An automatic equilibrium tension microlysimeter system for assessing the environmental impact of cattle slurry

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Abstract

To identify the correct management of cattle slurry, a 3-year plot experiment began in 1999 at Padova University Faculty of Agricultural Sciences Experimental Farm, on silage maize. An equilibrium tension microlysimeter system was set up to measure nitrogen leaching beneath the root zone. The device consists of a series of 16 ceramic plates kept in equilibrium with the surrounding bulk soil. Three pairs of electronic tensiometers placed above and next to each plate control the tension. This paper presents the features of the system and the procedures followed for its installation. The first results and the problems encountered in the setting-up phase are also briefly reported.

Keywords

microlysimeter; nitrate leaching

Introduction

In Italy cattle farms produce 76 million m^3 of slurry annually, containing 357.000 tons of total nitrogen and 82.000 tons of phosphorus (MURST-CNR, 2000). This is an important resource of fertilizers that must be exploited, but that can cause N and salt losses to surface and subsurface waters (e.g. BORIN et al., 1997) if improperly managed. The correct utilization of animal wastes requires, on the one hand, the optimal rate of slurry application to crops to be identified in order to maximise yield responses (BORIN et al., 2000) and, on the other, to assess the possible leaching of pollutants.

Several methods can be used to evaluate the leaching of pollutants to the groundwater, in particular nitrates. Ceramic cups are frequently used in plots and the open field (WEBSTER et al., 1993). They are relatively simple to install, with minimal soil disturbance during the subsequent sampling (LORD and SHEPERD, 1993). Their use in structured soils may be critical due to the possible occurrence of preferential flow, which could bypass porous cup samplers. These devices are also unable to measure drainage volumes, so it is necessary to estimate these with other approaches to evaluate the leaching rate (e.g. mathematical model).

Based on the same operative criteria, ceramic plates offer the advantage of collecting bigger samples of water, reducing the risk of preferential flow, and allowing the direct measurement of the amount of percolation.

To ensure that the water collected is a true measure of water percolating through the soil overhanging the plate, two solutions may be adopted: a) extending side walls above the porous plate (e.g. CEPUDER et al., 1992); b) keeping the plate in equilibrium with the surrounding bulk soil, controlling the tension by a pair of tension sensors placed above and next to the plate (equilibrium tension lysimeter) (e.g. BRYE et al., 1999). The first solution, although simpler to realize, may promote preferential flow down the side of the soil column upon drying and disturb lateral water movement.

To contribute towards identifying the correct management of cattle slurry, a 3-year plot experiment was set up in 1999 at Padova University Faculty of Agricultural Sciences Experimental Farm, on silage maize. In this experiment, an automatic equilibrium tension microlysimeter (ETMl) system was designed and installed to evaluate nitrate losses. In this paper, the features of the system and the first results on its functioning are presented.

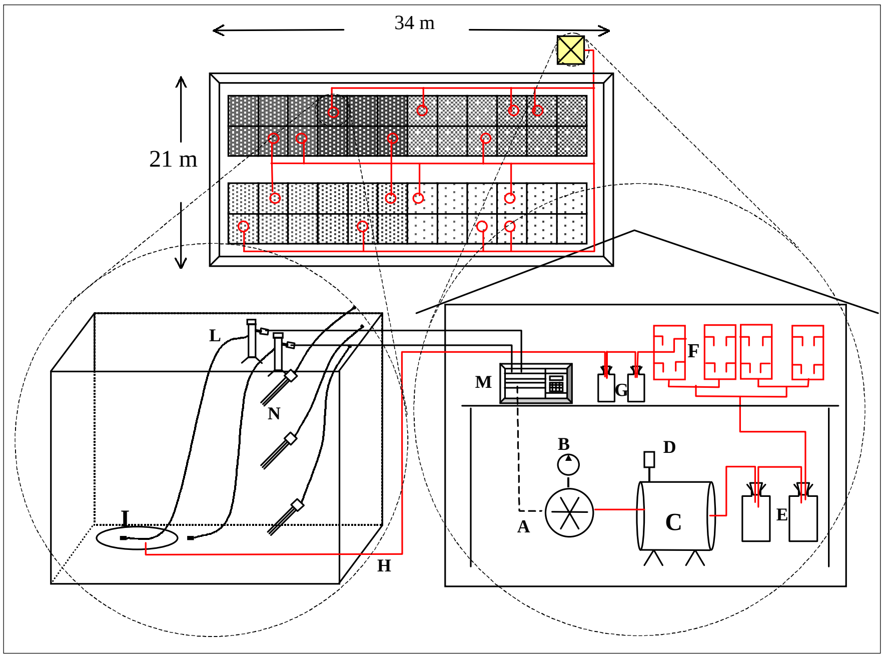

Figure 1: **Schematic diagram of the ETMl system. A) pump generating vacuum; B) vacuum gauge C) vacuum tank D) vacuum switches E) bottles for overflows F) panel for vacuum distribution G) sampling bottles H) Rilsan plastic pipes I) tension plate L) electronics tensiometers M) datalogger N) single-diode TDR probes**

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The experiment

ETMls were installed inside 16 growth boxes belonging to an experiment conducted on 48 plots (2 x 4 m sided) at field level and as many buried boxes (2 x 2 m sided) raised 1.3 meters above field level. The bottom of the box is open, to allow the water percolation. The experiment is a factorial combination of two types of fertilization (mineral and organic cattle slurry), four nitrogen rates (0, 112, 226, 340 kg/ha) and two water table depths. The experimental design is a split-plot without replications. ETMls were installed in the raised boxes to reduce disturbance to the water table that is very shallow during winter. The soil is loam (bulk density 1.3 t m^{-3}) with the following mean hydrologic characteristics: field capacity (10 KPa) = 32 % vol., wilting point (1500 KPa) = 8 % vol., saturated hydraulic conductivity higher then 1 m d^{-1}.

The ETMl monitoring system

The ETMl system is composed of peripheral and central components (*Figure 1*).

Peripheral components:

- 16 porous ceramic plates (Ø 27 cm), with air-entry suction of 50 kPa, and saturated hydraulic conductivity of 1.25 10^{-5} cm/s;
- 3 pairs of electronic tensiometers placed just above the same number of ceramic plates and in the adjacent bulk soil (it is planned to increase the number of tensiometers). At the beginning of the experiment 3 couples of mercury tensiometers were used;
- 16 Rilsan plastic pipes (internal diameter of 2 mm) for the conduction of the vacuum and for the collection of water samples;
- 48 one-diode probes (TDR MP-917, ESI) at three different layers to measure soil moisture. The probes, with wave guides 30 cm long, were inserted with a slope of 45 degrees; the soil moisture was measured ones a week.

Central components (*Figure 3A*):

- 1 electric vacuum pump (power 0.37 KW) provided with one mechanical vacuum gauge. The pump is connected to a tank (50 l), provided with two pressure switches that allow the regulation of minimum and maximum thresholds;
- 1 pair of 5-l bottles to collect overflows;
- 16 pairs of 1-l bottles for collecting samples; each pair is connected to one ceramic plate by a plastic pipe;
- 1 panel to control distribution of the vacuum; each ceramic plate is handled separately by means of a valve;
- 1 datalogger (CR7, Campbell Scientific) to record the tensiometer data and to automate (in the near future) the system, allowing the pump activation.

Installation and management of the ETMl monitoring system

The 16 ETMls were buried in spring 2000 at a depth of 90 cm, by digging a square hole (70 cm sides), 100 cm deep. During the digging the soil was divided into three depth horizons (0-20, 20-50, 50-90 cm).

The ceramic plates were placed at a depth of 90 cm because the majority of the maize roots extend 80 cm down into the soil of the experimental site. At one side of the hole, at a depth of 90 cm, a small cavity was excavated, approximately 30 cm wide by 5 cm tall by 40 cm deep. To ensure continuity between the soil and the ceramic plate, the cavity was completely filled with soil slurry, as suggested by BRYE et al. (1999), and the plate was inserted horizontally into the cavity, forcing the excess soil slurry out (*Figure 3B* and *C*). Each plate was then connected to a Rilsan plastic pipe and the holes were filled with soil, retaining the original profile. The pipes were buried inside a protective PVC tube. Due to the fact that late in the season the soil water potential could be negative and in

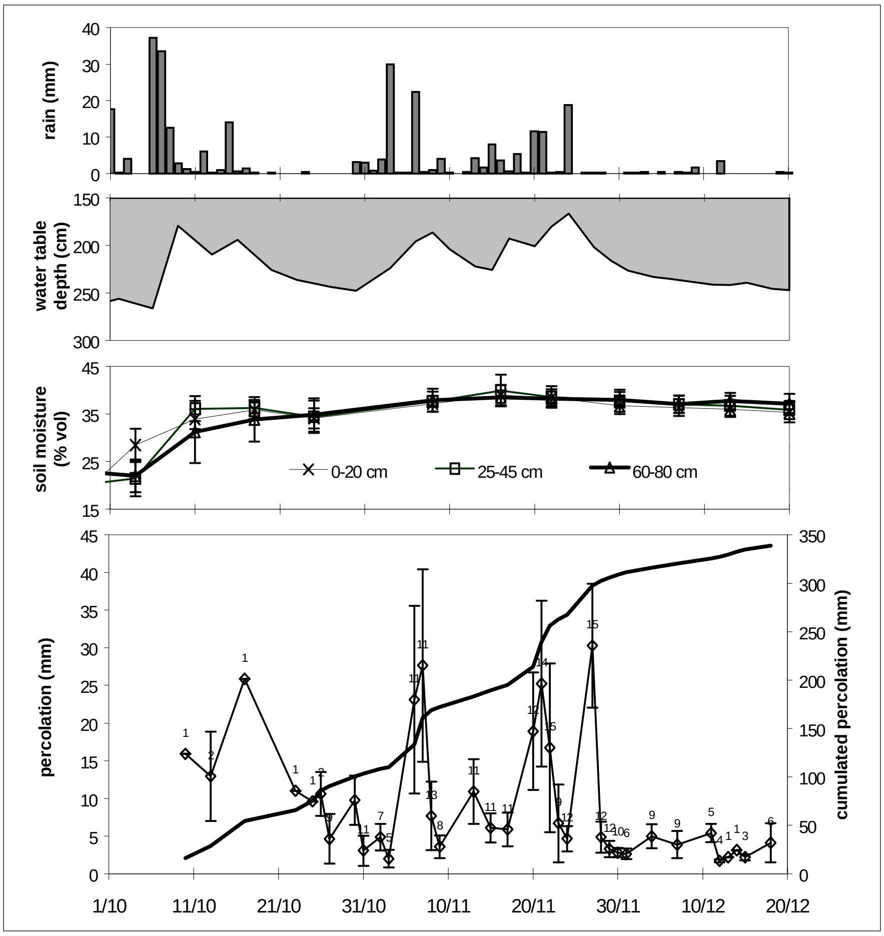

Figure 2: **Rainfall, water table depth, mean volumetric soil moisture and percolation (single values and cumulated values), observed during the first monitoring period. The vertical bars represent the standard deviation. Above the dots are reported the number of ceramic plates sampling the percolation event.**

Figure 3 A): **central components;** *B* and *C):* **installation of the ceramic plate (particulars)**

some instances could exceed the air-entry potential of the porous plate, it must be rewet from the inside out to re-establish hydraulic conductivity with the soil above. For this reason a valve connection was made just above the growth boxes allowing the ETMl to be rewet by siphoning water from a container at the surface into the sampling tube.

The activity of the pump is regulated according to matrix potential measured by the three pairs of tensiometers. The applied vacuum is adjusted manually (4-30 KPa) to equilibrate the tension between the ETMl and the surrounding bulk soil, avoiding the occurrence of pounding and consequent lateral movement.

First observations

The system has been operating since October 2000. *Figure 2* reports the rainfall, water table depth and average soil moisture content measured during the first months of monitoring.

This period was characterized by exceptionally high rainfall falling on bare soil (*Figure 2*) following a period of relatively dry weather. The water table fluctuated widely because of this rainfall. The volumetric soil content increased from 20-22 % at the beginning of October to a maximum of 36% on November 16th, then the values slowly decreased in the different layers until equilibrium was reached with the water table level.

Water samples were collected each day during the percolation periods. The time pattern of the average percolation depths with standard deviation bars is also reported in *Figure 2*.

Wide variability in terms of volumes and sampling times has been observed among the ceramic plates. The coefficient of variation ranged from 10 to 80%: the low values being observed during a period of low drainage.

This variability is probably partly due to

a) the natural variability of the soil hydrological behaviour, enhanced by the installation operations;

b) the different initial soil conditions;

c) the difficulties in correctly regulating the suction because of problems of leaking encountered during the setting-up phase of the system.

We expect to reduce the variability in the future with better control of the suction, also obtained by increasing the number of tensiometers.

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