EFFECTS OF LAND USE/COVER CHANGE IN THE DESERT OASIS SYSTEM ON TOPSOIL CARBON AND NITROGEN (MIDDLE HEIHE RIVER BASIN, CHINA)

ABSTRACT: Land use/cover change (LUCC) is one of the main factors that influence the terrestrial carbon (C) and nitrogen (N) cycle. We examined the effects of land use/cover change on topsoil C, N, and microbial biomass C, N (MBC, MBN) and their relationship with other soil properties in the middle of Heihe river basin along a land use change gradient of 100-year farmland, 27-year farmland, 33-year pine forest, 28-year poplar forest, and 21-year shrubland, as well as native desert from which all the above cultivated systems are converted. Results revealed that land use conversion from native desert to the above cultivated ecosystems not only changed the basic eco-hydrological factors of the soil, such as improving the soil moisture and field capacity, decreasing the pH and salinity, but also altered the nutrient factors, such as improving the concentrations of soil organic C (SOC), total N (TN), MBC, MBN, NO$_3^-$-N and NH$_4^+$-N. With the increase of cultivated years, land use conversion had an increasing impact on the C and N sequestration and soil nutrients stabilization.

KEY WORDS: carbon, Heihe river basin, land use/cover change, nitrogen

1. INTRODUCTION

Global carbon (C) and nitrogen (N) balance are affected by land use/cover change (LUCC) (Amundson 2001). It has been suggested that, at scales of decades to centuries, LUCC is the main factor determining soil C and N storage (Scott et al. 2002). Land use/cover change is a global concern due to its impact on biomass and C and N stocks. At the same time, changes in land use lead to modification of the physicochemical characteristics of the soils, which can induce changes in the soil organic reserves (Adger and Brown 1994, Neill et al. 1998, Desjardins et al. 2004). About 47% of the world’s terrestrial land is arid and semiarid (Lal 2004). Desert, like Gobi, interspersed with many oases of different sizes and shapes is the main geomorphologic feature in the arid region of northwest China (Cheng et al. 1999). These oases were formed naturally or artificially in river deltas or established in alluvial-diluvial plains and edges of diluvial–alluvial fans by irrigation in different historical periods (Zhang et al. 2003). In this region, oases represent only a very small portion (4%) of the land surface; they are important for agricultural and human activity and supporting more than 95% of the population and more than 90% of social wealth (Han 1999). To maintain the stability of oasis ecosystems, therefore, has become an important issue for
sustainable development in the arid region. Changes in the land use and C and N pool of these drier regions deserve more consideration when C and N balance were considered at the global scale, for example, in the Dry Chaco, Argentina, Himalayan watershed, Veracruz, Mexico, and the other Sandy Lands of China (Ojima et al. 1993, Adger and Brown 1994, San Jose and Montes 2001, Woomer et al. 2004).

The Heihe River basin covers an area of approximately 130,000 km², sandwiched between the southern Qilian mountains and the northern Mazong mountains (Li et al. 2001). Linze County, located in the middle of Heihe River basin, has a special landscape of oasis beset in desert, and is an important area for grain production. In recent years, this region has become one of the main planting areas of wine-making grape, ketchup-making tomato, and vegetables (Su et al. 2008). However, farmland has become the key limiting factor of agriculture development in this region. To prevent soil erosion and desertification of oasis agricultural ecosystem, the forest shelter belts are generally developed between oasis and desert systems and generating a typical gradient of different land use (Su et al. 2007); after some years, the forest shelter belts are usually turned into farmland. Therefore, a gradient of land use/cover was identified, including the cultivated lands of 100-year farmland, 27-year farmland, 33-year Pinus (Pinus sylvestris var mongolica Litv.) forest, 28-year poplar (Populus simonii) forest and 21-year shrubland as well as native desert soil (Yang et al. 2008). Annual irrigation was performed for all cultivated ecosystems except the shrub and native desert. Despite the importance for the ecosystem C and N cycle, no systematic and comparative research has been done to estimate the influences of land use/cover changes on C and N changes and stocks. Therefore, the objective of this study is 1) to quantitatively probe the information on the basic hydrological environment, material change, especially on the change of soil C and N, as well as the relationship with each other in different land use; 2) to provide theoretical reference for how to use and protect desert-oasis systems in relation to land use/cover change.

2. STUDY AREA

The research sites are located near the Linze Inland River Basin Research Station (39°21’N, 100°08’E; 1384 m a.s.l), Chinese Ecosystems Research Network (CERN) (Fig. 1A). The site has a temperate continental climate. The long-term average annual precipitation is 117 mm, which over 70% falls in the summer between June and September. Average annual temperature is 7.6°C, with a mean minimum temperature of −10.7°C in January and maximum temperature of 23.8°C in July (Liu et al. 2010). The soil texture is sandy and sandy loam (Lu et al. 2003).

3. METHODS

3.1. Sample collection and preparation

The six sites represent a range of land use/cover changes in the region, e.g. 100-year farmland, 27-year farmland, 33-year Pinus forest, 28-year poplar forest and 21-year shrubland and native desert (Fig. 1A; Table 1).

![Fig. 1. Satellite image of the research site containing an ecological gradient of six different land use types (A) and the schematic outlines of the sampling points with three replications in each site (B).](image)
This land use gradient of distinct ecosystem functions is indeed typical of the entire northwestern China (Yang et al. 2008). Corn and wheat are rotationally cultivated in 100-year and 27-year farmlands. All cultivated lands are developed from natural desert. Soil was measured in mid-August. For each site, three replicated soil samples were collected from the upper 20 cm (Fig. 1B). Each sample was a composite sample of three soil cores (2 cm diameter). Part of the soil samples was stored at 4°C and the rest was air-dried, and crushed with a rubber hammer at first and then passed a 2-mm nylon sieve for analyses.

3.2. Laboratory analysis

Concentration of soil organic carbon (SOC) was determined by dichromate oxidation of Walkley-Black; TN was measured by a micro-Kjeldhal procedure; Soil MBC and MBN were determined by the chloroform fumigation extraction method (Brookes et al. 1985, Vance et al. 1987). NH$_4^+$-N was extracted by 2 mol L$^{-1}$ KCl and analyzed by the phenate method, and NO$_3^-$-N was measured by the phenoldisulphonic acid (PDSA) method, using 2 mol L$^{-1}$ KCl as the extractor. Soil moisture content at a depth of 20 cm was measured with a portable TDR (TRIME-FM, IMKO Micromodultechnik Gmbh, Ettlingen, Germany). Soil pH was measured in a soil-water suspension (1:1 soil-water ratio). Soil salinity was measured following the procedure described by USSLS (1954). Field water capacity was obtained from periodical measurements of soil water content, after 8 h of continued infiltration (Simeon 1979). Bulk density measurements were made from undisturbed soil samples taken at each site and depth (Simeon 1979).

3.3. Data analysis

Differences of the indexes among the six types of land use and relationships between variables were analyzed using a one way ANOVA with Tukey a posteriori test, and simple regression analysis respectively. Statistical significance was evaluated at the level of 0.05.
4. RESULTS

4.1. Soil characteristics

Site descriptions and selected physical and chemical properties of all soil samples were given in Tables 1 and 2. Except for shrubland, soil moisture was significantly higher in the cultivated soils than that in native desert soil. The pH in each of the cultivated system was much lower than that in the native desert soil. The maximum salinity was found in the cultivated soil of 21-year shrubland. The field capacity in 33-year *Pinus* forest and 28-year poplar forest were significantly higher than that in the others, and that in the 100-year farmland was remarkably higher than that in the 27-year farmland, 21-year shrubland as well as native desert. Bulk density in 33-year *Pinus* forest and 28-year poplar forest were significantly lower than that in the other four types (Table 2).

4.2. Changes in carbon and nitrogen concentrations

The concentration of SOC and TN in different land use/cover types are showing in Fig. 2. Compared to 21-year shrubland and native desert, the SOC and TN concentrations in 100-year farmland, 27-year farmland, 33-year *Pinus* forest and 28-year Poplar forest were significantly higher, and there was insignificant difference between the 21-year shrubland and native desert. For example, the SOC concentration in 100 and 27-year farmland, 33-year *Pinus* forest and 28-year poplar forest was 6.78, 6.57, 5.34 and 5.85 g kg\(^{-1}\), respectively, and that in 21-year shrubland and native desert was only 0.55 and 0.56 g kg\(^{-1}\), respectively. The total nitrogen in the two types of farmland was higher than that in the two types of forest (Fig. 2). The ranking order of the C/N was 33-year *Pinus* forest > 28-year Poplar forest > 27-year farmland > 100-year farmland > 21-year shrubland > native desert (Fig. 2).

MBC and MBN contents in the six lands showed a gradually increasing trend along with the growth of the used years (Fig. 2). The MBC in 100-year farmland was remarkably higher than that in the other five types, and that of the 27-year farmland was in the second, and that in the two forest types were much higher than that in the 21-year shrubland and native desert. The MBN in 100-year farmland was the maximum, and then the 27-year farmland, and in other four types was relatively lower and there was no significant difference between them. The ratio of microbial biomass C to N (MBC/MBN) was an important index of N supply ability. The ranking of MBC/MBN in the six land use types was 28-year poplar forest > 33-year *Pinus* forest > 100-year farmland > 27-year farmland > 21-year shrubland > native desert (Fig. 2).

NH\(_4\)+-N concentrations in the cultivated soils of 100-year farmland, 27-year farmlands, 28-year poplar forest and 33-year *Pinus* forest were apparently higher than that in the 21-year shrubland and native desert (Fig. 2). There were no remarkable differences of NH\(_4\)+-N concentrations among 100-year farmland, 27-year farmlands, 28-year poplar forest and 33-year *Pinus* forest, and there were no significant difference between 21-year shrubland and native desert too. The concentration of NO\(_3\)-N in 100-year farmland, 27-year farmlands and 28-year Poplar forest were relatively higher than that in the other types, and the maximum concentration was in 100-year farmland, which was nearly up to 10 mg • kg\(^{-1}\), while the minimum concentration was 0.22 mg • kg\(^{-1}\) in 28-year poplar forest land.

**Table 2. Changes in soil properties along a land use type gradient.**

<table>
<thead>
<tr>
<th>System</th>
<th>Soil moisture (%)</th>
<th>pH (1:1 soil-water ratio)</th>
<th>Salinity (%)</th>
<th>Field water capacity (%)</th>
<th>Bulk density (g cm(^{-3}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>100-year farmland</td>
<td>12.90±1.26a</td>
<td>8.40±0.10bc</td>
<td>0.10±0.02cd</td>
<td>19.61±0.27b</td>
<td>1.54±0.01a</td>
</tr>
<tr>
<td>27-year farmland</td>
<td>11.70±1.35a</td>
<td>8.74±0.04b</td>
<td>0.09±0.01d</td>
<td>17.71±0.05cd</td>
<td>1.53±0.02a</td>
</tr>
<tr>
<td>33-year <em>Pinus</em> forest</td>
<td>4.63±0.39bc</td>
<td>8.21±0.14c</td>
<td>0.15±0.01b</td>
<td>21.03±0.32a</td>
<td>1.31±0.01c</td>
</tr>
<tr>
<td>28-year Poplar forest</td>
<td>5.73±0.51b</td>
<td>8.39±0.04bc</td>
<td>0.09±0.02d</td>
<td>21.59±0.46a</td>
<td>1.41±0.02b</td>
</tr>
<tr>
<td>21-year shrubland</td>
<td>2.70±0.16cd</td>
<td>8.11±0.004c</td>
<td>0.23±0.02a</td>
<td>18.46±0.14bc</td>
<td>1.55±0.003a</td>
</tr>
<tr>
<td>Native desert</td>
<td>2.18±0.04d</td>
<td>9.35±0.12a</td>
<td>0.11±0.01cd</td>
<td>17.62±0.30d</td>
<td>1.58±0.01a</td>
</tr>
</tbody>
</table>

Values are mean ± SD. Statistically significant difference is represented by the different letters following the values in each column at P <0.05 by ANOVA analysis.
Fig. 2. Concentrations of organic carbon, total nitrogen, microbial biomass C, N (MBC, MBN), soil C/N, MBC/MBN, NH$_4^+$-N and NO$_3^-$-N along a land use type gradient (100-year farmland (A), 27-year farmland (B), 33-year *Pinus* forest (C), 28-year Poplar forest (D), 21-year shrubland (E) and native desert (F) respectively). Different letters within each response variable indicate significant differences ($P<0.05$ from Tukey’s tests).
4.3. Interrelations among SOC/TN, soil inorganic nitrogen and microbial biomass

Information on available nutrient pools in soils, microbes, and plants is important for understanding nutrient cycling and ecosystem function (Yu et al. 2008). There have been many reports on the relationship between available soil N and MBN, especially in agricultural soils. Generally, soil MBN precedes NH$_4^+$-N to NO$_3^-$-N (Jackson et al. 1989, Recous et al. 1990). For example, Jansson et al. (1955) found that MBN primarily came from NH$_4^+$-N and not from NO$_3^-$-N during a straw decomposition study. Wickramasinghe et al. (1985) found that NH$_4^+$-N restrained microbes from absorbing NO$_3^-$-N and that few utilized NO$_3^-$-N because microbes require energy for NO$_3^-$-N absorption. Nevertheless, contradictory reports exist. For example, Bjarnason (1987) reported no difference in immobilization of NH$_4^+$-N and NO$_3^-$-N. In this study, there was a significant positive correlation between TN and MBN ($r=0.7042$, $P<0.001$, n=54), SOC and MBC ($r=0.8110$, $P<0.01$, n=54), NH$_4^+$-N and NO$_3^-$-N ($r=0.4215$, $P<0.01$, n=54) (Fig. 3).

5. DISCUSSION

5.1. Effects of land use/cover change on soil physical properties

Many researches have proved that the land use/cover change could alter the physical and chemical properties of soil and then affect the eco-hydrological process (Post and Kwon 2000, Murty et al. 2002, Guo et al. 2002, Gamboa and Galicia 2011). In this study, soil moisture, pH and field capacity changed gradually as land use time increases. As for soil moisture and field capacity, which were significantly higher in the cultivated soils than that in natural desert soil, it may indicate that cultivated soils have stronger water storage capacity. The pH in natural desert soil was significantly higher than that in the cultivated system, which indicated that land use/cover change from desert to cultivated lands could remarkably decrease the alkalinity. The maximum salinity was found in cultivated soil of 21-year shrubland, the reason of which must be that Haloxylon ammodendron shrublands without irrigation has significant salt accumulation, especially in the 0–10 cm surface layer. H. ammodendron is a

![Fig. 3. Regression analysis between soil organic C and microbial biomass C (MBC), soil total N and microbial biomass N (MBN), NH$_4^+$-N and NO$_3^-$-N in six land use types.](image-url)
5.2. Effects of land use/cover change on soil C and N

Generally, soil organic matter (SOM) content is an important indicator of soil fertility. In this study, concentrations of SOC and TN in the four types of cultivated land were significantly higher than that in the 21-year shrubland and native desert, which is in accordance with Lai (2002, 2004) and Sartori et al. (2007) who suggested that rehabilitation of desertified land and adoption of recommended management practices (including irrigation, conversion of desert land to intensively managed poplar plantation) had significant effects on soil carbon sequestration. In this study, the concentration of SOC and TN varied with different cultivated treatments and ages. In the less managed 21-year shrubland and native desert (no irrigation and fertilization) SOC and TN accumulation were lower than that in the 100-year farmland 27-year farmland 28-year poplar and forest 21-year, and the ranking order is 100-year farmland> 27-year farmland> 28-year poplar forest> 33-year *Pinus* forest> 21-year shrubland> native desert. The main reason of this result is likely related to receiving greater amounts of litter fall inputs from the vegetation cover and more deposition of fine particles through irrigation and fertilization, which resulted in a greater C and N accumulation in forest land and farmland. The accumulation of SOC and TN in the reclaimed soil was in accordance with the results from Li et al. (2006) and Su et al. (2010) who reported an increasing pattern in SOC within cultivation period.

Carbon and nitrogen of soil microorganisms can be one of the indexes of soil fertility in different types of land use. Parfitt et al. (2005) pointed out that biomass of soil microorganism could be more effectively reflected the condition of fertility than soil organic matter, because the content of SOC could not state the effectiveness of nutrient directly, while the biomass of soil microorganism could reflect the condition of soil active fertility pool. Generally, soil MBN is not only the main reservoir of soil nitrogen, but also the active source of valid nitrogen to plant. The soil-microbe-plant relationship is generally considered as a whole system. In this study, the concentrations of MBC and MBN in 100 and 27 year farmland, 28-year poplar forest and 33-year *Pinus* forest were obviously higher than that in the 21-year shrubland and native desert, but not significant. This result could be connected with the heterogeneity of hydrogeological environment and soil conditions. Owing to the changes in soil physical and chemical properties, for example, the soil moisture, pH, salinity and the concentration of carbon and nitrogen, it was more suitable for the growth and breeding of organisms, such as microbes in the farmlands and forests (Li et al. 2006).

The lowest C/N ratio in 21-year shrubland and native desert indicated that SOM in the two types land use is lower. C/N in the forest land was a little higher than that in the farmland, which may be closely connected with the concentrations of carbon and nitrogen in these lands (Fig. 2); furthermore, it may also indicated that SOM in farmlands may be more decomposable than that in the forests (Fig. 2), (Su et al. 2010). In addition, farmer’s neglection of SOM management practices and removal of crop residue contributed to decrease of the C/N ratio. In general, local farmers preferred chemical fertilizer to increase amount of nutrients in cropland (Liu et al. 2000). Large amounts of chemical fertilizer N but very little manure are added to the soil in growing seasons. Heavy application of chemical fertilizers reduced the C/N ratio (Fig. 2) (Su et al. 2010). The NH$_4^+$-N and NO$_3^-$-N, as the readily available forms of soil N for root uptake, were lower in the forest land and shrubland than that in the farmlands with addition of chemical fertilizer N, suggesting that conversion of forest land into farmland decreased the C/N ratio and improved soil mineral N by enhancing soil N immobilization.

Results obtained from this study confirmed that land use change can influence the eco-hydrological process of the oasis ecosystems, especially increase the soil ca-
pacity of carbon and nitrogen sequestration (Wright et al. 2005, Su 2006, Yu et al. 2008). In Heihe River basin, water shortage and excessive usage of fertilizer have been more serious, so how to change the land use strategy more adaptively is getting crucial. Some researches have been done in proper fertilization and efficient water use in different farmlands (Su et al. 2010, Yang 2010). This study may provide some theoretical supports for how to use the lands reasonably and effectively.

6. CONCLUSIONS

Soils in the middle of Heihe river basin of northwest China have relatively low soil C and N, especially in the shrubland and native desert soils. It was concluded that changes in land cover/use have produced significant impacts on the carbon and nitrogen stocks in the topsoil. Conversion of native desert soil to farmland and forest land can result in significant increase of SOC, TN, MBC and MBN, as well as soil C/N and MBC/MBN. Long-term land management led to a greater soil C and N accumulation in farmland and forestland than in natural shrubland and desert. There is a great need to carry out long term research to better understand the effects of human activities on protecting desert-oasis systems based on land use/cover changes.

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