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A METHOD FOR MONITORING DEPOSITED MATTER IN FOREST ECOSYSTEMS

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Systematic and elaborate multidisciplinary research of pedunculate oak and common hornbeam began in the Forest Research Institute in Jastrebarsko in 1991. That led to a development of a method for monitoring deposition in forest ecosystems which is now closely related to the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forest. Several forest communities on the territory of Croatia were monitored for Cl^-, SO_4^{2-}-S, NH_4^+-N, NO_3^--N, Na^+, K^+, Ca^{2+}, and Mg^{2+} using that method. Samples were collected by funnels (bulks). Plastic lysimeters were placed in the soil at the depth of 10 cm or beneath the humus layer. They served to collect liquid that seeped into the soil (seepage). Sampling was carried out once a month or once in three months. The results show that the monitored forest ecosystems absorbed more deposited particles (wet and dry sedimentation) than control areas.

Key words:
air pollution, forest communities, lysimeter, monitoring, soil solution

A total of 18 plots were equipped with lysimeters to monitor the impact of deposited matter on forest ecosystems until the year 2000. The soil types were defined and chemically and physically analysed in the laboratory of Forest Research Institute. The initial monitoring of wet and dry deposition from the atmosphere in Croatia included forests of the Dinaric Alps. Beech and beech-fir forests in the south-western Croatia were found to be exposed to strong deposition (1), which was confirmed by later research (2–6). There is little methodological experience in the study of liquid soil phase in forest ecosystems in Croatia, as only a few authors (7–9) applied the methods of lysimetric pedology in such research. These studies confirmed the existence of

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wet and dry deposition from the atmosphere into the liquid soil phase (percolate) of our forest ecosystems. Lysimetric pedology served to determine the quality and the quantity of percolate in soil (10).

METHODS

Plots were laid out and equipped for monitoring in forest communities of beech and fir (*Abieti-Fagetum illyricum*/Ht.), submontane forest of beech (*Homogino-alpine-Fagetum sylvaticae*/Ht 1938/Borh 1963), Aleppo pine, and evergreen oak (*Querco ilicis-Pinetum halepensis*/Lasiel 1971), forest of evergreen oak (*Querco ilicis*), and forest community of pedunculate oak and common hornbeam (*Carpino-betuli*, *Quercetum roboris*, Anić 1956/emed. Rauš 1969 (Figure 1). Twelve plots were laid out in

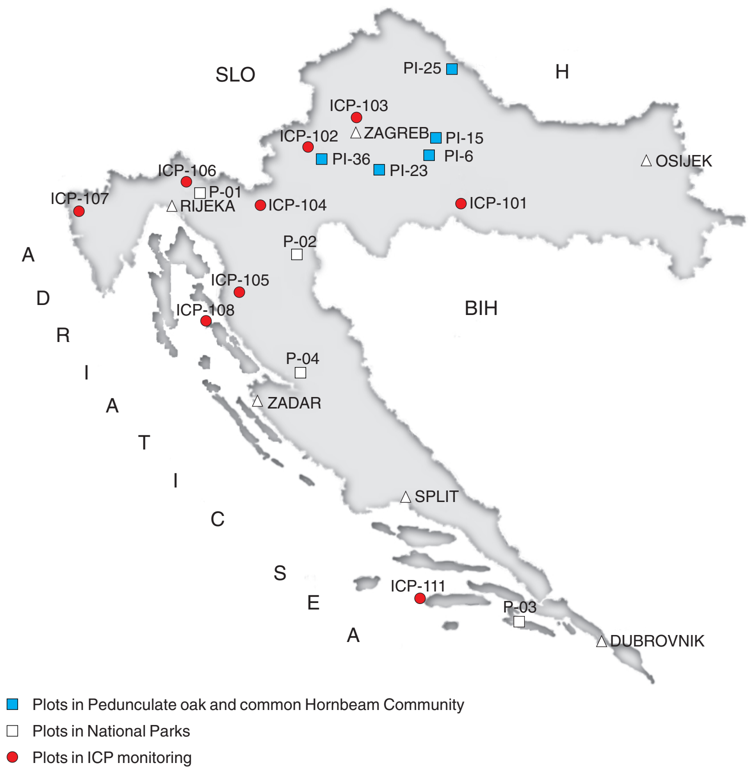

Figure 1 *Plot locations in Croatia*

Table 1 *Plots monitored in forest communities in Croatia*

Year of installation	Locality and No. of plot	Soil type	FAO symbol	Forest community	Lysimeter at depth	Rain-gauges and funnels	Control
	PI, ICP				cm	unit	unit
1992	River Česma (PI-1)	Pseudogley-gley	Lg	Pedunculate oak and common hornbeam	10, 100	6	6
1992	Čazma plain forests (PI-6)	Pseudogley level terrains	Lg	Pedunculate oak and common hornbeam	10, 100	6	6
1992	River Česma (PI-15)	Pseudogley level terrains	Lg	Pedunculate oak and common hornbeam	10, 100	6	6
1992	Šiljakovačka dubrava (PI-23)	Pseudogley level terrains	Lg	Pedunculate oak and common hornbeam	10, 100	6	6
1993	Repaš (PI-25)	Aluvium	Jc	Pedunculate oak and common hornbeam	10, 100	6	6
1993	Jastrebarsko plain forests (PI-36)	Pseudogley level terrains	Lg	Pedunculate oak and common hornbeam	10, 100	18	6
1996	Jastrebarsko foothill šume (ICP-102)	Pseudogley of sloping terrains	Lg	sessile-flowered oak and common hornbeam	10	18	6
1996	Medvednica (ICP-103)	Dystric cambisol	Bd	Beech and fir	3x10	18	6
1996	Korčula, Šakanj rat (ICP-111)	Terra rossa on limestone	Ie	Aleppo pine and evergreen oak	10	18	6
1996	Zavižan (ICP-105)	Calcocambisol on limestone	Bk	Sub-alpine beech	10	18	6
1997	Lividraga (ICP-106)	Rendzina on moraine	E	Beech and fir	10	18	6
1998	National Park Risnjak (PI-01)	Calcocambisol on dolomite	Bk	Beech and fir	10	18	6
1998	National Park Mljet (P-02)	Calcocambisol on limestone	Bk	Evergreen oak	10	18	6
1998	National Park Plitvice (P-03)	Calcocambisol on limestone	Bk	Beech and fir	10	18	6
1999	Umag, (ICP-107)	Terra rossa on limestone	Ie	Pubescent oak	10	18	6
1999	National Park Paklenica (P-04)	Calcocambisol on limestone	Bk	Beech and fir	10	18	6
2000	Pag, Lun ICP-108)	Terra rossa on limestone	Ie	Evergreen oak	10	18	6

the forest of pedunculate oak and common hornbeam of which only six plots are now in function due to damage caused by wild animals, sudden windstorms, or human action. Table 1 lists all plots of the monitoring system.

Plots were equipped with lysimeters to measure percolate and with funnels to sample liquids (sedimentation of dry and wet deposition). The opening surface of rain gauges was 60 cm^2, and the opening surface of funnels was at least 314 cm^2. Six to nine plastic rain gauges were placed on each plot and six to nine plastic funnels were placed diagonally under the crowns of the trees, according to the recommendation of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forest (ICP) (Figure 2).

Figure 2 *Plot in pedunculate oak and common hornbeam community (PI–36)(B. Vrbek)*

That many rain gauges and funnels were necessary to collect enough samples over summer when the precipitation is scarce and to measure the average precipitation in a forest stand. It is well known that dripping through tree crowns (throughfall) varies in intensity, and to avoid greater variability we had to place more measuring instruments. Three rain gauges and three funnels were placed in each control position such as open space where the impact of vegetation was excluded.

We also put small plastic lysimeters to monitor soil solution. Liquid percolated through soil was gathered at the bottom of a plastic rectangular container (dimensions 46.5x23.5x10 cm) and then carried off to a container below the collector (a canister of 25 to 30 l) (Figure 3). In liquid sampling, the liquid was sucked in from the container by a special pump and stored to plastic bottles for analysis. The area of

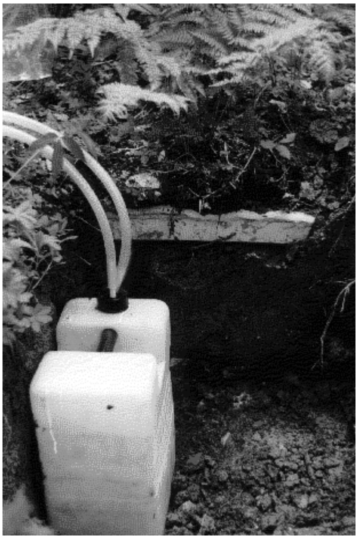

Figure 3 *Lysimeter beneath the humus layer in plot ICP–106 (B. Vrbek)*

collection with this kind of lysimeter was 1093 cm^2. The collector was filled with 96% clean quartz sand and had special filters to separate percolate from soil particles. Lysimeters were placed on two depth levels in the pedological profile; underneath the humus layer at 10 cm and in the mineral part at 100 cm, where the terrain allowed. Lysimeters can be placed at every 10–20 cm in more exhaustive measurements, but never one above the other. Each lysimeter was placed in a separate pit in the ground. Special attention was given to so called skeletal soil (containing a greater share of stone) and inclination while covering the lysimeters. We were careful not to mix layers. All soil had to be removed from the pit layer by layer and replaced in the same sequence. Liquid samples were taken for analysis after the soil above a lysimeter stabilised, that is, after one or two years.

Before the placement on plots, all instruments were washed with 10% nitrogen acid and repeatedly with redistilled water. Liquids were sampled once or several times where necessary. Samples were taken in rinsed plastic bottles with double lids and frozen or sent to laboratory for analysis on the same day. The acidity and conductivity of liquids were measured directly in the field, immediately after sampling. Chemical composition of liquids was determined in the Meteorological and Hydrological Service of Croatia. We applied analytical methods which are usually used to determine small quantities of matter in water and precipitation, that is, spectrophotometry (spectrophotometer Perkin Elmer Lambda-1) for SO_4^{2-} and NO^{3-} ions, ionselective electrodes (ORION – microprocessor ion analyser, 901 model) for NH_4^+ and Cl^- ions, and atomic absorption spectrophotometry (atomic spectrophotometer Perkin Elmer, 603 model) for the metal ions (Na^+ and K^+ – alkaline, Ca^{2+} and Mg^{2+} – earth alkaline. Conductivity (mS) and pH were measured in the field.

This method of monitoring deposition in forest ecosystems is similar in some aspects to methods described earlier (11–13).

RESULTS AND DISCUSSION

Measurements of precipitation and soil solution in the forest of pedunculate oak and common hornbeam (14) took six to seven years (since 1992). Monitoring of other forest communities began later (from 1996 to 2000, Table 1). Tables 2, 3, and 4 show the 1997 analyses of deposited matter which includes the vegetation period (1 April – 1 November) for four plots in the forest community of pedunculate oak and common hornbeam, for two plots in the beech and fir forest, submontane forest of beech and for one plot in the forest of Aleppo pine and evergreen oak. The average quantity of cations and anions determined in funnels placed below tree crowns and in soil solution was, as a rule, higher than in control locations. The increased deposition of Cl^-, Na^+, and Ca^{2+} in samples was noticeable on plot ICP-111. The finding was expected as the plot was (Island of Korčula) sprayed by strong winds carrying sodium, potassium, magnesium, and calcium from the sea. The increase of calcium and sodium in soil solution points to increased transport of these elements through

Table 2 *Average quantity of cations and anions collected below tree crowns during the vegetation period (1 Apr–1 Nov 1997)*

No. of plot	Number of samples	Cl^-	NO_3^--N	SO_4^{2-}-S	NH_4^+-N	Mg^{2+}	Na^+	K^+	Ca^{2+}	pH in	Ep
		mg/dm³								H_2O	mS
Pl-6	8	1.66	3.12	0.66	0.30	0.88	0.52	5.21	1.58	5.26	67.1
Pl-15	8	1.65	2.45	0.56	0.05	1.10	0.34	6.12	3.08	5.48	35.4
Pl-25	8	4.91	6.05	0.13	0.49	1.35	0.18	19.60	3.46	5.61	78.3
Pl-36	8	1.44	2.30	0.85	0.43	0.75	0.21	6.69	2.67	5.70	35.1
ICP-103	6	2.84	1.56	0.85	0.89	0.86	0.48	6.33	3.32	5.08	48.2
ICP-105	4	1.26	1.38	0.56	0.65	0.25	0.39	1.10	1.63	5.77	17.52
ICP-106	8	1.62	2.05	1.11	0.75	1.22	0.56	4.44	3.31	5.12	33.6
ICP-111	4	31.0	4.21	1.85	0.07	3.28	19.50	5.56	8.11	5.92	137.8

Table 3 *Average quantity of cations and anions in lysimeters during the vegetation period (1 Apr–1 Nov 1997)*

No. of plot	Number of samples	Cl^-	NO_3^--N	SO_4^{2-}-S	NH_4^+-N	Mg^{2+}	Na^+	K^+	Ca^{2+}	pH in	Ep
		mg/dm³								H_2O	mS
Pl-6	8	1.66	3.38	0.75	0.11	1.47	0.20	3.09	1.85	4.96	40.1
Pl-15	8	2.17	2.90	0.91	0.22	1.09	0.42	3.69	2.16	5.26	32.7
Pl-25	8	2.19	6.05	1.38	0.08	2.65	1.09	2.18	6.43	5.78	75.2
Pl-36	6	1.88	4.11	1.21	0.14	1.96	0.87	1.91	2.11	4.75	33.3
ICP-103	3	3.01	5.62	0.88	0.64	2.67	0.79	1.85	13.10	4.98	104.9
ICP-105	3	1.18	3.47	1.10	0.05	0.88	0.44	0.31	6.56	5.45	37.7
ICP-106	–	–	–	–	–	–	–	–	–	–	–
ICP-111	3	38.1	5.04	1.41	0.10	4.42	28.25	6.41	20.85	6.98	199.0

Table 4 *Average quantity of cations and anions in control locations during the vegetation period (1 Apr–1 Nov 1997)*

No. of plot	Number of samples	Cl^-	NO_3^--N	SO_4^{2-}-S	NH_4^+-N	Mg^{2+}	Na^+	K^+	Ca^{2+}	pH in H_2O	Ep
		mg/dm³									mS
Pl-6	8	0.79	1.10	0.31	0.06	0.19	0.19	0.27	0.85	5.11	14.3
Pl-15	8	0.77	1.23	0.38	0.12	0.22	0.21	0.33	0.42	5.23	15.1
Pl-25	3	0.76	4.70	0.34	0.15	0.37	0.47	3.07	1.51	5.79	27.1
Pl-36	6	1.06	1.14	0.44	0.05	0.33	0.26	0.15	1.09	5.29	13.1
ICP-103	4	0.61	1.12	0.54	0.11	0.22	0.28	1.03	1.11	5.38	16.2
ICP-105	3	0.72	1.23	0.48	0.10	0.31	0.34	0.85	1.21	5.76	17.1
ICP-106	4	0.56	2.12	0.56	0.16	0.42	0.23	0.92	1.73	5.62	26.2
ICP-111	3	5.90	1.58	1.35	0.12	0.64	2.70	2.03	3.64	6.39	42.0

soil and to constant soil alkalisation. The role of the forest is to filter and absorb most of the deposition impact. The deposition settles on the tree crowns; it is then washed down to the ground and further transported through soil. The damage to the soil depends on its capacity to buffer the impact, which is then manifested on the growth of trees. These results agree with previous studies (15, 16) which pointed to a major role of the forest and to the fact that total deposited matter was always higher below the trees than in control locations. Similar results were obtained by measuring throughfall in a forest of pedunculate oak and common hornbeam in three age categories in the area of the river Česma (17). Maximum allowed concentrations of sulphates in emission are 3–15 kg/ha a year. Natural deposition of nitrogen is 1–2 kg/ha a year and of chlorine 1–3 kg/ha a year. In the most endangered parts of Europe, sulphur depositions go as high as 100 kg/ha a year, and of nitrogen 3–15 kg/ha a year. Measurements in Zavižan, Zagreb (18), and Lividraga in Gorski Kotar (19) show that there is also an increased deposition by air transport. It is known that due to leaching of deposited matter, deposition of sulphur and other elements is higher in the forest than in the open area. Deposition of sulphur in the open area over a year amounts to 13 kg/ha, in a beech stand 22 kg/ha, and in spruce plantation 33 kg/ha (20). In Lividraga, the annual deposition of SO_4^{2-}-S was 23.77 kg/ha, of NO_3^--N 9.24 kg/ha, of NH_4^+-N 14.98 kg/ha, of Cl^- 32.63 kg/ha, and of Ca^+ 75.65 kg/ha (19). According to literature, the increased nitrogen poses greater danger to the forest ecosystems than does sulphur. Nitrogen acidifies the soil and causes imbalance in the nutrition of a tree, weakening its resistance to unfavourable abiotic (drought, low temperatures, and wind) and biotic factors (plant diseases and insects).

CONCLUSION

Deposition of matter in forest ecosystems has increased in all monitored locations in Croatia. It is particularly evident in the region of Korčula, where the spray of northwestern and south winds carries it to tree crowns. It is then washed into the soil and carried further below the humus layer. The spray is the main reason for the manifold increase in sodium, potassium, calcium, and magnesium in soil. On control locations, where the impact of vegetation is excluded, these amounts are always lower.

The method described in this paper may well serve to extend the monitoring to other major forest communities in Croatia in order to see how various types of trees and communities affect dry and wet deposition.

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Sažetak

METODA PRAĆENJA TALOŽNIH TVARI U ŠUMSKIM EKOSUSTAVIMA

U Šumarskom institutu, Jastrebarsko započeta su 1991. godine sustavna i detaljna multidisciplinarna istraživanja u šumi hrasta lužnjaka i običnoga graba. Tada je razrađena i metoda praćenja taložnih tvari u šumskim ekosustavima. Tom metodom do godine 2000. obuhvaćeno je nekoliko šumskih zajednica na području Hrvatske. Plohe su postavljene i opremljene za praćenje u šumskim zajednicama bukve i jele, hrasta kitnjaka i običnoga graba, pretplaninskoj šumi bukve, alepskog bora i crnike, šumi crnike te u šumskoj zajednici hrasta lužnjaka i običnoga graba. U šumi hrasta lužnjaka i običnoga graba bio je zastupljen najveći broj ploha (ukupno 12). Danas je u funkciji još 6 ploha zbog teškoća u praćenju i zaštiti objekata bilo zbog divljači, iznenadnih ciklona (u godini 1999. uništene su vjetroizvalama 4 plohe) ili zbog gospodarenja šumama jer objekti nisu bili ograđeni i čuvani. Od taložnih tvari praćeni su: Cl^-, SO_4^{2-}-S, NH_4^+-N, Na^+,K^+, Ca^{2+}, Mg^{2+}. Uzorkovanje se obavlja s pomoću lijevaka površine otvora od najmanje 314 cm^2, a količina padalina mjeri se plastičnim kišomjerima površine otvora 60 cm^2. Lijevci i kišomjeri postavljaju se pod zastorom krošanja te na otvorenom prostoru na svakoj plohi. Kišomjeri i lijevci postavljeni su u dijagonalnom rasporedu po 6–9 komada svaki na plohi veličine 30 X 30 m. Na kontrolnom mjestu bez utjecaja vegetacije lijevci i kišomjeri postavljeni su u slučajnom rasporedu ili u krugu. Plastični se lizimetri postavljaju u tlo na dubini od 10 cm ili ispod humusnog horizonta. Oni skupljaju procjednu tekućinu u tlu. Površina sabirnika (kadice) u ovom slučaju iznosi 1093 cm^2. Kao filtar u plastičnoj se posudi nalazi 96% čisti kvarcni pijesak radi pročišćavanja tekućine od čestica tala. Uzorkovanje se obavlja jednom na mjesec ili jednom tijekom tri mjeseca. Prema dobivenim rezultatima praćenja, naši šumski ekosustavi primaju više taložnih čestica (suho i mokro taloženje) u odnosu na kontrolne uzorke na otvorenom prostoru, a osobito je to izraženo na plohama na otoku Korčuli gdje je posolica jedan od glavnih razloga povećanja sadržaja natrija, kalcija, kalija i magnezija u uzorcima ispod krošanja drveća i u lizimetrijskim vodama.

Ključne riječi:
kalcij, kalij, lizimetar, magnezij, natrij, šumske zajednice, taloženje

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