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Bulk electrical conductivity as an indicator of spatial distribution of nitrogen and phosphorous at feedlots

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ABSTRACT

The increasing demands of producing beef for domestic and international consumption is leading to the development of feedlots in Argentina. Unfortunately, the great amount of manure produces leachate of nitrates and other ions which may affect groundwater quality. The objective of this paper was to identify the spatial distribution of bulk electrical conductivity (EC_b) of non-saturated zone and its association with variability of nitrates and bioavailable phosphorous, water content, topography and electrical conductivity of saturated paste extract (EC).

The analysis of the impact was done at two pens with different time of confinement of the animals (Pen1 and Pen 2, with 16 months and 7 years of animal occupation, respectively). The initial exploration phase was done by electrical resistivity tomography (ERT) and electromagnetic induction (EMI) surveys were subsequently performed at a subarea for studying the spatial distribution of EC_b. A grid of soil sampling up to 1 m depth was done at the same subarea of the EMI survey. A geostatistical interpolation of data was performed in order to map EC_b, water content, nitrogen, bioavailable phosphorous and EC.

Anomalies of higher conductivity (between 6 and 10 times the background values) were found near the feedbunk and the water trough, being greater on soils with larger period of manure recharge. Water content, nitrogen of nitrates (N-NO_3^-), bioavailable phosphorous ($P_{avail.}$) and EC showed patterns of spatial distribution similar to EC_b. These patterns are mainly associated with the runoff movement of water to the lower zones in the case of a steeper slope and the soil compaction as in the Pen 1. In the Pen 2, the patterns of spatial variability are similar for EC_b and water content while anomalies of high EC_b were found along an abandoned feedbunk. High values of N-NO_3^-, P_{avail}. and EC were found at this site. A longer period of manure recharge resulted in higher values of nitrogen and bioavailable phosphorous in soils.

It may be stated that bulk electrical conductivity was a good spatial indicator of water, nitrogen and bioavailable phosphorous in sandy loamy soils in these pens for the investigation depth of 1 m. The bulk conductivity seems to be primarily associated with water content which is the path of transport of ions through the porous medium. In all the cases, the major contents of nitrogen and bioavailable phosphorous in the soil were associated with high bulk electrical conductivity when water content was above an equivalent depth of water of 100 mm. The soil moisture status should be taken into account before an electromagnetic exploration for detecting soil contamination. Regarding the impact on groundwater pollution, the proximity of the water table to the surface seems to be more influential than the animal stocking rate for a longer period.

1. Introduction

The increasing demands of producing beef for domestic and international consumption is leading to the development of feedlots which are farms where animals are fed and raised inside pens. The production of beef cattle in feedlots, an increasing activity in Argentina, brings out the problem of the generation of large amounts of manure. Once this organic matter is mineralized, ions such as nitrates and phosphates, among others, may leach with rain events, through infiltration in the unsaturated zone. The ion nitrate is highly mobile in the soil; in the rural region, several studies reported higher impact of the manure on NO_3^- leaching and contamination of groundwater compared with inorganic fertilizer (Basso and Ritchie, 2005; Choi et al., 2007; Sims et al., 2005). Even if the movement of phosphorous (P) depends on soil's sorption capacity, some agricultural management practices and climatic conditions may result in P accumulation in subsoil and in its leaching to

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groundwater (Heredia and Fernández Cirelli, 2007). Moreover, the impact of feedlot activity may be particularly problematic in sandy soils where groundwater recharge may easily occur through non saturated zone with high hydraulic permeability.

To evaluate the environmental impact within a particular feedlot and to make management decisions about the control of nutrient runoff and leaching, it is necessary to know the spatial distribution of soil properties, including concentration of main contaminant ions. This knowledge is important to locate lagoons of effluents or vegetative treatment areas around the pens utilized to control superficial runoff, mainly through the absorption of nutrients by plants (Koelsch, 2005). It is also important to know where the highest concentrations of soil nutrients are located, to analyze the impact on groundwater. Some studies have been done to identify spatial variability and dynamics of nitrates and phosphorus in soil and groundwater (Ojekami et al., 2011; Pena-Yewtukhiw et al., 2009). Usually, these studies require a great number of soil samples at different depths, which are operatively difficult and cost prohibitive to obtain. Alternatively, geophysical exploration is being progressively used in the agricultural field albeit not so often at environments of cattle production with high contents of soil organic matter.

Electrical and electromagnetic induction (EMI) methods are based on the measurement of bulk electrical resistivity or conductivity (EC_b).These methods are rapid, cost effective and noninvasive. EC_b is a consequence of highly complex interactions of soil physical and chemical properties, as texture (for instance, clay content), cation exchange capacity, organic matter, and soil water content (Alldred et al., 2008). Water content and electrical conductivity of the soil solution are the major factors affecting its bulk electrical conductivity (Friedman, 2005).

The calculation of correlation coefficients between EC_b obtained from EMI measurements and values of soil properties has been successfully used in agriculture to understand the contribution of each of them, and to determine the properties that are spatially represented by the EC_b–directed sampling design (Alldred et al., 2008). However, the relationship between EC_b and these variables depends on soil and environmental additional attributes which often need site specific calibrations. It is necessary to understand what factors are most significantly influencing the measurements of EC_b within the field of study, to use spatial distribution of EC_b to make management decisions. Sudduth et al. (2005) related bulk electrical conductivity EC_b obtained with electromagnetic induction and electrical surveys with soil properties on 12 fields in 6 states of the north-central United States. High correlations of EC_b with clay content and cation exchange capacity were found while other soil properties as soil moisture, contents of silt, sand, organic carbon and electrical conductivity of saturated paste extract (EC) were strongly related in some studied fields but not in others.

During the last years, some electrical and EMI measurements have been done at sites of cattle production. The EC_b obtained through electrical resistivity tomography (ERT) has proved to be sensitive to soil salinization produced by mineralization of organic matter from manure and the subsequent groundwater contamination. Sainato et al. (2010) found, by means of ERT at a dairy in Argentina, anomalies in the distribution of EC_b associated with an increase of nitrates, sulphates and bioavailable phosphorous in soil and, in addition, chlorides in groundwater. In all cases, these high concentrations were probably related directly or indirectly to the animal wastes. Sainato et al. (2012) observed that ERT was sensitive to the detection of leachate of animal wastes below the pens of a feedlot, through the presence of bulk conductivity anomalies in non saturated and saturated zone. These results were associated with an increase in concentrations of sulphates, chlorides, potassium and nitrates due to urea, manure and animal diets. On the other hand, Eigenberg and Nienaber (2003), Woodbury et al. (2009), among others, carried out EMI studies in terms of correlations with soil properties and different ion concentrations of soil solution at sites of accumulation of animal manure. Eigenberg et al. (2005) applied electromagnetic soil surveys for locating areas of nutrient buildup at cattle feedlots.

In addition, De Neve et al. (2000) proved EC_b was good for monitoring N mineralization from organic matter (OM). In general, EC_b and OM have positive correlation (Alldred et al., 2008); on the other hand, Johnson et al. (2001) reported negative correlation between EC_b obtained with resistivity methods and OM; a general conclusion is that relations with soil properties may be very site-dependant (Johnson et al., 2001).

Preliminary results of ERT soundings obtained by Márquez Molina and Sainato (2010), at pens with different time of animal confinement, showed great variability in soil properties and some moderate classical correlations of the resistivity with the water content and nitrates concentrations. The study was integrated with deep samplings at different topographic positions. These results were important to find out that nitrates concentration was partially influenced by water content and that high concentrations may be found at depths close to water table. But it should be noted that it is relevant to know the spatial variability of soil properties, especially those nutrients which may be contaminants for superficial water bodies or groundwater. In particular, the influence of topography, characteristics of the soil and time of animal confinement (recharge of OM), are significant to make management decisions, even to apply the manure as an alternative for fertilization.

The objective of this paper was to identify the spatial distribution of EC_b at non-saturated zone and its association with variability of nitrogen of nitrates ($N\text{-}NO_3^-$), bioavailable phosphorous ($P_{avail.}$), water content, soil electrical conductivity of saturated paste extract and topography, at pens with different time of animal confinement. The intention of this work was to improve previous investigations carried out in these soils with high OM content, with the joint application of two geophysical methods applied at the same area: electrical resistivity tomography (ERT) and electromagnetic induction (EMI) surveys. It was also determined the influence of different period of accumulation of manure and OM levels (time of confinement of animals) on groundwater contamination.

The idea was to perform a systematic approach including a great number of soil data and geostatistical analysis to study spatial variability of soil properties and evaluate the prediction for locating critical zones by means of EC_b. This approach might be taken as a tool to make management decisions to reduce environmental impact of feedlot activity, which may be also applicable to other sites with similar levels of OM, soil texture and climatic conditions.

2. Methods

2.1. Description of the study site

The study site was a feedlot farm at the vicinity of Trenque Lauquen, at the W-NW of Buenos Aires Province, Argentina (Fig. 1). The farm is located at the region of the Chaco Pampeana plain. For this study, two pens at the same regional topographical elevation were selected, shown in Fig. 1: the Pen1 with an incipient activity (16 months of animal occupation at the moment of the survey) and Pen 2 with longer time of confinement of animals (7 years).

At the zone, the precipitations are around 900 to 950 mm per year. During humid periods, the elevation of water table may generate floods at the lower zones, and at drought periods the decrease of precipitation may produce great decrease of water table (Kruse et al., 2005). From the hydrological point of view, the study zone has practically no superficial watercourses and there is a predominance of vertical movement of water (precipitation, evaporation and infiltration) over the horizontal one.

Heredia et al. (2009) classified these soils as sandy loam through trenches up to 1.5 m deep made in both pens and background sites. These authors found that soil texture has similar clay contents at all the horizons explored. In background sites, values of 0.75 % were observed for oxidable carbon (OC) obtained by Walkley-Black technique (Page, 1982) while, at the pens, values range from 1 to 3.5 %; in all the cases, high OC was associated with an increase of soil water content. At pen 1, there is a hard compacted layer between 5 and 9 cm depth as consequence of manure accumulation and animal trampling. The