Estimating the flux of nitrate in a sandy loam soil under corn

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Abstract

Drainage and nitrate leaching were determined in an undisturbed sandy loam soil contained in two monolith lysimeters (L1 and L2; 1.2 m deep) cropped with corn, irrigated, and fertilized with 510 and 175 kg N ha⁻¹ in L1 and L2 respectively. Drainage was estimated at 0.9 m depth using Darcy's law and the hydraulic conductivity-soil water content relationship. Nitrate leaching at the same depth was obtained multiplying the estimated drainage by the nitrate concentration of the soil solution extracted with suction cups. A comparison between results from measurements at the bottom of lysimeters and that estimated at 0.9 m depth was made for the whole experimental period (March 1992–February 1993). The NO₃-N concentrations in the drainage water ranged between 2.8 and 151 mg l⁻¹ in L1 and between 0.1 and 34.4 mg l⁻¹ in L2. In the soil solution, they ranged between 5.9 and 240.3 mg NO₃-N l⁻¹ in L1 and between 0.1 and 42.3 mg NO₃-N l⁻¹ in L2. The total drainage at the bottom of lysimeters amounted to 139 and 203 mm and that estimated at 0.9 m depth amounted to 151 and 245 mm, in L1 and L2 respectively. Total NO₃-N leached in L1 and L2 was 80 and 30 kg ha⁻¹ respectively. The estimated amounts of NO₃-N leached below 0.9 depth were 64 and 42 Kg ha⁻¹ in L1 and L2 respectively. Total drainage and nitrate leached measured at the bottom were of the same order as the estimated values.

Introduction

In southern Spain, nitrogen management to increase crop yields usually involves high rates of N-fertilizer inputs. The use of N-fertilization rates that exceed the N requirements of crops increases the amounts of potentially leachable nitrate in the soil, and consequently a considerable amount of N-fertilizer can be lost from the soil (Roth and Fox, 1990). The NO₃-N leached below the root zone is one of the major pollutants of the groundwater. In large areas leaching of nitrate from agricultural land is the main no-point source for nitrate in groundwater (Duynisveld *et al.*, 1988; Cabrera *et al.*, 1994).

Jolley & Pierre (1977) sampled long-term corn fertility plots and found that 25 to 46% of the applied N fertilizer was lost from the soil after the third year of application. Losses of NO₃-N increase as N fertilizer rate or amount of subsurface drainage increase (Baker and Timmons, 1994; Fernández-Boy *et al.*, 1994).

Measurement of nitrate losses under field conditions is difficult. For both direct measurement and estimation of nitrate losses, at a depth below the root

zone, the water flux draining from the upper layers and the nitrate concentration of this water must be known. Good approaches are (i) the use of monolith lysimeter containing undisturbed soil (Dowdell *et al.*, 1984; Owens, 1990; Bergström and Johansson, 1991) in which direct measurement of drainage water and its nitrate concentration is possible; (ii) the water flow, at a determinate depth in the soil, can be estimated using Darcy's law and the relationship between the soil hydraulic conductivity (K) and the soil water content (θ) determined *in situ*, and the concentration of nitrate can be determined in the soil solution extracted with suction cups. In both cases, the amount of nitrate leached can be calculated multiplying the amount of drainage water by the concentration of nitrate in this water.

The objective of this study was to determine the nitrate leached under a cropped soil using undisturbed monolith lysimeters. A comparison was also made between the nitrate leached in the drainage water at the bottom of the lysimeter and that estimated below 0.9 m depth.

Fig. 1. Rainfall and irrigation during the experiment period

Materials and methods

The experiment on $\text{NO}_3\text{-N}$ leaching was conducted from March 1992 until February 1993 in two lysimeters in the Experimental Farm "La Hampa" of the Instituto de Recursos Naturales y Agrobiología de Sevilla (CSIC) in Coria del Rio (province of Seville, SW Spain). The soil of the lysimeters is a sandy loam (Xerochrept; $\text{pH}(\text{H}_2\text{O})$ 7.2 and 7.1; CaCO_3 5.2 and 3.1%; OM 0.88 and 0.69%; Kjeldahl-N 599 and 454 kg ha^{-1} ; $\text{NO}_3\text{-N}$ 44 and 61 kg ha^{-1} ; at 0–0.5 and 0.5–1.0 m depth respectively).

Two monolith lysimeters (L1 and L2, 1 m in diameter and 1.5 m deep) were installed *in situ* without disturbing the soil profile. The lysimeters were provided with a system to collect the drainage water at 1.2 m depth, an access tube for the neutron probe, two tensiometers at 0.7 and 0.9 m depth, and a suction cup at 0.9 m depth. They were sown with corn (*Zea mays* L., cv. PRISMA (G-4730)) on 24th March 1992 with a density of 75,000 plant ha^{-1} . The corn was irrigated following the same schedule as the surrounding plots – also cropped with corn. Dates and quantity of irrigation and rainfall are shown in Fig. 1. The total amount of water applied by irrigation was 661 mm. Rainfall was monitored throughout the experimental period (total rainfall 394.5 mm). The characteristics of the irrigation water were: E.C. 2.2 dS m^{-1} ; $\text{NO}_3\text{-N}$ 9.8 mg l^{-1} ; Cl 446.6 mg l^{-1} ; $\text{SO}_4\text{-S}$ 44.7 mg l^{-1} .

Two different fertilizations were used. L1 received one of the highest N-fertilization rates used by farmers of SW Andalucia: a deep fertilization with 1000 kg ha^{-1} of 15-15-15 complex NPK fertilizer and two top

dressings with 400 kg ha^{-1} of urea (46% N), equivalent to ca. 510 kg N ha^{-1} . The fertilization applied to L2 was one third of that applied to L1: a deep fertilization with 340 kg ha^{-1} of complex NPK fertilizer and two top dressing with 130 kg ha^{-1} of urea (ca. 170 kg N ha^{-1}).

Soil water content was measured periodically with a neutron probe and soil solution was extracted by suction cups and analysed for nitrate content by ionic chromatography using a solution of 0.0013 M borate–0.0013 M gluconate in acetonitrile (12% v/v) at pH 8.5 as eluent (Waters Ion Chromatography Cookbook, 1989). In addition, leachates were collected and volumes measured following each rain or irrigation event when they were sufficient to create a leaching. Nitrate was also analysed in drainage water.

Water flow, at 0.9 m depth in the lysimeter, was estimated using Darcy's law, and the hydraulic conductivity(K)–soil water content(θ) relationships determined *in situ* (Cayuela *et al.*, 1994).

Results and discussion

The concentrations of nitrate in the drainage water collected at the bottom of the lysimeters (1.2 m depth) ranged between 2.8 and 151 mg l^{-1} in L1, and between 0.1 and 34.4 mg l^{-1} in L2. These concentrations were sometimes much higher than the maximum admissible concentration allowed by the EC for drinking water – 11.3 $\text{mg NO}_3\text{-N l}^{-1}$ (Council of the European Community, 1980). The cumulative drainage water and the cumulative $\text{NO}_3\text{-N}$ leached during the experimental

Table 1. Cumulative drainage water and nitrate leaching measured at the bottom of the lysimeter (at 1.2 m depth) and estimated at 0.9 m depth.

Period	drained water mm				NO ₃ -N losses Kg ha ⁻¹			
	measured 1.2 m		estimated 0.9 m		measured 1.2 m		estimated 0.9 m	
	L1	L2	L1	L2	L1	L2	L1	L2
Crop season	131	137	125	175	77	26	47	35
Dry season	—	11	—	—	—	0.1	—	—
Rainy season	8	55	26	70	3	4	17	7
TOTAL	139	203	151	245	80	30	64	42

Fig. 2. Cumulative drained water and nitrate losses measured at the bottom of the lysimeters

period, in both lysimeters, are shown in Fig. 2. Three seasons can be distinguished during the experimental period, in the same way as has been reported by

Cabrera *et al.* (1994) in previous experiments in the same lysimeters: i) 'Crop season' (10 March 1992–11 August 1992); ii) 'Dry season' (11 August 1992–15 September 1992); iii) 'Rainy season' (15 September 1992–21 February 1993) in which the soil was bare. During the 'crop season' the lysimeters received a total of 661 mm of water by irrigation and 181 mm by rainfall. In this season the total water drainage was 131 mm and 137 mm in L1 and L2 respectively (Table 1), and the total NO₃-N leached was 77 and 26 kg ha⁻¹ in L1 and L2 respectively. The considerable nitrate leaching observed during the early growth period in the crop season (Fig. 2) was due to the rainfall (90 mm) when the soil was wet from previous irrigations. During the 'dry season' there was practically no drainage, and consequently no leaching of NO₃-N was observed in L1, and only a very small quantity (0.1 kg ha⁻¹) in L2 (Table 1).

During the 'rainy season', in which the lysimeters received 213 mm of rainfall, the water drainage was 8 and 55 mm in L1 and L2 respectively (Table 1). The NO₃-N leached was 3 and 4 kg ha⁻¹ in L1 and L2 respectively. The drainage observed in L1 was lower than in L2 due to the fact that at the end of the dry season the soil water content in the deepest layer (0.9–1.2 m depth) of L1 was much lower than in L2; thus the hydraulic conductivity was much lower in this layer of L1 than in the same one in L2, as has been shown by Cayuela *et al.* (1994) for the K(θ) function for this soil. Even though the drainage was different in the two lysimeters, the NO₃-N leached was practically the same, due to the higher NO₃-N concentrations in the drainage water in L1 than in L2.

The total drainage during the whole period was 139 and 203 mm in L1 and L2 respectively (Table 1), and

Fig. 3. Cumulative drained water and nitrate losses estimated at 0.9 m depth

the total $\text{NO}_3\text{-N}$ leached was 80 and 30 kg ha^{-1} in L1 and L2 respectively.

Nitrate concentrations in the soil solution at 0.9 m depth were always higher in L1 than in L2. These concentrations ranged between 5.9 and 240.3 $\text{mg NO}_3\text{-N l}^{-1}$ in L1, and between 0.1 and 42.3 $\text{mg NO}_3\text{-N l}^{-1}$ in L2. The cumulative drainage and $\text{NO}_3\text{-N}$ leached below 0.9 m depth are shown in Fig. 3. These results show similar patterns to those obtained at the bottom of the lysimeters (Fig. 2).

Considering the same three seasons mentioned above, the drainage estimated at 0.9 m depth during the 'crop season' amounted to 137 mm and 175 mm in L1 and L2 respectively (Table 1). In the case of L1 the estimated drainage is practically the same as that measured at the bottom of the lysimeter. In contrast, for L2 the estimated drainage was higher than that measured at the bottom. The $\text{NO}_3\text{-N}$ leached esti-

mated from the water flow and the concentration of the soil solution amounted to 47 and 35 kg ha^{-1} in L1 and L2 respectively. In the case of L1 the estimated value is much lower than that measured at the bottom. This may be due to the leaching of the residual $\text{NO}_3\text{-N}$ from the fertilization of the previous year (Cabrera *et al.*, 1993) in the deepest layer (0.9–1.2 m depth). During the autumn–winter period of 1991–1992 the rainfall was very low and the observed drainage was also very low. This did not occur in L2 because no fertilization was applied to this lysimeter in the previous year.

During the 'dry season', drainage and $\text{NO}_3\text{-N}$ leaching were not observed at 0.9 m depth, which agrees with the results at the bottom of the lysimeters (Table 1). In the case of the 'rainy season' the estimated drainage (Table 1) followed the same pattern as at the bottom of the lysimeters, but with higher values in both lysimeters.

Conclusions

The results obtained in this study show that in an irrigated corn crop, in SW Spain, a strong reduction in the N-fertilization rate used by farmers produces a considerable decrease in nitrate leaching. The volumes of drainage water measured at the bottom of the lysimeters (1.2 m depth) are of the same order as those estimated at 0.9 m depth using Darcy's law and the hydraulic conductivity–soil water content relationship. In both lysimeters the amount of nitrate leached at the bottom of the lysimeters agrees with the estimated amount of nitrate leached below 0.9 m depth.

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