Nitrate leaching losses following cattle slurry and mineral fertiliser applications

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Summary

To identify the correct management of cattle slurry as a fertiliser, in comparison with mineral fertilisers, a plot experiment began in 1999 at Padova University Faculty of Agricultural Sciences Experimental Farm, on silage maize. An original equilibrium tension microlysimeter system was designed and 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 beside each plate control the tension and automatically activate a pump that allows the collection of percolation water samples. This paper presents the preliminary results obtained with the system during the period October 2000- October 2002. Examples of system management and reliability are given, together with the assessment of N losses under different rates and sources of N applied to silage maize.

Introduction

In Italy, an annual production of 76 million m³ of animal slurry makes 357,000 tons of total nitrogen and 82,000 tons of phosphorus available (SANGIORGI, 2000), which must be exploited as fertilisers. However, if improperly managed, slurries can cause N losses to surface and subsurface waters (e.g. BORIN et al., 1997). Incorrect fertilisations promoting N leaching are often more common with the application of slurries than with mineral fertilisers because the former have more variable composition and may require to be spread on the fields during periods of lower crop requirements.

This paper presents the results on N leaching losses measured in a three-year plot experiment, with the aim of comparing two sources of N (chemical fertilisers and cattle slurry) at increasing N inputs as regards crop response and environmental impact.

Materials and Methods

A plot experiment began in 1999 at Padova University Faculty of Agricultural Sciences Experimental Farm. It was conducted in 48 field plots and the same number of 1.3 m tall open-based growth boxes (2x2m sided) placed on the soil surface. In this way, we aimed to limit the influence of water table on soil moisture content in the upper layers. During 2000 the experiment was a factorial combination of two types of fertilisation (mineral, M and organic cattle slurry, S), four nitrogen rates (0, M1 = 113, M2 = 226 and M3 = 340 kg/ha) and two water table depths (the normal one at the experimental site and that obtained in the growth boxes). In 2001 and 2002 the plots of one of the two controls were treated with 680 kg/ha of nitrogen (half from cattle slurry and half from mineral fertilisers). For each N rate, mineral fertilisation (urea) was applied twice, half rate immediately before sowing and half when plants were about 0.5 m tall. Theoretically, the same management was planned for N from slurry, so that the total amount of N would be the same in M1 and S1, in M2 and S2, in M3 and S3. However, the variable composition of the slurry used for the different fertilisations (total N concentration ranging from 0.14% to 0.47% on fresh matter) did not allow the N input at each application to be calibrated exactly. In fact, at the time of slurry application, its N concentration was unknown and the amount of slurry to be applied was decided on the basis of an average N concentration. Once the analytical data on the real N concentration were available, adjustments to fertilisation were made if required, applying more (or less) slurry at the successive distribution. Nevertheless, differences still existed between the desired and actual rate of applied N (*table 1*).

Table 1: **N fertilisation levels (Kg ha^{-1} year^{-1}) applied to different treatments**

Check		0	
M1	113	S1	137
M2	226	S2	275
M3	339	S3	413
M3+S3		790	

The plots were cultivated with maize, harvested to make silage.

The soil is loam with the main hydrological characteristics reported in *table 2*.

Nitrate leaching losses are measured using an automatic equilibrium tension microlysimeter system (ETML; MORARI et al., 2001) operative since October 2000, in 16 of the 48 growing boxes. Sixteen porous ceramic plates (∅ 27 cm) were buried at a depth of 90 cm in the boxes, preserving the vertical profile of the soil, and were connected with a va-

Table 2: **Main hydraulic properties of the soil layers**

	Layer 1	Layer 2	Layer 3
Depth (cm)	0-15	30-35	65-70
Bulk density (g/cm³)	1.39	1.53	1.61
Saturated hydraulic conductivity (cm/s)	$6.6\ 10^{-4}$	$2.8\ 10^{-4}$	$3.1\ 10^{-5}$
Soil water content at 0 KPa (mm/mm)	50.3	43.0	42.0
Soil water content at -10 KPa (mm/mm)	33.5	32.3	33.5
Soil water content at -30 KPa (mm/mm)	30.4	29.4	31.2
Soil water content at -1500 KPa (mm/mm)	14.0	15.2	16.5

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cuum pump to create the suction necessary to sample the percolating waters.

The suction was regulated according to the matrix soil potential measured with three pairs of electronic tensiometers (in an initial phase we used mercury tensiometers). The tensiometers of each couple were placed one just above the ceramic plate and one 1 m from the plate, at the same depth. The soil water tension was monitored continuously: when the difference between average tension outside the plates (external) and above the plates (internal) was higher than 5 hPa (5 cm of water column), the pump automatically started and applied vacuum for one minute. This way, we aimed to equilibrate the tension between the ETML and the surrounding bulk soil, avoiding the occurrence of ponding and consequent lateral movement. At the same time, we avoided applying excessive tension over the plates. Soil moisture was measured twice weekly in the same boxes by 48 one-diode probes (TDR MP-917 ESI) at three different depths (0-20, 25-45, 60-80 cm).

Samples were collected in two bottles (1 L each) for every plate and were immediately frozen until analysis. NO_3-N was determined by the salicylic acid method and spectrophotometer analysis (CATALDO et al., 1975). A total of 1161 samples were collected and analysed.

The climate of the site can be defined as sub-humid, with annual rainfall of about 825 mm distributed with an absolute peak (slightly more than 100 mm) in June, a relative peak in October (about 90 mm) and minima in December-February (50-60 mm per month). Temperature increases from January (average of minima: -1.2 °C) to July-August (average of maxima: 28.3 °C), for an average annual value of 12.5 °C.

Results

Functioning of ETML system. The system automation performed well, with a regular activation of the pump every time the tension difference threshold was reached. As an example, we present the behaviour during a period of frequent rainfall (spring 2002) (*figure 1*). The water tension was very low, ranging from 0 to 25 hPa both above the ceramic plates and beside them, due to downward

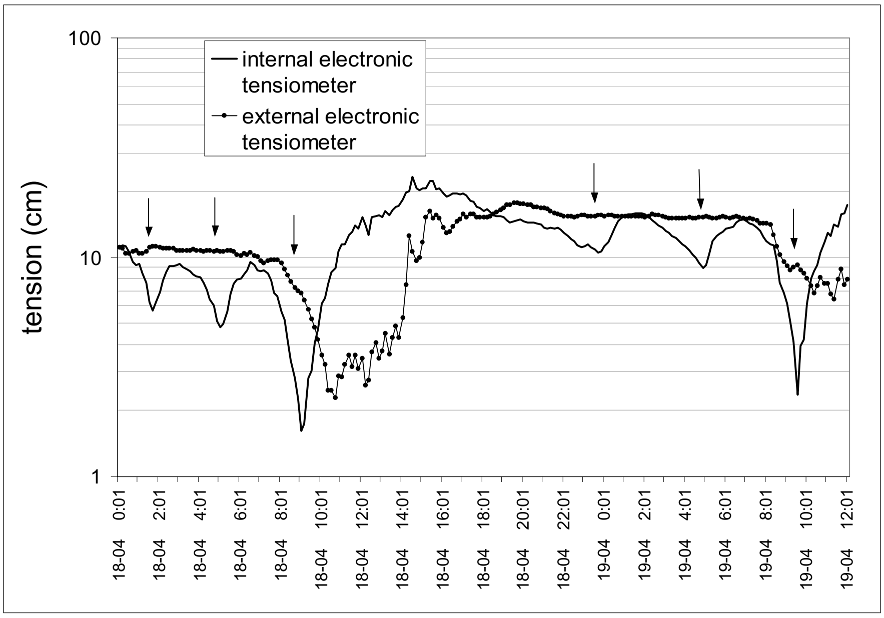

Figure 1: **Example of automated activation of the vacuum pump according to soil potential measured above and beside the ceramic plates**

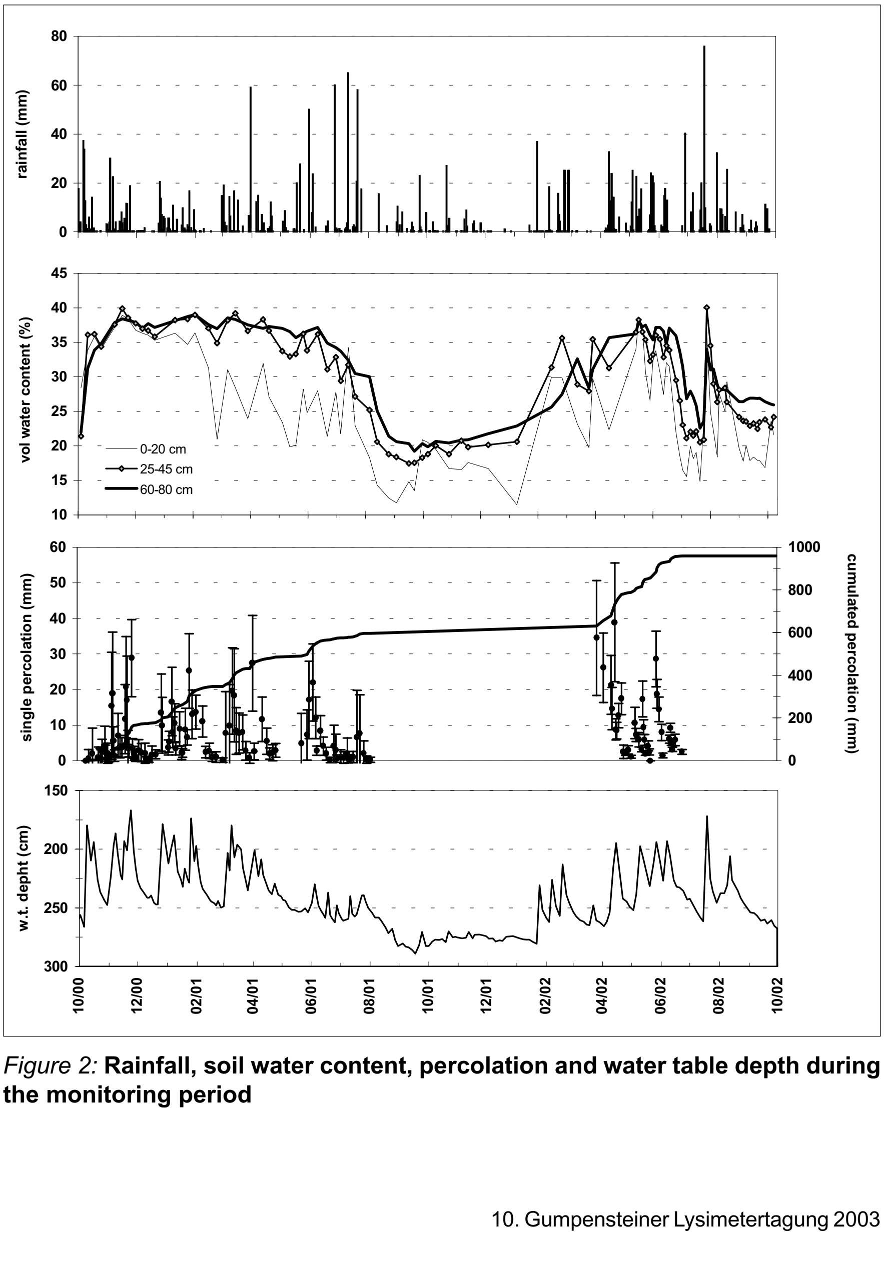

Figure 2: **Rainfall, soil water content, percolation and water table depth during the monitoring period**

movement of water. The pump activated frequently (six times in 36 hours) and after its activation the tension above the ceramic plate increased and the difference between external and internal tension disappeared in about two hours.

Water balance and soil moisture: after the ETML system became operative, a long period of exceptionally high rainfall occurred (*figure 2*). Spring and summer 2001 were quite dry, and during the maize growing cycle, soil moisture was influenced by abundant irrigations, which were applied both to favour maize growth and to stimulate percolation through the soil to continue system testing. Autumn-winter 2001-2002 was very dry, followed by a very rainy spring-summer 2002. Rainfall-irrigation regime strongly influenced soil moisture and water percolation. As expected, the surface layer showed the higher time variability of moisture content. At depths of 0.25-0.45 and 0.45-0.80 m, soil moisture remained steadily above 35% (tension less than 10 hPa) from October '00 to early summer '01, then decreased to about 20% and then returned to being higher than 35% in spring 2002 (*figure 2*). Percolation was detected on a total of 125 days. Most of the events were in the order of magnitude of a few mm of water, but in some cases 30-40 mm of daily percolation were measured. Wide variability was observed in the percolation volumes collected at the same time, probably as a consequence of preferential flow and heterogeneity of soil hydraulic properties. At the end of the period, the total water input (rainfall + irrigation) was 2048 mm and cumulative percolation was 959 mm. As a consequence, the water table depth fluctuated during the period from 1.6 to 2.8 m below the surface of the vegetation boxes. It was hence at least 0.9 m deeper than the level of the ceramic plates (*figure 2*).

NO_3-N concentration and losses. Taking all the water samples collected in each treatment, the concentration of NO_3-N was influenced by rate and source of N. It seemed that, at a similar application rate, mineral N fertilisation induced higher NO_3-N concentrations in percolation water than slurry fertilisation (*figure 3*). A time pattern of percolation losses has been constructed for each treatment and the cumulative loss has been calculated. The situation recorded in treatment 3M is reported as an example in *figure 4*. At the end of the two-year monitoring, total nitric nitrogen losses varied from about 70 Kg ha^{-1} in the control to 230 Kg ha^{-1} in the plot receiving 340 Kg ha^{-1} year^{-1} of mineral N (*figure 5*). Referring to similar N inputs, percolation losses were lower with slurry than with mineral fertiliser. Losses ranged from 30 to 23% of N applied in the first case, and from 19 to 8% in the second. In the treatment receiving the higher total amount of N (on average 790 Kg ha^{-1} year^{-1}, 340 of which from mineral fertiliser), percolation losses were slightly higher than 10% of the amount applied. These results are partial, because they refer to a monitoring period lasting until October 2002 and do not consider the autumn-spring phase, which is the most crucial for originating percolation. A precise N balance will be drawn up at the end of the experiment, planned for March 2003.

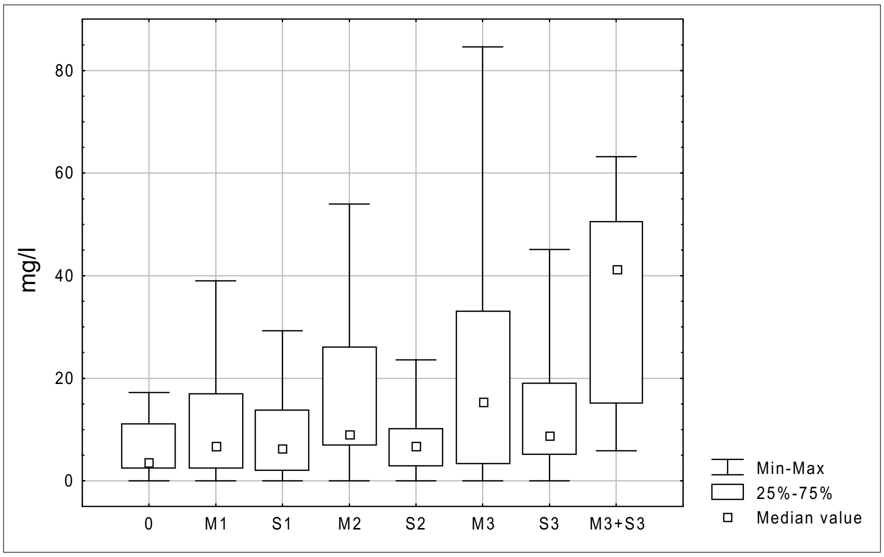

Figure 3: **Box and whiskers of NO_3-N concentration in the percolation water in the different treatments**

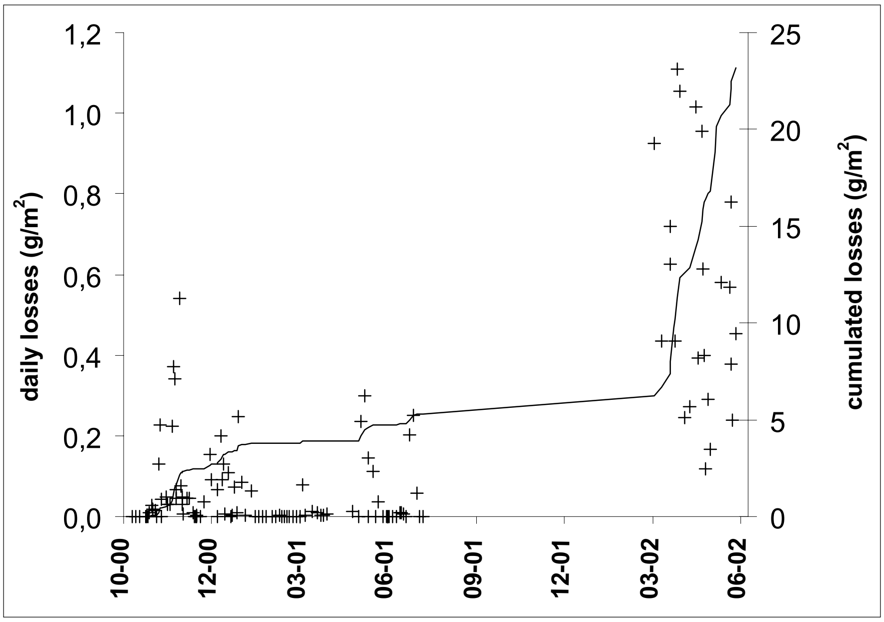

Figure 4: **Example of NO_3-N leaching losses detected during the monitoring: case of treatment M3**

Conclusions

The experiment demonstrated the great potential of the ETML system to study water and nitric nitrogen movement

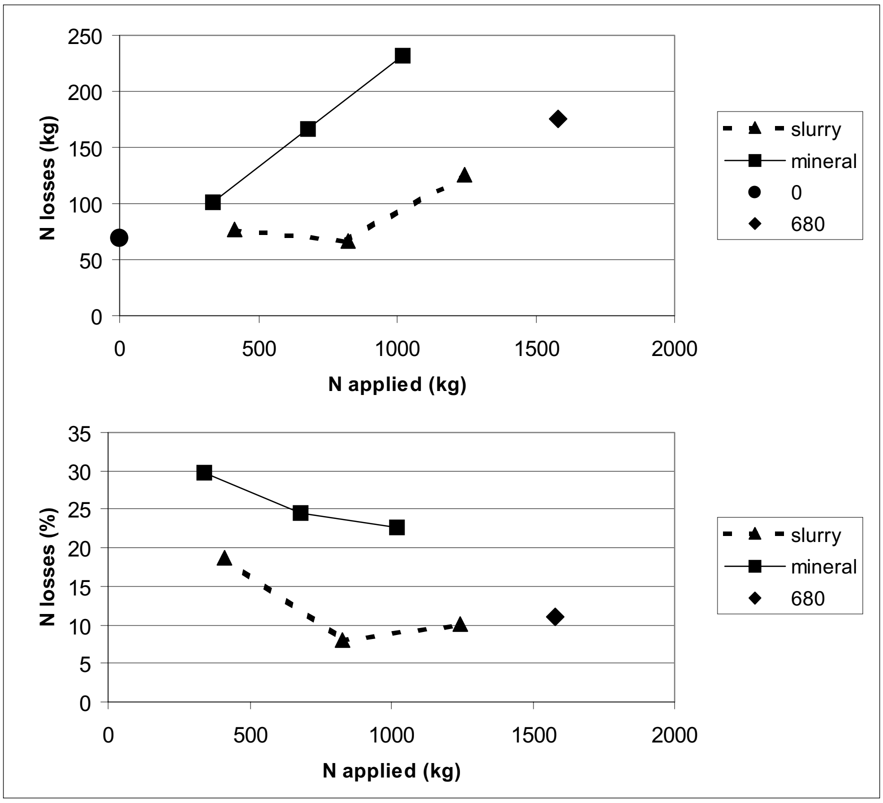

Figure 5: **Cumulative losses (above) and % losses (below) at the end of the period in relation to total applied N**

through the soil profile in detail. Its automation allowed the percolation to be measured and sampled very frequently, which is very important to identify pulses of N releases. Its good functioning was very useful for comparing the effects of rates and sources of N on percolation water quality and losses of the element. The analysis of the preliminary results reported in this paper suggests that N losses can be very different according N fertilisation management. In this sense, these preliminary data suggest that the use of bovine slurries as a source of N appears preferable to mineral fertilisers in terms of reduction of losses in the short term and with the same application time. This knowledge is strategic for implementing fertilisation programmes that aim to combine the objectives of satisfactory yield and respect for water resources.

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