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Rhizosphere-induced weathering of minerals in loess-derived soils of Golestan Province, Iran

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ABSTRACT

Weathering of minerals is the major source of nutrients to plants. The rhizosphere can play a central role in the weathering of minerals through the release of acid exudates that drive hydrolysis of minerals. Although many studies have examined the weathering of pure natural industrial minerals in rhizosphere, information on the weathering of clay and silt minerals from soils is limited. This study examined the weathering and K release of minerals in clay and silt fraction in the rhizosphere of corn. Growth medium was a mixture of quartz sand as filling materials and clay and silt fraction of four dominant soils formed on loess parent material with different characteristics (i.e., Aridisols, Alfisols, Inceptisols and Mollisols). During 100 days of the experiment, plants were irrigated with distilled water and complete and K-free nutrient solution as needed. At the end of cultivation, plants were harvested and their K uptake was measured. Clay and silt fractions were separated from quartz sand and analyzed by X-ray diffraction (XRD) and XRF both before and after the experiment. Intense weathering of mica and chlorite was observed in silt fraction of Aridisols and Mollisols. The high acidity of the rhizosphere induced by root exudates has resulted in the release of structural K from mineral lattice. In contrast to the silt fraction, the X-ray patterns of the clay fraction showed minor changes following plant growth such as the formation of mixed layer mica-vermiculite and vermiculite. The K content extracted by corn was significantly greater for silt than the clay sizes. The highly weatherable silt sized minerals therefore, could be regarded as the major source of nutrients to plants.

1. Introduction

Potassium is one of the most essential macronutrients for plants because it plays a central role in several physiological processes in plant nutrition (Al-Zubaidi et al., 2008; Marschner, 2008). Potassium in soil is often divided into exchangeable, non-exchangeable, soluble and structural forms (Sparks, 1987). Between 90 and 98% of total soil potassium is in structural forms and the remaining 2–10% is found either as non-exchangeable or exchangeable and soluble forms (Brady and Weil, 2007). The most important source of potassium in soil is K-bearing minerals including alkali feldspar, muscovite, biotite and illite, which release K by weathering (Marschner, 1995; Mengel, 2007). In fact, if the amount of soluble and exchangeable K reach low levels due to K uptake by plants (Mclean and Watson, 1985), non-exchangeable K from the interlayer of K-bearing minerals is released into the soil solution (Tributh et al., 1987). Barré et al. (2007) demonstrated that interlayer K of K-bearing clay minerals chemically known as non-exchangeable is available for plants. Velde and Peck (2002) reported the clay mineral transformation induced by K depletion. Barré et al. (2008a) showed that 2:1 clay minerals behave as a huge and a renewable K reservoir.

Until now, few studies have investigated the role of plant roots and associated microorganisms in the rhizosphere zone on the transformation and dissolution of clay minerals. The rhizosphere, defined as the volume of soil that is directly influenced by root secretion and associated soil microorganisms, differs in many aspects from the bulk soil as a result of water and nutrient uptake by roots and to root respiration and microbial activity. The chemical changes that occur in the rhizosphere was demonstrated by some authors (e.g., Bakhshandeh et al., 2011; Norouzi and Khademi, 2010; Shelobolina et al., 2012). Root activity in the rhizospheric zone can influence the soil weathering processes by decreasing pH, production of mucilaginous material and excreting organic acids (Drever, 1994; Kodama et al., 1994). Some associated soil microorganisms are able to dissolve K-bearing minerals by excreting organic acids, which directly solubilize K-bearing minerals or chelate silicon ions to release K into soil solution (Basak and Biswas, 2009).

In the last few years, several studies were carried out on mineral weathering with pure minerals (Hinsinger and Jaillard, 1993; Hinsinger et al., 1992) comparing the rhizosphere soil with non-

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rhizosphere mineralogy in forest (Arocena and Glowa, 2000) and agricultural soils (Kodama et al., 1994). Berthelin and Leyval (1982) demonstrate the ability of rhizospheric microflora of maize (*Zea mays* L.) to weather biotite by measuring K and Mg uptake by plants. Naderizadeh et al. (2010) showed that the rhizospheric acidity was increased by root activities and organic matter decomposition, which facilitated K release from phlogopite minerals and induced the formation of vermiculite and a minor quantity of smectite. Khademi and Arocena (2008) reported that the addition of organic matter could enhance the quantity of kaolinite from the transformation of palygorskite and sepiolite in the rhizosphere of different crops.

Rhizospheric studies investigating the weathering of clay minerals are needed. Most previous researches have been done with pure natural industrial minerals. Therefore the aims of this paper were as follows: (1) to investigate the weathering of minerals in clay and silt fraction of soils in the corn rhizosphere; and (2) to compare the ability of crops to extract structural K from clay and silt fraction.

2. Materials and methods

2.1. Description of the study area

The area studied is located in northern Iran, Golestan Province between 36° 46′ and 37° 17′N latitude and 54° 10′ and 54° 30′E longitude (Fig. 1). Along the south–north transect in the province, minimum and maximum precipitation range from 800 mm to 200 mm respectively. The parent material of the study area is mainly composed of loess deposits. Four pedons were investigated in different climatic regions and surface soils (A horizons, 0–30 cm depth) were sampled for clay mineralogical and greenhouse studies. The soil moisture regime is aridic (profile 1), udic (profile 2) and xeric (profiles 3 and 4). These 4 profiles were described and classified according to Keys to Soil Taxonomy (Soil Survey Staff, 2014) and WRB (2014) (Table 1).

2.2. Growth media

In order to understand the mineralogical composition of samples and the separation of clay and silt fraction, chemical cementing agents were removed from samples according to Kittrick and Hope (1963) and Jackson (1975). Removal of carbonates were done by using 1 N sodium acetate buffered at pH 5 and the addition of sodium acetate was continued until no effervescence was observed with 1 N HCl (Jackson, 1975). For oxidizing the organic matter, the carbonate-free soils were treated with 30% H_2O_2 in a water bath at 80 °C. The free iron oxides were removed by the dithionate citrate bicarbonate method (Mehra and Jackson, 1960). The clay and silt fraction were separated by sedimentation method. To exclude the soluble and exchangeable K, the samples were saturated with $CaCl_2$ using a 1 N $CaCl_2$ solution. For removing the excess $CaCl_2$, the saturated samples were washed with distilled water for several times. Following all treatments, the samples were dried and crushed for use in pot experiments. Sand sized quartz (0.1–0.5 mm) collected from Hamadan province was used as a major plant growth medium. It is consisted of 100% quartz and was free of clay minerals or other substances. To prepare the quartz sand for the experiment, first it was washed with 0.2 M HCl and then rinsed with distilled water and oven-dried at 105 °C. The elemental composition of the samples was determined with X-ray fluorescence.

2.3. Cultivation condition

The experiment was carried out under the greenhouse condition. Pots were filled with a mixture of 20 g samples (either clay or silt fraction) and 480 g of quartz sand. Corn (single cross variety) was used to create the rhizospheric zone. 5 seeds of corn were cropped and grown for a period of 100 days. Pots were irrigated with distilled water or Stagner nutrient solution as needed. The K-free nutrient solution was similar to the complete nutrient solution without KNO_3 and KH_2PO_4 but 40 ml/l of $Ca(H_2PO_4)_2 \cdot H_2O$ (Stagner, 2002).

The experimental design was a completely randomized 5 × 2 × 2 factorial with 20 treatments and 3 replications making a total of 60 experimental pots. The treatments were a combination of 5 growth media, 2 levels of size fraction and 2 levels of nutrient solution. At the end of the experiment, plants were harvested and their shoots and root biomass were measured.

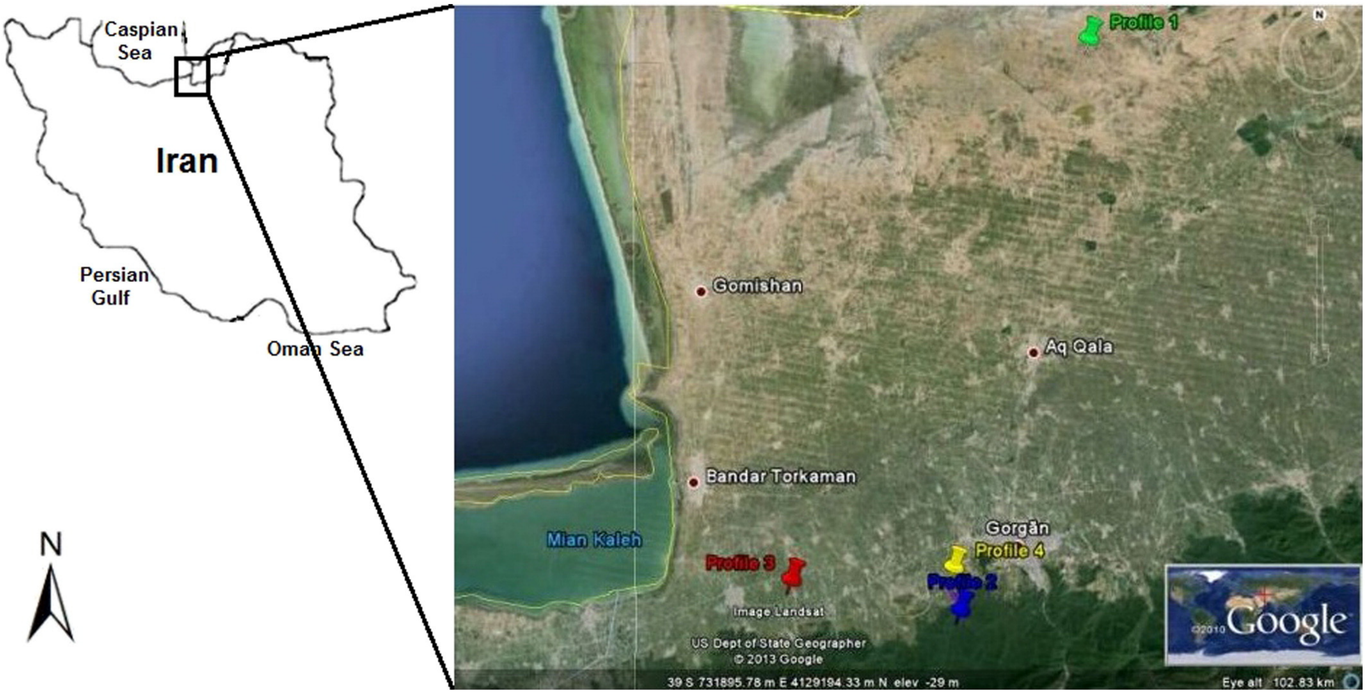

Fig. 1. Location map of the profiles studied.