Geoderma 160 (2011) 384–393

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Nitrogen dynamics in volcanic soils under permanent pasture

J.C. Fontes [a], M.R. Cameira [b,*], L.G. Borba [a], E.D. Amado [a], L.S. Pereira [b]

[a] University of Azores, 9700 Angra do Heroísmo, Portugal
[b] Biossystems Engineering Research Center, Institute of Agronomy, Technical University of Lisbon, Tapada da Ajuda, 1349-017, Portugal

ARTICLE INFO

Article history:
Received 8 February 2010
Received in revised form 11 October 2010
Accepted 12 October 2010
Available online 12 November 2010

Keywords:
Azores
Andosols
Grasslands
N mineralization rate
Minilysimeters
Laboratory incubation
N losses

ABSTRACT

In Terceira Island (Azores, Portugal), 87% of the agricultural land is used for permanent pasture under periodical grazing. The edaphoclimatic conditions promote nitrate leaching into the groundwater and runoff, which carries sediments and fertilizers into the surface waters. Of particular interest is the fact that volcanic Andosols are rarely study to analyze nitrogen dynamics. The soil capacity to provide mineral N from its organic matter pool through mineralization was estimated using two methods: in laboratory under controlled moisture and temperature conditions; and in natural conditions using *in situ* minilysimeters. The direct N input through animal's excreta was determined by a field mass balance. It was observed that mineralization and animal excreta contributed respectively with 160 and 65 kg mineral N ha^{-1} for the N budget. N losses by leaching and runoff amount respectively for 89 ± 18 kg ha^{-1} and 0.5 ± 0.08 kg ha^{-1}, representing 53% of the fertilizer inputs. To control such losses the fertilizer amount should be recalculated considering the direct input through the animal excreta and the mineral N input from the net mineralization process. In addition, due to the random characteristics of the rainfall events, the fertilization should be split into two or more applications, hence reducing the amounts of mineral N available for leaching. Further studies may be developed using a modeling approach to allow the fertilizer management optimization.

1. Introduction

In Terceira Island, Azores, 87% of the agricultural land is used for permanent grazing pasture, mainly ryegrass (*Lolium perenne*) and clover (*Trifolium repens*). Nitrogen (N) fluxes in grazed grasslands differ greatly from those of other agricultural land uses due to the periodical presence of the grazing animals. The removal of N from the field is often less than for other cropping systems and there is substantial recycling of N in the soil–crop system due to animal excreta (Hutchings et al, 2007). The presence of grazing animals also contributes to an increase in spatial heterogeneity in the cycling of N. This is primarily due to the deposition of excreta in patches rather than evenly over the field (West et al., 1989; Haynes and Williams, 1999; Hutchings et al., 2007). This non uniform distribution may modify soil chemical and physical attributes such as soil organic C and N, soluble salts and soil pH (Haynes and Williams, 1999; Franzluebbers et al., 2000) and creates technical and logistical problems that make the field investigation of N dynamics difficult (Velthof and Oenema, 1995; Anger, 2002). Within cattle urine and dung patches, the N deposited in a single event is typically equivalent to values ranging from 200 to 2000 kg N ha^{-1} (ten Berge et al., 2002), depending upon the grass quality. As a result, the soils in these agricultural systems have high organic matter (OM) contents in the surface layer, which can contribute, after mineralization, as an important input to satisfy the crop needs in nitrogen. Also, nitrate (NO_3^-) leaching and nitrous oxide (N_2O) emissions are known to be high from urine and dung patches in grazed pastures (Iyyemperumal et al., 2007).

The climatic conditions in the Terceira Island (mild oceanic climate), are characterized by frequent rainfall events and mild temperatures. The latter vary within a narrow annual range and promote a high OM mineralization rate. The soils are Andosols, more often Ferric and Haplic Andosols (FAO, 1998) of recent volcanic origin containing allophane and imogolite. These constituents confer unusual properties to these soils, including very low bulk density, high values of water holding capacity, total porosity and hydraulic conductivity. Allophane refers to a group of clay-size minerals containing silica, alumina and chemically bound water (Parfitt, 1990; Tan, 2000). The high porosity and water retention are thought to result from the abundance of inter and intra-particle pores of allophane (Quantin, 1985). The hydraulic properties favor deep percolation of the excess rainfall water and, consequently, the leaching of agrochemicals below the root zone (0–40 cm) and into the groundwater (Fontes et al., 2004a,b). Because land is very steep, the high intensity rainfall events originate runoff that carries sediments and agrochemicals into the surface waters (Fontes et al., 2004b). Therefore, this agricultural system has a considerable potential for the contamination of surface and ground waters with agrochemicals.

* Corresponding author. Instituto Superior de Agronomia, Tapada da Ajuda, 1349-017, Lisbon, Portugal. Tel.: +351 21 3653399.
E-mail address: roscameira@isa.utl.pt (M.R. Cameira).

0016-7061/$ – see front matter © 2010 Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2010.10.008

Nutrient enrichment of surface waters (primarily nitrogen and phosphorus) is undesirable both as a result of changes in the freshwater and related eutrophication, with negative impacts on drinking water supplies. Groundwater contamination with nitrates has led to the delimitation of vulnerable zones to water pollution from nitrogen compounds. In these areas the aquifer presents nitrate (NO_3^-) concentrations higher that 50 mg L^{-1} or nitrate-nitrogen (N-NO_3) concentrations higher that 11 mg L^{-1}. These concentrations have been related to health issues e.g. methaemoglobinaemia (blue baby syndrome) (Heathwaite et al., 1993).

Recently, attention has focused on nitrogen-prevention measures as a result of the EC Nitrate Directive (91/676), which insists that nitrogen control should be by prevention at source and gives recommendations for changes in agricultural land use. The key changes include the accurate determinations of the crop nitrogen requirements, especially in those cases when other sources of nitrogen exist, like in the direct grazing pasture systems.

Eight vulnerable zones have been already identified in the Azores Islands. In Terceira there is not yet any vulnerable zone but there is the need to develop an appropriate strategy to manage the permanent grazing pastures. This strategy will prevent future problems in surface and ground waters used as drinking water supplies. This strategy must be based upon preventive measures and couple nitrates contamination control with the economics of dairy farming systems (Dentinho et al., 2008). In these systems the only water input is rainfall. Because rainfall events are random and their impacts upon deep percolation cannot be controlled, the nitrate storage in the root zone must be, at each time, minimized in order to reduce the leaching potential. This requires the accurate determination of crop N needs throughout the year, the estimation of the soil capacity to provide mineral N from its organic matter pool (mineralization rate) and the estimation of the ammonium input into the system by animal excreta.

Aiming to support the development of the previously referred strategy, the objectives of this study were:

(1) To analyze the N dynamics in volcanic soils of Terceira Island, under permanent pasture and periodic grazing. The following N budget terms were addressed: i) the soil capability to provide mineral N from its organic matter pool (soil net mineralization rate); ii) the direct inputs of ammonium through the grazing animals' excreta; and iii) the losses of mineral N by leaching and runoff;
(2) To identify potential measures to reduce the mineral N losses and to contribute to the sustainability of the system.

This lies within the scope of the general conclusions resulting from the concerted research action “Soil Resources of European Volcanic Systems” implemented by the European Union COST Program (Óskarsson and Arnalds, 2004). They state that Andosols have special properties that make them an important and unique natural resource and that in Europe most of the Andosol areas are subjected to increasing pressure by humans, such as urban expansion and chemical pollution.

2. Material and methods

Three sets of experiments were designed (Table 1) in order to estimate different terms of the nitrogen budget. Two sets were designed with the common objective of estimating the net mineralization rate of the soil. The third one had the objective of providing information about the N dynamics in field conditions, necessary for the quantification of the ammonium inputs through the grazing animal's excreta and the N losses by leaching and runoff.

2.1. Experimental site

The experiments were carried out in a small watershed called Granja (Fig. 1), located in the Island of Terceira, Azores (38º 41´ 55˝ N, 27º 10´ 14˝ W). The watershed outlet is 380 m above the sea level. The catchment's area is 3500 m^2, with an average slope of 9%. During the experimental year (2002) rainfall was 1766 mm (average of 15 years = 1510 mm), total runoff was 80 mm (average of 15 years = 47 mm), the average air temperature was 20 °C (average of 15 years = 19.4 °C) during the summer and 12 °C during winter (average of 15 years = 11.7 °C). Fig. 2 presents daily maximum and minimum air temperatures and rainfall for the experimental year.

The soil is classified as a Ferric Andosol (FAO, 1998). Andosols are volcanic ash soils, generally rich in OM and containing allophane and imogolite (Tan, 2000). Basic soil physical and hydraulic properties are presented in Table 2 (Fontes et al., 2004a), reflecting the characteristics of Andosols with allophanes. The water contents at saturation (θ_s) (h = 0 kPa), field capacity (θ_{FC}) (h = 100 kPa) and wilting point (θ_{WP}) (h = 1500 kPa) are much greater than those currently expected for soils with similar textural characteristics. The soil has very low bulk density (0.45 to 0.78) and very high total porosity, which explains the high saturated hydraulic conductivity (19 to 38 mm h^{-1}). Selected chemical properties of the soil are presented in Table 3. The profile presents considerably high OM contents, decreasing with depth. C/N values are

Table 1
Summary of the experiments performed in this work.

Period	Methods	Objectives	Sampling strategies
Laboratory experiment			
March to October 2002	Incubation method under controlled conditions	Estimate the net mineralization rate of the soil in optimal and controlled conditions for temperature and moisture	•Soil samples collected randomly in the field and put into 51 incubation jars; •2 soil layers sampled; •3 replications per soil layer; •17 sampling dates.
In situ experiments			
March to October 2002	Minilysimeters in natural field conditions (bare soil)	Estimate the net mineralization rate preserving natural soil temperature and water dynamics of the field	•9 minilysimeters installed in the field; •2 soil layers covered; •3 replications per soil layer; •13 sampling dates.
March to August 2002	Field monitoring in natural pasture conditions with periodical direct grazing and a fertilization event	Estimation of ammonium inputs through animal excreta; N losses by leaching and N losses with runoff	Nitrogen in soil: •samples collected over the watershed in a zigzag pattern; •4 soil layers sampled ; •9 replications per soil layer; •5 sampling dates; soil water: (neutron probe) •measurements at 8 depths; •9 replications for each depth; •13 measurement dates; Nitrogen in runoff: •samples collected after each runoff discharge