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# Water and chloride transport in a fine-textured soil in a feedlot pen

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ABSTRACT

Cattle feeding in feedlot pens produces large amounts of manure and animal urine. Manure solutions resulting from surface runoff are composed of numerous chemical constituents whose leaching causes salinization of the soil profile. There is a relatively large number of studies on preferential flow characterization and modeling in clayed soils. However, research on water flow and solute transport derived from cattle feeding operations in fine-textured soils under naturally occurring precipitation events is less frequent. A field monitoring and modeling investigation was conducted at two plots on a fine-textured soil near a feedlot pen in Argentina to assess the potential of solute leaching into the soil profile. Soil pressure head and chloride concentration of the soil solution were used in combination with HYDRUS-1D numerical model to simulate water flow and chloride transport resorting to the concept of mobile/immobile—MIM water for solute transport. Pressure head sensors located at different depths registered a rapid response to precipitation suggesting the occurrence of preferential flow-paths for infiltrating water. Cracks and small fissures were documented at the field site where the % silt and % clay combined is around 94%. Chloride content increased with depth for various soil pressure head conditions, although a dilution process was observed as precipitation increased. The MIM approach improved numerical results at one of the tested sites where the development of cracks and macropores is likely, obtaining a more dynamic response in comparison with the advection–dispersion equation.



## 1. Introduction

Argentina's economy relies strongly on exports of agricultural and livestock production. Three decades ago, cattle grazing occurred almost exclusively on vast grasslands extending mainly in Argentinean Pampas region. However, during the nineties there was a remarkable agricultural transformation driven by the adoption of transgenic crops under the no-tillage system (Pengue, 2005). This transformation caused an increase of crop-covered land and the reduction of the land devoted to grazing, giving rise to feedlot activities. It is estimated that in 2009, 30% of all consumed and exported bovine meat came from feedlot establishments.

Cattle feeding in feedlot pens produces large amounts of manure and animal urine. Manure solutions resulting from surface runoff after precipitation events are composed of dissolved organic matter, nutrients, salts, antibiotics and

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heavy metals, among other constituents (García et al., 2012). Early scientific contributions regarding feedlot activities focused on the potential impact on groundwater pollution by direct measurements of salt and nitrogen species concentration in water samples (Stewart et al., 1967; Mielke et al., 1970; Lorimor et al., 1972; Elliott et al., 1972; Smith et al., 1980). The studies conducted by Dormaar and Sommerfeldt (1986), Smith et al. (2001) and Olson et al. (2005) focused on nitrate groundwater pollution derived from manure application over agricultural soils. The environmental impact of livestock production has been extensively addressed for water and surface soil quality (Steinfeld et al., 2006). Nevertheless, the effect of manure solution leaching on the increase of salt content in the profile of fine-textured, highly productive soils has received less attention.

Fine-grained clay soils are prevalent in irrigation agriculture in many parts of the world. In vast extensions of the Argentinean Pampas, soils silt and clay fractions combined exceed 85%, being greater than 95% in some places (Castiglioni et al., 2005; Imhoff et al., 2010) resulting in highly productive soils due to their high nutrient content and water holding capacity. However, serious difficulties arise for solute transport assessment due to the combination of low saturated hydraulic conductivity, high bulk density, and the formation of desiccation cracks under unsaturated conditions (Chertkov and Ravina, 1998; Parker et al., 2001).

Feedlot operations in fine-textured soils introduce further complexity in the soil–water dynamics and the resulting solute transport that has not been extensively studied, especially in Argentina. Manure accumulation on the ground and livestock trampling lead to physical changes in the soil profile of feedlot pens. These changes, in turn, cause an increase in bulk density in the top horizons and constant soil moisture in the lower horizons (Mielke et al., 1974). This situation, as a result, modifies the dynamics of surface and subsurface water flow after precipitation events as large volumes of manure and animal urine are transported outside the pens into adjacent soil parcels via surface runoff (García et al., 2012). Those hydrological processes may be highly influenced by the soil clay content, prone to the presence of preferential flow paths due to alternating swelling/cracking in response to wetting/drying natural conditions.

Besides laboratory investigations and experimental plots, numerical modeling became a standard tool to assess the impact of agricultural/farm activities on soils and groundwater pollution. Hanson et al. (2006), Mantovi et al. (2006) and Crevoisier et al. (2008) have used numerical simulations to assess unsaturated flow and solute transport for chloride ($Cl^-$) and nitrogen under controlled irrigation regimes which provide a few examples of the above. Bouma (1981), Booltink and Bouma (1991), Greve et al. (2010) and Ventrella et al. (2000) have contributed to preferential flow characterization and modeling in fine-texture clayed soils under controlled irrigation conditions. These studies present some advantages by commonly reaching near saturation moisture conditions of the soil profile, thus facilitating monitoring activities and water sample collection. Instead of controlled water application conditions, Olson et al. (2005), Vaillant et al. (2009) and Miller et al. (2008) conducted field-scale experiments within feedlot premises or dairy farm premises (Baram et al., 2012a,b) under meteorological forcing. In Argentina, García et al. (2012) and Wyngaard et al. (2012) advanced in the chemical characterization of soil water on soil impacted by feedlot effluents without testing with modeling tools.

The randomness of precipitation events does not pose major difficulties in continuous data recording on the field scale. However, this can be challenging for in-situ soil water sampling. Some precipitation events, combined with low antecedent soil moisture, may not be enough to wet the soil profile favoring the migration of soil water into sample collection devices such as suction cup lysimeters. This is of particular relevance in fine-textured soils where soil moisture and solute transport in the profile are highly dependent on precipitation characteristics (Helling and Gish, 1991; Flury et al., 1994; Jacques et al., 2002). Baram et al. (2012a) demonstrated a large migration of nitrates in clayey soils under precipitation events due to preferential infiltration channels in a dairy farm enterprise. They also found that temporal variations in water content were largely associated with significant precipitation events.

This work investigates and documents the dynamics of water flow and leaching of a non-reactive solute through the unsaturated zone on a very fine-textured soil adjacent to a feedlot pen. The study site selected is located between a pen and a waste disposal lagoon representing transitional conditions. Water infiltration occurs under both natural precipitation conditions and water ponding conditions. Based on field data and numerical modeling, this work aims to address the following question: how do antecedent moisture and precipitation characteristics determine the migration of the non-reactive solute through 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 $Cl^-$ concentration in order to represent preferential flow patterns that may develop on fine-textured soils.

## 2. Materials and methods

### 2.1. Study area

The study site corresponds to an active feedlot located 5 km north of San Justo city in the Province of Santa Fe, Argentina (Fig. 1). The feedlot has been in continuous operation for over the last 13 years, and it occupies 11.4 ha holding up to 9000 cattle in 33 pens. Pens are oriented east–west, each with a size of 40 m by 70 m.

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 minimum and maximum mean temperatures are 12 °C and 26 °C for the winter and summer season, respectively.

Feedlot activities take place on a transitional undulating land surface located between high flat areas of the landscape (average slope 0.05%) and flat lowland areas of the Salado River floodplain (Fig. 1). Soil characteristics across the area correlate well with geomorphological units of the landscape, from Typic Argiudoll on the Highland to Natracualf to the lowland areas of the Salado River floodplain (INTA, 1992).

Runoff washes pens surface producing a manure solution that is collected into surface channels near the