Agriculture, Ecosystems and Environment 160 (2012) 29–39

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

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

Nitrate leaching from a maize × oats double-cropping forage system fertilized with organic residues under Mediterranean conditions

J.P. Carneiro[a,c,*], J. Coutinho[b], H. Trindade[c]

[a] CERNAS - Center for the Study of Natural Resources, Environment and Society, Instituto Politécnico de Castelo Branco, Escola Superior Agrária, Castelo Branco, Portugal
[b] Chemistry Center, Dep. Biologia e Ambiente, ECVA - Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal
[c] CITAB - Centre for the Research and Technology of Agro-Environment and Biological Sciences, Universidade de Trás-os-Montes e Alto Douro, Vila Real, Portugal

ARTICLE INFO

Article history:
Received 30 November 2010
Received in revised form 2 August 2011
Accepted 1 September 2011
Available online 23 September 2011

Keywords:
Fertilization
Cattle slurry
Sewage sludge
Urban waste compost
Nitrification inhibitor
Leaching mitigation

ABSTRACT

Further information about the environmental effects and best management options for agricultural use of organic residues in Mediterranean areas is required. A field experiment was carried out over two winter seasons in central Portugal, to evaluate NO_3-N leaching losses originating from the soil application of cattle slurry (CS), sewage sludge (SS) and urban waste compost (UWC) to a double-cropping system producing oats and maize. A mineral fertilizer treatment (MIN) and a Control were included. The use of a nitrification inhibitor (DCD) with MIN (MIN + I) and CS (CS + I), an organic residue with high C/N ratio (pulp mill sludge – PMS) together with mineral fertilizer (PMS + M), and split application of residues (SS and UWC), were evaluated as measures to mitigate N leaching. Total fertilizer N applied in treatments were 80 and 170 kg N ha^{-1} to oats (*Avena sativa* L.) and maize (*Zea mays* L.), respectively. Water samples were collected at 0.70 m deep, using porous ceramic cups. The highest annual NO_3 losses were measured in MIN + I, PMS + M and MIN (185, 152 and 145 kg N ha^{-1}, respectively) and with the split application of SS (145 kg N ha^{-1}). In Control the maximum loss was 50 kg N ha^{-1}. The use of DCD in spring fertilization is not recommended. The N lost by leaching and runoff following the application of organic residues was less than to 30% of N applied (IPCC factor). Compared to mineral N application, the use of organic residues in agriculture with an appropriate management can contribute to lower nitrate losses.

1. Introduction

The downward movement of water through soil can result in the transport (leaching) of nitrogen (N) out of the rooting zone of plants, and usually in the nitrate (NO_3^-) form of N. Leaching of NO_3^- is an economically undesirable flux of plant nutrient which can result in adverse effects to the environment, such as water contamination. From 2004 to 2007, about 30% of Portuguese network stations reported mean NO_3^- concentrations in groundwater greater than 25 mg NO_3^- L^{-1} (MAOTDR and MADRP, 2008).

Water contamination from NO_3^- can be directly related to the intensification of agricultural production, involving the application of mineral N fertilizers and organic residues (Di and Cameron, 2002). In Mediterranean areas, efforts to develop improved management strategies for the application of these products to soil have been made, with particular attention to better utilization of mineral N fertilizers. However, the environmental advantages to be gained from the adoption of recommended practices when mineral fertilizers are used (e.g. simultaneous use of a nitrification inhibitor (NI), or simultaneous application of organic residues with high C/N ratio) have not been clarified specifically for double-cropping systems under Mediterranean environmental conditions. Also, the agricultural use of organic residues (e.g. sewage sludge or urban waste compost) in these regions is increasing, and more information about the environmental effects and best management options for soil application of those materials is required.

Results of studies on nitrate leaching losses from soils amended with organic residues or receiving applications of mineral fertilizers are often discordant (Diacono and Montemurro, 2010). For instance, Basso and Ritchie (2005) in a 6-year maize–alfalfa rotation conducted in southwest Michigan, USA, observed the highest amount of NO_3^- leaching in the manure treatment, followed by compost, inorganic N and control. In contrast, Mallory and Griffin (2007) in a 13-year experiment using soil collected from Presque Isle, Maine, USA, found that, despite similar ammonium (NH_4^+) inputs and rates of NH_4^+uptake for manure and fertilizer N

* Corresponding author at: CERNAS - Center for the Study of Natural Resources, Environment and Society, Instituto Politécnico de Castelo Branco, Escola Superior Agrária, Castelo Branco, Portugal. Tel.: +351 272 339 900; fax: +351 272 339 901.
E-mail address: jpc@ipcb.pt (J.P. Carneiro).

0167-8809/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.agee.2011.09.001

treatments, residual NO_3^- accumulation was lower in the manure treatment. This is because the N from manure became available more slowly than fertilizer N.

The two major factors controlling leaching losses of NO_3^- are the concentration of NO_3^- in the resident soil solution and the amount of water percolating through the soil matrix (Nieder and Benbi, 2008). In Mediterranean climates, characterized by cool, wet winters and hot, dry summers, NO_3^- losses by leaching are particularly important between October and January. In the region of Valencia Community, 56% of NO_3^- leaching losses were measured during October-November (De Paz et al., 2009); in north-west Portugal, Trindade et al. (1997) observed that 80–90% of total N losses by leaching occurred before February. In Mediterranean areas, it is common to establish two annual crops per year (maize/sorghum and oats/ryegrass as spring–summer and autumn–winter crop, respectively) with both crops receiving two applications of mineral N (1/3 and 1/2 of total N is applied at sowing of autumn–winter and spring–summer crop, respectively; the remaining fraction is supplied as a top-dressing). The N applied in autumn and during spring–summer, contributes to the high amounts of available N in the soil at the start of the rainy period (Trindade et al., 2009), conditions that promote significant N leaching (Trindade et al., 1997). The application of organic residues with high C/N ratios to the soil, such as primary paper mill sludge, results in a reduction of NO_3^- leaching due to net immobilization of N during decomposition (Burgos et al., 2006). Therefore, the simultaneous application of this residue with mineral N fertilizers in autumn could result in an effective mitigation measure to reduce N leaching.

In intensive dairy farming systems, slurry is applied regularly at the sowing of each crop. Results from field experiments carried out in a Mediterranean area showed that the NO_3^--leaching potential from the application of slurries could be lower than those from N mineral fertilizer application (Daudén and Quílez, 2004; Trindade et al., 2009). However it has also been recognised that NO_3^- leaching can be a common and sometimes serious problem when such effluents are used (Trindade et al., 1997; Daudén et al., 2004). To reduce N losses, the use of nitrification inhibitors (NI) among other practices should be considered with autumn applications of effluents (Trindade et al., 1997). In other situations, the application of NIs with slurries or mineral fertilizers has resulted in reduced N losses by leaching (Shoji et al., 2001; Zerulla et al., 2001; Di and Cameron, 2005) since these synthetic compounds are able to temporarily inhibit the microbial oxidation of NH_4^+ to NO_3^-. Nevertheless, the effectiveness of NIs depends on factors such as: type of fertilizer used (Merino et al., 2001), temperature (Di and Cameron, 2004), soil moisture (Kumar et al., 2000), application form (Di and Cameron, 2005), application rate (Chaves et al., 2006), or even repeated high effluent-N loadings (Williamson et al., 1998). In Mediterranean areas, the use of NIs to control nitrate leaching has been successfully tested in irrigated crops (Vallejo et al., 2005; Díez et al., 2010). However, information about the use of NIs in winter crops is limited, especially concerning the application of NIs in autumn. Arregui and Quemada (2006) did not observe any significant impact on subsequent N-leaching losses when ammonium sulfonitrate and the nitrification inhibitor DMPP were applied to winter cereals in February. In Portugal and in many other countries, dicyandiamide (DCD) is the NI most widely used because it is economical, less volatile and relatively soluble in water (Zaman et al., 2008) compared to other commercially produced NIs and has no lasting effect on the community composition of soil microbial populations but does reduce their abundance (Carneiro et al., 2010).

Much of the field research into the principles of sustainable use of organic residues in Mediterranean agro-ecosystems has been carried out using slurries. However, there is only limited information on the timing of applications and effects on NO_3^- leaching for sewage sludge and urban waste compost. In Portugal these residues are mostly applied to the soil at the end of the summer and before autumn–winter crop sowing, mainly for practical reasons (drier residues allow easier transportation and soil distribution). However, in double-cropping systems under Mediterranean climates, a split application of sewage sludge or urban waste compost between autumn and spring, or even confining incorporation to spring could facilitate better synchronization of N release from residues with plant-N demands, minimizing NO_3^- leaching losses. The economic value of the N contained in organic wastes makes this worthwhile; however, adverse environmental impacts from application to the soil must be determined before mitigation options can be proposed. Better N management has been recognized as the key component of efforts to increase N use efficiencies and reduce N losses by leaching (Delgado and Follett, 2010).

Table 1
Some physical and chemical properties of the soil at the start of the experiment.

Parameter	Depth (cm)	
	0–30	30–70
Fine earth (g kg^{-1})	697	537
Water content at pF 1.00 (g kg^{-1})	176	166
Water content at pF 2.00 (g kg^{-1})	124	103
Water content at pF 2.54 (g kg^{-1})	100	82
Water content at pF 3.00 (g kg^{-1})	86	70
Bulk density (g cm^{-3})	1.52	1.39
Organic matter content (g kg^{-1})	12.2	3.3
pH (water)	6.0	5.9
NH_4^+-N (g kg^{-1})	4.7	1.0
NO_3^--N (g kg^{-1})	20.7	24.1
P (mg kg^{-1})	116	32
K (mg kg^{-1})	243	112

The objective of this study was to evaluate losses of NO_3^- by leaching in a double-cropping system producing oats (*Avena sativa* L.) and maize (*Zea mays* L.) forage under Mediterranean conditions when different organic wastes (cattle slurry, sewage sludge and urban waste compost) were used as N sources compared to mineral N fertilizers. The use of a NI (DCD), split applications of residues or incorporation in the spring only, and the use of an organic residue with a high C/N ratio (pulp mill sludge) simultaneously added with N mineral fertilizers, were evaluated as possible mitigation measures to reduce leaching.

2. Materials and methods

2.1. Experimental site

A field experiment was conducted over a 2 year period (May 2006 to May 2008), on a farm in central Portugal (Castelo Branco), with treatment establishment after the harvest of an autumn–winter crop (oats). The study started after the harvest (May 2006) of an autumn–winter crop (oats). The study was conducted on a field of slope 1–2% on a sandy loam soil, classified as Dyistric Cambisol (FAO, 1998). The field received inorganic fertilizer following the agricultural practices of the region and had not received any organic amendments. Some properties of the soil are summarized in Table 1.

The Castelo Branco region has a Mediterranean influence (average annual rainfall, 821 mm; mean annual temperature, 15.6 °C) with 90% of the annual rainfall concentrated in an 8-month period (October–May). Temperature and rainfall data were recorded daily at an on-site weather station during experiments, and important differences in the amount of precipitation were observed between years (Fig. 1). In July of 2006, very high temperatures were recorded (maximum daily-values above 36 °C between days 8 and 18): the heat wave during this month was the most significant since 1941.