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Changes in soil organic carbon, nutrients and aggregation after conversion of native desert soil into irrigated arable land

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ABSTRACT

This study aimed at investigating the effects of agricultural exploitation on desert soil organic C, N and P, and soil aggregation. Four land uses were assessed: (1) 5-year wheat (*Triticum aestivum* L.)/barley (*Hordeum vulgare* L.) + 5-year maize (*Zea mays* L.); (2) 5-year wheat/barley + 5-year alfalfa (*Medicago sativa* L.); (3) 6-year wheat/barley + 4-year acacia (*Robinia pseudoacacia* L.) and (4) uncultivated desert soil. The desert soil contained total organic C (TOC) of 3.1, 3.7 and 4.2 g kg^{-1} and particulate organic C (POC) of 0.6, 0.7 and 0.8 g kg^{-1} at 0–10, 10–20 and 20–30 cm depths, respectively. The soil TOC concentration was increased by 32–68% under wheat–maize rotation and by 27–136% under wheat–acacia at 0–20 cm depth, and by 48% under wheat–alfalfa only at 0–10 cm depth. This contrasted with an increase in the soil POC concentration by 143–167% at depth 0–20 cm under wheat–maize and by 217%, 550% at depth 0–10 cm under wheat–alfalfa and wheat–acacia, respectively. The desert soil had 13 Mg ha^{-1} TOC stock and 2 Mg ha^{-1} POC stock at depth 0–30 cm, whereas crop rotations increased the soil TOC stock by 30–65% and POC stock by 200–350%. Over the 10-year period, the rates of TOC accumulation were 0.6, 0.3, 0.8 Mg ha^{-1} $year^{-1}$ and the rates of POC accumulation were 0.4, 0.4 and 0.7 Mg ha^{-1} $year^{-1}$ under wheat–maize, wheat–alfalfa and wheat–acacia rotations, respectively. At 0–30 cm depth, total soil N was increased by 61–64% under wheat–maize and wheat–acacia, but total soil P was reduced by 38% under wheat–alfalfa. A significant improvement in clay stability but not in aggregate water-stability was observed in cultivated soils. The results showed a significant increase in soil organic C pool but unimproved macro-aggregation of the desert soil after 10 years of cultivation.

1. Introduction

In China, desert soil accounts for about 20% of its total land and is widely distributed in the northwestern and northern regions (Institute of Soil Science, Academia Sinica, 1978a). Desert soils in these regions have been cultivated for cropping since the Han Dynasty (206 B. C.–220 A. D.) where water supply is less limited. As population and food demand continuously increase, conversion of desert soils into arable lands has been largely expanded in the northwestern China over last several decades. However, the agricultural exploitation has threatened the long-term sustainability of desert soils due to scarce water resources and increased wind erosion (e.g. generation of air-born dusts from the surface of newly-cultivated soils during windy seasons). In addition, because of very dry climate, the desert soils in China are highly saline and have low clay and organic matter contents (Institute of Soil Science, Academia Sinica, 1978a; Zhao et al., 2006). As a result, these soils are naturally loosely-aggregated (Li et al., 2006), and are susceptible to wind erosion, especially under conventional tillage. The growing threat of food insecurity and under-privileged population in China and across the globe necessitates a critical appraisal of agronomic strategies needed to enhance and sustain productivity while mitigating climate change, improving biodiversity, restoring quality of soil and water resources, and improving the environment (Lal, 2009).

Soil organic matter serves as an important storehouse of nutrients, drives nutrient cycle, maintains soil structural stability, aids the infiltration of air and water, promotes water retention, and reduces erosion (Gregorich et al., 1994). Under crop cultivation, changes in soil organic matter status would determine the dynamics of desert soil quality. The size-fractionation of soil organic C is an important technique in assessing short-term changes in soil organic C induced by land use. The coarse (2–0.05 mm) organic C represents the recently incorporated residues (litters and dead roots), and is a sensitive indictor of soil organic C (Quiroga et al., 1996; Conant et al., 2003). Mineralized C over short-term in laboratory incubation is frequently used to evaluate the

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influence of land management on soil organic matter status and bio-availability (Saggar et al., 2001). Total soil N concentration estimates total N pools that are mostly in organic form in soil and transformed into inorganic form during decomposition of soil organic matter. Soil P is often low and poorly mobile, and critically limits plant growth (Sharpley, 2000). The measurement of Olsen-P can estimate the level of soil P supply. Soil aggregation is closely related to soil organic matter content (Tisdall and Oades, 1982) and affect many soil biological, chemical and physical processes including erodibility (Kay, 2000). Thus, changes in soil aggregation may play an important role in the soil quality of desert soils under crop cultivation.

The impacts of converting native grasslands and bushlands to arable lands on soil organic C, nutrients and physical properties are widely reported in the literature. However, changes in soil properties caused by agricultural exploitation of desert soils are hardly documented. In this study we investigated the effects of crop cultivation on temporal changes in soil organic C, N and P and soil aggregation of desert soils in the northwestern China. Such knowledge would assist the farmers to conduct proper agricultural practices for the long-term sustainability of desert soils.

2. Materials and methods

2.1. Description of experimental site

The experimental site (39°14′N, 99°84′E) was located in Gaotai County in Hexi Corridor of northwest China, with a flat topography and an altitude of 1350 m. The climate is of typically dry continent, with an annual precipitation of 79 mm, a pan evaporation amount of 1967 mm and an annual average temperature of 7.6 °C. The vegetative lands naturally form on semi-locomotive ridge dunes and wind-eroded billabongs with a relative height of 1–3 m, and the depth of water table varies from 6 to 9 m around the year. The dominant plant species are some xerophil and ultra-xerophil types such as *Nitraria sibirica* Pall., *Calligonum* L., *Alhagi pheud alhagi* Desv., *Artemisia*. The soil was classified as grey brown desert soil (Institute of Soil Sciences, Chinese Academia of Sciences, 1978a), similar to the Aridisols.

The site was surrounded by man-made oasis (croplands, cultivated from desert soil decades ago) to the north, west and east, and adjacent to a vast desert to the south. In 1996–1997, a total of 2900 ha desert soil was converted into agricultural land with irrigation using the water from Heihe River with its origin as melted glaciers in the Qilian Mountains. The salt concentration of the river water was 575 mg l^{-1} and pH 7.63 (Zhou and Dong, 2002).

2.2. Experimental design

Our investigation was conducted on a farm, which started to grow spring wheat (*Triticum aestivum* L.) and barley (*Hordeum vulgare* L.) in a field of 56 ha (800 m × 700 m) in 1996 and continued the same cropping for 5 years under conventional tillage. In April 2001, an area of 20 ha was converted into continuous maize (*Zea mays* L.) and 33 ha into continuous alfalfa (*Medicago sativa* L.). In April 2002, the remaining 3 ha were seeded as acacia (*Robinia pseudoacacia* L.) nursery to provide saplings for building a windbreak.

Maize was sown in early April and harvested in mid September with a grain yield of about 6–7.5 t ha^{-1}. Over the growing season, 516 kg N and 86 kg P_2O_5 ha^{-1} were applied, including one base fertilization of urea and di-ammonium phosphate, and three topdressings of urea later. Irrigation was applied 4–5 times through the growing season, totaling 11250 m^3 ha^{-1}. Maize straws were removed for fodder each year. During the maize growing period, the soil was mulched with plastic film. This practice is common for maize and other crops in the region mainly for increasing soil temperature and reducing evaporation. Alfalfa was sown in April 2001 and grew for 5 years, and was irrigated at 11250 m^3 ha^{-1} annually (allotted at 3–4 times). Nil fertilizer was applied throughout 5 years of growth, except for base fertilizer at sowing with urea at 69 kg N ha^{-1}. The annual hay production was about 15 t ha^{-1}. Acacia was irrigated at an annual rate of about 7500 m^3 ha^{-1} without fertilization. Leaf biomass was not collected for fodder or any other usage. At the time of soil sampling, acacia plants had grown to a height of about 3 m.

The experimental design was applied in one piece of land for each treatment, a common practice with these types of studies (*cf*. Ashagrie et al., 2007; Noellemeyer et al., 2008; He et al., 2008). With the provision of a big area and random sampling, the obtained information would certainly reflect the changes in soil organic C, nutrients and aggregation induced by cropping, because the topography, vegetation and cultivation were comparable between the treatments.

2.3. Soil sampling

In April 2006, three blocks (each >667 m^2) were randomly selected from each of the three treatments for soil sampling to produce three pseudo replications. At each block, five sub-samples at each depth of 0–10, 10–20 or 20–30 cm were taken using a scoop and mixed as a composite sample. Adjacent to sampling areas of the three treatments, three uncultivated blocks were randomly selected and sampled in the same way. The three land uses (5-year wheat/barley + 5-year maize; 5-year wheat/barley + 5-year alfalfa; 6-year wheat/barley + 4-year acacia) were compared with the native desert soil. Overall, 36 composite soil samples were collected, comprising four land uses, three depths and three replicates.

Soil bulk density was determined at depths of 2.5–7.5, 12.5–17.5 and 22.5–27.5 cm using a cutting ring (inner diameter of 5.03 cm, and volume of 100 cm^3) (Institute of Soil Science, Academia Sinica, 1978b), to represent the bulk density of soil depths 0–10, 10–20 and 20–30 cm, respectively.

After air-drying, each composite sample was split into two parts. One part was sieved at <2 mm for the analysis of soil basic properties, clay dispersion, and organic C and nutrient contents. The other part was passed through a 5-mm sieve for measuring soil aggregate stability.

2.4. Measurements of basic soil properties

Soil pH was measured at the ratio of 1 soil:2.5 water, and electrical conductivity (EC) in saturated extracts. Soil carbonate contents, expressed as $CaCO_3$, were determined by CO_2 volumetric method (Qin, 2002). Soil particle distribution was determined by the pipette method, following the procedure described by the Institute of Soil Science, Academia Sinica (1978b), with the exception of $CaCO_3$ washing by acid. This minor change made it possible that particle composition data matched dispersible clay contents in the soils (see below).

2.5. Measurements of total, particulate and mineralizable organic carbons

Thirty grams of air-dried soil (2-mm fraction) were shaken for 2 h in 60 ml of 0.5% (w/v) hexametaphosphate solution to disperse the soil. The dispersed soil was wet-sieved through a 0.05-mm sieve, and the fractions of sand and sand-sized organic materials (particulate fraction) retained on the sieve were oven-dried at 60 °C and weighed. Total and particulate (2–0.05 mm) organic C were analyzed with the Walkley and Black's dichromate oxidation method (Nelson and Sommers, 1982). Mineral-associated