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Soil Water Samplers in Ion Balance Studies on Acidic Forest Soils

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During the last years an increasing consciousness has appeared of the injurious effects of acid rain on the forest ecosystems both in Europe and North America. At several localities ion balance studies have been implemented in order to evaluate the impact of the atmospheric deposition of acidic substances and heavy metals on the forest ecosystem (e.g. Cronan 1980; Johnson et al. 1981; Mollitor and Raynal 1982; Ulrich and Matzner 1983; Bergkvist 1983; Rasmussen 1984). Some ecosystems are underlain by a tight bedrock or some other impermeable base comprising the possibility of measuring the total output from the watershed in the drainage streams. However, in many localities the leaching of material to the ground water or output from the ecosystem has to be determined by means of tensiometer measurements and soil water sampling. Even if concentrations of elements in the soil water samples are determined in accordance with standardized methods, the basic sampling method of the soil water solution may influence the final findings. Many different soil water samplers are available on the market and they show useful applicability under the given circumstances. But in many cases soil water samples taken with different equipment give incommensurable results leading to differing explanations of the effects of acid precipitation on elements and their cycling in the ecosystem.

The purpose of the present study is twofold. Firstly, the sorption characteristics of different types of soil water samplers (lysimeters) are examined under acidic soil conditions both by installation in the field and by laboratory experiments. Secondly, a new method is introduced for current and constant soil water sampling under varying soil suctions in the unsaturated zone.

MATERIALS AND METHODS

The sorption characteristics of four different types of lysimeters were examined:

1. The "percolation lysimeter" (soil column lysimeter) consists of a plexiglass cylinder (diameter 292 mm, basal area 661 cm^2) closed at the lower end by a polyester net (mesh 80 µm) resting on a bottom

plate, uniformly pierced by 129 holes (4 mm). Under the bottom plate a polyethylene funnel is mounted with polyethylene screws and glue. The funnel tip is placed in a 10 l polyethylene collecting flask. A soil core of the same diameter is punched out with a stainless steel cylinder and placed with a minimum of disturbance in the plexiglass lysimeter. The lysimeter is installed in a supporting PVC cylinder in the soil, in this case without a vacuum pump (Fig. 1). This type of lysimeter is a modification of the type described by Nilsson and Bergkvist (1983).

2. The "ceramic cup lysimeter" (vacuum soil water sampler, Soil Moisture Equipment Corp., Model 1900) consists of a 45 mm OD PVC tube with a porous ceramic cup (same diameter, height 57 mm) bonded to one end. The opposite end is sealed with a neoprene stopper and attached with nylon tubing from the bottom of the ceramic cup to the vacuum pump via a collecting flask. The lysimeter is installed into a cored hole containing a slurry of distilled water and soil from the same depth. This is done in order to insure adequate contact between soil and the ceramic cup.

3. The "porcelain cup lysimeter" (vacuum soil water sampler, Porzellane Berlin, P 80 Material) is made of a 20 mm diameter PVC tube with a porcelain cup (same diameter, height 50 mm) mounted at one end. The opposite end is sealed with a 1/4" Swagelok nylon tube fitting. The installation and tubing is otherwise done in the same way as the ceramic cup lysimeter (Fig. 1).

4. The "teflon lysimeter" (vacuum soil water sampler, C.S. Cronan, University of Maine), is made of a 45 mm OD PVC tube with a 40 mm diameter porous teflon disc mounted at one end. The installation and tubing is otherwise done in the same way as the cup lysimeters.

Before use all lysimeters were flushed through with a 0.1 N HCl succeeded by distilled water. In order to avoid contamination, only material without contents of heavy metals was used when possible.

The percolation and ceramic cup lysimeters were installed in the field in a 50 yr spruce forest, the Strødam Reserve, Zealand, Denmark. The soil was an acidified, sandy moraine, podzol (clay 4%, silt 5%, fine sand 36%, coarse sand 55%, loss on ignition 2,5%). Soil water samples were taken at the lower part of the A horizon at a depth of 25 cm. All tubing was kept under the soil to prevent freezing in winter and heating in summer. For the same reason sampling flasks and the vacuum pump installations were kept in a thermo box digged down 60 cm. The vacuum pump (Thomas Industries Inc., Model 107ADC20) was driven by a 12 V storage battery giving a maximum vacuum of 560 mm Hg. In order not to start the pump with the vacuum on, a magnetic valve was inserted. The pump was connected to the lysimeters via the low pressure side of a differential pressure switch (Dwyer Instruments, Model 1823-80) mounted with a Magnehelic differential pressure gauge (Dwyer Instruments, Model 2000). The high pressure side of the differential pressure switch was connected to a tensiometer installed at the same depth as the lysimeters. The pump

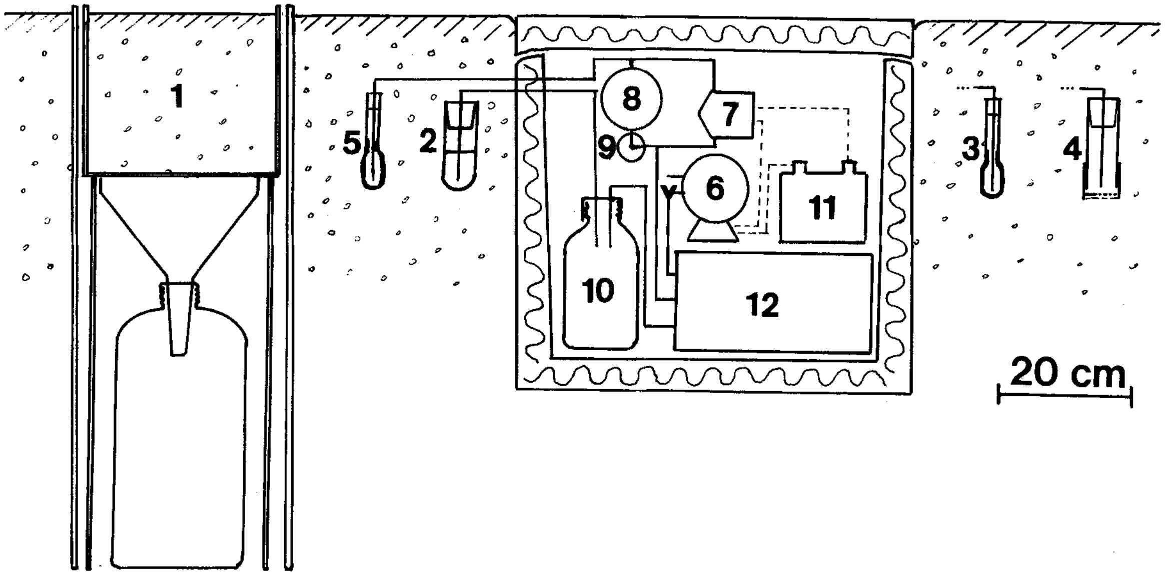

Fig. 1. Field installation of lysimeters. 1. Percolation lysimeter. 2. Ceramic cup lysimeter. 3. Porcelain lysimeter. 4. Teflon lysimeter. 5. Tensiometer. 6. Vacuum pump. 7. Differential pressure switch. 8. Pressure gauge. 9. Valve. 10. Collecting flask. 11. Storage battery. 12. Vacuum tank. v. Magnetic valve.

was in that way currently controlled to establish a vacuum on the lysimeters which always was a little larger than the soil tension (adjustable between 23 and 210 cm colomn of water). The assembling as described here is new in the way that the current sampling is constant whether the soil is wet or dry.

The laboratory experiments were performed to evaluate the sorption on the different types of lysimeters using soil water collected from the percolation lysimeters or distilled water adjusted to pH 3.0 with a mixture of H_2SO_4 and HNO_3 (2:1). The suction time giving the same amounts in the collection flask was 2 h for the cup lysimeters and 10 min. for the teflon disc lysimeter.

All elemental concentrations were measured directly in the solutions using atomic absorption spectrophotometry (AAS) with atomization in an air/acetylene flame, except for Al where a nitrous oxide/acetylene flame was applied.

RESULTS AND DISCUSSION

The percolation lysimeters and the ceramic cup lysimeter were installed during the period February-October. In the beginning of the period no big differences were observed in pH and chemical concentrations of the soil water collected by the two different types of lysimeters (Fig. 2). However, on the one hand it was expected that the increased mineralisation during late spring and summer might result in increased elemental concentrations in the soil water. This was fulfilled especially for the percolation lysimeters where the uptake from living tree roots is excluded. In addition, the newly cut off of roots may also have increased the mineralisation. On the other hand, mineralisation processes increase the organic content of the soil water solution, and since most of the elements are adsorbed hereto, the concentrations of elements in the cup lysimeter samples may decrease when the organics are retained on the outer surface of the cup. This aspect is obvious for Al (Fig. 2) and Fe (80% decrease, data not shown). According to Nilsson and Bergkvist (1983) 83-97% of the dissolved Al consisted of organic species. But for the other elements and pH the values increased unexpectedly during the summer compared to the percolation lysimeter measurements (increase Cd 20%, Mg 60%, Mn 220%, Na 30%, Ni 30% and Zn 90%).

By the laboratory experiments (Table 1) it was revealed that by the passage of the ceramic cup both soil leachates and blanks were enriched with considerable amounts of most elements, especially Ca. This phenomenon is ascribed to a simple mineralisation of the ceramic cup itself under the acidic conditions in question. Since the Ca/Al-relation is a very important parameter in the description of the ion balance budgets for forest ecosystems under the influence of acidic precipitation, this type of ceramic cup lysimeters should not be used. As regards soil water sampling for measurements of NO_3^- and SO_4^{2-}, similar problems have not been observed in the present study, and therefore results are not included in this paper.

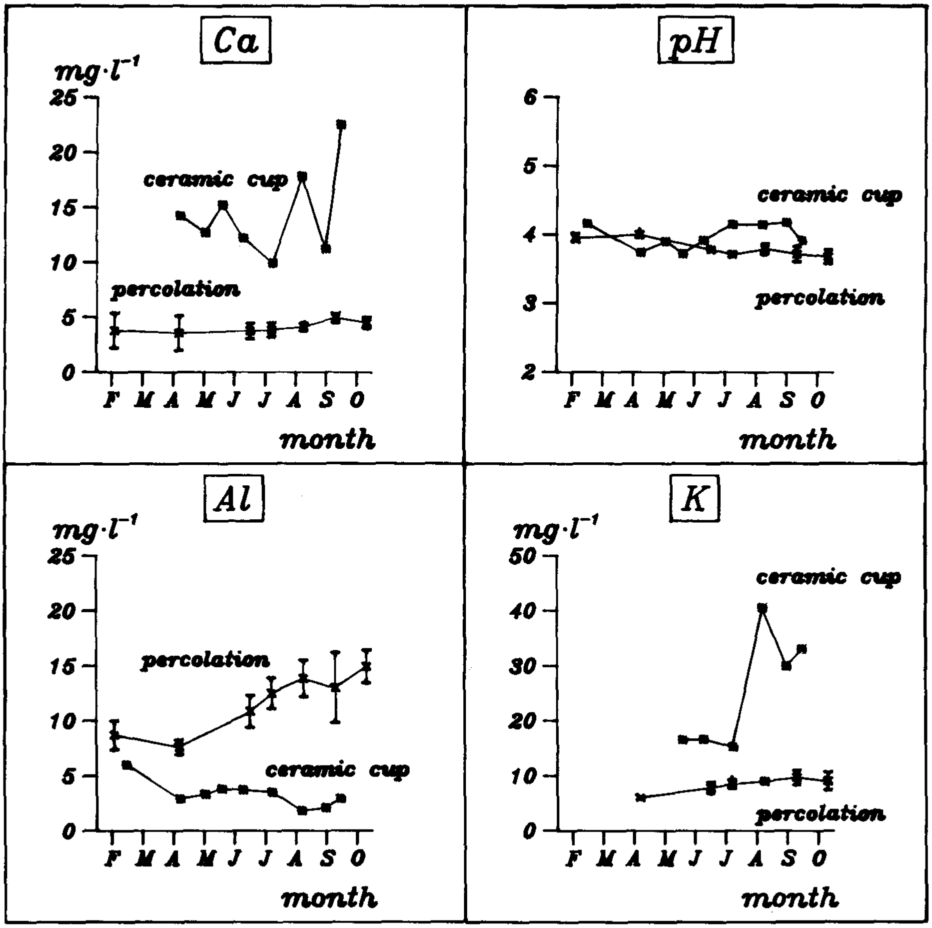

Fig. 2. Concentrations of Ca, Al, K and pH in soil water at a depth of 25 cm measured after sampling in percolation and ceramic cup lysimeters. Vertical bars indicate s.e., n = 3.

Table 1. Laboratory experiment on the adsorption (-) or enrichment (+) of elements in soil water solutions and blanks (pH 3.0) after suction through the lysimeters.

	Soil water before suction	CERAMIC CUP		Soil water before suction	PORCELAIN CUP		TEFLON DISC	
		soil water after suction	blank after suction		soil water after suction	blank after suction	soil water after suction	blank after suction
pH	3.65	3.88	3.13	3.80	3.64	3.10	3.87	2.92
Ca mg l^{-1}	3.0	7.0 (+133%)	0.38	8.8	6.4 (- 27%)	0.07	7.7 (- 13%)	0.06
Mg "	0.71	0.86 (+ 21%)	0.05	2.0	1.69 (- 16%)	0.05	2.0 (0%)	0.00
K "	11.1	12.6 (+ 14%)	7.4	13.6	13.7 (0%)	0.1	14.7 (+ 8%)	0.2
Na "	7.8	8.5 (+ 9%)	0.4	9.3	9.5 (+ 2%)	0.0	10.0 (+ 8%)	0.4
Al "	12.4	9.7 (- 22%)	0.8	5.5	4.3 (- 22%)	0.7	5.2 (- 5%)	0.2
Fe "	0.57	0.31 (- 46%)	0.09	0.48	0.13 (- 73%)	0.02	0.46 (- 4%)	0.01
Mn "	0.11	0.13 (+ 18%)	0.00	0.55	0.51 (- 7%)	0.00	0.56 (+ 2%)	0.00
ZN "	0.11	0.20 (+ 82%)	0.08	0.17	0.15 (- 12%)	10.00	0.20 (+ 17%)	0.00
Cd µg l^{-1}	1.8	2.3 (+ 28%)	0.5	0.75	1.5 (+100%)	0.0	2.0 (+167%)	0.4
Ni "	4.3	11.5 (+167%)	1.3	7.3	5.5 (- 25%)	2.3	7.5 (+ 3%)	1.3

From Table 1 it appears that although the porcelain cup lysimeters by the laboratory experiments retain a great part of the organic material on the cup surface, the major part of elements is passing through with only a minor enrichment or adsorption. In respect of that the teflon disc lysimeters seem to work even better.

Teflon is a hydrophobic material and the disadvantage with this type of lysimeter is therefore, that the disc must be very porous in order to let water through. This means that soil water may be sucked too fast into the lysimeter, making it difficult to maintain the capillary connection between the soil water inside and outside the lysimeter. Thus, the applicability of the teflon disc lysimeter is very much depending on the soil texture and water conditions.

The applicability of the percolation lysimeters is depending on the soil characteristics as well, since in the case of fine grained soils the bottom layers may become water locked and thereby induce anoxic conditions if vacuum equipment is not applied. However, the advantage of the percolation lysimeter when installed in sandy soils or with an isokinetic vacuum is, that it besides giving information about chemical concentrations in soil water, also gives a first estimation of the drainage output from the ecosystem.

In conclusion, the porcelain cup lysimeters seem the most applicable under all conditions. The percolation lysimeters also seem to work under all conditions. In the case of a larger clay content in the soil mounting of a vacuum pump may be necessary. However, the exclusion of living roots should be taken into account by interpretation of the findings. Although the teflon disc lysimeters are not suited for soil with a low clay content they have the advantage of no important elemental adsorption or enrichment of soil solutions, whereas the ceramic cup lysimeter should not be used at all in ion budget studies on acidic soils. Both plastic cup lysimeters and none hydrophobic teflon cup lysimeters are to-day under development. They are expected to be able to combine the proper porosity characteristics of the porcelain cup lysimeters with the none sorption characteristics of the teflon disc lysimeters. However, for all vacuum lysimeters an adjustable current suction installation equipped with a differential pressure switch as presented here should be recommended.

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