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Irrigation with sediment-laden river water affects the soil texture and composition of organic matter fractions in arid and semi-arid areas of Northwest China

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A B S T R A C T

Soil organic carbon (SOC) is the largest reservoir of organic carbon in the terrestrial ecosystem, and is an effective mean of enhancing crop production in the irrigated area of the arid and semi-arid regions. Understanding long-term changes in composition of SOM under irrigation from sediment-laden Yellow River water is essential to manage sustainability issues in the agro-ecosystem. A total of 45 soils, including 39 of irrigated fields differing in irrigation history and 6 of non-cultivated and non-irrigated natural fields as the control, were sampled at 0–20 cm depth. The soil was analyzed for total SOC content, partitioning of light (LFOM) and heavy (HFOM) fraction organic matter based on NaI solution density of 1.7 g m^3 and for particle size distribution. Compared to the non-irrigated and non-cultivated control soil, the LFOM and HFOM in irrigated soils increased with the duration of irrigation though SOM existed dominantly as the heavy fraction. The soils irrigated for < 50 years have overall lesser LFOM and HFOM and more sand compared to those with > 50 years irrigation. Further, a positive relationship existed between the fine particle and the SOM or its fractions (negative relation with coarse particle) suggesting either SOM accumulated as fine particles or the fine mineral particles better preserved SOM. In addition, field soil moisture at the time of sampling during October 2009 correlated with HFOM ($p < 0.001$) and LFOM ($p < 0.01$). The study suggested that the long-term irrigation with water diverted from Yellow River increased fine particle, SOC and the light and heavy fraction in the Ningxia Irrigation Zone.

1. Introduction

Soil organic carbon (SOC) storage that has an important role in supply of plant nutrients and in mitigating global warming (Strong et al., 1999; Cheng et al., 2009; Dong et al., 2015; Blanco-Moure et al., 2016). Soil organic matter (SOM) increase under appropriate agro-management measures leading to a new equilibrium for higher level (Banger et al., 2009; Fultz et al., 2013; Tong et al., 2014). The decomposition and accumulation rates are influenced by distribution of SOM fractions, soil properties, environmental factors and human activity (Su et al., 2006; He et al., 2008; Chivenge et al., 2011; Wiesmeier et al., 2014; Wight et al., 2016) indicating a need for regional studies. Evaluation of long-term changes in fractions of the SOM as an indices of SOC stability under irrigated agro-ecosystem in arid and semi-arid regions need further research (Li et al., 2007; Tarchouna et al., 2010; Song et al., 2013).

Irrigation enhances crop production in arid and semi-arid regions, and the source of irrigation has strong effects on both SOC and texture (He et al., 2008; Bhattacharyya et al., 2008; Omron et al., 2012; Wight et al., 2016; Dong et al., 2017). Omron et al. (2012) reported that, under irrigation with sewage water, an increase in SOM was found particularly during the later period, contrary to the result of Delibacak et al. (2009) that a decrease in SOM was observed. In addition, they both found that there was no change in the silt and clay content for the entire irrigation period. A significant increase in SOC content specifically in coarse size fractions has also been reported under regulated

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deficit irrigation (Zornoza et al., 2016).

Soil texture is intimately associated with SOC storage for its role in carbon sequestration and mineralization (Hassink, 1996; Huang, 2000; Tong et al., 2014; Wight et al., 2016). Silt and clay particles preserve SOC (Hassink, 1997; Hedges and Oades, 1997; Fultz et al., 2013; Wight et al., 2016) as shown through a positive relation between fine silt and clay and SOC content for uncultivated and cropped lands (Albaladejo et al., 2013; Blanco-Moure et al., 2016). Secondly, soil clay slows SOM decomposition while in coarse textured soils decomposition is fast, therefore, rate of accumulation is affected through decomposition (van Veen and Kuikman, 1990; Hassink, 1996; Strong et al., 1999). The stability of SOC is also mediated through the formation and stabilization of soil aggregate, where aggregate stabilization is greater in soil with higher content of clay (Six et al., 2002; Chivenge et al., 2011; Xu et al., 2016) Third, the predictive accuracy of the SOC model is affected by clay content (Wight et al., 2016). The clay content is a sensitive parameter for predicting total SOC using the Century model (Bricklemyer et al., 2007) as well as the Roth C model (Sakurai et al., 2012; Ludwig et al., 2005). The clay content determines the allocation of C (Setia et al., 2011; Wan et al., 2011; Álvaro-Fuentes et al., 2012). Though generally accepted that the clay is an important property when analyzing SOC stocks (Batjes et al., 2007; Xu et al., 2011; Sakurai et al., 2012; Raj et al., 2011; Wang et al., 2010; Wiesmeier et al., 2014), a few show no influence of clay content on SOC change (Percival et al., 2000; Saiz et al., 2012).

Irrigation through canals carrying water diverted from rivers is widespread in the arid and semi-arid regions of Northwest China (Wang, 1993; Li et al., 2006; Yang et al., 2013) that changes SOM and soil texture in the regions (Gong et al., 2005; Li et al., 2006; Dong et al., 2015). Irrigation derived sediment in the Yellow River command areas form soils under long-term cultivation (Gong et al., 2005; Dong et al., 2015; Dong et al., 2017) had greater SOM content by $\geq 4\ \mathrm{g\ kg^{-1}}$ attributed to the integrated actions of irrigation and cultivation, manure addition and the silting of sediments. An evaluation of long-term changes in the fractions of SOM as indices of SOC pool (Li et al., 2007; Tarchouna et al., 2010; Song et al., 2013) is needed to project sustainability of the irrigated agro-ecosystem in the northern Ningxia Province, Northwest China. The hypothesis is that the duration of irrigation is related to the changes fractions of SOM and soil particle size distribution. The objectives of this study were (1) to determine the temporal effect of irrigation and cultivation with sediment-laden Yellow River water on SOM content and fractions and soil particle size distribution, and (2) to evaluate the interactions between soil texture and SOC accumulation processes.

2. Materials and methods

2.1. Study area and sampling

The study area was located between 35°14′25″ to 39°23′10″N and 104°16′55″ to 107°38′53″E in the northern Ningxia Province in Northwest China (Fig. 1). The area occurred in a semi-arid continental temperate monsoon climate with an annual temperature of 8 to 9 °C and precipitation of 300 mm to 180 mm decreasing from south to north. The Yellow River flows through northern Ningxia from the south towards the north irrigating 460 Mha through nine main channels carrying water under gravity flow or under water head generated by pumping (Table 1). The Ningxia Irrigation Zone region has a recorded history of irrigation from Yellow River water.

Forty-five sites with history of irrigation ranging from 10 to 2200 year and the non-cultivated and non-irrigated site as control (soils with 0 year irrigation) were selected to represent the chronosequence of irrigation. The six control sites belong to three soil type namely sierozem, aeolian sandy, and tidal soils. The number of samples for a particular soil types in the irrigated category were adjusted for the aerial extent. During October 2009 before winter irrigation, each site was sampled from 3 locations at 0 to 20 cm depth for a composite sample. After mixing and removing the plant parts, a portion was collected into plastic Ziploc bag. In addition, a double-ring stainless steel core sampler of 7.5 cm length and 5 cm inner diameter was driven vertically at three locations in the field to obtain intact sample for soil bulk density measurement.

2.2. Soil preparation and analysis

The soil was air-dried, and sieved to pass 2 mm nylon mesh. The soil core was dried at 105 °C until its constant weight. The soil water content and bulk density were calculated. The soil particle sizes were separated into coarse sand (2–0.1 mm), fine sand (0.1–0.05 mm), coarse silt (0.05–0.02 mm), fine silt (0.02–0.002 mm) and clay (< 0.002 mm), which were determined by pipette method after dispersion in 1 M Na-hexametaphosphate and expressed on dry soil weight basis (Lu, 2004).

2.3. Soil organic matter analysis

Density fractionation of soil organic matter was performed to determine the light ($< 1.7\ \mathrm{g\ m^{-3}}$) and heavy ($> 1.7\ \mathrm{g\ m^{-3}}$) fractions (Tisdall and Oades, 1979). Ten grams of air dried soil (< 2 mm) was placed into a 100 ml centrifuge bottle with 40 ml NaI of $1.7\ \mathrm{g\ cm^{-3}}$ density, the suspension was sonicated for 10 min, and then centrifuged for 10 min at $3500\ \mathrm{r\ min^{-1}}$. The light and heavy fractions collected separately, were washed thoroughly with $CaCl_2$ and deionized water, dried at 60 °C for 48 h, and then weighed. The heavy fraction organic carbon content was determined using $K_2Cr_2O_7$ oxidation-titration (Lu, 2004) and the light fraction organic carbon determined by the dry combustion method (1150 °C) using a C/N analyzer (Vario macro cube organic material analyzer, Elementar, Germany).

2.4. Calculation of variation of SOM and soil particles

The effect of irrigation year on SOM and soil particles was obtained by subtracting the mean value of the control i.e. un-irrigated and uncultivated sierozem, aeolian sandy and tidal soils. For irrigation-silted and recent deposited soils, the effect of irrigation year was obtained by subtracting the mean value of the 6 control soils as they are formed on all the 3 types of control. The mean variation was the average value of all variations in the same irrigation year category or soil type. The variations of organic matter and particle percentage divided by the value of control soils in the same soil type was multiplied by 100 to get the percent increase of organic matter and its fractions or particles size.

2.5. Statistical analysis

First, the descriptive statistics was obtained. Second, the data was analyzed to contrast variance of un-irrigated versus that of group of irrigated soils using *t*-test. Third, analysis of variance (ANOVA) was performed to determine the effect of soil types and durations of irrigation on SOM content, fractions and on the soil particle size classes. The means were compared using least significance difference (LSD) at 5% confidence level. The strength of relationships between the SOC fractions and soil particle sizes was assessed through Pearson correlation coefficients. The statistical analysis was carried out using SPSS software version 16.0 (SPSS Inc. Chicago, Illinois).

3. Results and discussion

3.1. Effects of irrigation on soil organic matter

A significant ($p > |t|$ 0.0001) differences in variance in the non-irrigated control compared to the irrigated was found for SOM, HFOM and LFOM in surface soil. The effect of long-term irrigation was significant ($p < 0.0001$), and the mean for SOM, HFOM and LFOM