NITRATE LEACHING FROM SOILS AMENDED WITH DIFFERENT ORGANIC RESIDUES

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1 INTRODUCTION

Leaching of nitrate (NO_3^-) is a flux economically undesirable, and involves negative consequences to the environment, such as water contamination. Along 2004-2007, about 30% of Portuguese network stations presented a mean nitrate concentration in groundwater >25 mg NO_3 L^{-1}. Under similar conditions, NO_3^--N leaching losses from effluents are generally lower than those from N fertilizers (Di and Cameron, 2002). However, numerous studies have shown that NO_3^- leaching is a common and sometimes serious problem when organic wastes are used (Sims, 1995). The effect of climate, cropping system used, time of N application and use of a nitrification inhibitor, are some of the factors that, according to Randall and Goss (2001), can affect nitrates in subsurface drainage.

The objective of this trial was to evaluate losses of NO_3^--N by leaching in Mediterranean conditions, when different organic wastes (cattle slurry, sewage sludge and urban waste compost) were used as N sources in a double-cropping system producing oats and maize forage. The use of a nitrification inhibitor (DCD), the splitting application of residues and the use of an organic residue with high C/N ratio (pulp mill sludge) were evaluated as leaching mitigation measures.

2 MATERIALS AND METHODS

2.1 Study site and experimental conditions

The experiment was conducted over a 2.5-year period (November 2006 to May 2008) on a farm in central Portugal (Castelo Branco). The 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 to May). Temperature and rainfall data were daily recorded with an on-site weather station during experiment, and important differences in the amount of precipitation from October to May were observed among years, (Table 1). The 2006 autumn was considered the third most rainy since 1931, and 2007/2008 one of the year most dried of last decade.

TABLE 1 **Monthly rainfall (mm) during October and May periods of the three years under study**

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
2005/2006	194.7	97.0	83.5	29.6	52.3	142.4	57.8	0.0
2006/2007	201.8	352.8	50.9	13.1	83.5	27.8	67.3	57.7
2007/2008	13.5	64.4	22.3	82.2	98.2	8.9	171.6	57.4

The soil used was a sandy loam soil, classified as Dyistric Cambisol, with 8.1g kg^{-1} organic C, pH (H_2O) 6.2, and high P and K levels (>120 mg kg^{-1}).

2.2 Treatments and crop management

A double-cropping forage system producing oats (*Avena Strigosa* Schreb.), cultivar Saia, and hybrid maize (*Zea mays* L), cultivar NK Furio (FAO 300), was established, and both cultures were conducted like under commercial practice.

The use of a nitrification inhibitor (DCD), the splitting application of residues and the use of an organic residue (pulp mill sludge) with high C/N ratio (420) were evaluated as leaching mitigation measures. The ten treatments tested consisted of: the splitting application at the establishment of the oats and maize crops of the organic residues sewage sludge (treatment SS), urban waste compost (UWC) and cattle slurry (CS); the yearly application of pulp mill sludge (PMS) to the oats crop, and SS and UWC to the maize crop (SSm and UWCm); a mineral fertilizer treatment (MIN) and a Control were included, and the DCD effects were tested together with MIN (MIN+I) and CS (CS+I). PMS was applied in the two first years only. Mineral fertilizers used were: a special fertilizer with DCD incorporated, ammonium sulfate at sowing and ammonium nitrate in the top-dressing applications. DCD (12 kg active ingredient ha^{-1}) was applied to the slurry just before its soil distribution, and organic residues were incorporated to the soil just before crop sowing. Total N input was equal for all fertilization treatments (oats 80 kg N ha^{-1}; maize 170 kg N ha^{-1}), but amount of N applied by organic residues was variable (Table 2).

TABLE 2 **N applied (kg ha^{-1}) in each culture and treatment, through organic and mineral fertilizers**

Treatment	**Oats**			**Maize**		
	Organic fertilization	**Mineral fertilization**		**Organic fertilization**	**Mineral fertilization**	
		Sowing	**Top-dressing**		**Sowing**	**Top-dressing**
Control	0	0	0	0	0	0
MIN	0	30	50	0	90	80
MIN+I	0	80	0	0	170	0
PMS	10	20	50	0	90	80
SS	80	0	0	90	0	80
SSm	0	30	50	170	0	0
UWC	80	0	0	90	0	80
UWCm	0	30	50	170	0	0
CS	80	0	0	170	0	0
CS+I	80	0	0	170	0	0

The field was divided in plots of $45m^2$ (5,6m x 8m), and the experimental design was a randomized complete block design**,** with 3 replications.

2.3 Measurements and statistical analyses

The nitrate (NO_3^--N) concentration in drainage water was measured in samples collected 0.70m depth using porous ceramic cups (four cups per plot). Sampling was done always when drainage occurred, which happened between October/November and April/May each year. In total there were 24 sampling dates. NO_3^--N concentration of each plot and sampling data was calculated using the Finney-Sichel estimator. Percolation at 0.70m depth was daily calculated using the Thornthwaite & Mather water balance model. The NO_3^--N leaching losses were calculated as the product of the mean nitrate concentration between two sampling dates multiplied by percolation volume during that period.

For each year, the significance of the difference between NO_3^--N leaching losses from the treatments was analysed by analysis of variance (One-Way ANOVA, $p < 0.05$), using treatment as source of variation. The Duncan test at 5% significance level was used for multiple comparisons between means. All results of NO_3^--N leaching losses were transformed to natural logarithms to obtain stable variance. All statistical analyses were carried out using SPSS 17.

3 RESULTS AND DISCUSSION

The most important losses and differences ($p < 0.05$) between treatments (Figure 1), were observed in the second year (May 2006 / May 2007), when important values of precipitation (>500mm) occurred at the end of summer/beginning of autumn. In this year, NO_3^--N losses ranged from 50 to 185 kg N ha^{-1}, corresponding, respectively, to treatments Control and MIN+I. With traditional fertilization (MIN) those losses (ca. 145 kg N ha^{-1}) were 3 times greater than in Control, and were similar to the losses measured in SSm. In the same year, the lowest NO_3^--N losses among amended treatments were obtained with cattle slurry application, without DCD. In CS treatment the amount of NO_3-N lost by leaching process ascending to 78 kg N ha^{-1}, representing -46% and +59% of the values measured in MIN and Control, respectively.

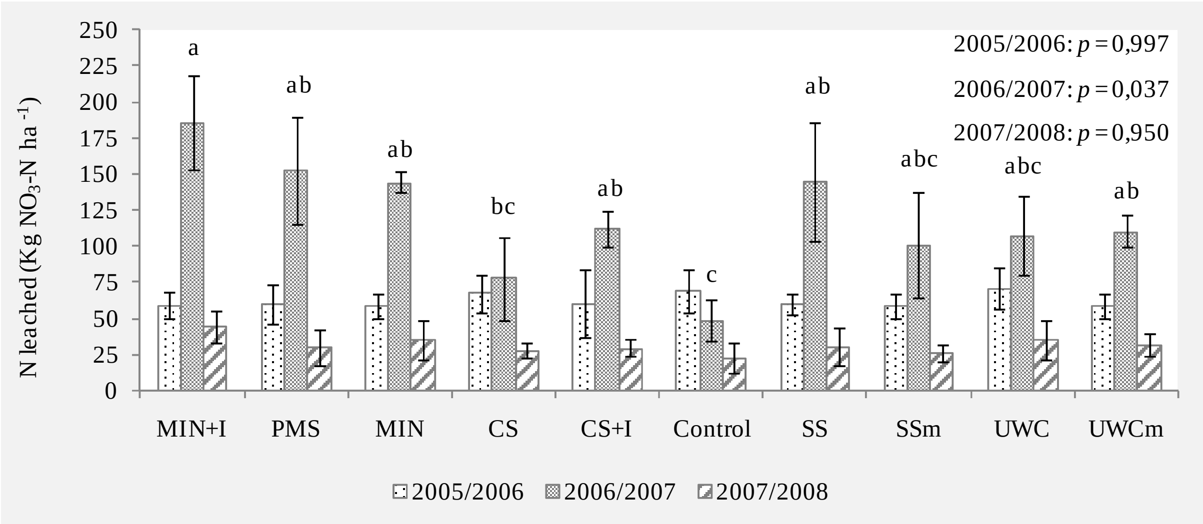

FIGURE 1 Nitrate leaching losses from soil with a double-cropping system producing oats and maize under different fertilization treatments. Columns of the year 2006/2007 with the same letter are not significantly different (p > 0.05 Duncan test). Bars represent standard errors of the mean (n=3).

In 2005/2006 and 2007/2008, treatment effects were not significantly different ($p > 0,05$). In general, the NO_3^--N losses were around 60 and 30 kg N ha^{-1} in the first and second year, respectively, representing 24% and 12% of total N applied to the soil in both cultures (250 kg ha^{-1}) in each year.

Considering the 3-drainage periods mean result, the loss of NO_3^--N by leaching with no N fertilization was 47 kg N ha $year^{-1}$, a very similar value to that estimated by Trindade *et al*. (2008) for an agricultural soil located in the north-west region of Portugal, when no nitrogen was applied to a similar forage system production (48 kg N ha $year^{-1}$). In MIN, the amount of nitrogen lost was 1.7 times greater (79 kg N ha $year^{-1}$).

In several experiments, lower leaching losses of nitrogen with the incorporation to the soil of organic residues than with mineral fertilizers were observed (Di and Cameron, 2002, Trindade *et al*., 2008). However, opposite results had been reported as well (Bergström and Kirchmann, 2006). In our work, when favourable conditions to leaching occurred (2006/2007), a tendency for higher losses was identified with a more intensive use of mineral nitrogen fertilizers (185, 152 and 145 kg NO_3^--N ha^{-1}, in MIN+I, PMS and MIN, respectively). In UWC and UWCm less 25% of N was lost relatively to MIN (in SSm less 30%). The same trend was observed when all nitrogen was applied through the use of cattle slurry. Less 22% and 46% of the NO_3^--N losses measured in MIN were quantified when DCD was, respectively, incorporated or not to CS. Among organic residues, only with sewage sludge application twice a year at the establishment of both cultures no lower N losses relatively to MIN were observed. In fact, during 2006/2007, the amount of NO_3^--N lost by the soil-plant system by leaching in SS (145 kg N ha^{-1}) was equal to the quantity measured in MIN. Some aspects that can explain this result are the mineralization of organic nitrogen present in the soil originated from previous incorporations (oats 2005/2006 and maize 2006), the incapacity of the residue to promote immobilization (Carneiro *et al*., 2007) and their ability to increase the amounts of available N especially during spring-summer period (data not show).

The incorporation to the soil of organic residues with high C/N ratio originate mineral N immobilization, reducing the nutrient availability during cultures development, namely in NO_3^- form (Sarrantonio, 2003); this process may markedly contribute to the reduction of nitrate leaching. In the second year of the experiment, when precipitation favoured highest values of percolation, the loss of NO_3^--N in PMS was 153 kg N ha^{-1}, a result not very different from that presented for MIN. The simultaneous use of paper mill sludge and nitrogen mineral fertilizer (including the mineral N applied to the precedent spring-summer crop) could had promoted less immobilization and more elevate availability of N in soil to be leached.

Most of the research results agree in the beneficial effects of the use of nitrification inhibitors in the reduction of N losses by leaching, when incorporated in mineral fertilizers or applied to organic residues originated by animals. However, any significant effect as well even an increase of N losses has also been reported with the use of nitrification inhibitors (Gioacchini *et al.*, 2002). The differences in NO_3^--N losses between MIN and MIN+I, and between CS and CS+I were not significantly different ($p > 0.05$). However, these losses suffer an increment of around 29 and 44%, when DCD was used in mineral fertilizer and cattle slurry, respectively. The action of DCD over nitrification for a period of 40-50 days in spring-summer culture (data not show), could have limited the nutrient uptake by the maize plants, namely when applied to organic residue (156 and 114 kg N uptake ha^{-1} in CS and CS+I, respectively, in 2006 culture), and increased the level of nitrogen in the soil at the beginning of the raining period, contributing to an increase on N leaching.

4 CONCLUSIONS

NO_3^--N losses through percolated water were more important with high values of precipitation at the end of the summer / beginning of the autumn, when nitrogen in mineral forms in the soil were elevated. When more favourable conditions to leaching process occurred, the NO_3^--N losses were higher when mineral fertilizers were used more intensively. Relatively to MIN, the NO_3^--N losses in SSm, UWC, UWCm, CS and CS+DCD were, respectively, 70, 74, 77, 54 and 78%. According to those results, measures that could reduce nitrogen concentration in the soil at the beginning of autumn should be taken.

Implementing the split application of residues to avoid N losses, did not make difference when urban waste compost was used. Besides, with sewage sludge applications and when favourable conditions to leaching happened, this practice promoted a 30% increment in the losses.

Reduction effects on N leaching losses by incorporation of residues with high C/N ratio simultaneously with mineral nitrogen fertilizers tend to disappear in a short period of time.

The use of DCD in spring-summer fertilization is not recommendable, since the promoted delay in nitrification seems originate higher levels of nutrient in soil at the start of the raining period.

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