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Light acidification in N-fertilized loess soils along a climosequence affected chemical and mineralogical properties in the short-term

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ABSTRACT

Some evidences indicate that N-fertilization of crops decreased pH values of loess soils of the Argentinean Pampas in the last decades. We analyzed the A-horizons of four N-fertilized (F) and non-fertilized (NF) paired soils, developed on similar parent materials, within a climatic sequence (ustic to udic water regimes), and measured: 1) the extent of pH changes, 2) how these changes affected chemical and mineralogical soil properties and 3) how the soils, according to their H^+ buffering substances, can react in the future if N-fertilization and acidification continue. Results indicated that all F- and NF soils were lightly acidified (differences between pH_W and pH_{KCl} higher than 1.0) and that fertilization produced pH decreases in all studied soils, but particularly in those with udic water regimes, in agreement with their longer N-fertilization histories. Fertilized ustic soils showed less crystalline illites and kaolinites and higher contents of amorphous Al oxides than NF soils. It remains unclear if the higher contents of amorphous Al are related with the dissolution of phyllosilicates, the transformation of the abundant volcanic glasses of these soils or both processes at the same time. The cation exchange capacity (CEC) and the percent of base saturation (V) did not change between F- and NF soils, probably due to the large influence of soil organic matter (SOM) in the studied soils. If N-fertilization, and consequently pH decreases continue, soils placed in both the moistest- (Argiudolls) and the driest extremes of the climosequence (Haplustolls) would be the less affected. This is because udic soils contain high SOM as well as illitic clays and silts while ustic soils contain free lime and high density charged clay minerals, which have high H^+ neutralization capacity. The most affected soils by acidification should be those placed in the intermediate zone of the climosequence (Hapludolls), which have low amounts of substances with high buffer capacity.

1. Introduction

Soil acidification has been mostly studied in soils of tropical and subtropical regions where natural conditions are the main driving factors of this process (Hulugalle, 1992; Eppinger and Fuge, 2009; Vendrame et al., 2013). Anthropogenic acidification has been also detected in highly industrialized regions, being acid rains its primary cause (Drever, 1997; Mather et al., 2004). Less information is available on soil acidification produced by continuous N-fertilization which seems to be occurring in agricultural loess soils of the Pampas of Argentina. In this region, N-fertilizers have been applied for more than 30 years since the introduction of no-till systems in the middle 1980s (FAO, 2004). As a matter of fact, some acidification evidences have been detected in these soils (Fabrizzi et al., 1998; Urricariet and Lavado, 1999; Iturri et al., 2011), but neither the effects of these pH decreases on other soil properties, nor the resistance of soils against future N-fertilization inputs have been evaluated.

It is largely known that acidification can affect several soil properties, such as the decrease of the exchangeable bases (Darusman et al., 1991; Dubiková et al., 2002) or the increase of elements like Al, Mn and Fe in the soil solution (Hell and Stephan, 2003; Borůvka et al., 2005; Watmough et al., 2007; Rust Neves et al., 2009), which in high concentrations could be phytotoxic. When the acidification process is pronounced, the dissolution of clay minerals can also occur, leading to a higher acidification due to the release of aluminum ions from mineral structures to the soil solution (Barré et al., 2009; Céspedes-Payret et al., 2012).

The use of N-fertilizers, mainly urea, is carried out in loess soils of a wide range of climatic conditions but with similar fertilization histories within the Argentinean Pampas. This situation gives an opportunity to study the effect of pH decreases associated with N-fertilization on soils developing on similar parent materials and under similar fertilization histories but variable climatic conditions. It is known that associated with climatic conditions (ustic to udic soil moisture conditions), soils of the Pampas show different evolution rates (Teruggi, 1957). This is

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still a question how soils with different development rates can react to N-fertilizer inputs. Therefore, the purpose of this study was to evaluate the extent of pH decreases of N-fertilized soils of a climosequence of the Pampas, the effects of these pH changes on some chemical and mineralogical properties, and to estimate the reaction of the soils to future pH changes if N-fertilization continues.

2. Material and methods

2.1. Studied area and soils

All the studied soils have developed on the same parent material, loessic-like sediments, the so-called "Pampas-loess" of pleistocenic and holocenic ages (Teruggi, 1957; Buschiazzo, 1988; Zárate, 2003). The mineralogy of this parent material is qualitatively- but not quantitatively homogeneous, due to the fact that the sedimentation of aeolian materials by winds of different speeds, and therefore different transport energies, sedimented variable amounts of minerals with different densities at different depths (Buschiazzo and Taylor, 1993). These sediments contain variable amounts of volcanic glasses, accumulated during the frequent volcanic eruptions which occurred during those geological periods (Teruggi, 1957). One of the last volcanic events took place in 1932, when an eruption of the Andes-Quizapu volcano sedimented a 10 cm-thick-ash layer along a 1000 km-long W–E oriented strip in the semiarid Pampas of Argentina (Larsson, 1936).

Four sites placed in regions with different climatic conditions of the Argentinian Pampas (Fig. 1) were selected for this study. All studied plots are within experimental stations and belong to long-term experiments developed since several years in order to test the effect of N-fertilization on no-till produced crops. All analyzed soils were classified as Mollisols (Soil Survey Staff, 1999) and varied from dry to moist climatic conditions as follows: an Entic Haplustoll (EH), two Typic Hapludolls (TH-I and TH-II) and a Typic Argiudoll (TA). Soils EH and TH-I contain some amounts of volcanic glass while both, TH-II and TA, are volcanic glass free soils. The main characteristics of the soils and their management practices are presented in Table 1.

At each site two different fertilization conditions were sampled: a non-fertilized (NF) plot and a urea- (46:0:0, Finck, 1979) fertilized plot (F). Triplicate topsoil samples were taken from triplicate 10 m^2 NF- and F plots at each site. Both NF- and F plots were located adjacently.

2.2. Laboratory procedures

Soil samples were air dried and sieved (<2 mm). The following determinations were carried out in each of them: 1) pH in both, water (pH_W) and 1 eq dm^{-3} KCl dissolution (pH_{KCl}) (1:2.5 soil:liquid ratio in both cases) (Mc Lean, 1982). Both pH values were determined in order to analyze the extent of the soil acidification process, considering that differences between both values higher than 1.0 indicate some degree of soil acidification (Gandois et al., 2011); 2) neutralization curves of all NF soils by volumetric titration (Vázquez et al., 2009), which included the contact of soil samples with different quantities of 0.1 eq dm^{-3} $HCl_{(ac)}$ dissolutions for a period of 8 h, and the subsequent measurement of pH in the supernatant solutions; 3) the cation exchange capacity (CEC) by saturating the samples with a 1 eq dm^{-3} ammonia acetate dissolution at pH 7 (Rhoades, 1982); 4) the contents of exchangeable Ca, Mg (Lanyon and Heald, 1982), K and Na (Knudsen et al., 1982); with these data the percent of base saturation (V) was calculated; 5) the contents of soil organic matter (SOM), determined by wet digestion (Walkley and Black, 1934); 6) the contents of free lime ($CaCO_3$) (Schlichting et al., 1985); 7) the contents of amorphous Al-, Mn- and Fe oxides (Alo, Mno and Feo, extracted for 2 h in the darkness with oxalic acid) and crystalline Al-, Mn- and Fe oxide forms (Alos, Mnos and Feos, extracted for 6 min with boiled oxalic acid) (Schlichting et al., 1985). The ratios between amorphous- and crystalline forms (Alo:Alos, Mno:Mnos, Feo:Feos) were calculated; higher values of these ratios indicate lower crystallinity of these oxides, 8) the mineralogical composition of the clay fraction of each soil using X-ray diffraction analysis. This determination was carried

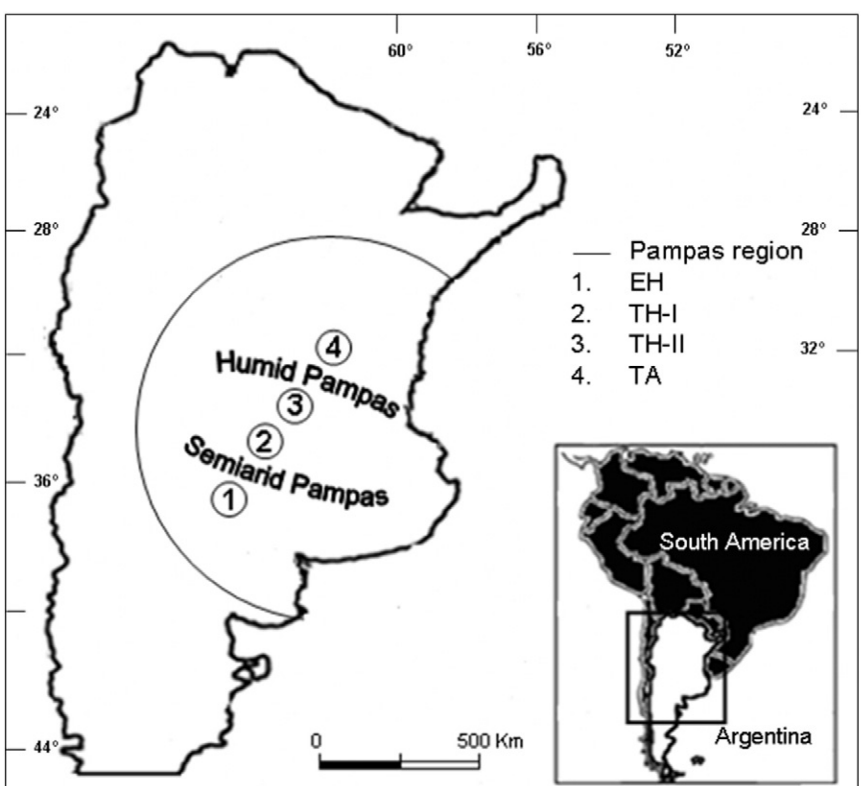

Fig. 1. Location of the studied sites. EH: Entic Haplustoll; TH-I: Typic Hapludoll I; TH-II: Typic Hapludoll II; TA: Typic Argiudoll.