

Monolithic lysimeters as tools to study the composition of pore and drainage waters responding to high water table in boreal acid sulphate soil

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Abstract

Impacts of high water table on the quality of pore and discharge waters in an acid sulphate soil (*Sulfic Cryaquepts*) were studied using ten PVC lysimeters (200 dm³, diameter 50 cm, height 100 cm). Each lysimeter contained a monolith of undisturbed soil horizons B, BC and C equipped with the system for water supply and for continuous measurements of soil moisture, temperature, bulk electrical conductivity and redox potential. Elemental composition and other quality parameters of pore and discharge waters were analysed. The water balance of lysimeters was calculated from the water supply, ground water level and measured discharge. The experimental treatments were: cropped high (HWC) and low (LWC) water table treatments, and uncropped high water table treatment (HWB). Water table elevation induced reducing conditions in the soil both in summer (HWC) and in winter (HWC, LWC) despite low temperatures (< +10 °C). Reducing conditions gave rise to high iron concentrations in pore and discharge waters as opposed to the lowered concentrations of aluminium. The cumulative iron loads from HWC (17.8 kg/ha) exceeded those from LWC (1 kg/ha). The Al loads from LWC (3.6 kg/ha) exceeded those from HWC (2.2 kg/ha), even if less water discharged from LWC than from HWC.

Key Words

Acid sulphate soil, redox potential, pore water quality, discharge water quality, lysimeter

Introduction

The acidity and high metal concentrations of discharge waters from cultivated acid sulphate soils have deteriorated the water quality in recipient waters in Finland (Åström 2005; Roos 2006). For this reason, a research project was established to investigate the impact of high water table on the quality of pore and drainage waters, and on the growth of reed canary grass, a perennial bioenergy crop. Lysimeters have been used for a long time in studies on water flow and leaching of elements in agricultural soils (Goss 2009). They are also the most practical tool to study the impacts of controlled ground water level on acid sulphate soils at near field scale. Acid sulphate soils have distinct soil horizons from the well-structured A horizon down to the massive C horizon, soil redox status varying from oxidized to reduced, respectively. In order to get undisturbed horizons into the lysimeter a simple method to take monoliths from acid sulphate soil was developed. We report here the methods for monitoring soil redox status in different soil horizons, the initial response of redox potential and the pore and discharge waters quality to the water table elevation in boreal conditions at the beginning of the experiment.

Material and methods

Ten monolithic lysimeters were taken from a poldered cultivated acid sulphate soil of the University of Helsinki at Viikki in southern Finland (60° 13.4' N, 25° 0' E) in summer 2008. The soil presented in Table 1 is classified as *Sulfic Cryaquepts* according to Soil Taxonomy (Yli-Halla 2008, Mokma *et al.* 2000). In the field, the B horizon is actual acid sulphate soil. The transition horizon (BC) is located at the depth of the subsurface drainage pipes at about 1 m below soil surface and the reduced C horizon (potential acid sulphate soil) is constantly water-logged. The results presented here are from the beginning of the experiment to the end of year 2008. The study will be continued to the end of year 2010 so that it will comprise a total of two hydrological years and two harvested yields.

Table 1. Selected physical and chemical properties of the soil sampled into the lysimeters.

Horizon	Depth in a lysimeter (cm)	pH	Clay (%)	Total S (g/kg)	Oxalate extractable		Carbon (%)	Redox potential in the field E _h (mV)
					Al (g/kg)	Fe (g/kg)		
Ap	0 - 20	6.4	33	0.4	1.6	4.7	3.8	500
Bgjc	20 - 50	3.8	61	4.2	4.1	13.2	1.9	500
BCgc	50 - 80	4.2	57	4.6	2.5	11.7	2.5	300
C	80 - 100	6.5	59	14.9	1.7	2.2	2.8	75

The lysimeter body was a PVC tube 50 cm in diameter, 100 cm in length and with 4.5 mm wall thickness. The technique for sampling the lysimeters by a special cutting tool and an excavator was developed in the pre-experiment in 2007. Soil monoliths were dug up from the depths between 70 cm to 150 cm, so that they finally comprised of a 60-cm of structured actual acid sulphate soils layer and 20-cm of massive potential acid sulphate soils layer (sulphidic materials). After sampling, the bottom of lysimeters was sealed with a PVC cap. The monoliths transported into a greenhouse compartment with wire-net walls and glass roof, where controlled treatments could be carried out. The turfs (20-cm thick) of one-year old reed canary grass grown on a non-acid soil were planted on the top of cropped monoliths, whereas the uncropped lysimeters were filled with 20 cm layer of non-acid topsoil material. In order to facilitate high water level treatment, the lysimeters were made waterproof up to 1 m hydraulic pressure. All access holes were made watertight. The drainage tubes were installed at the depth of 70 cm in all lysimeters. The overflow height was defined according to the water table treatment. The ground water table in each lysimeter was controlled by an external water supply tube, and monitored through two observation pipes connected to the depths of 70 and 90 cm.

The experiment consisted of eight cropped and two uncropped lysimeters. The water table treatments were high (HW) or low (LW) water table. The treatments started on 22.7.2008 when the water table was raised in the high water table treatments (HWC and HWB) to a level 20 cm below the soil surface, whereas in the LWC treatment it was allowed to drain freely to the depth of 65 cm. In order to prevent shrinkage of soil in LWC and the possibility of consequent preferential sidewall flow of water during the later experiment, the water table of LWC was raised to 30 cm from the soil surface at the beginning of January 2009 for four months. Because the lysimeters were not buried into the ground, they were exposed to the boreal climate as a whole. To mimic soil temperatures in the field, the lysimeters were equipped with insulation and heater against frost in winter and with sunshades in summer, so only the top of lysimeters were subjected to open air temperatures.

The water supply tubes were filled daily to the levels corresponding to the desired water table depths. In addition, the lysimeters were watered from above at three-day intervals with amounts corresponding to the mean monthly long-term precipitation at a local weather station. The daily water consumption of a lysimeter was measured from the water level in the water supply tube. The water balance of a lysimeter was determined from the irrigation (P), the discharge (Q) and the water consumption and water table change in a lysimeter (ΔS). The evapotranspiration was calculated from equation 1.

$$E = P - Q - \Delta S \quad (1)$$

An automatic data acquisition system for soil redox potential consisted of a common Ag/AgCl reference electrode (Inlab 301), a saturated KCl salt bridge (Linebarger 1975) and a Agilent 34980A datalogger (input impedance 10 G Ω) scanning the Pt electrodes at 10-minute intervals. Soil redox potential was measured continuously at a known buffer solution (220 mV, Schott) and at five soil depths: 10 cm (A), 30 cm (B), 50 cm (B) and 70 cm (BC) and 90 cm (C). Air temperature was measured by the datalogger with thermocouples in open air, under the heat insulation or solar shades, and among plant canopy. The measured redox potentials (E_m) were converted to temperature-corrected E_h values (SHE) using equation (2).

$$E_h = E_m + 199 - 55 + 0.7 \{(273 + t) - 298\} \text{ (mV)} \quad (2)$$

Soil moisture content, temperature and bulk electrical conductivity were measured continuously at 10-min intervals with 5TE probes and data loggers (Degacon Em50) in three soil horizons (A, B, BC). Soil pH was measured manually with an ISFET electrode through access holes. Soil water was sampled by pore water extractor (Rhizon, MOM) to plastic vacuum tubes. Total and filtered (0.45 μ m) discharge water were sampled to plastic bottles cleaned with acid. Part of pore and discharge water samples were used for pH and EC measurements. The elemental composition of water samples was analysed by ICP-OES (Thermo Scientific, ICAP 6000). The cumulative discharge was calculated by summing all discharges from a lysimeter, and the cumulative loads by summing the weekly products of measured elemental concentration and discharge.

Results

Temperature varied from +25 to -5 °C during the study period. At the beginning of experiment, soil temperatures followed the air temperatures at all depths because the insulation and solar shade was not installed. In winter, insulation and heater kept soil temperatures between +3 and +7 °C (Figure 1).

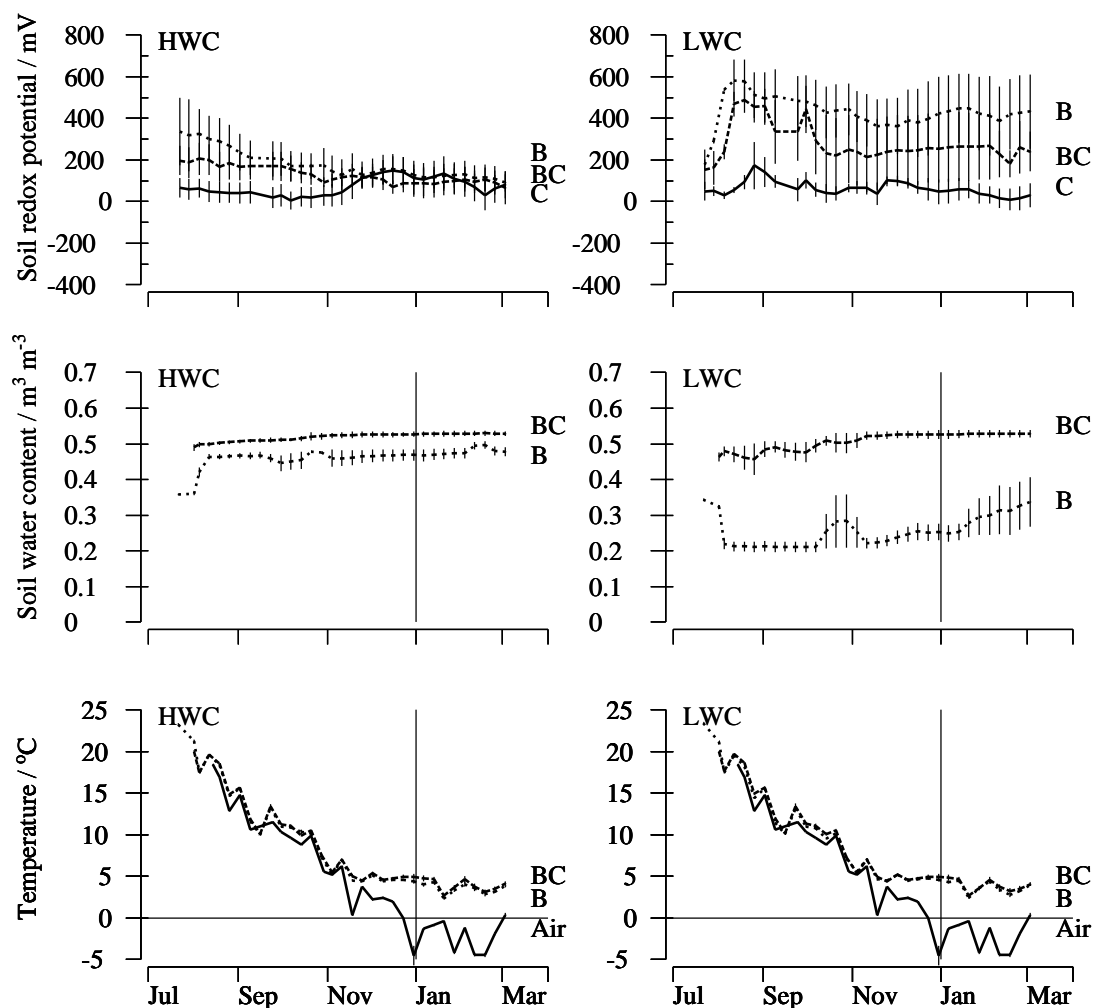


Figure 1. Temporal variation of redox potential and moisture content in the different soil horizons in HWC and LWC in July 2008 - March 2009. The error bars represent standard errors of the mean.

The redox status varied from oxic in the plough layer (Eh c. 500 mV) to reduced in the C horizon (Eh < 300 mV). At the beginning of experiment, all subsoil horizons were reduced. In HWC, the C horizon remained always reduced, and the saturation by water induced reduced conditions also in the horizons B and BC (Figure 1). In LWC, the C horizon remained always reduced, but the BC and B turned oxic within two weeks from treatment start.

The elemental composition of pore water differed between soil horizons but in a given horizon the differences were minor in all lysimeters in the beginning of the experiment. Elevation of water table induced changes in the pore water composition, the variation in the oxidized horizons being high as compared to that in the reduced horizons (Figure 2). The concentrations of Fe and Al responded to the reduction of soil horizons dissimilarly. For instance, in B horizon, the mean concentration of Fe rose up to 188 ± 30 mg/l in the HWC treatment but remained low at 8 ± 4 mg/l in the LWC treatment. On the contrary, the maximum Al concentration was smaller in HWC (7 ± 2 mg/l) than that in LWC (203 ± 92 mg/l).

The timing and volume of water discharge differed between the treatments. In the beginning of the experiment, the volume of discharge water was larger in LWC treatment, probably because of free drainage and preferential flow through the macropores and fractures induced by soil shrinking. The evapotranspiration of reed canary grass exceeded the amount of watering so that during the growing period there was no discharge from HWC treatment. In autumn, the volume of discharge was multiplied. The variation in Fe and Al concentrations was higher in LWC than in HWC (Table 2).

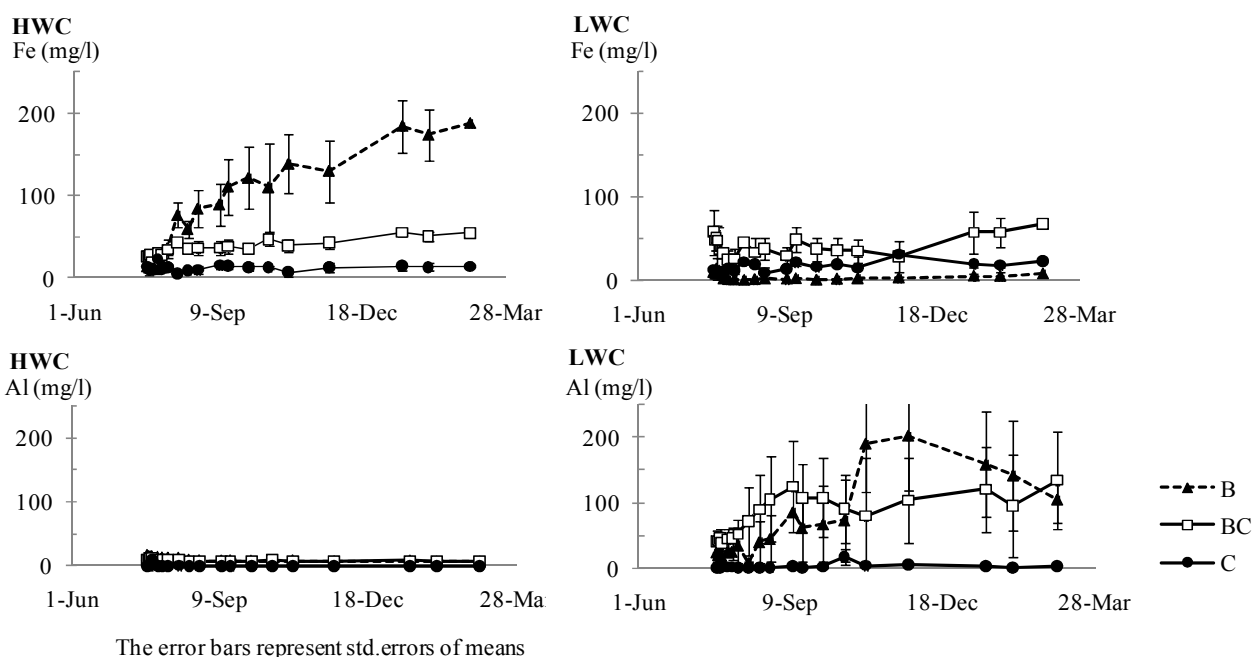


Figure 2. The Fe and Al concentrations in the pore water of soil horizons B, BC and C in HWC and LWC.

Table 2. Total elemental discharge loads and concentrations in the lysimeter experiment in autumn 2008.

	Total load (kg/ha)			Mean concentration (mg/l)		
	HWC	LWC	$F_{(1,6)}$	HWC	LWC	$F_{(1,6)}$
Fe	17.8 ± 7.8	1.0 ± 0.8	4.57 ($p < 0.01$)	39.4 ± 0.4	6.4 ± 0.2	14.7 ($p \approx 0.08$)
Al	2.2 ± 0.8	3.6 ± 1.5	0.70 ($p > 0.40$)	4.9 ± 0.1	22.4 ± 0.6	3.5 ($p > 0.1$)

Treatment effects were tested by F-test (the significance in parenthesis). Replicates $n = 4$. Measurement period 22 Jul – 31 Dec 2008.

Discussion

High water table in a cropped acid sulphate soil induced reduced conditions in saturated soil horizons in the temperature range of $+3 - +20$ °C. The response of Fe and Al concentrations in the pore and discharge waters to the reduction was asymmetric; Fe concentration increased while Al concentration decreased. Although the ferric oxides are very sparingly soluble in water, the microbially catalysed reduction enhanced the dissolution at favourable conditions. The B horizon is rich in ferric oxides and supposedly the roots of reed canary grass at that depth provide easily decomposable organic matter to the microbes. This is the probable reason for the extremely high Fe concentrations in the pore water in the B horizon of HWC. In LWC, the B horizon is very acidic (pH 3.8) resulting to dissolution of Al oxides. This fact accounts for the high Al concentration in the pore water in the B horizon of LWC. In the first 0.5-yr of the experiment, the high Al and Fe concentrations in the discharge water in LWC and HWC, respectively, stem from their high concentrations in B horizon.

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