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Monitoring of nitrate leaching during flush flooding events in a coarse-textured floodplain soil

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ABSTRACT

The demand for foods in central Chile is increasing and arable land is expanding rapidly onto floodplain soils, which are being cleared for maize cultivation. After harvest, a significant amount of residual nitrogen (N) may be still present in the soil in autumn–winter, when a high risk of nitrate leaching (NL) is expected due to occasional flooding events. Determining nitrate (NO_3^-) movement through the vadose zone is essential for studying the impact of agricultural practices on surface water quality. This study focused on understanding the processes of NO_3^- leaching in a floodplain environment and compared the effectiveness of four different methods: soil coring (T0), an observation well (T1), ceramic suction cup lysimeters (T2) and a capillary lysimeter (FullStop^{TM} wetting front detector) (T3) for monitoring NL using an infiltration cylinder to simulate the conditions generated during flush flooding events during autumn–winter season in a typical coarse-textured alluvial floodplain soil. The comparison showed that T0 and T3 can be used for monitoring NL during flush flooding events during autumn–winter season in stratified coarse-textured floodplain soils, whereas T1 and T2 are not appropriate for these site conditions. A correlation was found between NO_3 and soluble salt (Cl^- concentration and EC) only in the first measurements after the dry summer period. The results of this study suggest that most of the surplus N could be leached by excessive irrigation during the crop growing season (spring–summer), while a lower amount of residual N may still be present in the soil in autumn–winter available to be lost by NL during flush flooding events. Overall the two monitored flushing events could have leached around 6% of the total NO_3–N load. There was no significant effect of sampler devices on saturated hydraulic conductivity.

1. Introduction

Maize (*Zea mays* L.) is the most important crop in the O'Higgins Region of central Chile, covering 47,419 ha during the growing season 2011–2012. It is cultivated mainly on flat soils located in alluvial terraces (Casanova et al., 2013), under furrow irrigation systems during spring–summer (September–April). However, demand for food is increasing and arable land is expanding rapidly to soils with limitations, with e.g. floodplain soils having been cleared for maize cultivation. These production systems normally use high nitrogen (N) fertilisation rates (350–560 kg N ha^{-1}), together with low irrigation efficiency (<45%). Moreover, on average 200 kg N ha^{-1} are not taken up by the maize and are susceptible to leaching if water percolates through the soil profile (Salazar and Nájera, 2011). Although it is possible for a substantial amount of applied N to be leached by excessive irrigation during the crop growing season (spring–summer) (Gehl et al., 2006), a significant amount of residual N may still be present in the soil in autumn–winter, posing a high risk of nitrate leaching (NL) during the fallow period.

Maize production in Chile is mainly located in the central zone, under Mediterranean climate conditions with most rainfall falling in autumn–winter. Thus streams have a snow-pluvial regime, where floodplain soils can be occasionally flooded following intensive rainfall events. Under these conditions, NL monitoring is a complex task, particularly on coarse-textured floodplain soils, where water movement mainly occurs under unsaturated conditions with occasionally saturated flow during flush flooding events.

Noe (2013) noted that the biogeochemistry of N cycling in floodplain soils is very sensitive to spatial and temporal variations in hydrogeomorphology, in particular floodplain wetness and sedimentation. In their natural state, floodplain soils are an effective nitrate (NO_3) sink throughout the whole year when permanent vegetation covers the area, by protecting the surface water from large nitrate (NO_3^-) inputs irrespective of season (Lewandowski

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and Nützmann, 2010). Floodplains can favour NO_3^- removal by creating sites of high denitrification when intermittent flooding provides the anaerobic conditions necessary for denitrification to occur (Fellows et al., 2011; Shrestha et al., 2012). However, during this process there may be some release of nitrous oxide (N_2O), which is a powerful greenhouse gas (GHG) and the single most important depleter of stratospheric ozone (Butterbach-Bahl et al., 2013). There is thus particular concern about the effects of land use change on floodplain soils, as the alteration in N balance may convert the floodplain into an important nonpoint source of N pollution to surrounding water ecosystems (Krause et al., 2008). For instance, the NO_3^- abatement function of the cultivated floodplain can be lost during fallow, with flood events directly moving NO_3^- down to the shallow groundwater. However, few studies have evaluated the N dynamics in floodplain soils with short hydroperiods (1–3 days of inundation) (Noe and Hupp, 2007; Huber et al., 2012), so the links between NL and water flow dynamics in these particular soils are unclear.

Monitoring and quantification of NL below the root zone can determine the contribution of agricultural practices to NO_3^- contamination of surface and subsurface water bodies, but NL is difficult to measure without disturbing the soil (Webster et al., 1993). Different methods have been employed for monitoring and quantifying NL in coarse-textured soils and different advantages and disadvantages have been reported, depending on interactions with the soil solution, the heterogeneous nature of soils, the range of water tensions and the frequency of sampling (Litaor, 1988; Fares et al., 2009). Nieminen et al. (2013) divided these methods into non-destructive and semi-destructive. Non-destructive methods involve the installation of a soil solution collector (tension lysimeters) that samples the soil solution at the same location over time, whereas semi-destructive sampling concerns zero-tension lysimeters, the installation of which can cause major, long-term changes to the soil hydrology and aeration of the sampling point. The methods can also be broadly divided into active sampler methods, such as soil coring, ceramic suction cups and observation wells, which need action by an operator to obtain a sample, and passive samplers, such as capillary lysimeters, which usually have a small cavity in the base where free water can be automatically stored for later sampling. A number of studies have compared the effectiveness of these methods for evaluating NL in coarse-textured agricultural soils (Barbee and Brown, 1986; Webster et al., 1993; Gehl et al., 2005; Zotarelli et al., 2007; Arauzo et al., 2010; van der Laan et al., 2010; Wang et al., 2012), but did not consider the dynamics of soil–water–NO_3^- interactions in floodplain soils within short hydroperiods. It is also important to evaluate how the setting of these sampling methods affects water percolation and thus the downward movement of NO_3^- in the soil profile, which can be assessed by measuring changes in saturated hydraulic conductivity (K_s).

In addition, methods based on concentration of ions can be used to study flow paths, reactions between soil and solute, and groundwater recharge (Allison et al., 1994). One of most widely used is the chloride (Cl^-) concentration profile method, because in most soils Cl^- acts as a tracer since it moves with water in the soil (Lo Russo et al., 2003; Rasiah et al., 2005; Huang et al., 2013). Some of these conservative salt concentration methods, such as Cl^- and electrical conductivity (EC), are easier to determine than NO_3^- and may be used to identify the risk of NL in coarse-textured soils.

It is important to note that a key step in assessing the impact of residual N in coarse-textured cultivated floodplain soils on water quality would be to monitor and quantify its NL potential through a suitable technique that allows soil solution samples to be taken during flush flooding events. Fares et al. (2009) concluded that accurate sampling and analysis of the soil solution can provide an early warning of potential groundwater contamination. Thus best management practices to enhance water quality in floodplain soils should be evaluated in terms of minimising the risk of NO_3^- contamination along waterways in the O'Higgins Region of central Chile.

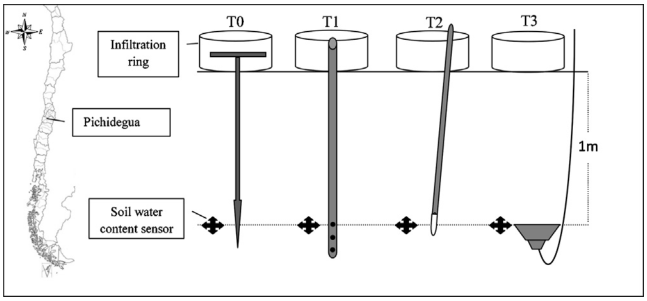

Fig. 1. Location of the Pichidegua experimental site in central Chile and method layout in a microplot.

The overall aim of the present study were to understand the processes of NO_3^- leaching in a floodplain environment and to evaluate four different methods: soil coring, an observation well, ceramic suction cup lysimeters and a capillary lysimeter (FullStop^{TM} wetting front detector) for monitoring NL using an infiltration cylinder to simulate the conditions generated during flush flooding events during autumn-winter season in a typical coarse-textured alluvial floodplain soil. Specific objectives were: (i) to evaluate if conservative salt measurements, such as Cl^- and electrical conductivity (EC), may be used to identify the risk of NL; (ii) to quantify the NL during flush flooding events using FullStop^{TM} wetting front detector and (iii) to evaluate the effects of the sampler devices installation on water percolation by measuring K_s in a typical coarse-textured alluvial floodplain soil.

2. Materials and methods

2.1. Site description

The study site was located in the Pichidegua commune, O'Higgins Region (34°22′S, 71°25′West, altitude 124 m a.s.l.) in central Chile (Fig. 1). The soil was prepared using a disc plough in September 2011 and maize was sown in October 2011 and harvested in early April 2012. The grain yield was 15 Mg ha^{-1} and maize stalks were removed from the experimental area. During the growing season, 470 kg N ha^{-1} were applied as urea and compound fertiliser ($N–P_2O_5–K_2O$: 25–10–10), and a N balance estimated 200 kg N ha^{-1} surplus were available for NL. This study was carried out during autumn–winter (April 2012–August 2012) after harvest of the maize, when the field was fallow.

The climate in the study area is classified as temperate with dry, warm summers, corresponding to Csb according to the Köppen–Geiger system (Peel et al., 2007). The mean annual temperature at the site is 14.1 °C and mean annual precipitation is 696 mm (Santibañez and Uribe, 1993). The rainfall distribution is strongly seasonal, with 75% falling in the winter months. The experimental field was located near the Tinguirica river (300 m north), where occasional flooding events with short hydroperiods occur during intensive precipitation events in winter. Climate data (i.e. precipitation, temperature, etc.) were obtained from a weather station located 2 km north-east of the experimental site, which also provided the weather data needed to calculate reference evapotranspiration (ETo) according the FAO Penman–Monteith combination equation (Allen et al., 1998).