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Application of high doses of organic amendments in a Mediterranean agricultural soil: An approach for assessing the risk of groundwater contamination

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ABSTRACT

Groundwater contamination by nitrate is one of the several environmental problems that may be caused by the application of organic amendments to agricultural soils, and is a key issue in the European Union's environmental policy. The use of predictive tools such as flow and transport models for soluble forms could be helpful for preventing the risk of contamination after the application of organic amendments. We investigated the dynamics of leachable inorganic nitrogen forms (NH_4^+-N and NO_3^--N) produced by a single high-dose application of three different organic amendments (a municipal solid waste compost (MSWC), and aerobically (AES) and anaerobically (ANS) digested sewage sludge) in an agricultural soil over a two-year period and how solutes migrate through the vadose zone under a Mediterranean climate. Although the mineralization process was determined by the type of amendment, seasonal variations led to the release and transformation of leachable inorganic nitrogen forms. Sewage sludge (AES and ANS) treatments provide a higher proportion of soluble nitrogen forms than MSWC treatment, which produces a more stable organic matter. Under our field conditions, pollutants can accumulate in the vadose zone, constituting a time bomb which may lead to aquifer contamination further down the line. Hence an increase in water input would accelerate the migration of pollutants and increase the risk of groundwater contamination.

1. Introduction

The application of organic amendments such as sewage sludge (SS) and municipal solid waste (MSW) to agricultural soils has been a common practice in Mediterranean areas and acts as a source of carbon and nitrogen to offset the low content of soil organic matter (SOM) in these soils. However, this practice may entail a number of environmental problems (Korboulewsky et al., 2002; Epstein, 2003; Esteller et al., 2009) such as water contamination by nitrate from agricultural land, which has been flagged as one of the key priorities of the European Union's environmental policy as described in Directive 91/676/EEC (European Commission, 1991). The correct management of organic amendments in agriculture is therefore essential in order to minimise environmental risk.

The mineralization of organic amendments releases large amounts of nitrogen as ammonium which may turn into nitrate (Kleber et al., 2000). Due to its high mobility in soil, nitrate can readily leach towards groundwater. An understanding of the mineralization processes of organic matter amendments, together with the dynamics of nitrogen forms and the migration of soluble compounds through the vadose zone, is a key factor in the effective management of organic amendments. The mineralization process is also affected by the type of organic amendment. In a previous study, González-Ubierna et al. (2012) reported that the application of a single high dose of three different organic amendments (aerobically and anaerobically digested SS, and MSW compost) in a semi-arid Mediterranean soil shows different mineralization patterns which can be explained by the varying chemical properties of the organic amendments involved in each case. There are a large number of studies on the effect of different organic amendments on soil nitrogen dynamics (Fagnano et al., 2011; Smith and Tibbett, 2004; Tarrasón et al., 2008); however, the evolution of leachable nitrogen after the application of a high single dose of different organic amendments under a Mediterranean climate has been less widely studied.

Nitrate leaching is influenced by the type of climate, which determines the spatial and temporal rainfall patterns and thus the amount of water percolating through the soil matrix (Nieder and Benbi, 2008). The Mediterranean climate is characterised by a period of summer drought (for at least two months) and a high variability of rain periods,

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mainly concentrated in spring and autumn. This implies that the processes of water percolation and solute leaching can only take place during certain periods. These particular climate conditions also cause seasonal variations in leachable inorganic N content (Ochoa-Hueso et al., 2013) and thus in the nitrogen transformation processes in the soil. Numerous field studies (Carneiro et al., 2012; De Paz et al., 2009; Trindade et al., 1997) have demonstrated the influence of the Mediterranean climate (low rainfall concentrated mainly in autumn and spring, high evapotranspiration) on nitrate leaching. However, the potential risk of groundwater pollution by nitrate after the application of a high dose of different organic amendments has been less widely studied under these climate conditions. Groundwater pollution depends mainly on the migration of nitrate in leachate; that is, if there is no transport to the water table the impact will occur strictly in the vadose zone. This points to the need for a mathematical model of flux and transport in the vadose zone to determine this impact.

The aims of this study were therefore: i) to investigate the dynamic of leachable inorganic N forms (NH_4^+-N and NO_3^--N) produced by a single high-dose application of three different organic amendments (municipal solid waste compost (MSWC), and aerobically- (AES) and anaerobically- (ANS) digested sewage sludge) over two years under the Mediterranean climate; and ii) to determine whether nitrate leaching can reach the groundwater under the experimental conditions and what the transit time would be. Based on the results, we propose some recommendations for use and management in order to minimise the risk of groundwater contamination.

2. Material and methods

2.1. Description of the study area, soil and organic amendments

The experiment was carried out in an experimental station in Arganda del Rey, in the southeast of the province of Madrid, Spain (UTM X: 457673, UTM Y: 4462824) (Fig. 1). The study area lies on the former alluvial terrace of the Jarama river basin, on quaternary sediments (mainly sand and silt). These sediments have caused the ancient calcareous Fluvisol to have its present Anthrosol characteristics (FAO, 2006). Morphologically, the following horizons can be distinguished: an Ap horizon (0–40 cm) with low surface stoniness characterised by a basic pH of 8.3; contents of total nitrogen, total organic carbon and carbonates of 1.4, 13.1 and 88 g kg^{-1}, respectively; available phosphorous content of 25.6 mg kg^{-1} and cation exchange capacity (CEC) of 15.32 $cmol_{(+)}$ kg^{-1} (Jorge-Mardomingo et al., 2013); a subsurface horizon (40–105 cm) and diverse C horizons (105–200 cm) showing textural changes of material from fluvial transport (Casermeiro et al., 2007). There are signs of the typical characteristics of agricultural land and subsurface compaction due to the intensive use of farm machinery. The physical and hydraulic properties of the soil and vadose zone in the experimental plot were determined up to a 200 cm depth (Jiménez-Hernández et al., 2009). The results of the granulometric analysis and the values for bulk density and saturated hydraulic conductivity (Ks) are summarised in Table 1.

As detailed in González-Ubierna et al. (2012) and Jorge-Mardomingo et al. (2013), three types of amendments were used: municipal solid waste compost (MSWC), and aerobic (AES) and anaerobic (ANS) sewage sludge. MSWC was produced in the facilities in Valdemingómez by composting the organic fraction of MSW from the metropolitan area of Madrid. Aerobic sewage sludge (AES) and anaerobic (ANS) sewage sludge were collected from wastewater treatment plants. After generation, the AES underwent only an air-drying process, whereas the ANS was treated in digesters with no added oxygen. Table 2 shows the chemical properties of the organic amendments. The heavy metal levels in all the organic amendments used in the experiment were below the limits established by European legislation (European Commission, 1986).

2.2. Field experiment

Three randomised complete blocks were established with three replicates. Four soil plots (10 × 15 m) were designed on each block to contain the treatments: three types of organic amendments (MSWC, AES and ANS) as cited above, and an un-amended control (CONT) (Fig. 1). The rate was 160 Mg ha^{-1} (dry mass) in a single application. This amount was selected in view of the fact that in our previous experiment (González-Ubierna et al., 2013) we found significant effects on some soil properties compared to lower doses. The organic amendments were applied and mixed with the topsoil using a rotary tiller to a depth of 20 cm. The application took place in the spring of 2010, and

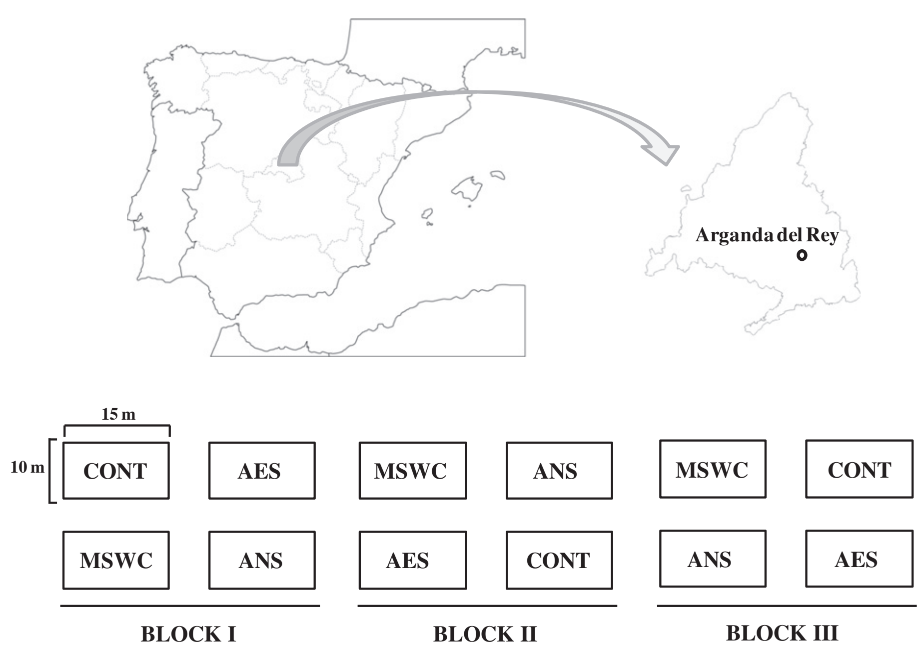

Fig. 1. Study area and experimental plots.