amount of important cations and anions in kg ha^{-1} in throughfall liquids at a depth of 10 cm, i.e. under the humus-accumulative horizon and at a depth of 100 cm, i. e. in the mineral part of soil.
- Amount of important cations and anions in $kgha^{-1}$ which are deposited in a forest of pedunculate oak and common hornbeam and in an open space without the effect of vegetation.

MATERIALS AND METHODS

Monitoring of the quality and amount of liquids on plots under crown cover (precipitation under crown cower), percolate in soil (lysimetric waters) and precipitation in the control (open space without influence of vegetation), was performed in the vegetation period from April to October. Experimental plots on which the investigations were carried out are in a typical forest community of pedunculate oak and common hornbeam. This community is not exposed to floods, but in winter the soil is saturated with water. It grows on elevations and micro-elevations on more drainable terrain. The community includes the highest-positioned pedunculate oak forests of our lowland areas. According to Rauš *et al.* (*13*) the community of pedunculate oak and common hornbeam (*Carpino betuli-Quercetum roboris*, Anić 1956/emed. Rauš 1969), which toward lowlands borders on flood-

TABLE 1

Review of plots monitored in pedunculate oak and common hornbeam forest communities with basic descriptive data.

Locality and plot number	Soil type (HR)	Soil type (WRB)	Stand age, years	Canopy cover, %
Bjelovarska Česma (P–15)	Pseudogley on level terrains	*Luvic, gleyic* Planosol	101	94,6
Repaš (P–25)	Fluvisol	*Molic, eutric* Fluvisol	87	92,7
Pokupski bazen (P–36)	Pseudogley on level terrains	*Endogleyic Luvic* Stagnosol	115	90,4

plain forests of pedunculate oak (*Quercus robur* L.), narrow-leaved ash (*Fraxinus angustifolia* Vahl.) and common alder (*Alnus glutinosa* L.), and in higher positions borders on forests of sessile oak (*Quercus petraea* Liebl.) and common hornbeam (*Carpinus betulus* L.), displays wide ecological amplitude. This is also reflected in the diverse and standard layer of ground vegetation. It spreads in a belt between 110 and 120 m above sea level.

Monitoring the quality of soil solution and input of deposition substances through precipitation was carried out on experimental plots 1 ha in size, within which a smaller plot of 30 x 30 m was laid out. Table 1 shows data for three characteristic plots which were laid out in a forest community of pedunculate oak and common hornbeam (*Carpino betuli-Quercetum roboris,* Anić 1956/emed. Rauš 1969), while Figure 1 shows the position of the plots. In all three regions (Pokupski Basin, Čazma and Repaš) the plots were supplied with rain-gauges, bulks and lysimeters.

Small plastic zero tension lysimeters were set up in the soil comprising a system for monitoring throughfall water (percolate) in soil. (Figure 2). Lysimeters were filled with 96% pure quartz sand, which, together with additional filters separate soil particles from percolate. Throughfall water was collected and measured at two depths in the soil profile: under the humus horizon at a depth of 20 cm and in the mineral part of the soil at approximately 100 cm depth.

Each plot was also provided with nine plastic rain-gauges for measuring the amount, and nine plastic funnels under the tree crowns for measuring the quality, of precipitation (throughfall), in a diagonal arrangement under tree crowns (Figure 3). Three rain-gauges and three bulks were set up for measuring and collecting precipitation at control sites, outside the influence of vegetation, i.e., in an open space (bulk).

Figure 1. *Plot locations in northwest Croatia.*

Figure 2. *Zero tension lysimeter beneath the surface horizon.*

Figure 3. *Pedunculate oak and common hornbeam community monitoring plot.*

The following ions were determined by the analysis of chemical compositions of liquids: Cl^-, SO_4^{2-}-S, NO_3^--N, NH_4^+–N, Na^+, K^+, Ca^{2+} and Mg^{2+}. Standard or common analytical methods were used to determine small amounts of substances in waters and precipitation: spectrophotometric method (spectrophotometer Perkin Elmer Lambda-1) was used to determine SO_4^{2-} ions, NO^{3-} ions. The method of ion-selective electrodes (ORION – Microprocessor ionanalyser, model 901) was used to determine NH^{4+}-ion and Cl^- -ion, and metal ions (sodium and potassium, calcium and magnesium – earth alkaline) were determined by atomic absorption using spectrophotometry (Atomic spect. Perkin Elmer, model 603). In the field, pH and electric conductivity μS/cm were measured. Methods are described in WMO (*14*), Standard Methods (*15*) and Mohler *et al. (16)*.

Once a month the amounts of precipitation and throughfall liquid were measured in lysimeters on the plots in mm (L/m^2) in order to establish the mgL^{-1} values for ions to convert into kgha^{-1} for corresponding region and plot. The vegetation period receives from 54.5 to 56.5% mm of precipitation in relation to the whole year.

TABLE 2

Total and average annual amount of precipitation in mm (L/m^2) on three localities beneath crowns, on control site without the effect of vegetation and throughfall water in lysimeters.

Sample	Locality	Total	Average	Locality	Total	Average	Locality	Total	Average
		mm			mm			mm	
Throughfall	ČESMA (P-15)	1028.55	68,57	REPAŠ (P-25)	992,14	66,14	POKUPSKI BAZEN (P-36)	1449,13	96,61
Bulk		1300,97	86,73		1264,23	84,28		1685,80	112,39
Lysimeter 100 cm		532,14	35,48		391,28	26,09		1232,34	82,16
Lysimeter 10–20 cm		1034,25	68,95		511,49	34,10		1397,41	93,16

TABLE 3

Total amounts of cations and anions in throughfall, open space (bulk), and lysimeters at 10 and 100 cm.

Locality	NH_4^+-N	Na^+	Ca^{2+}	Mg^{2+}	K^+	Cl^-	NO_3^--N	SO_4^{2-}-S
	kgha^{-1}							
Throughfall								
ČESMA	1,46	1,45	14,56	5,45	48,72	7,23	17,57	5,46
REPAŠ	3,23	1,11	10,18	4,28	53,35	8,16	14,65	5,60
POKUPSKI	6,80	1,10	7,09	2,87	19,73	5,82	12,56	4,16
Bulk								
ČESMA	0,67	1,30	5,38	1,08	2,60	4,44	5,68	2,06
REPAŠ	0,65	1,53	7,35	1,31	7,66	5,08	12,33	4,38
POKUPSKI	0,95	1,28	5,42	1,26	0,71	5,25	6,69	4,61
Lysimeter (L_{10})								
ČESMA	0,28	3,09	10,57	7,51	5,65	7,06	8,52	7,92
REPAŠ	0,14	0,91	14,12	5,66	3,86	3,51	10,44	4,76
POKUPSKI	0,17	5,97	9,49	6,05	2,33	10,99	8,66	8,50
Lysimeter (L_{100})								
ČESMA	0,26	3,69	102,89	27,72	1,10	3,85	2,33	7,39
REPAŠ	0,07	0,94	32,39	7,65	1,80	2,06	5,66	2,02
POKUPSKI	0,52	56,53	8,35	6,96	0,53	15,05	5,80	10,65

Precipitations in the form of snow, outside of the vegetation period, were not sampled and analyzed, and also rain, hoar-frost, etc. Thus, the data shown in the tables include only a part of approximately 56% substances which arrived by dry and wet deposition.

RESULTS

Values in Table 3 show the total amount of cations and anions in kgha^{-1} over the whole year in the vegetation period by measurement sites and plots. Comparison of data which were calculated on the localities under tree crowns (throughfall) by regions shows that the total content of cations and anions in kgha^{-1} was considerably lower in the open space without vegetation influence. The highest values were in the region of Repaš for anions, while the values for cations, apart from ammonium ion content, were highest in the region of Česma.

In lysimetric specimens for cations, the highest content of calcium and magnesium in kgha^{-1} was found in the region of Repaš and Česma, while the highest average concentrations for sodium were found in the area of the Pokupski Basin. Increased leaching of cations was due to the structure of soil profile, because the lowest part contained most carbonate in soils from the region of Repaš, followed by carbonaceous loess in the lower part of the profile in the Česma region. In the case of anion content in lysimetric liquid, the highest concentrations of anions in kgha^{-1} were recorded in the region of the Pokupski Basin, followed by the Česma region. The increase in sodium, as well as chloride, in the Pokupski Ba-

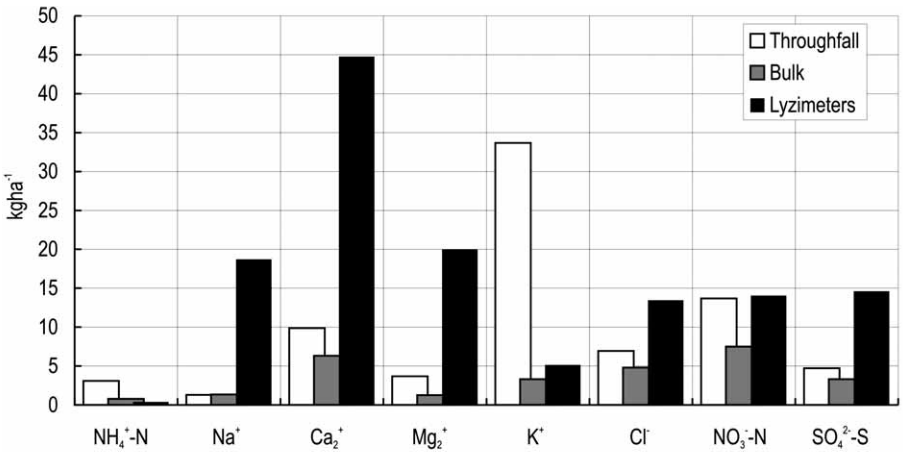

Figure 4. *Total amounts of cations and anions in kgha^{-1} on average from tree plots according to sampling sites in forest (throughfall), control (bulk) and lysimeters ($L_{10}+L_{100}$) in all plots.*

sin is possibly related to the relative vicinity of the motorway Zagreb-Karlovac from where salinity could spread laterally by the inflow of waters or air pollution. This problem should be further investigated.

Figure 4 shows that the average deposition in the forest ecosystem (forest) of all cations and anions was higher than in the control site (control) in a forest of pedunculate oak and common hornbeam in north-west Croatia. This is one more indication that the forest ecosystem of pedunculate oak and common hornbeam, by its area of biomass, enables increased dry deposition of substances which are later leached through tree crowns by precipitation. Amounts of NH^{4+}-N in lysimeters were lower than those in controls and forest, amounts of potassium were lower than in the specimens under the trees, amounts of NO^{3-}–N were equal to those in the forest and lower than the controls, while all other substances (Na^+, Ca^{2+}, Mg^{2+}, Cl^- SO_4^{2-}-S) were increased up to several times.

Average values of pH liquids in the open ranged from 5.73 to 5.97, and under the crowns from 5.42 to 6.24. The lowest pH values were in lysimetric specimens where pH was from 4.86 to 5.49. The differences, in deposition within forest ecosystems in relation to the control can, according to Brechtel and Vukorep (*1*), be attributed to the fact that as a rule deposition of sulfur in the form of sulfates under forest ecosystems is 3–4 times greater than in the open space. For chlorides, this difference is to 1.5–3 times greater, for nitrates and ammonium 1.5–2.5 times greater, while deposition of hydrogen ion was 2–4 times greater.

For all regions there was an increase for almost all cations and anions under tree crowns in relation to the open space in kgha^{-1}. In lysimeters, apart from nitrate and ammonium, increase in relation to control specimens was for some substances several times higher. Clearly, with the passing of precipitation through tree crowns and by stemflow, an increase occurs in the concentration of some substances, which is reflected in an increase in forest soils.

DISCUSSION

During vegetation period, sedimentation under tree crowns in the forest community of pedunculate oak and common hornbeam amounted to 17 to 19 kgha^{-1} of nitrogenous compounds (NO_3^--N+NH_4^+-N), 1.10 to 1.45 kgha^{-1} Na^+, 7 to 14 kgha^{-1} Ca^{2+}, 3 to 8 kgha^{-1} Mg^{2+}, 19 to 48 kgha^{-1} K^+, 5 to 8 kgha^{-1} Cl^- and 4 to 5 kgha^{-1} SO_4^{2-}-S. According to the results obtained, more nitrogenous compounds were deposited than sulfur. During the last 30 years in Europe, the input of nitrogen increased from 3–4 kgha^{-1} per year to 10–20 kgha^{-1} per year. According to data by Komlenović and Gračan (*17*), the input of nitrogen of 10–40 kgha^{-1} per year represents a critical loading for the forest ecosystem. The surplus of nitrogen stimulates growth of foliar mass and slows down processes of lignifications, and has an unfavorable effect on development of the root system and mycorhiza. This leads to disturbance in nutrition and lowering of plant resistance to drought and low temperatures.

Fluckinger and Braun, (*18*) in their investigations in Switzerland in a forest of beech and spruce, measured deposition in bulks in the open from 10 to 12 kgha^{-1} per year N (NH_4^+-N) in lowland areas, and in sub-Alpine regions from 13 to 20 kgha^{-1} per year N. In forest stands of beech and spruce, the values were higher and amounted to 25 kgha^{-1} per year. In northern Italy, Ugolini *et al.* (*19*) reported deposition of nitrogen from 10–14 kgha^{-1} per year to 20 kgha^{-1} per year, depending on the site of sampling (geographic area, altitude, exposition, etc.). Similar problems were investigated by Nguyen *et al.* (*20*) in Denmark who reported that the presence of acids in precipitation varied at measuring sites as a result of varied atmospheric deposition of SO_2 and NOx transported by wind, clouds, etc. In this process the strength of rain is important and size of the raindrops. The main causes of acidification in wet deposition in Europe are sulfuric (H_2SO_4) and nitrogen acid (HNO_3). Transformation of Nox in HNO_3 is faster than transformation of SO_2 into H_2SO_4.

The needs of this forest ecosystem, with the input of nitrogen by dry and wet deposition, are satisfied up to 100%, which can have positive and also negative consequences for the growth and development of the forest (*21*). The amounts of sulfhur, which were deposited during vegetation period in the forest of pedunculate oak and common hornbeam, are not great (4–5 $kgha^{-1}$). A probable cause is a decrease in the emission of sulfur into the atmosphere during recent years, which was reflected in the decrease of sulfur deposition. For the purpose of comparison, Simončić (*21*) cites sulfur deposition in the region of TE »Šošanj« of 13 $kgha^{-1}$ in the open and 22 $kgha^{-1}$ in a beech stand. In a culture of spruce, deposition amounted to 33 $kgha^{-1}$ of sulfur. Data from 1993 for Slovenia (*22*) shows deposition of sulfur between 28 and 36 $kgha^{-1}$ in urban regions, and for nitrogen 15 $kgha^{-1}$. For the Alpine regions of Austria, deposition in the open by Smidt (*23*) amounted to 7–15 $kgha^{-1}$ for sulfur and 7–17.5 $kgha^{-1}$ for nitrogen. Führer (*24*) in Hungary registered 16 $kgha^{-1}$ of sulfur and 12.5 $kgha^{-1}$ total nitrogenous compounds. Data for North America for sulfur amounted to 25–45 $kgha^{-1}$ (*25*).

For Croatian regions, data vary in relation to forest community, altitude, position of the plot on which sampling took place, etc. Thus, Komlenović *et al.* (*26*) reported for Lividraga in Gorski Kotar 23.77 $kgha^{-1}$ for sulfur (SO_4^{2-}–S) and total 27.87 $kgha^{-1}$ nitrogen NO_3^--N + NH_4^+-N). According to recent data collected during 1999 (*12*) in the region of Medvednica, the amount of sulfur (SO_4^{2-}-S) was 27.5 $kgha^{-1}$, in the region of Zavižan on Velebit 28.0 $kgha^{-1}$, and highest in the region of Lividraga 50.2 $kgha^{-1}$. Data for total nitrogen were still higher. Thus, 15.2 $kgha^{-1}$ was recorded in the lowlands, 27.0 $kgha^{-1}$ in the region of Medvednica, approximately 26.0 $kgha^{-1}$ on Zavižan, and in the area of Lividraga even 74.2 $kgha^{-1}$, which is much higher than the critical load for nitrogen.

Comparison of data reveals that the deposition of sulfur in lowland forest ecosystems of pedunculate oak and common hornbeam is smaller in relation to other regions in Croatia and neighboring countries. The input of NH_4^+–N and NO_3^-–N, namely nitrogen, has increased. For the forest of pedunculate oak and common hornbeam, 44% was added which was the difference in precipitation for the whole year, as monitoring was carried out during vegetation period. According to literature data deposition in winter can be higher than in summer. High content of nitrogen points to its increased supply. The trees have more exuberant growth, and become more susceptible to wind throw, crown break, and trees are less resistant to attacks by fungi and pests.

The highest amount of ions in $kgha^{-1}$ was found in lysimeters of nitrates and ammonium, while there was less potassium. The amounts in $kgha^{-1}$ for Ca_2^+, Mg_2^+ and Na^+ were as expected, because the process of leaching these cations from soil is always present, especially at low pH values. The soils bind sulfate ions and release alkaline cations (*17*). In the same way leaching of Ca_2^+ and K^+ from leaves is considerably increased. Total amounts of cations and anions in control measuring sites are regularly lower than the values under tree crowns, and are still lower in relation to the lysimetric liquid. These amounts correspond to data from the Hydrometeorological Institute for the city of Zagreb, where the amount of chlorine (Cl^-) ranges from 4.015 to 13.83 $kgha^{-1}$, for sulfur from 40 to 76 $kgha^{-1}$ and for nitrogenous compounds 2.7 – 9.1 $kgha^{-1}$.

CONCLUSIONS

According to measured precipitation data in the forest of pedunculate oak and common hornbeam, less liquid in mm was on average recorded under the canopy than in the open space. In the Česma region the amount of precipitation measured under tree crowns was 81.17% in relation to the control. In the region of the Pokupski Basin, the amount was 89.12% in relation to the control, and in the Repaš region 80.22% in relation to the control. Interception amounted to around 10.9 – 19.8% in an older forest of pedunculate oak and common hornbeam in the region of north-west Croatia.

Results of analyses of cations and anions indicate that it is not sufficient only to measure the concentration of particular elements in the solution, but the quantity has to be changed to g/m^2 or $kgha^{-1}$ in order to gain insight into the amount of deposition and leaching in a forest ecosystem.

According to statistical analysis most chlorine was found in lysimeters at the depths of 10 and 100 cm in the region of the Pokupski Basin and Šiljakovina, followed by Česma and Repaš.

Most SO_4^{2-}-S was found in lysimeters at a depth of 10 cm in all areas, and most in Repaš, followed by Česma and the Pokupski Basin. The increase in sulfur was also found in lysimeters at a depth of 100 cm in the region of Pokupski and Česma, and less in Repaš.

Increase in NO_3^--N was highest under tree crowns in all regions. A somewhat smaller increase was found in surface lysimeters. This increase mainly related to nitrates, as they are leached from soil into ground water.

The contents of sodium and chloride were most increased in the region of the Pokupski Basin, in a lysimeter at a depth of 100 cm. This increase is manifold in relation to all other measuring sites and plots.

On average, most potassium was found in Česma in specimens under tree crowns.

On average most calcium was found in the Česma region in lysimeters at a depth of 100 cm, which can be explained by the increased amount of $CaCO_3$ in the deep layers of soil profiles.

The highest content of magnesium was found in Česma, in lysimeters at a depth of 100 cm, followed by those at a depth of 10 cm. Somewhat less was found in specimens under tree crowns.

According to results, the poorest buffer capacity was determined in soils in the area of the Pokupski Basin, followed by the river basin of Česma. In these regions, the breakthrough of acids in lysimeters occurred at a depth of 10 cm, and the measurement sites under tree crowns and those on the control measurement site proved to be negative.

The Repaš region has no negative ionic differences in the lysimeters which were therefore sufficiently buffer active to be able to neutralize acids deposited by dry and wet deposition in a community of pedunculate oak and common hornbeam.

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