



# Soluble silicon in differently textured mollisols of Argentina

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## ABSTRACT

Soluble compounds of silicon (Si), such as monosilicic acid and polysilicic acid, affect many of the soil chemical and physicochemical properties of the soil. In Argentina the Chaco Pampean Plain is hugely important as it is one of the main areas of global agricultural production. The main objectives of this study were to examine the distribution of the concentration of soluble Si in soils of different genesis of the Chaco Pampean Plain and to evaluate the relationship between the physical and chemical properties of soils and the Si solubility. A soil sampling in the Pampa region was performed; where 12 soil profiles samples were taken at 1.5 m depth. The Si soil levels were separated into two groups. Group A (fine texture) had a high Si content while Group B (coarse texture) was lower. All soils show poorly provided of soluble Si in the surface horizon, but differences were observed in the subsurface. A finer soil with >100 years of an agricultural system had 30/40% less of Si soluble.

Si correlates positively with pH and with clay content. These clays and the phytoliths can be a source or adsorb silicic acid. There is a negative correlation between Si and sand content, so the sandy loam to sandy soils are to suffer the greatest impact of agriculturalization. There is a significant and negative relationship between Si and phosphorus suggesting a competition might exist between these two elements.

Evaluation of Si in these soils is very important due to its relevance in agricultural production worldwide. Si values may directly affect the production since its deficiency may cause crops disease.

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## 1. Introduction

Silicon (Si) is the second most abundant element in the surface of the earth's crust and in the soil, where it's content is 28.8% (Epstein, 1994; Sposito, 2008). It is present in >370 rock-forming minerals. Being an element of almost all parent materials, Si is one of the basic components in most of the soils (Sommer et al., 2006). However, Matichenkov and Bocharnikova calculated that 210–224 million tons of Si are removed from agricultural soils each year (Haynes, 2014). Likewise, weathering of Si from feldspars and quartz takes place mainly over multi-millennial to million-year timescales. On the other hand, biogenic produced silica (amorphous opal), mainly found in the shells of several different aquatic organisms, is soluble at time-scales ranging from days to years. Although quartz is a major constituent in rocks, quartz does not control silica concentration in solution because of its slow dissolution kinetics ((Mierzky & Cirelli, 2004), Fig. 1).

Hydrated silica represents the second most abundant biogenic mineral after carbonate minerals (Fauteux et al., 2005). Dissolution of the

amorphous Si in terrestrial soils has been shown to control dissolved Si export from catchments dominated by wetlands, forests and grasslands (Clymans et al., 2011a). Si plays a very important role in the carbon global matter cycle. The Si influences the carbon (C) cycle in two ways, first because the CO<sub>2</sub> affects the weathering processes and second it impacts the Si flow into the oceans because diatoms, representing 50% of the biomass of the oceans, need Si for their skeleton (Sommer et al., 2006).

The genesis of the soil can determine its chemical properties, such as the pH and the texture (Heredia, 2014). The variables present in the different horizons, i.e. clay content, may be positively correlated with the concentration of soluble Si (Korndörfer et al., 2004) and this may affect the Si cycle. Soil processes control the dissolution stock and the precipitation of silicate minerals governing the bioavailability of Si. As well, the variability of the rates of Si cycling in terrestrial ecosystems is largely governed by pedogenesis (Cornelis & Delvaux, 2016).

Si in soils comes from three main sources, which are (1) primary minerals inherited from parent material, (2) secondary minerals (crystalline phases) developed through soil formation (mainly clay minerals) and (3) secondary microcrystalline minerals (autogenic quartz, opal). Silicic acid (H<sub>4</sub>SiO<sub>4</sub>) form is the main component of Si soil solutions, mostly as monomeric silicic acid (Dove, 1995; Drees et al., 1989; Iler,

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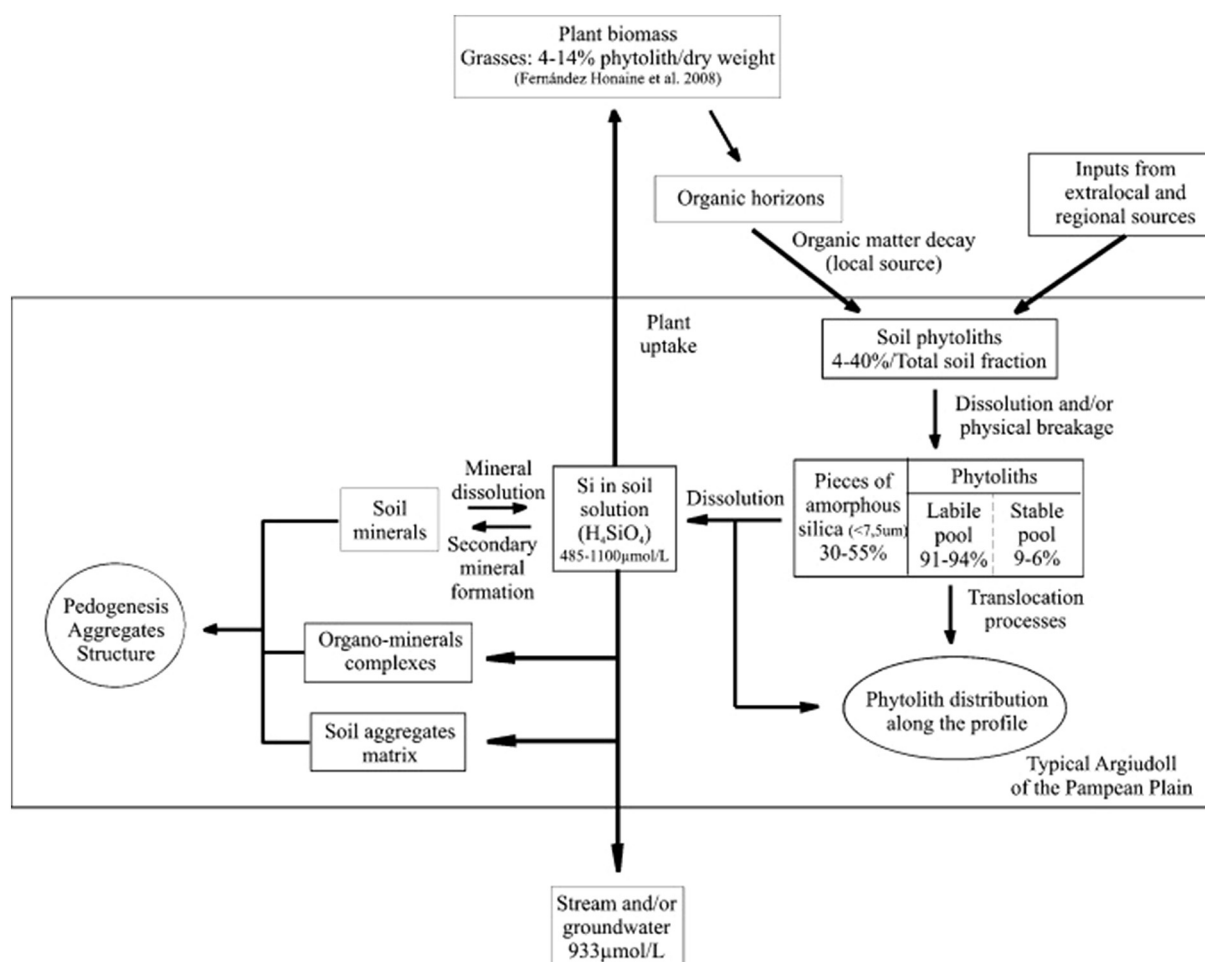


Fig. 1. Silica biogeochemical cycle in the southeastern area of the Pampean Plain (Borrelli et al., 2010).

1979). Polymeric species become stable beginning with  $\text{pH} \approx 10$  and the rate of polymerization and depolymerization is slow. (Dietzel, 2000; Dietzel, 2002). Polymeric silicic acid is composed of two or more Si atoms and may appear in different forms, e.g., chains, branching forms, or spherical clusters (Sommer et al., 2006).

Soluble compounds of Si, such as monosilicic acid and polysilicic acid, affect many of the chemical and physicochemical properties of the soil. The monosilicic acid can react with aluminum, iron and manganese in the formation of slightly soluble silicates. Furthermore, under different concentrations, the monosilicic acid can be combined with heavy metals (Cd, Pb, Zn, Hg, etc.) forming soluble complex compounds when the concentration of monosilicic acid is low, and silicates of heavy metals slightly soluble when monosilicic acid concentration is higher in the system. Thus, the application of active Si forms (soluble and extractable Si) offers the possibility of managing the mobility of heavy metals (Matichenkov & Bocharnikova, 2008).

In regards to polysilicic acids, these mainly affect the physical properties of soil because they can bind soil particles. The formation of soil structure occurs through silicates bridging between particles. With increasing polysilicic acids, the degree of soil aggregation, water retention capacity, exchange capacity and the regulatory capacity of sandy soils increases (Matichenkov & Bocharnikova, 2008).

The sequestration of Si in soil clay-sized Fe-oxides can thus affect the Si terrestrial cycle by influencing Si concentration in solution, and hence in waters drained from watersheds. Three major Si reservoirs have been identified. First, Si-rich precipitates (opal, quartz) induce very large uptake of preferentially light Si isotopes. Second, Si uptake by biota favors

the absorption of Si in plants, and diatoms. Third, soil clay-sized components sequester light Si isotopes (Opfergelt et al., 2009).

The soil is the primary source of plant Si and therefore a key reservoir of the Si biological cycling (Cornelis & Delvaux, 2016). The process of Si uptake can be classified as active, passive or rejective, and accordingly plants can be classified as accumulators, intermediates, and excluders. Plants are considered as Si accumulators when the tissue Si concentration is  $>10 \text{ g kg}^{-1}$  and as excluders when they have concentrations  $<5 \text{ g kg}^{-1}$  (Haynes, 2014). The Si concentration in plants depends primarily on the concentration of silicic acid in the soil solution and it is not correlated with the total Si concentration of the soil (Guntzer et al., 2012). Plants can influence chemical weathering rates by producing various organic ligands and acidity, by affecting the soil water budget through transpiration, and by root uptake of Si (Gérard et al., 2008). Si biocycling may be the most important source of available Si to plants (Guntzer et al., 2012). Biological uptake of Si can enhance silicate weathering by decreasing aqueous silica concentrations. Conversely, the release of Si from dead plant biomass and its decomposition in the organic soil layer leads to an increased phytoliths concentration in the soil and may therefore inhibit the rate of chemical weathering (Gérard et al., 2008).

Phytogenic Si is now recognized as one of the most important sources of Si in soil solution among all soil minerals. It is, however, important to note that phytoliths can be highly resistant to dissolution and may remain in soils for thousands of years, thus, contributing to C sequestration (Haynes, 2014). The biogeochemical C sequestration by phytoliths provides a longer-term opportunity to sequester atmospheric  $\text{CO}_2$  (Marxen et al., 2016; Yang et al., 2018). The distribution of

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