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Investigating nitrate dynamics in a fine-textured soil affected by feedlot effluents

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ABSTRACT

Feedlots concentrate large volumes of manure and effluents that contain high concentrations of nitrate, among other constituents. If not managed properly, pen surfaces run-off and lagoons overflows may spread those effluents to surrounding land, infiltrating into the soil. Soil nitrate mobilization and distribution are of great concern due to its potential migration towards groundwater resources. This work aimed at evaluating the migration of nitrate originated on feedlots effluents in a fine-textured soil under field conditions. Soil water constituents were measured during a three-year period at three distinct locations adjacent to feedlot retention lagoons representing different degrees of exposure to water flow and manure accumulation. A simple statistical analysis was undertaken to identify patterns of observed nitrate and chloride concentrations and electrical conductivity and their differences with depth. HYDRUS-1D was used to simulate water flow and solute transport of Cl^-, NO_4^+—N, NO_3^-—N and electrical conductivity to complement field data interpretation. Results indicated that patterns of NO_3^-—N concentrations were not only notoriously different from electrical conductivity and Cl^- but also ranges and distribution with depth differed among locations.

A combination of dilution, transport, reactions such as nitrification/denitrification and vegetation water and solute uptake took place at each plots denoting the complexity of soil-solution behavior under extreme polluting conditions.

Simulations using the concept of single porosity-mobile/immobile water (SP-MIM) managed structural controls and correctly simulated $^-$all species concentrations under field data constrains. The opposite was true for the other two locations experiencing near-saturation conditions, absence of vegetation and frequent manure accumulation and runoff from feedlot lagoons.

Although the results are site specific, findings are relevant to advance the understanding of NO_3^-—N dynamics resulting from FL operations under heavy soils.

1. Introduction

Historically, beef cattle production has been one of the traditional activities and significant support to the economic growth of Argentina (Guevara and Grünwaldt, 2012). Until the 1990s, 100% of cattle were grazed in rangeland. Towards the end of the 1980s, a steady increase in soybean planting started competing for land with the meat industry. Cattle were either displaced from traditional production areas in Argentina's Pampa plains to other regions of the country or raised in confined cattle operations (feedlots-FL) (Arelovich et al., 2011). Due to flawed legislation and environmental controls, the rapid growth of FL activities has generated environmental concerns because of the potential point and diffuse source of pollution these establishments may produce.

FLs concentrate large volumes of manure by-products and effluents vulnerable to weathering if not properly managed. Manure accumulated on the surface of pens is periodically removed and temporarily placed in stockpiles. Waste retention lagoons are common systems to hold FL effluents (Pordomingo, 2003). However, wastes not promptly removed from corrals or managed within FLs are subject to environmental factors; inadequate maintenance of retention lagoons may cause unwelcome environmental consequences to soils and groundwater surrounding these structures. Pen surfaces and stockpiles-generated run-off and lagoons overflows may spread solid and liquid effluents to surrounding land (Veizaga, 2015).

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Manure solutions resulting from surface runoff after precipitation events are composed of dissolved organic matter, nutrients, salts, antibiotics, and heavy metals, among other constituents (Sweeten, 2000; Pepple et al., 2011; García et al., 2012). Soil nitrate mobilization and redistribution in the profile are of great concern due to its potential migration towards groundwater resources.

Many pioneering studies in the 70s have focused on the characterization of soil and soil water underneath FL pen surfaces and their relation to hydrological and biogeochemical processes. These works reported little nitrate ($NO3^{-}$—N) mobilization below FL due to lack of infiltration (Mielke et al., 1974; Mielke and Mazurak, 1976) and high concentrations in the first 15 cm of the soil profile during the summer season that enhanced nitrification processes (Elliott et al., 1972). Lack of $NO3^{-}$—N presence in the subsoil was attributed to the loss of nitrate via denitrification processes.

However, more recent works have focused on the leaching and distribution of salts and nutrients deep in the soil profile and surrounding groundwater as a result of the long-term operation of FLs. Maulé and Fonstad (2000, 2002) found that 50% to 67% of sampled groundwater near five 25- to 35-year-old feedlots in central Saskatchewan (Canada) had elevated concentrations of solutes due to the presence of manure but cautioned about the use of NO_3^-—N as a reliable indicator of manure seepage due to its no-conservative nature subject to biological transformations (Maulé and Fonstad, 2002). A different pattern of the distribution of nutrient elements (nitrogen, phosphorus, potassium) and some of the elements participating in soil cation exchange have been reported below FL soils. Olson et al. (2005) found that while nutrients concentrations were significantly affected only in the top soil layer (0.15 m) of a FL in southern Alberta (Canada), remarkable increases in other soil properties were observed at a depth of 0.6 m with chloride reaching its maximum concentration at a depth of 1.5 m. Chloride accumulation in the soil profile due to leaching was also reported by other studies in the same geographical region for moderately fine and coarse soils up to a depth of 70 cm and 50 cm, respectively (Miller et al., 2008).

A growing need to investigate the chemical composition and transformation processes of waste from FL operations has driven new research. Recent studies reassessed the potential for leaching into the soil profile. Vaillant et al. (2009) observed a notable reduction in ammonium, organic nitrogen, carbon and chloride below one-meter depth in the soil profile.

Chloride (Cl^{-}) content in FL manure is considerably greater than in soils, and can be considered as an indicator of potential movement of nitrates due to their similarity in mobility and solubility (Tyler and Thomas, 1977). It is a stable, soluble anion not affected by biological processes. These properties make it an appropriate candidate for processes understanding and comparison with the complex dynamics of nitrate in soils below FL (Kachanoski et al., 1992; Czapar et al., 1994; Schuh et al., 1997; Lobb et al., 1999; Derby and Knighton, 2001). However, the behavior of NO_3^-—N in the unsaturated zone or groundwater varies widely from site to site. Consequently, the choice of monitoring sites becomes crucial to analyze the suitability of Cl^{-} as a proxy for NO_3^--N evaluation in environments that have a strong polluting activity (Baram et al., 2012a).

Flow and solute transport modeling are often used to complement field studies to gain additional insights from process-based simulations (Hanson et al., 2006; Mantovi et al., 2006; Crevoisier et al., 2008; Saso et al., 2012). Those investigations used numerical simulations to assess unsaturated flow and solute transport for Cl^{-} and nitrogen (N) under controlled flow and irrigation regimes, while Ramos et al. (2011) extended their research to integrate field-modeling studies for multicomponent solute transport for nitrogen. For the above studies near saturation moisture conditions of the soil profile were reached, facilitating in turn, monitoring activities, water sample collection, and numerical model result interpretations. Only more recent studies undertook field-scale experiments and modeling under real meteorological forcing within feedlot premises (Olson et al., 2005; Miller et al., 2008; Vaillant et al., 2009) and dairy farm facilities (Baram et al., 2012a, 2012b).

In the Argentine Pampas region, field investigations were recently undertaken to assess solute distribution in soils in FL pens and adjacent land affected by runoff. High concentrations of chloride at 20 cm depth were found at FL sites when compared to adjacent soils non-affected by trampling, highlighting the role of water runoff in this ambient (Wyngaard et al., 2012). These authors extended their investigation to assess whether the high concentration of these compounds, mobilized by surface runoff from FL pens, promotes movement through the soil to deeper horizons. Changes in inorganic N concentrations, urea content, urease activity in the soil up to 60 cm depth were evaluated across a topographic transect from high to low ground in an FL and adjacent pasture land. The effect of topographic location on the distribution of nitrogen species in the soil profile was profound with NH_4^+—N showing its peak between 40–60 cm depth and NO_3^-—N at a depth of 10 cm for the lower and higher topographic locations. Nonetheless, there is a lack of combined field and numerical modeling investigations to assess the fate and transport of nitrogen, and in particular NO_3^-—N—N, in an FL under natural forcing. Scarce studies on Argentina's Pampa plains soils limit the knowledge and capacity to inform suitable management strategies to mitigate negative impacts from FL operations.

The objective of the present work is to contribute towards the above issue by evaluating the transport and transformation processes of nitrate originated on FL effluents within a fine-textured soil. Several soil water constituents were measured during a three-year period at three distinct sites adjacent to effluents retention lagoons and temporary water ponding areas. The sites were carefully selected to investigate how different flows of water and manure solution accumulation on the surface affect the distribution of nitrate in the soil profile.

HYDRUS-1D was used to simulate water flow and solute transport resorting to the concept of mobile/immobile water (MIM) for solute transport of Cl^{-}, NH_4^+—N, NO_3^-—N concentration and electrical conductivity (EC). The analysis and interpretation of results focused on identifying: 1) the quantitative differences between plots, 2) the vertical variations, mean values, and range of the aforementioned variables; and 3) first-order controls on observed NO_3^-—N distribution in the soil profile.

2. Materials and methods

2.1. Site characteristics

The investigation was carried out in an FL establishment located 5 km north of San Justo city in the Province of Santa Fe, Argentina (30° 47′ 21″, 60° 35′ 31″) with a maximum of 9000 animal holding capacity, distributed within 33 pens that occupy 11.4 ha.

The climate in the area is temperate, with an average annual precipitation of 1057 mm (Series 1920–2011, National Institute of Agricultural Technology — INTA). Winter months (June to August) are the driest, with 40% of the annual precipitation falling in the summer months (January to March). The average minimum and maximum temperatures are 12 °C and 26 °C for the winter and summer season, respectively.

The study region is characterized by highly productive soils and an intense agricultural-livestock activity. Soil characteristics across the area correlate well with the landscape geomorphological units. At the FL and surrounding lands, soil is classified as Typic Argiudol in highland areas to Natracualf in lowland areas.

2.2. Experimental design

A detailed topographic survey performed at the feedlot premises allowed to identify the most suitable spots for water-manure solution investigation. The selected area corresponds to a topographically low zone around the effluents retention lagoons (Fig. 1). A soil pit 130 cm deep was excavated to describe soil horizons and extract disturbed