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Influence of rotation cropping and sugarcane production on the clay mineral assemblage

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ABSTRACT

The present study examines the influence of unfertilized crop production on Calcic Haplustept soils in southwestern Iran. Soil profiles from about 100 years of rotation cropping (wheat, corn, barley and vegetables) and those from 40 years of irrigated sugarcane production were compared with the adjacent uncultivated soils. Particle size analysis revealed there was an increase in clay contents of soils from the rotation cropping. There was 66.1% clay in the Ap horizon of rotation cropping soil and 56.8% was in the A horizon of uncultivated soil. On the other hand, the sums of sand and silt fractions were 43.2 and 33.9% for uncultivated and rotation cropping soils, respectively. Therefore, differences between clay contents could be attributed to cultivation and subsequent mineral alteration. Organic matter contents were greater under cultivated soils; consequently the cation exchange capacity under sugarcane (19 $\mathrm{cmol_c\,kg^{-1}}$) and rotation cropping (30 $\mathrm{cmol_c\,kg^{-1}}$) were greater than for the uncultivated soils (16 $\mathrm{cmol_c\,kg^{-1}}$). Under cultivation, both the gypsum and calcium carbonate content of soils were lower, especially in the surface horizon. The lower electrical conductivity of soil solutions further reflected enhanced leaching of the cultivated soils. Depletion of K by the sugarcane is due to the release of nonexchangable K from interlayer positions in micaceous minerals. Expandable minerals were abundant in the Ap horizon of the cultivated soils, unlike in the uncultivated soils, while only small amounts were found in C horizons of cultivated soils. This trend agrees with changes in soil physico-chemical properties, especially for fixed K and increased CEC. TEM showed that the subsurface horizons of the cultivated soils contained more palygorskite than the surface. It can be concluded that intensive cropping and strong irrigation over a long time could have brought about changes from micaceous and palygorskite minerals to expandable minerals.

1. Introduction

K-feldspars and micas are the two main groups of K-bearing minerals, and are also among the most common minerals in most soils. In micas, interlayer K is tightly held by electrostatic forces and is not normally exchangeable or available to plants (Singh and Goulding, 1997). However, under appropriate conditions, this fixed K can be quickly released (Fanning et al., 1989). The release of K from micas can proceed either by ion exchange and the consequent transformation of micas to expandable 2:1 layer silicates, or by dissolution (Singh and Goulding, 1997; Moritsuka et al., 2002). It has been found that plants growing on soils rich in K-feldspars and micas can uptake notable amounts of non-exchangeable K (Rahmatullah et al., 1994).

For the release of interlayer K from 2:1 type clay minerals to occur, a decrease of the K activity in the surrounding solution, below a certain threshold, is a prerequisite. Such threshold values have been reported for several minerals: 50 to 400 mmol $\mathrm{K\,l^{-1}}$ for biotite, 2.5 for muscovite and illite (Mengel and Kirkby, 2001) and 80 for phlogopite (Hinsinger and Jaillard, 1993). The diffusion of K from micas is retarded by the presence of very small concentrations of K in the equilibrium solution (Bassett, 1959). When the K concentration is greater than a critical solution value, expandable 2:1 minerals can fix K from the solution (Fanning et al., 1989). Interstratified clay minerals such as biotite/vermiculite, vermiculite/smectite and muscovite/vermiculite are typically formed during this process (Henderson et al., 1976). These changes are evidenced by a decrease in the d_{001} from 1.5 nm to 1.25, then to 1.0 nm, with a corresponding decrease in the cation exchange capacity (Sachsenhofer et al., 1998).

Stimulation of mica transformation by the roots of various field crops has been demonstrated in pot cultures (Mojallali, 1976; Ghorayshi, 1988; Moritsuka et al., 2002). Plant roots enhance the transformation of micas by releasing H^+, which can enter the crystal structure, decrease the negative layer charge and cause the exchange of interlayer K (Mengel and Rahmatullah, 1994; Moritsuka et al., 2002). Furthermore, and more importantly, the uptake

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of K causes a decrease in K concentration in the rhizosphere, driving its exchange-controlled release (Hinsinger and Jaillard, 1993). Sugarcane has a very high demand for K. The extract contains about 80% of the total K present in the millable stalk (Malavolta, 1994). By harvesting 100 t ha^{-1} millable stalks, more than 200 kg K ha^{-1} is usually removed from soil. Potassium absorption rates of 0.71 kg ha^{-1} day^{-1} for the plant and 0.95 kg ha^{-1} day^{-1} for the ratoon have been reported in sugarcane cultivation (Malavolta, 1994). Although laboratory and greenhouse studies have provided valuable information regarding K depletion, and associated mica transformations, there are few reports on the apparent weathering of micaceous minerals under long-term field experiments or even by exhaustive cropping in pot experiments.

The palygorskite in arid soils is thought to originate from two main sources: (1) inheritance from parent materials; and (2) pedogenic formation through neoformation or transformation of 2:1 minerals (Khormali and Abtahi, 2003). Though sometimes difficult to detect by X-ray diffractometry (XRD), palygorskite can be seen very well by transmission electron microscopy (TEM) (Lv Flores and Martinpozas, 1995). Paquet and Millot (1973) showed that palygorskite is not stable and transforms to smectite when annual precipitation is ≥300 mm. The following reactions are reported for chlorite in serpentinic soils: chlorite → interstratified chlorite/vermiculite → vermiculite → high-charge smectite (Lee et al., 2003). Several researchers consider that palygorsite in the soils of Iran has formed pedogenically (Khormali and Abtahi, 2003). Furthermore, very few occurrences of vermiculite have been reported in soils of arid and semi-arid regions of Iran (Khademi and Mermut, 1998; Khormali and Abtahi, 2003).

Agriculture in the Haft-Tapeh region of southwestern Iran is dominated by rotations of wheat, corn, barley and vegetables, which have been conducted for more than a century, as well as more than 40 years of continuous irrigated sugarcane. Neither system has benefited from the addition of K-fertilizers, but rather have relied on the release of K from clay minerals especially micaceous minerals (Naghshinehpour, 1978; Nadian and Solhi, 1992). It is anticipated that the steady depletion of K from the soil system will enhance the transformation of minerals in the clay fraction. The objective of this research was to evaluate the apparent changes in K content and the transformation of clay minerals in two dominant production systems by comparison with local uncultivated soils.

2. Methods and materials

2.1. Site description

The study site was in the Haft-Tapeh agro-industry region of Khuzstan province, in southwestern Iran (Fig. 1). The Khuzstan region (48° 21″ longitude east and 32° 04″ latitude north), about 100 km north of the city of Ahvaz, is a continuation of the Mesopotamian plain, and is covered mainly by the flood plains and deltas of the Shavoor and Dez Rivers. It has a level to nearly level topography, where the possibility of standing water is greater than in adjacent areas. The local elevation ranges from 42 to 82 m above mean sea level. This region experiences a mean annual rainfall of 266 mm, with a maximum in January and February, and a mean annual soil temperature of 23.7 °C. The potential evaporation of the area was measured according to the evaporative pan method and it was about 3000 mm annually. Accordingly, the soil moisture and temperature regimes are ustic and hyperthermic, respectively. The soils were classified as: fine, mixed, carbonatic, hyperthermic, Calcic Haplustepts (Soil Survey Staff, 1999).

Rotation cropping and sugarcane production, both with irrigation, have been performed on the soils for long, but different periods of time. Rotation cropping (wheat, corn, barley and vegetables) occupies about 200,000 ha of the region. Sugarcane production occupies about 10,000 ha of the region; its production has occurred for 42 years, and has resulted in 35 harvests and 7 years of fallow. The production of millable stalk has averaged 110 t ha^{-1}. Approximately 30,000 m^3 ha^{-1} (or 300 cm) irrigation water are consumed annually for sugarcane production in Haft-Tapeh; in comparison, more than 10,000 m^3 ha^{-1} have been consumed annually for typical rotation cropping over 100 years without any fallow. The mean composition of the irrigation water has been: EC (electrical conductivity) = 0.57 dS m^{-1}, Ca^{2+} = 2.47, Mg^{2+} = 1.32, Na^+ = 1.38, K^+ = 0.03 meq l^{-1} and total dissolved salt = 0.5 mg l^{-1}. Turbidity of irrigation water was between 15 and 35 NTU during irrigation time. Irrigation was conducted in fields during the months of May to October by means of a furrow surface irrigation every 10 days.

2.2. Soil collection and basic characterization

The study area was located in an old flood plain physiographic unit in which all soils have the same age and parent material. Soil samples were collected from (1) the sugarcane fields of Haft-Tapeh Agro-industry Co (Iran), (2) a nearby uncultivated area, and (3) fields under rotation cropping. Two soil profiles of each of the different plantation types were described and sampled according to conventional procedures (Soil Survey Staff, 1996).

The soil samples were air-dried and the <2-mm fraction was separated by sieving (Soil Survey Staff, 1996). Particle size distribution of the <2 mm fraction, after removing organic matter and calcium carbonate, was determined by sieving and pipette methods (Gee and Bauder, 1986). Soil pH was determined using a 1:2.5 soil/water mixture and EC was determined on saturation paste extracts (U.S. Salinity Laboratory Staff, 1954). Cation exchange capacity (CEC) was determined using 1 M sodium acetate saturation (NaOAc) at a pH of 8.2 (Chapman, 1965). Organic matter was determined by using the Walkley and Black procedure (Jackson, 1975), and $CaCO_3$ equivalent was measured by digestion in HCl (Nelson, 1982). Gypsum content was determined by dissolution in acetone and measurement of EC (U.S. Salinity Laboratory Staff, 1954). Soluble K in the saturation extracts was determined, using atomic absorption spectroscopy (AAS, Carlziessyena model 5FL), (Martin and Sparks, 1985), exchangeable K was determined by repeated exchanges with 1 M NH_4OAc (Martin and Sparks, 1985), and fixed K was measured by boiling with 1 M HNO_3 and calculated by subtracting the concentration of exchangeable K (Al-Kaman et al., 1984).

2.3. Mineralogical analysis

Samples for clay mineralogy were a 1:1 mixture of those from each of the two profiles from each type of land use. Prior to separation of the clay fraction, samples were treated to remove flocculants and cementing agents (Kittrick and Hope, 1963). Soluble salts (including gypsum) were removed by repeated washing with deionized water. Carbonates were removed by dissolution in 1 N acetate buffered at pH 5, at a temperature of 80 °C (maintained by a water bath); the addition of 1 N sodium acetate was continued until no effervescence was observed with 1 N HCl (Jackson, 1975). Organic matter was oxidized by treating the carbonate-free soils with 30% H_2O_2 at 80 °C; this treatment also dissolved MnO_2. Iron oxides were removed from the samples by dissolution with dithionate–citrate–bicarbonate (Mehra and Jackson, 1960). Separation of the sand fraction (53–2000 μm) was accomplished by passing the soil suspensions through a 53-μm sieve. From the remaining suspension, the <2-μm fraction was removed by repeated siphoning after sedimentation; this was continued until the suspension was free of clay.

X-ray diffraction analysis of the clay fraction (<2-μm) were carried out on oriented glass slides. Analyses were performed on a computer-controlled Philips PW 1840 X-ray diffractometer using CuKα radiation (40 kV and 30 mA). A step interval of 0.04° 2θ and a scan speed of 1° 2θ per second were used; all samples were scanned from 2 to 30° 2θ. Five pretreatments were used to enable