A lysimeter station for contaminated soil studies

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A lysimeter station has been set up by AMRA for the study of the reactive transport of contaminants in soil at the field-scale. It consists of eight lysimeters that can operate individually and simultaneously. Each lysimeter is a steel cylinder (diameter 1.14m, height 2m) filled with an undisturbed soil monolith, whose upper surface is directly exposed to the external environmental agents. A set of sensors enables the remote monitoring of overall lysimeter weight as well as of temperature, water potential and water content at several soil depths along the soil monolith. Water and gas samples can be obtained for chemical and biological analysis. A programmable hydraulic system is provided to simulate the fluctuations in water-table level. A gas-sparging system is already installed for bioventing applications.

Introduction

Remediation of soil and groundwater contamination by organic chemicals and metals has become an urgent problem. Besides of laboratory studies, real-scale studies are required for the validation of remediation techniques.
The challenge of real scale studies can be better understood by considering the genesis and evolution of soil and groundwater pollution (see for example Newell et al. 1995). The pollution source can consist in a liquid that had been spread accidentally or in a solid waste, leaking liquid pollutants, both directly or under the action of surface waters and rain. Pollutants percolate through soil, simultaneously releasing into the gas-phase volatile components, if any, that can also diffuse back to the atmosphere. Once the capillary fringe has been reached, the water-soluble pollutants are dispersed into the groundwater. The insoluble pollutants either stop or keep carrying on their vertical motion if their density is less or greater than that of water, respectively. In the former instance, a pollutant lens is formed, that floats on top of the groundwater table and follows its seasonal level-variations. In either case, the soluble components are released into the groundwater.
Pollutant percolation, in both its vertical and horizontal components, is dictated by soil morphology. The time-scale of pollutant dispersion falls within an interval bound between days (percolative phenomena) and years (pollutant solubilization into the water table).
External environmental agents such as rainfalls, seasonal and daily variations in ambient temperature, ventilation, biological activity of vegetables, insects, microorganisms, fluctuations in water-table level affect the system dynamics.

Microcosm experiments at lab-scale can only be utilized to assess that biodegradation can actually take place. The lab-scale system cannot replicate the effect of site hydrogeology, local heterogeneity and availability of limiting nutrients. A *mesocosm* experimentation at field-scale is necessary to obtain such information.

Several difficulties arise, however, in dealing with field experimentation. The required mass balances are more difficult to perform in the field. 3D-modeling of system requires the measurement and/or estimation of crucial data such as the vertical distribution of water tension and volumetric fraction, the vertical distribution of the gas-phase composition, the flow-rate of percolating liquid/s, the fluctuations in water-table level, mass variations in the control volume. Last but not least, direct dispersion of pollutants into the soil (in order to simulate a pollution event) is obviously illegal. Indeed, severe limits exist for the introduction of xenobiotics into the environment, even of potentially amending nature, unless their absolute harmlessness has been completely acknowledged.

All these general remarks have been taken into account in defining the layout of the AMRA mesocosm installation hosted by EURECO SpA (Piana di Monte Verna (Caserta)). The technical solution adopted in the AMRA mesocosm is that of a multiple-lysimeter station. It consists in eight units that operate individually and simultaneously.

A *lysimeter* is a device that isolates a volume of soil between the soil surface and a given depth and includes a percolating water sampling system at its bottom. Although originally thought for hydrogeological and agronomical studies, it is increasingly used in the field of environmental protection (see for example Lanthaler (2004) and the online database of European lysimeter installations maintained by the Austrian Lysimeter Research Group).

It consists in a confined system of the same dimension as that of the characteristic scale of the aquifer (meters); it is filled up with unperturbed-soil samples; it is directly exposed to all the external environmental agents. Programmable hydraulic systems are provided to simulate the fluctuations in water-table level, as well a complete set of sensors that enable the continuous monitoring of all the crucial parameters, including the soil sample weight.

The system is confined, thus overall mass balances can be performed; xenobiotics can be freely dispersed into the soil for both the simulation of pollution and the implementation of remediation strategies; phytoremediation can be analyzed, as well, by sowing amending crops onto the exposed surface of the lysimeter.

Technical description

Each lysimeter is a soil-filled steel vessel of 1.14 m in diameter and of 2 m in height (Figure 1).

Soil samples have been collected into each single lysimeter in such a way as to keep the natural texture unperturbed, in terms of local heterogeneities, macrostructure, microstructure.

As of now, four units contain an uncontaminated agricultural soil (from a nearby field) and four an industrial soil that has undergone co-pollution by organics and heavy metals in a dismissed industrial site (ex-ILVA Bagnoli, Napoli).

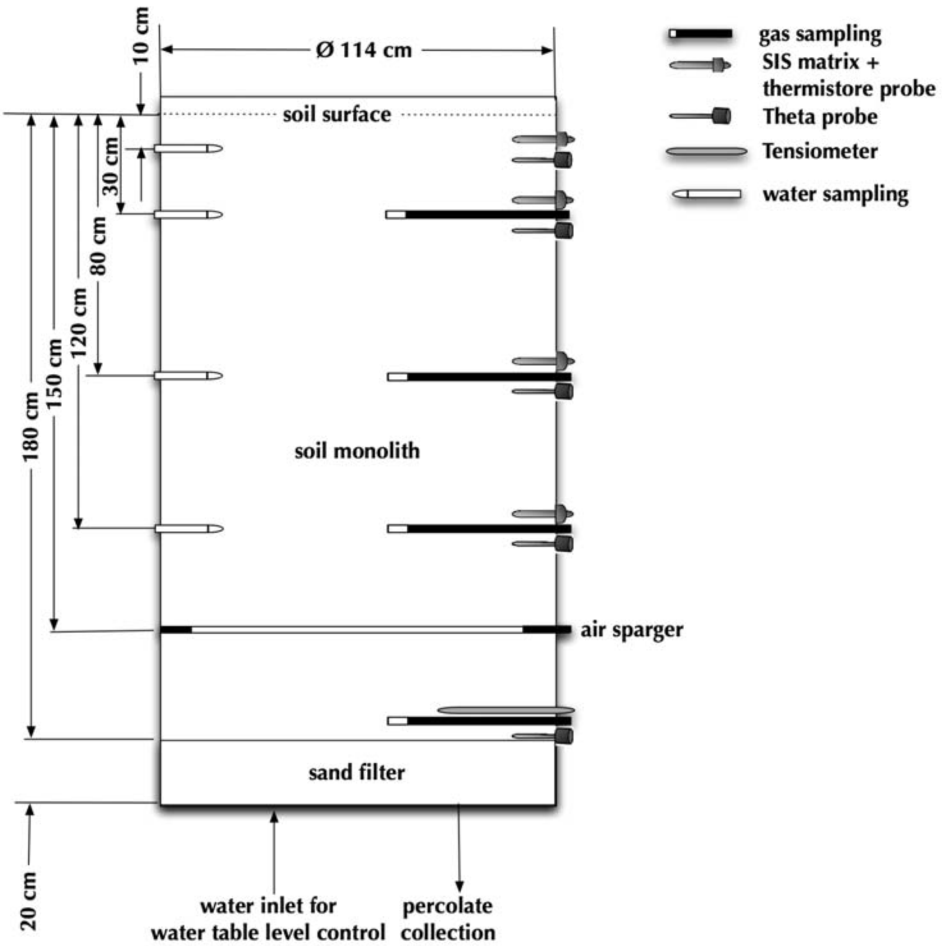

Figure 1. Arrangement of sensors, samplers and air/water injection points in the soil lysimeter

In case specific needs should arise to analyze an individual remediation strategy, the necessary number of lysimeters can be emptied and filled-up again with ad hoc soil samples, drawn from the contaminated site.

The monitoring system

The monitoring system of each lysimeter consists in a set of different probes placed at five depths from the external surface, namely at 10, 30, 80, 120, 180 cm, in order to provide the longitudinal distribution of:

- temperature, measured by thermistor probes;

- water tension, measured by a single ceramic-membrane tensiometer placed at 180cm that enables the measurement of the hydrostatic head, as well and by SIS matrix sensors at the other depths,
- volumetric water fraction, measured by impedance metering Theta probes.

The overall weight of each lysimeter (approximately 3 tons) is monitored continuously by a strain gage, within ±100 g.

All sensors have been installed after the soil sample had been loaded, in order not to disturb the texture of the latter. All sensors are connected to a data acquisition system that enables data storage and conversion into suitable formats. Data can be retrieved by FTP.

Commands can be issued to remote actuators through the on-line connection, to perform programs such as the opening or closing of electro-valves at predetermined times, to simulate a story of water-table level fluctuations.

Sample retrieval

Gas and water samples can be gathered through sampling ports along the depth of each lysimeter. All liquid and gaseous samples are analyzed off-line.

Water is collected under vacuum by porous ceramic suction cups. Interstitial air samples are collected through gas lances for extraction of soil gas, made of stainless steel, outer diameter 8 mm, total length 500 mm, with gas diffusion zone (porous Teflon tube) 50 mm.

Water-table level control system

Each lysimeter has a water-level control system consisting in two electro-valves actuated by the data-logger. The system can be programmed to supply a constant water-level, as well as to follow a complex time-profile. The water-input line is provided with a flow-rate meter.

An exit line is placed at the lysimeter bottom, provide with a remotely-actuated electro-valve and a flow-meter. This enables the simulation of conditions when the water-table level is below that of the lysimeter bottom.

Air sparging

A gas-sparging system is placed at the depth of 150 cm. It consists in a porous steel tube, coated with a porous Teflon membrane. Its length is just less than the vessel inside diameter.

Applications

The soil lysimeter can be used as an experimental tool for the study of pollutant transport and degradation in both soil and groundwater at the field-scale, providing the necessary data for 1D-modeling. Variations undergone by the autochthonous microflora under the effect of contaminant addition can be monitored, as well.

The soil lysimeter can aid the implementation of *in situ* bioremediation techniques, such as bioventing (stimulation of aerobic biodegradation by air injection into the unsaturated zone), air sparging (stimulation of aerobic biodegradation by air injection into the aquifer zone), biostimulation (addition of nutrients in soluble compounds or gases in poor soils), bioaugmentation (addition of adapted microorganisms to carry out degradation of recalcitrant compounds).

References

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