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Dynamics and Availability of Different Pools of Manganese in Semiarid Soils as Affected by Cropping System and Fertilization

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ABSTRACT

Manganese (Mn) deficiencies are common in soils on the Loess Plateau of China. This research provided essential information on improving Mn availability in semiarid soils through agricultural practices. Twelve cropping system and fertilization treatments were designed in a 28-year experiment. The cropping systems included long-term fallow, continuous winter wheat cropping, pea (1 year)-winter wheat (2 years)-millet (1 year) rotation (crop-legume rotation) cropping, and continuous alfalfa cropping. The fertilizer treatments under the cropping systems included no-fertilizer control (CK), application of P fertilizer (P), application of N and P fertilizers (NP), and application of N and P fertilizers and manure (NPM), but the NP treatment was excluded in the continuous alfalfa cropping system. Available Mn and Mn fractions of soil samples (0–20 and 20–40 cm depths) were measured and further analyzed quantitatively using path analyses. Results showed that the crop-legume rotation and continuous alfalfa cropping systems significantly increased available Mn compared with the fallow soil. Compared with the no-fertilizer control, manure application increased available Mn in soil of the continuous wheat cropping system. Across all treatments, the averaged content of mineral-, oxide-, carbonate- and organic matter-bound and exchangeable Mn accounted for 42.08%, 38.59%, 10.05%, 4.59%, and 0.09% of the total Mn in soil, respectively. Cropping significantly increased exchangeable Mn in soil and the highest increase was 185.7% in the continuous wheat cropping system at 0–20 cm depth, compared with the fallow soil. Fertilization generally increased exchangeable and carbonate-bound Mn in soil. Carbonate-bound Mn was the main and direct source of available Mn in soil, followed by exchangeable and organic matter-bound Mn. These results indicated that crop-legume rotation cropping, continuous alfalfa cropping and application of manure, have the potential to promote Mn availability in soils of rainfed farmlands.

Key Words: available Mn, crop-legume rotation, micronutrient, Mn availability, Mn deficiency, Mn fraction, the Loess Plateau, trace element

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INTRODUCTION

Manganese (Mn) is an essential micronutrient to plant growth and human health (Malini *et al.*, 1995; Zou and Mo, 1995; Welch and Graham, 2005). It governs the behavior of other trace elements in soils as a very important metallic redox catalyst (Kabata-Pendias, 2004). According to Aubert and Pinta (1977), most soils contain an average of 500–1 000 mg kg^{-1} total Mn, which is higher than those of other micronutrients, except for iron (Fe). However, Mn deficiency in soils has occurred worldwide. This deficiency is not caused by a low total Mn in soils, but by an insufficient amount necessary for plant uptake (Van Campen and Glahn, 1999). As a valence-variable element, its valence and availability in soils for plant uptake are affected by changes of soil conditions caused by natural factors, such as soil parent material and particle size, and anthropogenic factors, such as agricultural practices (Webb *et al.*, 1993; Plekhanna, 2007; Trebien *et al.*, 2011).

Heilu soils, a typical soil type on the Loess Plateau, were derived from loess and contain more than 50% silt. All these properties result in the good permeability of Heilu soil, which is not conducive for the nutrient accumulation. Moreover, the degree of calcareousness of this kind of soil is 7%–15%, and calcareous soils are listed as one of the main soil types associated with Mn deficiency (Ashraf *et al.*, 2012). Abundant literature with the same conclusions is available in the USA, Canada, UK, Australia and India (Graham *et al.*, 1988). Deficiency of Mn in calcareous soils has been reported in different areas of Northern China (Liu *et al.*, 1983; Graham *et al.*, 1988), particularly the Loess Pla-

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teau (Yu *et al.*, 1991; Wei *et al.* 2006). According to the investigation by Yu *et al.* (1991), the average total Mn in soils on the Loess Plateau was 573 mg kg^{-1} ($n = 2\,460$), which is considerably lower than the average level in China (710 mg kg^{-1}) and the world (850 mg kg^{-1}). The average content of the available Mn was 7.7 mg kg^{-1} ($n = 2\,460$) on the Loess Plateau, which is close to the critical value for Mn deficiency (7 mg kg^{-1}). Mn-deficient land accounted for 48.3% of the total land in the region. Therefore, Mn deficiency has largely impeded the agricultural production in semiarid soils on the Loess Plateau, and the underlying mechanisms should be further studied.

Some studies have highlighted the influence of Mn fractionations on Mn availability (Ghanem *et al.*, 1971; Pavanasasivam, 1973; Liu *et al.*, 1983; Shuman, 1985; Wei *et al.*, 2008). The results from Wei *et al.* (2008) showed that exchangeable Mn (Ex-Mn) and organic matter-bound Mn (Om-Mn) were most available to plants. The same conclusion was drawn by Liu *et al.* (1983) and Shuman (1985). Kabata-Pendias (2004) studied the effect of the origin of micronutrients on their fractions' availability. Good estimates of available Mn fractions are difficult to obtain because the division and extraction of Mn fractions has no uniform standard (Quevauviller *et al.*, 1997; Moral *et al.*, 2005; Behera and Shukla, 2014). Thus, it is necessary to assess the relationship between Mn fractions and Mn availability through the study of long-term experiments.

The composition and quantity of root exudates in a rotation system are different from those in a monocropping system because of the number of species. The root exudates from some species may create favorable rhizosphere conditions for growth of other plants (Zhang *et al.*, 2003). Thus, agricultural practices, such as cropping systems and fertilization, might also affect Mn availability and fractions in soils (Soon, 1994; Gupta, 2005; Li *et al.*, 2007; Harrell *et al.*, 2009; Li *et al.*, 2010), particularly in farmlands. Furthermore, Kabata-Pendias (2004) pointed out that the availability of trace elements in soils had been a hot topic in both environmental and agricultural studies for years. Therefore, combining local agricultural practices and studies on the effects of agricultural practices on Mn availability is necessary to protect and make use of any potential available Mn pool to satisfy plant needs and maintain agricultural sustainability.

In this study, available Mn and Mn fractions were investigated in semiarid soils on the Loess Plateau of China. The objectives were: i) to understand the effects of cropping system and fertilization on available Mn and Mn fractions in semiarid soils, ii) to quantitatively analyze the effects of Mn fractions on available Mn, and iii) to establish the relationship between available Mn and Mn fractions. This study could provide suggestions for improving Mn availability in semiarid soils through agricultural practices.

MATERIALS AND METHODS

Study area

This study was conducted in Changwu County (35°12′ N and 107°40′ E), Shaanxi Province, in the southern part of the Loess Plateau, China. The study area was 1 200 m above sea level in a warm-temperature zone of continental climate, with a frost-free period of 171 days. The mean annual temperature and precipitation was 9 °C and 579 mm, respectively. The soil in the study area is a Heilu soil, which was classified as a Calcarid Regosol according to the FAO/UNESCO soil classification system (FAO/UNESCO, 1988). The initial contents of organic matter, total nitrogen (N), total phosphorus (P), available P, available potassium (K) and $CaCO_3$ of the soil were 10.5 g kg^{-1}, 0.8 g kg^{-1}, 0.7 g kg^{-1}, 3.0 mg kg^{-1}, 129.3 mg kg^{-1}, and 108.4 g kg^{-1}, respectively. The soil pH was 8.3. The soil nutrients could represent the local land fertility.

Experiment design

A field experiment was established in 1984 in the study area. The experiment included 12 treatments of cropping system and fertilization with three replicates. The experimental plots (10.26 m × 6.5 m) were randomly arranged. The cropping systems included long-term fallow, continuous winter wheat cropping, pea (1 year)-winter wheat (2 years)-millet (1 year) rotation (crop-legume rotation) cropping, and continuous alfalfa cropping. The crop varieties used and their seedling and harvesting time are shown in Table I. The fertilizer treatments under the cropping systems included a no-fertilizer control (CK), application of P fertilizer (P), application of N and P fertilizers (NP), and application of N and P fertilizers and manure (NPM), but the NP treatment was excluded in the continuous alfalfa cropping system. Crops and fertilizers were absent in the fallow soil. The N fertilizer was applied at 120 kg ha^{-1} as urea, P fertilizer at 26.2 kg ha^{-1} as superphosphate, and manure at 75 t ha^{-1} as cow dung. The average concentrations of Mn in the superphosphate and cow dung were 753.2 and 483.1 mg kg^{-1}, respectively.

The management in all treatments was the same as that in routine field crop. Weeds were removed by