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EFFECT OF THE CEMENT AND LIMESTONE INDUSTRY ON THE CHEMICAL PROPERTIES OF WATER BENEATH TREE CANOPIES

WPŁYW PRZEMYSŁU CEMENTOWO-WAPIENNICZEGO NA WŁASCIWOŚCI CHEMICZNE OPADÓW PODOKAPOWYCH

Abstract: This study is a continuation of earlier research aimed at determining the changes in the quality of precipitation beneath the canopy in pine stands affected by the emission of alkaline pollutants. This study was conducted in the Gorazdze Forest District, in a forest complex in south-western Poland affected by the cement and limestone industry. The rainwater measurements under the canopy of Scots pine were made according to the methodology of the environmental monitoring. Wet and dry deposits, thus the total pollution load brought into the forest ecosystem, were analysed. The pH and electrical conductivity was measured in collected water samples. The results showed differences between precipitation in winter (1.10–31.03 next year; fourth and first quarters), and in the growth season (during the second and third quarters – 1.04–30.09). Precipitation sampled beneath tree canopies in the winter half year had higher pH than those from the growth season half year (Table 2).

Keywords: alkalization, precipitation, deposition, pine stand

Introduction

The effect of precipitation on forest communities is considered mostly in terms of the water supply for plants. However, the chemistry of precipitation affects the chemical, physical and biological processes in the atmosphere-plant-soil relationship, which is equally important [1, 2, 3, 4]. The exploitation of raw materials from rocks in southern Poland has a long tradition and the alkalinisation of this region is mostly a result of the concentration of cement and limestone factories, as well as of gravel factories in the area. Cement dust that permeates soil in excess enriches its genetic levels, which causes a sequence of effects in phytocenoses [5]. Oligotrophic associations of pine forests are especially susceptible even to small changes. The extent of the alkaline deposits' effects

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depend on the source and type of emission, the distance from the emitters, the orography of the area, and the frequency and direction of winds.

In forest ecosystems the chemical content of rain sampled beneath tree canopies might vary considerably from the content of rain sampled in open areas. Rainwater contacts the surface of leaves and branches as it passes through the canopy and then runs along the trunk, which might change the physical and chemical properties of the water [6, 7, 8]. The speed and volume of flow along the trunk depend on the smoothness of the bark and on the interception capacity of tree canopy. Quantitative and qualitative differences in precipitation sampled below canopies depend on tree species [9].

Aside from wood production, forests serve as air filters drawing pollution from air by tree canopies. About 20% more ions are deposited in the soil beneath pine canopies in coniferous forests than in the open. This is associated with the quantity and quality of the dust that accumulate in tree canopies and of the components eluted from conifers' foliage [10].

This study is a continuation of earlier research aimed at determining the changes in the quality of precipitation beneath the canopy in pine stands affected by the emission of alkaline pollutants.

Material and methods

The study was conducted in south-western Poland. The study plot was established in pine monoculture in section 226l of the Gorazdze Forest District. This area is located 500 m from the Gorazdze-Wapno S.A. limestone factory and about 3 km from the Gorazdze-Cement S.A. cement factory in Chorula. Studies in this area have been conducted since 2001, but this paper presents the results of three years of investigation from 2015–2017.

Ten Scotch Pine trees of various heights were selected based on the Kraft classification system. A stemflow collar collector was fitted on each tree trunk at a height of 130 cm. The stemflow collectors were made of polyurethane foam covered with silicone; each collar had a small Igelit hose that discharged water to sterile containers. Each collar had 0.25 m^2 of collecting surface, allowing it to collect water from short and low-intensity precipitation [10]. Samples were collected, then the pH and electrical conductivity were measured, directly after each rainfall. Wet and dry deposits, thus the total pollution load brought into the forest ecosystem, were analysed. The results were presented for three periods, from the beginning of the growth season in 2015 till the end of the growth season in 2018. Thus the analysis of results was conducted for the following periods: 1 April 2015 – 31 March 2016, 1 April 2016 – 31 March 2017 and 1 April 2017 – 31 March 2018. This choice of analysed periods was determined by comparisons of precipitation in the growth season (1 April – 30 September) and in the winter season (1 October – 31 March).

Results and discussion

Between 1 April 2015 and 31 March 2018, 923 samples of water from beneath tree canopies were collected. The pH values were within a range of 3.54–7.97 (Table 1).

Table 1

Values of pH and electrical conductivity of the precipitation from beneath tree canopies in the study area in the Gorazdze Forest District

Measures of central tendency and dispersion	Forest District Gorazdze					
	2015[a]		2016[b]		2017[c]	
	pH [-]	conductivity [mS/cm]	pH [-]	conductivity [mS/cm]	pH [-]	conductivity [mS/cm]
$\bar{x}$	5.67	0.304	6.31	0.352	6.22	0.532
SD	0.617	0.209	0.525	0.211	0.382	0.261
Min.	3.54	0.083	5.42	0.066	5.40	0.118
Max.	7.31	1.525	7.97	1.262	7.13	1.827
Me	5.67	0.264	6.18	0.302	6.18	0.457
Mo	5.45	0.125	6.82	0.316	6.00	0.326
v%	10.9	68.7	8.33	59.6	6.15	49.0
n	450		180		293	

Symbols: research period: [a] 1.04.2015 – 31.03.2016; [b] research period 1.04.2016 – 31.03.2017, [c] research period 1.04.2017 – 31.03.2018.

Three years of study showed considerable variation in the pH and the electrical conductivity of precipitation. Precipitation in 2015 had a lower pH ($\bar{x}$ = 5.67) than in 2016 ($\bar{x}$ = 6.31) and 2017 ($\bar{x}$ = 6.22). The distribution of pH values in 2015 fell within a range of 3.54–7.31 (Fig. 1). By the classification of pH used in Austria [11] strongly alkaline precipitation (pH > 6.5) constituted 11 % of samples in 2015, 33 % in 2016 and 24 % in 2017. Greszta [12], based on an analysis of precipitation in areas unaffected by industrial emissions, showed that so-called "background pollution" creates precipitation with pH in the range of 4.5–5.5, and 4.9 on an average in continental areas covered with

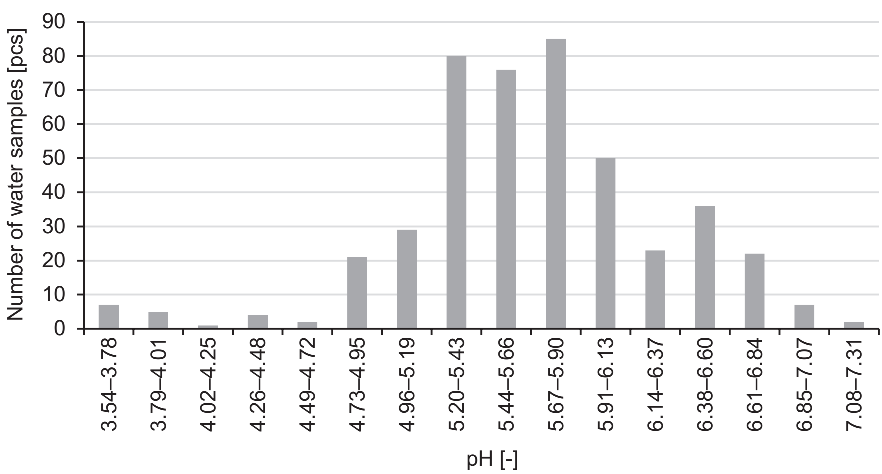

Fig. 1. Distribution of pH of water from under canopy Gorazdze Forest District – 2015

vegetation. During our studies 93 % of water analysed from beneath tree canopies had a pH of ≥4.9 in 2015. In 2016 and 2017, 100 % of the analysed precipitation had a pH > 4.9 (Figs. 1, 2, 3).

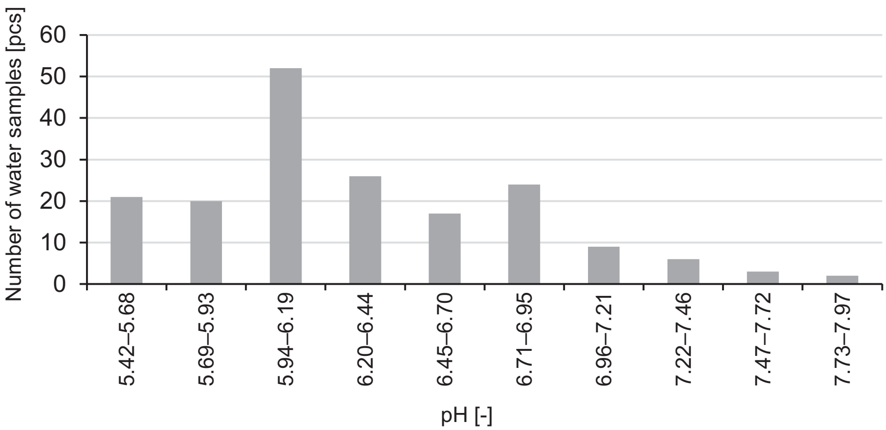

Fig. 2. Distribution of pH of water from under canopy Gorazdze Forest District – 2016

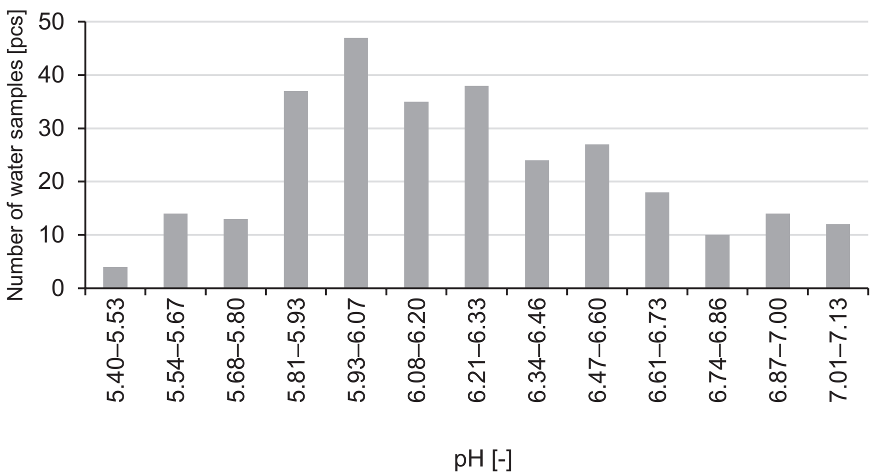

Fig. 3. Distribution of pH of water from under canopy Gorazdze Forest District – 2017

Seasonal changes in pH were clearly visible in water sampled beneath tree canopies in the three years of the study. The pH of all examined precipitation was higher in the first and fourth quarters of the year (winter half year) than in the second and third quarters (growth season). Mean pH values of winter precipitation (1.10–31.03 next year) of each year (2015/16, 2016/17, 2017/18) were 6.42, 6.82 and 6.33, respectively (Table 2). A similar tendency was shown in earlier studies by the author in the same area. The mean pH of winter precipitation in 2001 was 6.53; in the growth season it was

5.40. Precipitation in 2003 showed a similar tendency [10]. Winter precipitation in 2016 had a normal distribution, where the mean, the mode and the median were all 6.82. The highest pH of that winter, and of the whole analysed period, was 7.97. The precipitation in the 2017 winter season had lower pH, 50% of the analysed samples had a pH below 6.25 (Table 2).

Table 2

Statistical analysis of the pH of precipitation beneath tree canopies in the growth season and in winter in the study area in the Gorazdze Forest District

Measures of central tendency and dispersion	pH sub-canopy precipitation [-]					
	2015		2016		2017	
	O_w	O_z	O_w	O_z	O_w	O_z
$\bar{x}$	5.48	6.42	6.05	6.82	6.15	6.33
Min.	3.54	4.88	5.42	5.55	5.40	5.50
Max	6.51	7.31	6.95	7.97	6.68	7.13
Me	5.52	6.53	6.06	6.82	6.15	6.25
Mo	5.54	6.59	6.13	6.82	6.48	6.00
v%	9.11	7.09	5.38	6.79	4.56	6.71
n	450		180		293	

Symbols: O_w – sub-canopy precipitation in vegetation season (II and III Quarter (1.04–30.09)); O_z – sub-canopy precipitation in winter (IV and I Quarter (1.10–31.03 next year))

The concentration of pollution increases in winter because chemical compounds can accumulate longer in snow cover. Even after rainfall, dusts and gases can precipitate on or be absorbed by the snow. In the presence of such strong pollution emitters as cement and limestone factories, increased pH and electrical conductivity might indicate strong dust pollution in the forest ecosystem. Some of the samples collected in winter came from snow on collectors beneath tree canopies, some from melted snow and a small proportion from rain. These samples clearly differed in conductivity. During constant precipitation over several days, the first samples had higher pH and higher conductivity than the later ones, probably an effect of rinsing dust from the tree canopies. Samples collected from snow standing for a few days also had higher values. In turn, samples collected after three days of constant precipitation had lower conductivity and lower pH, in the range 4.8–6.0, than the earlier samples. This relationship was also confirmed by analyses of precipitation collected during the growth period. Other authors [13, 14] show a relationship between the pH of precipitation and dust pollution. In industrial areas with high emissions of dust, precipitation might reach a neutral or even alkaline pH.

Alkalinisation of precipitation that filters through canopies is determined mainly by the extent of dry deposits retained by the assimilation surface and then rinsed from it. The total surface of foliage (needles) is crucial for retaining dusts and gases, because it is up to a dozen times greater than the ground surface covered by trees [15].

Mineralisation of the precipitation in our study as expressed by its electrical conductivity, which had values within the range of 0.066–1.827 mS/cm (Table 1).

These values, as with those for pH, were similar to the results obtained during the author's earlier studies conducted in the area in 2001–2003. The range of electrical conductivity of precipitation in 2001–2003 ranged from 0.031 to 2.12 mS/cm. The calculated median showed that precipitation in 2002 had the highest conductivity of all studied years, when half of the sampled precipitation was above 0.460 mS/cm [10]. Precipitation in 2017 had a similar conductivity, with a median of 0.457 mS/cm.

Many authors observed a distinct increase of conductivity under tree canopies. For example Kolander [16] in Storkowo obtained the following values for precipitation inside the canopy: 0.0569 mS/cm, in the flow along pine trunks: 0.262 mS/cm, and for the open space: 0.0211 mS/cm. Thus the value of conductivity in water flowing along the trunk was ca 13 times higher than values for an open area. Krzysztofiak [17] in Wigierski National Park recorded conductivity values under pine canopy within the range 0.094–0.11 mS/cm, while in an open area they were in the range 0.0359–0.0516 mS/cm. The results obtained in Gorazdze were characterised by higher electrolytic conductivity than given above, which can indicate a significant dust pollution of the atmosphere.

Studies by Kozlowski [14, 18] in an area with a strong concentration of the cement and limestone industry confirm the increased mineralisation of precipitation after it flows through tree canopies and down trunks. The mean yearly values of the conductivity in precipitation from an open area were in the range of 2.61–5.48 mS/m. Precipitation from beneath tree canopies was twice as conductive, and water running down the trunks had nine times higher conductivity (35.97 mS/m).

Conclusions

1. Studies of pH values and electrical conductivity of precipitation confirm that forest ecosystems are under constant threat from industrial air pollution.
2. The pH of water sampled beneath tree canopies in the Gorazdze Forest District in 2015–2017 indicated an alkalinisation of the forest ecosystem; 80 % of precipitation samples had a pH above 5.5.
3. High electrical conductivity (0.066–1.827 mS/cm) of the sampled water confirm high pollution of the study area.
4. During winter the concentration of pollutants increased compared with the growth season, because chemical compounds accumulated for a longer time in the snow.

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WPŁYW PRZEMYSŁU CEMENTOWO-WAPIENNICZEGO NA WŁASCIWOŚCI CHEMICZNE OPADÓW PODOKAPOWYCH

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Abstrakt: Prowadzone badania są kontynuacją wcześniejszych prac, których celem jest określenie dynamiki zmian jakości wód opadowych pod okapem drzewostanów sosnowych, znajdujących się pod wpływem imisji zanieczyszczeń alkalicznych. W pracy przedstawiono wyniki trzyletniego okresu badawczego, obejmującego lata 2015–2017. Badania prowadzono w kompleksie leśnym w południowo-zachodniej części Polski (Leśnictwo Górażdże), będącym pod wpływem przemysłu cementowo-wapienniczego. Pomiary wody deszczowej pod okapem sosny zwyczajnej wykonano zgodnie z metodologią monitoringu środowiska Analizie podlegał zarówno depozyt mokry jak i suchy, czyli łączny ładunek zanieczyszczeń jaki wnoszony jest do ekosystemów leśnych. W pobranych próbach wody oznaczono odczyn (pH) oraz przewodność elektrolityczną. Trzyletnie badania wykazały znaczne zróżnicowanie odczynu i przewodności elektrolitycznej opadów atmosferycznych. Uzyskane wartości pH mieściły się w przedziale 3,54–7,97 (tab. 1). Wyniki badań wskazują na różnicę między opadami zimowymi (1.10–31.03 następnego roku IV i I kwartał) a opadami w okresie wegetacyjnym (1.04–30.09; II i III kwartał). Opady podokapowe półrocza zimowego miały wyższy odczyn niż w miesiącach przypadających na okres wegetacyjny (tab. 2).

Słowa kluczowe: alkalizacja, opady atmosferyczne, depozycja, drzewostan sosnowy