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Changes in soil properties and the availability of soil micronutrients after 18 years of cropping and fertilization

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Abstract

Micronutrient deficiencies are common in many parts of China's Loess Plateau. The objective of this experiment was to study the effects of long-term cropping and fertilization practices on soil properties and micronutrient availability in this region. The field plot experiment began in 1984. It included five cropping systems and four fertilizer treatments. In September 2002, soil samples were collected and soil pH, organic matter content, available P, and $CaCO_3$ were measured. Total and available Zn, Cu, Mn, and Fe were also determined. The relationship between soil properties and available micronutrients was determined by correlation and path analysis. After 18 years, soil pH and $CaCO_3$ levels were lower in the cropped and fertilized treatments compared to the fallow treatment. In contrast, soil organic matter and available P levels were higher in cropped compared to fallow treatments. A comparison of unfertilized treatments indicated that available Zn and Cu levels in cropped treatments were lower compared to the fallow treatment, probably due to the removal of these micronutrients from the system through crop uptake and harvest. In contrast, available Mn and Fe levels were higher in cropped treatments compared to the fallow treatment. The impacts of fertilization on available micronutrients varied with cropping systems. Generally, available Zn and Fe were higher in fertilized compared to unfertilized treatments, but available Cu was not significantly influenced by fertilization. Fertilization tended to increase available Mn in continuous wheat and maize, but reduced available Mn in continuous clover and the crop–legume rotation. The total (plant available + unavailable) micronutrient contents were lower in the four cropped-treatments compared to the fallow treatment. The addition of manure or P fertilizer increased total Zn, Fe, and Mn, but had no significant effect on total Cu. The results of correlation analysis and path analysis indicated that soil organic matter exerts a significant and direct effect on the availability of Zn, Mn, and Fe, but has little influence on available Cu. The effects of available P, $CaCO_3$, and pH on micronutrient availability were indirect, passing through soil organic matter. The results of this study suggest that long-term cropping and fertilization altered several important soil properties and increased the plant available micronutrient content of this loess-derived soil.

Keywords: Cropping; Fertilization; Soil properties; Micronutrients; Availability

1. Introduction

Soil provides the micronutrients that are needed by plants in order to complete their life cycle. Previous studies have shown that the availability of soil

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micronutrients is largely influenced by the soil microenvironment as well as soil properties, such as pH, $CaCO_3$, organic matter, and available P (Christensen et al., 1951; Jenne, 1968; Lutz et al., 1972; Olomu et al., 1973; Yuan, 1983; Shuman, 1988a,b). Cropping systems and fertilization practices also influence micronutrient availability. Liu et al. (2002) studied the effects of rice-based cropping on Mn distribution in a paddy soil profile derived from red earth and found that a rice-upland crop rotation prompted the reduction of Mn in the surface soil and accelerated the oxidation and accumulation of Mn in the subsoil, especially when large amounts of manure were applied to the soil. Gao et al. (2000) conducted a 9 years fertilization study on a purple paddy soil in southwest China and found that manure was a better source of available Fe, Mn, and Zn compared to synthetic fertilizers, but manure accelerated the depletion of available Cu.

Soils in the Loess Plateau of China are calcareous with a low organic matter content. Soil pH values range from 7.6 to 8.7. $CaCO_3$ content varies from 1 to 300 g kg^{-1}. Under these conditions, soil micronutrients are often in forms that are unavailable to the plant. This leads to nutrient deficiencies and reductions in crop yield. Although micronutrient deficiencies have often been observed in the Loess Plateau, little is known about the long-term effect of cropping systems and fertilization practices on micronutrient availability in the region.

In this paper, we report results from an 18 years experiment conducted in the southern part of the Loess Plateau. The objective of this research was to study the effect of cropping systems and fertilization practices on soil properties and micronutrient availability.

2. Materials and methods

2.1. Experimental site and soil characterization

The long-term field experiment was initiated in September 1984 at the Agro-ecological Experiment Station of the Chinese Academy of Science, Changwu County, Shaanxi Province, China (35°12′N, 107°40′E). Average annual temperature is 9.1 °C and annual precipitation is 585 mm. In China, the soil is referred to as a Heilu soil, which corresponds to a Calcarid Regosol according to the FAO/UNESCO classification system (FAO/Unesco, 1988). Its properties are shown in Table 1. Soil loss due to water and wind erosion is very low.

Table 1
Chemical properties of the soil at the start of the experiment in 1984

Chemical property	Content
Organic matter (g kg^{-1})	10.5
Total nitrogen (g kg^{-1})	0.8
Available nitrogen (mg kg^{-1})	37.0
Total phosphorous (mg kg^{-1})	0.7
Olsen phosphorous (mg kg^{-1})	3.0
Available potassium (mg kg^{-1})	129.3
DTPA extractable Zn (mg kg^{-1})	0.8
DTPA extractable Cu (mg kg^{-1})	1.1
DTPA extractable Mn (mg kg^{-1})	9.4
DTPA extractable Fe (mg kg^{-1})	5.9
$CaCO_3$ (g kg^{-1})	108.4

2.2. Experiment design and management

The experimental design was a randomized complete block in a split-plot arrangement. Cropping system was the main plot treatment and fertilizer was the split-plot treatment. The cropping systems were long-term fallow, continuously cropped clover (*Trifolium repens* L.), continuously cropped maize (*Zea mays* L.), continuously cropped winter wheat (*Triticum aestivum* L.), and pea (*Pisum sativum* L.)–winter wheat–winter wheat–millet (*Panicum miliaceum* L.) as a crop–legume rotation system. The fertilizer treatments were unfertilized control (CK), nitrogen (N), phosphorus (P), nitrogen + phosphorus (NP), and nitrogen + phosphorus + manure (NPM). Fertilizer treatments differed according to the cropping systems. Continuously cropped clover received the CK, P, and NPM treatments. Continuously cropped maize received the NP and NPM treatments. Continuously cropped wheat received the CK, N, P, and NPM treatments. The crop–legume rotation system received the CK, P, NP, and NPM treatments.

Urea and superphosphate were used as the source of N and P. Manure came from cattle. In all the fertilizer treatments, the N rate was 120 kg ha^{-1}, the P rate was 26 kg ha^{-1}, and the M rate was 75 t ha^{-1}. Total N content of the manure was 1.97 g kg^{-1} and available N was 91 mg kg^{-1}. Total P content of the manure was 0.97 g kg^{-1} and available P was 115 mg kg^{-1}. The Zn, Cu, Mn, and Fe contents of the P fertilizer were 70, 9, 332, and 408 mg kg^{-1}, respectively, and of the manure were 65, 19, 24, and 50 mg kg^{-1}, respectively.

The experiment was replicated three times. Each plot was 10.3 m × 6.5 m. Crop varieties, seeding rates, and sowing and harvest times are shown in Table 2. Routine crop management practices for this region were used. Prior to seeding, fertilizers were broadcast on the soil surface, and then the land was plowed two times with a