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# Newly-reclaimed alfalfa forage land improved soil properties comparison to farmland in wheat–maize cropping systems at the margins of oases

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ABSTRACT

The increased demand for economic benefits has led to an extensive conversion of native sandy steppe at the margins of oases into alfalfa forage land and farmland in northwestern China. Understanding the impacts of alfalfa forage land and farmland on soil properties is crucial for maintaining the stability of oases. However, the effect of this newly-reclaimed alfalfa forage land and farmland on soil properties remains unknown. Native sandy steppe and 10-year-old alfalfa forage land and farmland (both converted from native sandy steppe) were chosen for use in this study. It was shown that the conversion of native sandy steppe to alfalfa forage land and farmland significantly increased the amounts of soil organic carbon (SOC), total nitrogen (TN) and total phosphorus (TP). Over the period of 10 years, the sequestrations of SOC, TN and TP were almost the same for both alfalfa forage land and farmland. After the period of 10 years, the soil water holding ability, water stable macro-aggregates aggregates, soil microbial biomass C (MBC) and microbial biomass N (MBN) contents and urease, β-glucosidase, and alkaline phosphatase activities were all significantly higher in the alfalfa forage land than in the farmland. These results suggest that the newly-reclaimed alfalfa forage land is more propitious for amending soil environments than farmland, thus it should be widely used to improve the soil properties at the margins of oases.


## 1. Introduction

Desert ecosystems are widely distributed in the inland arid regions of north western China, covering about 20% of China's land surface (Institute of Soil Science, Academia Sinica, 1978). In general, a desert ecosystem is a matrix consisting of desert, oasis and a transitional belt between the oasis and desert (Cheng et al., 1999). The desert–oasis transitional zone plays an important role in the ecological system of the oasis, as it maintains the internal stability of agriculture, and protects the oasis from wind-blown sand damage (Su et al., 2007; Su and Yang, 2008; Wang and Li, 2012; Bo and Zheng, 2013).

The Hexi Corridor region is one of the main sandy desertification regions induced by wind action in northern China (Research Group of 'Study on Combating Desertification/Land Degradation in China', 1998). Since the early 1970s, rapid population growth in these arid regions has led to a large-scale conversion of desert into agricultural land on the edge of the oasis (Wang et al., 2010a,b). In the newly-reclaimed farmland on the marginal oasis, wind erosion is a serious concern. The stability and sustainability of the farmland ecosystem on the edge of the oasis are threatened by desertification. In order to improve the eco-environment in the central and western regions of China, the Central Government has proposed a policy of 'Conversion of Farmland to Forest and Grassland Regeneration' for 10 provinces including 363 counties located in central and western China (UNCCD, 2002). In this program, alfalfa has been widely re-introduced into the agricultural ecosystem, to promote economic development of the western regions and readjustment of the rural economic structure, and to alleviate poverty among farmers. The oasis–desert ecotone comprises an important part of the program.

Jiang et al. (2015) reported that the soil properties in the riparian zones of desert oases are affected significantly by land use/land cover change (LUCC). In addition, soil organic carbon, pH and total K were found to be closely related to LUCC, and can be explained by wetland–arable, forest–grassland, grassland–desert,

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and wetland–desert transitions, respectively. Land exploitation also resulted in soil salinization in a desert-oasis ecotone under long-term irrigation (Luedeling et al., 2005; Wang and Li, 2012). The soils at the margins of oases have great potential to sequester C and N following the conversion of cropland to alfalfa forage land (Su, 2007). Biological soil crusts which were formed through artificial ecological restoration significantly enhanced soil urease, invertase, catalase and dehydrogenase activities, and promoted soil C and N cycling in the Tengger Desert (Liu et al., 2014). For the ecological security of the oasis ecosystem and economic benefits, large areas of native desert shrub land have been reclaimed into alfalfa forage land and farmland in northwestern China. Understanding the impacts of alfalfa forage land and farmland on soil properties is crucial for maintaining the stability of oases. However, little information is available regarding the changes in soil properties of the newly-reclaimed alfalfa forage land and farmland on the edge of the oasis.

The objective of the present study is to quantify the soil properties of the newly-reclaimed alfalfa forage land and farmland at the edge of the oasis.

## 2. Materials and methods

### 2.1. Description of study site

The study was conducted in a desert area in the central reaches of the Heihe River Basin (39°20′N, 100°08′E, 1380 m asl), the second largest inland river basin (135,000 $km^2$) in the arid regions of China. The climate is strongly continental with long, cold winters and dry, hot summers. The mean annual precipitation over the past 30 years is 117 mm, and more than 70% of the precipitation occurs from June to September, which is only one-twentieth of the mean annual pan potential evaporation (2390 mm). The mean annual air temperature is 6 °C, varying from −10.7 °C in January to 23.8 °C in July.

### 2.2. Experimental design

An old artificial oasis with an area of about 6000 $km^2$ was selected for the study. At the margins of the oasis, native sandy vegetation, along with cultivated soils of 10-year-old alfalfa forage land and farmland converted from native sandy steppe, which chosen as the study system. This system allowed us to quantify the impacts of land conversion from native sandy steppe to alfalfa forage land and farmland on the soil properties. The native sandy steppe has a soil type that the Chinese Soil Taxonomy classification system identifies as an "Aridi-Sandic Primosol of sand origin" (Chen and Li, 1998).

In this study, three replicate sites (each having a sampling area of 100 × 150 m), at least 100 m apart, were chosen in each of the three habitat types. The native sandy steppe sampled at the three sites was dominated by the shrub species *Calligonum mongolicum*, *Nitraria sphaerocarpa*, and *Nitraria sibirica*, along with herbaceous species such as *Agriophyllum squarrosum*, *Bassia dasyphylla*, *Halogeton glomeratus*, and *Pugionium cornutum*. The alfalfa forage land and farmland sampled at the three sites had been established on former native sandy steppe for 10 years. The annual mean irrigation input on alfalfa forage land was 6000 $m^3\ ha^{-1}$. A crop rotation of maize and wheat had been practiced in the surrounding farmlands. The annual mean irrigation input of farmland was 12,000 $m^3\ ha^{-1}$, and the annual mean chemical fertilizer input was 1500–1800 $kg\ ha^{-1}$ ($N{:}P_2O_5{:}K_2O = 1{:}1{:}1$), and farmyard manure (compost heap) was applied at a rate of 15,000–18,000 $kg\ ha^{-1}$ at 2–3 year intervals. In the present study, the stalks and main roots of maize and wheat were removed as fuel after harvest, and only a small amount of the residues was returned to the soil. The alfalfa was harvested three to four times each year, and had a greater return of residues into soil after cutting.

### 2.3. Sampling and measurements

At each of the three sites in each habitat, three replicate plots (30 × 30 m) were randomly set and within each plot. In each site, 15 soil cores (diameter: 8 cm, height: 10 cm) were taken and combined into a composite sample in early September 2011 (3 plots per site × 5 samples per plot) (i.e. generally abundant precipitation occurred in September, and soil microbial activities were detected more easily). The samples were air-dried, ground, sieved (2, 0.9 and 0.15 mm), and stored at room temperature until needed. To determine the microbial biomass C (MBC) and N (MBN) and soil enzymes activities, the samples were brought to the laboratory and stored at 4 °C for up to 10 days before analysis.

In each habitat, nine soil samples were collected from depths of 0 to 10 cm for determination of soil water potential (3 site × 3 plots per site × 1 sample per plot). Soil water potential was measured on undisturbed samples in the laboratory. Sample saturation was performed in a sandbox by adding water slowly to about half way to the top of the sample rings, which was then left to soak overnight. Before soaking the samples in the sandbox, cheesecloth was fastened to the lower end of each ring with a rubber band to avoid loss of soil during manipulations. After saturation, the soil water retention curves were measured at desorption after saturation using the H–1400 pF (Kokusan, Japan). Matric potentials of −1, −3, −6, −9, −10, −30, −50, −90, −120, −150, −300 and −1500 kPa were applied successively over the same undisturbed cube samples, until water ceased to flow from the pressure chambers.

The particle size distributions of < 2 mm particle fractions were determined using the laser detection technique on the Microtrac S3500 Particle Size Analyzer (Microtrac Inc, USA). The soil samples were pretreated by destroying organic matter using $H_2O_2$ (30%, w/w) at 72 °C. The aggregates were then dispersed using sodium hexametaphosphate (NaHMP) and ultrasonics for 30 s (Gui et al., 2010). The distribution of soil water stable aggregates (WSA) was determined by placing the soil sample on a nest of sieves, before sieving. A 100 g sample of bulk soil was slaked by submerging it in deionized water on the top 2.0 mm sieve for 5 min at room temperature. WSAs were then separated by moving the sieve up and down 30 times per minute for 15 min. The proportions of the wet stable aggregates > 2, 2–1, 1–0.5 and < 0.5 mm were calculated. The soil retained in each sieve was oven-dried at 50 °C and weighed to compute the percentage of WSA (Nimmo and Perkins, 2002). The soil fraction of < 0.5 mm was obtained by collecting the sediment after decanting the water and determining the oven-dry weight. A portion of these oven-dry samples from each aggregate-size fraction was ground and sieved to obtain a 0.15 mm fraction to determine the total SOC concentration.

SOC was determined using the HT1300-microN/C3100-analyzer (Jena, Germany). Then, a KJ (Kjeldahl) Auto Analyzer (TECATOR Product, Sweden) was used to measure the soil total nitrogen (TN) after digestion with salicylic acid-$H_2SO_4$. Total phosphorus (TP) was determined colorimetrically after digestion with perchloric acid. Available phosphorus (AP) was determined using the Olsen method (Olsen et al., 1954). Dried samples weighing 10 g each were added to 50 mL of 2 M KCl, shaken for 1 h, then analyzed with a FIAstar 5000 Analyzer (FOSS Tecator, Sweden) for nitrate nitrogen ($NO_3$-N) and ammonium nitrogen ($NH_4$-N) (Su et al., 2007; Zhang and Zhao, 2015). Soil microbial biomass carbon (MBC) and nitrogen (MBN) were estimated using the fumigation extraction method (Brookes et al., 1985), which using purified $CHCl_3$ treatment followed by 0.5 M $K_2SO_4$ extraction of fumigated and unfumigated soil (Singh and Singh, 1993). Soil samples (each equivalent to 25 g of dry weight

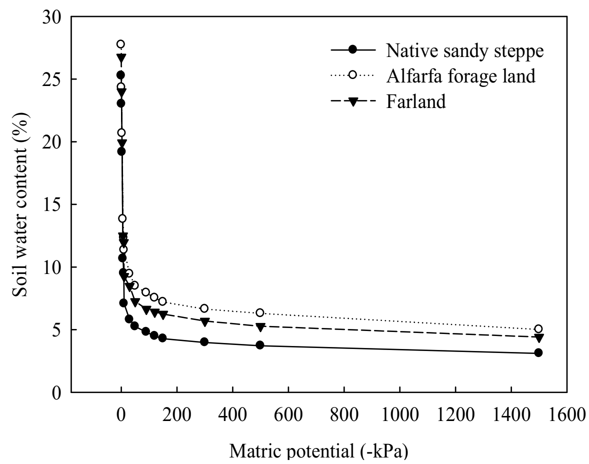


**Fig. 1.** Water retention curves in different land use types in the 0–10 cm soil layer.

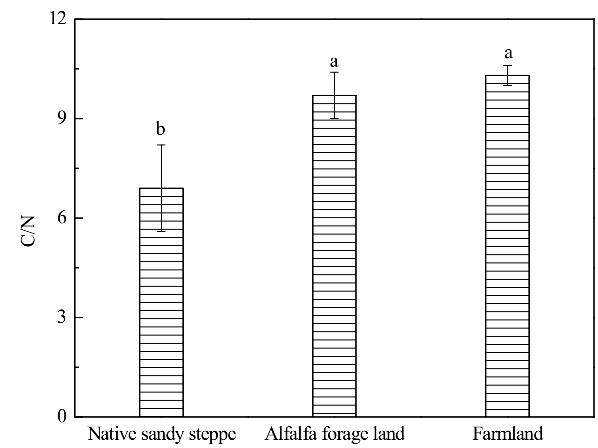


**Fig. 2.** Ratios of soil organic C to total N (C/N) in the 0–10 cm soil layer. Means with different letters indicate significant differences at $P \leq 0.05$. Bars indicate SD ($n = 3$).

soil) were fumigated for 24 h at 25 °C with $CHCl_3$ (ethanol-free). Following fumigant removal, the soil was extracted with 100 mL of 0.5 M $K_2SO_4$ by shaking for 1 h at 200 rpm, followed in turn by filtering. The non-fumigated portions were extracted at the same time. After extraction, MBC and MBN were measured by determining the C and N masses in the filtrate using a multi N/C 3100 analyzer (Jena, Germany). Microbial biomass C was calculated as follows: microbial biomass carbon = ($C_{org}$ (fum) − $C_{org}$ (non))/0.38 (Ocio and Brooks, 1990). Microbial biomass nitrogen was calculated as follows: microbial biomass N = (TN (fum) − TN (non))/0.45 (Ocio and Brooks, 1990). In the present study, the ratios of MBC to total C (MBC/SOC) and MBN to total N (MBN/TN) were calculated. β-glucosidase enzyme activity was determined according to the method described by Dick et al. (1998). Activities of urease and alkaline phosphatase activities were assayed as described by Tabatabai (1994).

### 2.4. Statistical analysis

Statistical analysis was carried out using the SAS software package (SAS Institute, 1990). The differences among treatments were evaluated with the least significant difference (LSD) at $P < 0.05$. Linear regression analysis determined the relationship between soil particle size and SOC and TN, as well as the relationship between MBC, MBN and soil enzymes activities, and field moisture capacity and microbial activities.

## 3. Results

### 3.1. Soil water retention properties, aggregates and particle size distribution

The conversion of native sandy steppe to alfalfa forage land and farmland increased the soil water holding capability (Fig. 1), which was higher in the alfalfa forage land than in the other land use types.

Macro-aggregates aggregates (>0.5 mm) in the 0–10 cm soil layer were significantly affected by the conversion of native sandy steppe to alfalfa forage land and farmland (Table 1), increasing sharply from 0 in the native sandy steppe to 3.37% in the 10-year-old farmland and 8.85% in the alfalfa forage land.

The conversion of native sandy steppe to alfalfa forage land and farmland significantly decreased the 1000–250 μm soil particle content (Table 2), and significantly increased the fine particle content of the 100–2 μm in the 0–10 cm soil layer. Compared with the native sandy steppe, the fine particle contents in the alfalfa forage land and farmland increased by 1.9 and 1.8 times, respectively.

### 3.2. Soil C, N and P

The conversion of native sandy steppe to alfalfa forage land and farmland had significant effects on soil C, N and P (Table 3). The SOC, TN, TP and AP contents were significantly higher in the alfalfa forage land and farmland than in the native sandy steppe, with no significant differences observed between the alfalfa forage land and farmland. The conversion of native sandy steppe to alfalfa forage land significantly increased the soil MN content, with no significant differences observed between the native sandy steppe and farmland. The conversion of native sandy steppe to alfalfa forage land and farmland significantly increased the ratios of soil organic C to total N (C/N) (Fig. 2). There was a significant positive correlation between the particle content of 100–2 μm and SOC, as well as that of 100–2 μm and TN (Figs. 3 and 4).

### 3.3. Soil microbial biomass C (MBC), N (MBN) and enzymes activities

The MBC increased sharply from 47.5 mg $kg^{-1}$ in the native sandy steppe to 138.3 mg $kg^{-1}$ in the alfalfa forage land and 67.1 mg $kg^{-1}$ in the farmland; MBN increased from 11.2 mg $kg^{-1}$ in the native sandy steppe to 25.3 mg $kg^{-1}$ in the alfalfa forage land and 14.1 mg $kg^{-1}$ in the farmland; MBC/SOC significantly decreased from 8.2 in the native sandy steppe to 4.2 in the alfalfa forage land and 2.0 in the farmland; MBN/TN significantly decreased from 12.8 in the native sandy steppe to 7.3 in the alfalfa forage land and 4.4 in the farmland; urease activity significantly increased from 2.2 mg N-$NH_4^+$ $kg^{-1}$ $h^{-1}$ in the native sandy steppe to 21.3 mg N-$NH_4^+$ $kg^{-1}$ $h^{-1}$ in the alfalfa forage land and 8.1 mg N-$NH_4^+$ $kg^{-1}$ $h^{-1}$ in the farmland; β-glucosidase activities significantly increased from 0.5 mg pNP $kg^{-1}$ $h^{-1}$ in the native sandy steppe to 7.3 mg pNP $kg^{-1}$ $h^{-1}$ in the alfalfa forage land and 2.7 mg pNP $kg^{-1}$ $h^{-1}$ in the farmland; and alkaline phosphatase activities significantly increased from 11.4 mg pNP $kg^{-1}$ $h^{-1}$ in the native sandy steppe to 202.3 mg pNP $kg^{-1}$ $h^{-1}$ in the alfalfa forage land and 84.7 mg pNP $kg^{-1}$ $h^{-1}$ in the farmland (Table 4). There was a positive correlation between the MBC, MBN and soil enzyme activities (Fig. 5).

## 4. Discussion

Irrigation agriculture is generally well developed in artificial oases, thus frequently causing the over-exploitation of water resources and degradation of natural ecosystems. Water shortage has become the major obstacle for plant productions which rely entirely on oasis irrigation (Kang et al., 2004; Zhao et al., 2010).

**Table 1**
Soil water-stable aggregate size classes (%) for different land use types in the 0–10 cm soil layer (means ± SD, $n = 3$).

| Cover type | Macro-aggregates (>0.5 mm) | | | | Micro-aggregates (<0.5 mm) |
|---|---|---|---|---|---|
| | >2 mm | 1–2 mm | 0.5–1 mm | Sum | <0.5 mm |
| Native sandy steppe | 0.00 ± 0.00c | 0.00 ± 0.00c | 0.00 ± 0.00c | 0.00 ± 0.00c | 100.00 ± 0.00a |
| Alfalfa forage land | 5.23 ± 0.99a | 1.74 ± 0.23a | 1.89 ± 0.06a | 8.86 ± 0.91a | 91.14 ± 0.91c |
| Farmland | 0.92 ± 0.08b | 0.89 ± 0.19b | 1.56 ± 0.06b | 3.36 ± 0.14b | 96.64 ± 0.14b |

Values within a column followed by the same letter do not differ significantly at $P \leq 0.05$.

**Table 2**
Soil particle-size distribution for three lands covers types at 0–10 cm soil depth (means ± SD, $n = 3$).

| Covers types | Particle size distribution (%) | | | | |
|---|---|---|---|---|---|
| | 1000–250 μm | 250–100 μm | 100–50 μm | 50–2 μm | <2 μm |
| Native sandy steppe | 24.50 ± 3.15a | 66.09 ± 2.73b | 8.92 ± 0.93b | 0.49 ± 0.09b | 0 ± 0.00a |
| Alfalfa forage land | 15.52 ± 2.26b | 65.77 ± 1.13b | 11.76 ± 0.82a | 7.05 ± 1.64a | 0 ± 0.00a |
| Farmland | 7.51 ± 0.94c | 74.09 ± 0.72a | 11.86 ± 0.80a | 6.54 ± 0.44a | 0 ± 0.00a |

Values within a column followed by the same letter do not differ significantly at $P \leq 0.05$.

**Table 3**
Soil nutrients for different land use types at 0–10 cm soil depth (means ± SD, $n = 3$).

| Covers types | SOC (g $kg^{-1}$) | TN (g $kg^{-1}$) | MN (mg $kg^{-1}$) | TP (g $kg^{-1}$) | AP (mg $kg^{-1}$) |
|---|---|---|---|---|---|
| Native sandy steppe | 0.58 ± 0.10b | 0.09 ± 0.02b | 5.4 ± 0.7b | 0.25 ± 0.04b | 1.0 ± 0.1b |
| Alfalfa forage land | 3.39 ± 0.59a | 0.35 ± 0.05a | 13.8 ± 3.0a | 0.35 ± 0.02a | 2.1 ± 0.6a |
| Farmland | 3.37 ± 0.25a | 0.33± 0.03a | 6.75 ± 1.1b | 0.38 ± 0.02a | 1.9 ± 0.3a |

SOC: soil organic C; TN: total nitrogen; MN: mineral nitrogen; TP: total phosphorus; AP: available phosphorus. Values within a column followed by the same letter do not differ significantly at $P \leq 0.05$.

**Table 4**
Soil microbial biomass C and N contents, and enzymes activities for three lands covers types at 0–10 cm soil depth (means ± SD, $n = 3$).

| Covers types | MBC (mg $kg^{-1}$) | MBN (mg $kg^{-1}$) | MBC/SOC (%) | MBN/TN (%) | Ure (mg N-$NH^{4+}$ $kg^{-1}$ $h^{-1}$) | Glu (mg pNP $kg^{-1}$ $h^{-1}$) | Pho (mg pNP $kg^{-1}$ $h^{-1}$) |
|---|---|---|---|---|---|---|---|
| Native sandy steppe | 47.5 ± 3.2c | 11.2 ± 1.7c | 8.2 ± 0.9a | 12.8 ± 1.2a | 11.4 ± 0.8c | 0.5 ± 0.1c | 11.4 ± 0.8c |
| Alfalfa forage land | 138.3 ± 11.5a | 25.3 ± 0.7a | 4.2 ± 1.1b | 7.3 ± 1.4b | 202.3 ± 12.6a | 7.3 ± 0.2a | 202.3 ± 12.6a |
| Farmland | 67.1b ± 9.0b | 14.1 ± 1.3b | 2.0 ± 0.4c | 4.4 ± 0.8c | 84.3 ± 3.6b | 2.7 ± 0.3b | 84.3 ± 3.6b |

MBC: soil microbial biomass C; MBN: soil microbial biomass N; MBC/SOC: the ratio of MBC to soil organic carbon (SOC); MBN/TN: the ratio of MBN to soil total nitrogen (TN); Ure: urease; Glu: β-glucosidase; Pho: alkaline phosphatase. Values within a column followed by the same letter do not differ significantly at $P \leq 0.05$.

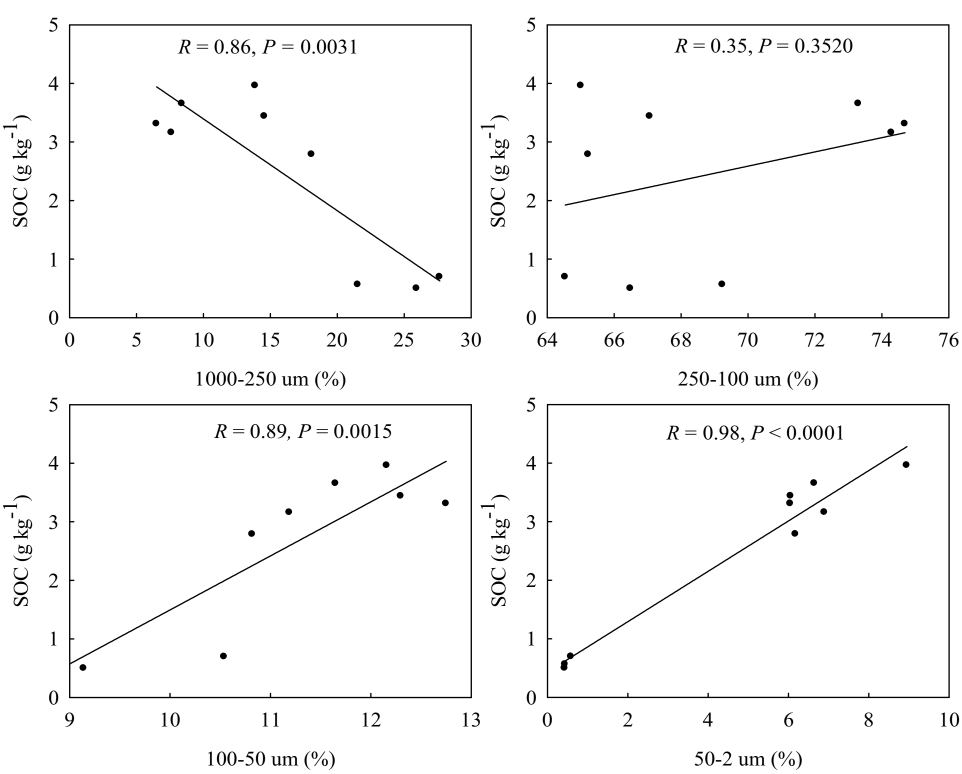


**Fig. 3.** Relationship between soil particle-size content and soil organic C (SOC).

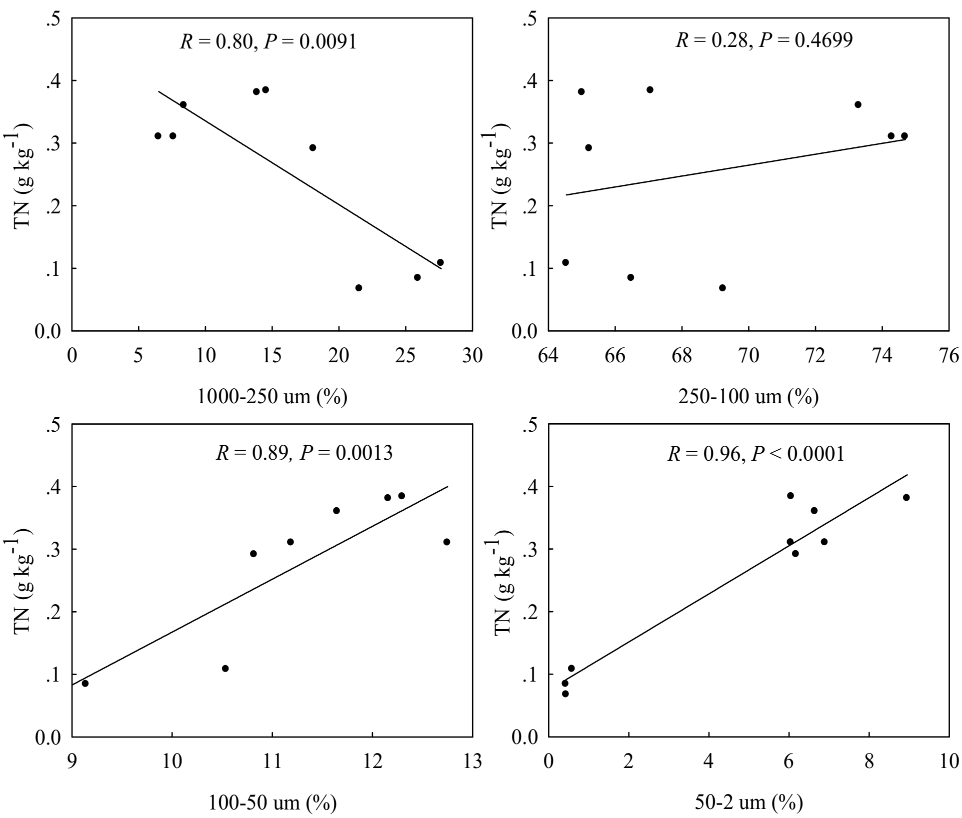


**Fig. 4.** Relationship between soil particle-size content and soil total N (TN).

Soil water holding capability is an important factor for conserving soil water, and has been significantly positively correlated with soil water stable macro-aggregates (Wang et al., 2006). Our study results showed that the conversion of native sandy steppe to alfalfa forage land and farmland increased the soil water holding capacity, being higher in the alfalfa forage land than in the farmland. The improved soil water holding capacity of the alfalfa forage land is due to the increased soil water stable macro-aggregates (Fig. 1). In this study, the annual mean irrigation inputs was 6000 $m^3$ $ha^{-1}$ and 12,000 $m^3$ $ha^{-1}$ for alfalfa forage land and farmland, respectively. Wang and He (2005) reported that, compared with wheat and maize, the amount of irrigation was reduced by 110–210% in alfalfa, and the economic water benefit of wheat and maize was US $0.17 $m^{-3}$, while it reached US $1.38 $m^{-3}$ in alfalfa at the edge of the oasis. This suggests that alfalfa not only increases soil water holding capacity, but also has greater economic water benefits than a wheat–maize tillage system on the edge of the oasis.

Understanding changes in soil C and N content is critical when determining soil quality and ecosystem productivity. In this study, the conversion of native sandy steppe to alfalfa forage land and farmland significantly increased the soil SOC and TN contents. Over the period of 10 years, the sequestrations of SOC and TN were almost the same for the alfalfa forage land and farmland. The scarce precipitation (about 100 mm) in this region leads to sparse vegetation, and thus limited organic matter input into the soil (Institute of Soil Sciences, Chinese Academia of Sciences, 1978). Li et al. (2009) reported that irrigation largely increased soil moisture and plant biomass input in the cultivated desert, and the leaves, dead roots and stem remnants were the primary sources of coarse organic C and N. Zhao et al. (2009) defined the capacity of soil to reserve C and N by its association with silt and clay particles (<50 μm). Our results indicated that the conversion of native sandy steppe to alfalfa forage land and farmland significantly increased the fine clay and silt contents in the soil surface. Our results agree with those of other reports (Su et al., 2007; Wang et al., 2010a,b), which suggested that alfalfa land and farmland could increase soil anti-erosion capability, and thereby receive more fine particles from dust deposition than the native desert shrub land. Silt-laden water for irrigation is another important way by which to increase soil fine particles for alfalfa forage land and farmland. Meanwhile, the farmland also received a large number of the fine particles by inputting farmyard manure. In the present study, a significant positive correlation was found between the particle contents of 100–50 and 50–2 μm and SOC, and the particle contents of 100–50 and 50–2 μm and TN. This suggests that the particle content of 100–50 μm also plays an important role in SOC and TN accumulation and soil development in newly-reclaimed alfalfa forage land and farmland on the edge of the oasis.

In this study, the conversion of native sandy steppe to alfalfa forage land and farmland significantly increased the ratios of C/N, which was in accordance with the results from Su et al. (2010), who reported that the rehabilitation of severe sandy desertified land resulted in a significant increase in the C/N ratio. The increases of C/N ratios in alfalfa forage land farmland may be due to the high C/N ratio in farmyard manure (C/N > 15) and the residue of alfalfa (C/N > 12) (Puget and Drinkwater, 2001). The ratio of SOC to TN (C/N) is a reliable indicator of the ability of soil microorganisms to assimilate and mineralize N. Chen (1990) and Huang (2000) reported that a C/N ratio of 6–11 enhanced the mineralization of soil organic N and significantly increased MBC, and soil organic matter also decomposed more quickly when the C/N ratio was significantly lower than 11. Li et al. (2003) found a positive feedback loop between SOC content and C/N when the C/N ratio ranged from 6 to 11 in a similar agro-ecosystem characterized by mulch in typical Loess soils, i.e. mulching and chemical fertilizer application lowered the C/N ratio, which in turn accelerated the

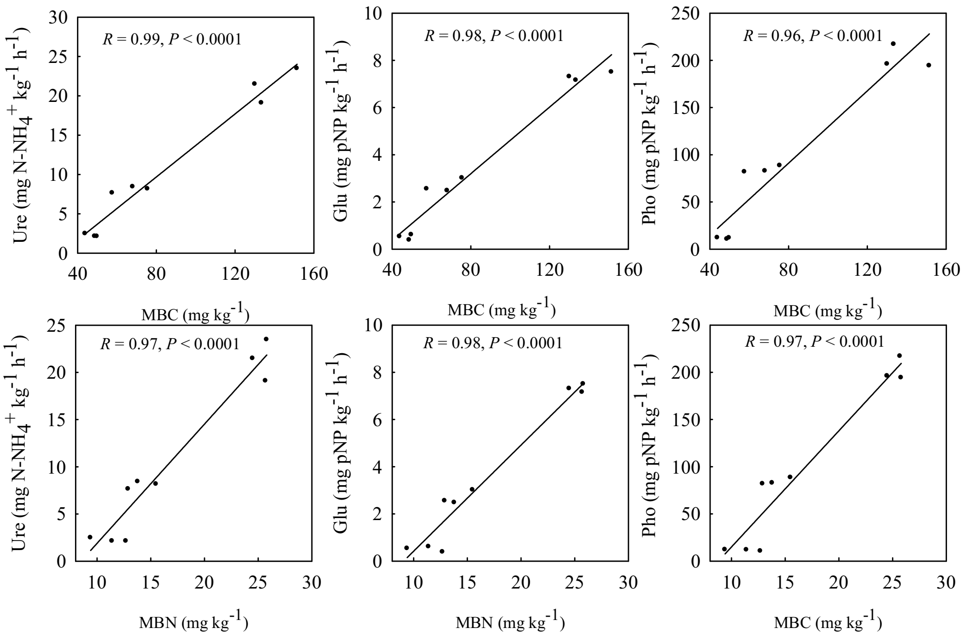


**Fig. 5.** Relationships between soil microbial biomass C (MBC), N (MBN) and enzymes activities in the 0–10 cm soil layer. Ure: urease; Glu: β-glucosidase; Pho: alkaline phosphatase.

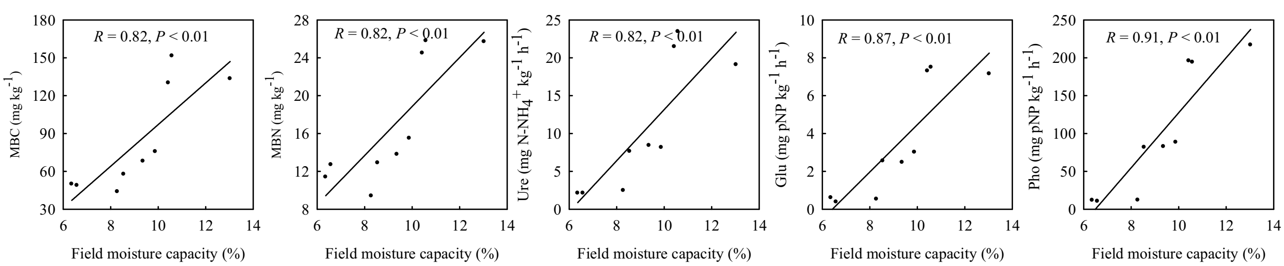


**Fig. 6.** Relationships between field moisture capacity and soil microbial activities in the 0–10 cm soil layer. MBC: soil microbial biomass C; MBN: soil microbial biomass N; Ure: urease; Glu: β-glucosidase; Pho: alkaline phosphatase.

decomposition of SOC, thus lowering the ratio even further. Therefore, in semi-arid and arid regions, increasing the SOC and C/N ratio improves soil quality and reduces N loss. After 10 years, the C/N ratio was 9.7 in the alfalfa forage land and 10.3 in the farmland, proving that these two land use types are superior at preserving organic N and, in turn, sustaining soil productivity.

Soil microbial biomass is sensitive to soil resource availability and land management strategy (Wu et al., 2016; Ravindran and Yang, 2015; Spohn et al., 2016). In the present study, we found that soil MBC in 10-year-old alfalfa forage land was significantly higher than in 10-year-old farmland. This indicated that alfalfa plantations are more propitious for improving soil microbial activity than farmland of the same age on the edge of the oasis. The MBC/SOC ratio can be a good measure of the efficiency of organic C conversion into microbial C and the losses of soil C during decomposition (Sugihara et al., 2010; Zhu et al., 2014). If soil is degraded, then the MBC/SOC ratio generally declines at a faster rate than soil organic matter. In our study, the sequestration of SOC was almost the same for both alfalfa forage land and farmland (3.4 g $kg^{-1}$). Therefore, a high MBC/SOC ratio in alfalfa forage land would be more beneficial to soil biological activity than in farmland. However, for the lower SOC, the high MBC/SOC ratio means the organic matter decomposes quickly, which would be harmful to soil quality (Jiang et al., 2006). In this study, we found that the MBC/SOC and MBN/TN ratios in native desert shrub land were significantly higher than in the alfalfa forage land and farmland, but the SOC and TN contents in native desert shrub land were only 0.58 g $kg^{-1}$ and 0.09 g $kg^{-1}$, respectively. This indicated that the C and N sequestration potentials in native desert shrub land will be limited by the high MBC/SOC and MBN/TN ratios. In this study, the sequestration of SOC, TN and TP was almost the same for both alfalfa forage land and farmland (3.4 g $kg^{-1}$), but the MBC and MBN contents were significantly higher in the alfalfa forage land than the farmland. Soil moisture is the major factor influencing soil microbial activities (Guenet et al., 2012; Brockett et al., 2012). In our study, we also found that the soil water holding capacity in the alfalfa forage land was obviously higher than in the farmland. Soil enzymes play essential roles in nutrient mineralization and decomposition of organic matter, and their activities are key drivers of nutrient supply to plants (Bowles et al., 2014; Kotroczó et al., 2014; Liang et al., 2014). In this study, β-glucosidase and phosphatase activities were shown to be significantly higher in the alfalfa forage land than in the other land use types. The possible reason for this is the improved soil water holding capacity, which promoted soil microbial biomass activity and increased soil enzyme activity. In this study, significant positive correlations ($p < 0.0001$) were found among the MBC, MBN and soil enzyme activities (Fig. 5). In addition, significant positive correlations ($p < 0.01$) were found between the field moisture capacity and soil microbial activities (Fig. 6). This indicated that the increase of soil water capacity was pivotal for improving soil microbial activities and promoting nutrient cycling in a desert-oasis ecotone. These results suggest that the newly-reclaimed alfalfa plantations are more propitious for amending soil biological environments than the wheat–maize tillage systems on the margins of oases.

## 5. Conclusion

The study results show that the conversion of native sandy steppe to alfalfa forage land and farmland significantly increased the levels of SOC, TN, TP and C/N. Over the period of 10 years, the sequestrations of SOC, TN and TP were almost the same for both alfalfa forage land and farmland. Due to the fact that a lower C/N ratio accelerates SOC decomposition, the higher C/N ratio in alfalfa forage land and farmland may limit the mineralization of soil N, conserving soil nitrogen and SOC. After 10 years, the conversion of native sandy steppe to alfalfa forage land had the most positive effects on soil water holding ability, water stable macro-aggregates, microbial biomass, and enzyme activity. Soil water holding capacity was pivotal for improving soil microbial activities and promoting nutrients cycling in a desert-oasis ecotone. These results suggest that alfalfa forage land is more propitious for improving soil properties than farmland in a wheat-maize cropping system at the margins of oases.

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