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SHORT COMMUNICATION

Nitrate Leaching in an Argiudoll Cultivated with Sugarcane

R. de los A. Portocarrero · M. M. Acreche

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Abstract The aim of the study was to quantify nitrate leaching from an Aquic Argiudoll cultivated with sugarcane in Tucumán, Argentina. Two field trials were conducted during the 2010/2011 and 2011/2012 seasons with the variety LCP 85-384. Treatments consisted of nitrogen fertilisation with urea with doses of 0 and 81 or 88 kg N/ha for second or third ratoon, respectively. Fertilisation was performed following standard cane farming recommendations in Tucumán on 26 October 2010 and 16 November 2011. In order to determine nitrate concentration, samples were taken from soil solutions at 85 cm depth using ceramic soil water suction samplers, while water flow was simulated with the LEACH-W model. There were similar trends in both seasons. In 2010/2011, unfertilised plots had no nitrates in soil solution, while fertilised plots leached nitrates from 29 to 57 days after fertiliser application, coinciding with the onset of percolating rains. In 2011/2012, although unfertilised plots had nitrates in solution, they were significantly less than in fertilised plots. In the latter, leaching time lasted from 16 to 34 days after nitrogen fertilisation. The main conclusions of this study are: (1) there is low nitrate leaching from sugarcane cultivation, in an Argiudoll, with frequent nitrogen fertilisation doses used in the production systems in Tucumán, and (2) nitrate leaching was observed at the onset of the rainy season, when both deep drainage of water and available nitrates are simultaneously present.

Keywords N fertiliser · vadose zone · Nitrogen Fertilization · Sugarcane production · Tucumán · Argentina

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R. de los A. Portocarrero (✉) · M. M. Acreche
Instituto Nacional de Tecnología Agropecuaria (INTA), Estación Experimental Agropecuaria (EEA) Famaillá, Provincial Route N° 301, km 32, 4132 Famaillá, Argentina
e-mail: rportocarrero@correo.inta.gov.ar

Nitrates are the most stable nitrogen (N) form in soil, and generally come from N fertiliser or organic matter mineralisation. They are characterised by their high solubility and thus if there is water drainage, they can be leached generating aquifer pollution. If nitrate levels are higher than 45 mg/L, and this water is used as a human supply, there is a threat to human health. In addition, aquifers with N dissolved could discharge in surface water, increasing the risk of eutrophication.

Studies of N fertiliser losses due to leaching are very important in crops such as sugarcane, where high amounts of N fertilisation are used in large areas with differing aquifer vulnerability.

In the depressed plain region of Tucumán, where sugarcane is cultivated, the first layer of the aquifer system is shallow and unconfined; thus it has a relatively high pollution potential.

N leaching in the sugarcane root zone, or its impact on water quality, has been studied in sugarcane production in Brazil, Australia, and the USA (Thorburn et al. 2003; Muchovej and Newman 2004; Ghiberto 2009; Ghiberto et al. 2009, 2011; Armour et al. 2012). In Argentina, N leaching studies have been focused in Pampa region crops, such corn, soybean and wheat (Aparicio et al. 2008; Portela et al. 2009). A case study was performed in sugarcane, in which losses of 22.4 kg N/ha were found in a Typic Argiudoll due to fertilization with 90 kg N/ha (Fogliata personal communication, 2011).

The aim of this study was to quantify nitrate leaching from an Aquic Argiudoll cultivated with sugarcane in Tucumán, during second and third ratoon.

A field trial was established in the EEA INTA Famaillá (Tucumán), in an Aquic Argiudoll, classified as low pollution potential to the aquifer system (Aller et al. 1987). The sugarcane variety used was LCP 85-384. The annual average potential evapotranspiration is 1,348 mm, while the annual average precipitation, concentrated during November–April, is 1,324 mm.

Treatments consisted of one yearly N fertilisation with urea with doses of 0 and 81 or 88 kg N/ha for second or third ratoon, respectively. Plots, consisting of five rows 1.6 m apart and 10 m long, were arranged in a randomised complete block design with three replications. Fertilisation was performed following standard sugarcane farming recommendations in Tucumán on 26 October 2010 and 16 November 2011. Fertiliser was applied before the rainy season.

Nitrate leached was calculated weekly by Eq. (1), for second and third ratoon, during the periods after fertilisation till the end of the rainy season, at 85 cm depth.

$$NL = {}^{D \times C}/_{100} \quad (1)$$

where NL is nitrate losses by leaching (kg/ha), D is drained water volume (mm) and C is nitrate concentration in soil solution (mg/L).

Nitrate concentration was determined weekly in soil solution. Soil solution was extracted in the field by means of a ceramic soil water suction sampler installed at 85 cm depth in each plot. The nitrate concentration was determined by the nitracheck reflectometer methodology (Merckoquant nitrate strips, Merck KGaA, Germany). Drained water volume was estimated using the LEACH-W model. This is a deterministic model, which solves the Richard's equation to calculate the soil water flux (Aparicio et al. 2008).

The data input needed for LEACH-W model are:

- Soil profile properties. The profile was described by direct observation and laboratory determinations. Texture, bulk density, saturated hydraulic conductivity (k_s) and organic carbon (OC) were calculated for each horizon by hydrometer, cylinder, and Walkley and Black methods, respectively (Table 1). The a and b constants needed to solve the Campbell's equation, were taken from a soil with similar characteristics.
- Initial soil moisture, which was measured gravimetrically.
- Meteorological data for the studied period. Daily precipitation, weekly temperature and potential evapotranspiration, were obtained from the EEA INTA Famaillá meteorological station.
- Crop characteristics. The following phenological stages of the sugarcane crop were considered: emergence and tillering during September and October, growth from November to March, ripening from March to July and harvest in July.

Since the water table during the modelled period was below 3 m depth, free drainage was used as a lower boundary condition.

Model efficiency was verified using a normalised objective function (NOF) (Aparicio et al. 2008). The soil moisture modelled was compared with the soil moisture measured gravimetrically in different points of the field at 25 cm intervals to 100 cm depth, six times during the trial.

During the first year of the trial (second ratoon, 2010/2011), unfertilised plots had no observable nitrates in soil water. On the other hand, fertilised plots started leaching nitrates from 29 days after N application, coinciding with the onset of effective rains. Two of the three plots leached until 57 days after fertilisation. Subsequently, no nitrate was detected in soil solution at 85 cm depth till the end of the rainy season.

In the second year of the trial (third ratoon, 2011/2012), unfertilised plots leached nitrates at the onset of the rainy season (16–21 days after fertilisation), but significantly less than the fertilised plots. Subsequently, no nitrate leaching was detected in unfertilised plots. However, the fertilised plots started leaching at 16 days and continued to 34 days after fertilization. Subsequently, fertilised plots did not leach any nitrates till the end of the rainy season.

For both years, nitrate concentration in soil solution had a negative regression with days after the first effective precipitation:

$$\text{First year:}\quad y = 59.0 - 1.72x \quad R^2 = 0.5;\quad p = 0.0008 \quad (2)$$

$$\text{Second year:}\quad y = 85.6 - 3.04x \quad R^2 = 0.7;\quad p = 0.0002 \quad (3)$$

Table 1 Profile properties of Aquic Argiudoll from Famaillá, Argentina

Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Bulk density (g/cm)	k_s (cm/h)	OC (%)
1	0–22	20	45	35	1.2	24.74	1.86
2	23–48	20	42	38	1.07	23.74	1.57
3	49–69	18	42	40	1.35	0.07	0.93
4	70–102	17	58	25	1.28	5.95	0.35

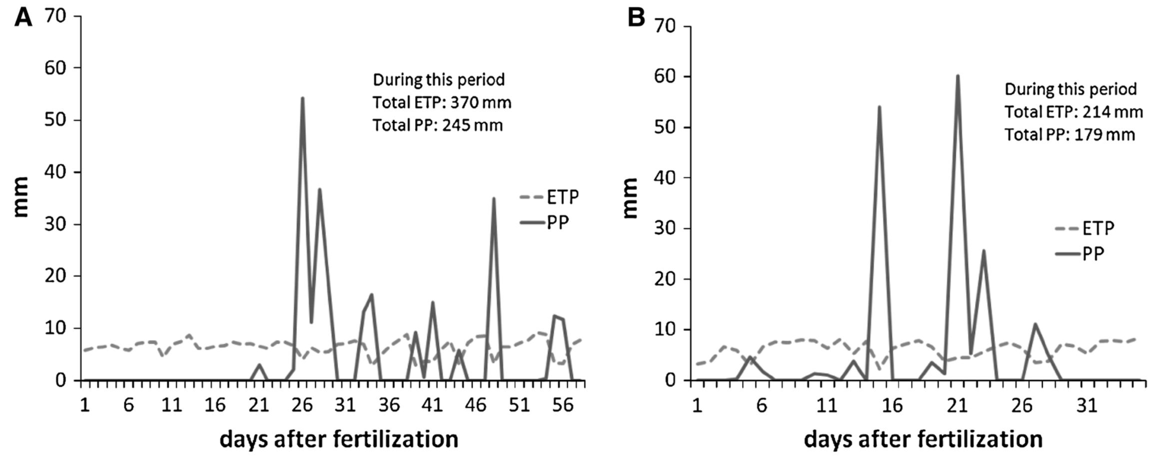

Fig. 1 Precipitation (PP) and potential evapotranspiration (ETP) from fertilisation until the end of the leaching period in the first (2010/2011; **a**) and second (2011/2012; **b**) years of the trial

Table 2 Average nitrate losses and their standard deviation (SD) for the 2 years of trial of Aquic Argiudoll from Famaillá, Argentina

First year of trial (2010/2011)				Second year of trial (2011/2012)			
Day after fertilisation	Drainage (mm)	Nitrate losses average (kg/ha)	Nitrate losses SD (kg/ha)	Day after fertilisation	Drainage (mm)	Nitrate losses average (kg/ha)	Nitrate losses SD (kg/ha)
29	0.3	1.2	0.8	16	0.1	1.3	1.1
36	0.9	0.2	0.3	21	0.0	0.0	0.0
42	1.9	0.5	0.5	30	1.0	0.3	0.3
49	1.2	0.2	0.2	34	0.9	0.1	0.1
57	0.9	0.0	0.0				
Total	5.2	2.2			2.0	1.7	

where y is nitrate concentration in soil solution (mg/L) after the fertilisation and x is day after the first effective precipitation.

In the first year (2010/2011), the first effective rainfall occurred 25 days after fertilisation (Fig. 1). From fertilisation until the end of the leaching period, precipitation was 125 mm less than the potential evapotranspiration, and the total amount precipitated represented 22 % of the total amount during the rainy season (November to April). On the other hand, in the second year (2011/2012), the first effective rainfall occurred earlier (15 days after fertilisation). The precipitation during this period represented 29 % of the total amount of the rainy season. In both years, precipitation was lower than the potential evapotranspiration.

The soil moisture modelled agreed well with measured soil moisture, according to the following equation and index:

$$y = 0.078 + 0.66x \; R^2 = 0.7; \quad p = 0.0001 \tag{4}$$

$$NOF = 0.4$$

where y is soil moisture modelled and x is soil moisture measured.

During the leaching period, total water drainage was 5.2 and 2.0 mm for the first (2010/2011) and second (2011/2012) years of the trial, respectively (Table 2).

Nitrate losses for the fertilised plots were quantified as 2.2 and 1.7 kg NO_3^-/ha for the first (2010/2011) and second (2011/2012) years of the trial, respectively (Table 2).

The nitrate losses reported in this study are low in respect to the amount of fertiliser applied, and according with the results in previous research. In Brazilian sugarcane systems, with N fertilisation rates similar to this study (100–120 kg N/ha), losses between 1.1 and 34.5 kg N/ha due to leaching were reported (Ghiberto 2009; Ghiberto et al. 2009; 2011). In Australia, Armour et al. (2012), during the first to third ratoon, found N losses by leaching between 0.6 and 9.2 kg N/ha, when 136–148 kg N/ha fertiliser was applied.

In this study, the period of nitrate leaching occurred at the onset of the rainy season, when evapotranspiration was still higher than precipitation, so that drainage was not significant (nitrate losses are directly related with water drainage, see Eq. 1). A similar temporal pattern of leaching period (Eqs. 2 and 3), was observed by Armour et al. (2012).

The fact that the water drainage was under-estimated (Eq. 4) indicates that a better calibration process should reflect more water drainage and N losses.

Conclusions

There was low nitrate leaching from sugarcane cultivation in an Argiudoll with frequent N fertilisation doses (around 85 kg N/ha as urea) used in the production system in Tucumán, Argentina. Nitrate leaching was observed at the onset of the rainy season when both deep drainage of water and available nitrates from the annual sugarcane fertilisation were simultaneously present. This period was characterised by low water drainage, and therefore the nitrate losses were low too. Thus, one would expect to find vertical nitrate recharge from sugarcane fertilisation in a shallow aquifer during the onset of the rainy season.

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