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# Land cover changes and the effects of cultivation on soil properties in Shelihu wetland, Horqin Sandy Land, Northern China

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**Abstract:** Land cover change plays an essential role in the alternation of soils properties. By field investigation and applying satellite images, land cover information in the Shelihu wetland was carried out in an area of 2,819 $hm^2$ in 1985, 1995, 2000, 2005, 2010 and 2011, respectively, in Horqin Sandy Land. A total of 57 soil sampling sites across Shelihu were chosen in wet meadow (CL0), cropland (CL) and sandy land (SL) according to the spatial characteristics of water body change. Soil texture, organic carbon (SOC), total nitrogen (TN) and total phosphorus (TP) contents, electrical conductivity (EC) and pH were measured at the soil depths of 0–10, 10–20 and 20–40 cm to examine the influence of agricultural conversion and continuous cultivation on soil properties. The results showed that the study area was covered by water body in 1985, which gradually declined afterwards and then reclaimed rapidly at a mean annual rate of 132.1 $hm^2$/a from wet meadow to cropland since 1995. In 2011, water body was drained and the area was occupied by 10.8% of CL0, 76.9% of CL and 12.3% of SL. Large amounts of SOC, TN and TP were accumulated in the above depths in CL0. Soil in CL0 also had higher EC and silt and clay fractions, lower pH than in SL and CL. Soil in SL was seriously degraded with lower contents of SOC, TN and TP than in CL and CL0. SOC, TN content and EC in CL decreased with the increase of cultivation age, while pH showed a reverse trend with significance at plough horizon. The agricultural conversion in Shelihu was driven by the comprehensive factors of precipitation reduction, economic development and intense competitions for irrigation water. Continuous cultivation in this process is not sustainable because of SOC degradation and nutrient content reduction. The key point is that conventional tillage and removal of residuals induced further land degradation. Wetland reclamation for immediate economic interests led to greater costs in the long-term environmental restoration in Horqin Sandy Land.

**Keywords:** wetland; soil degradation; wetland reclamation; continuous cultivation; Horqin Sandy Land

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Land use/cover is considered as a core factor mediating relationships between socioeconomic, political and cultural behaviors and global environmental change (Meyer and Turner II, 1994), and further couples human-environment system in the field of global environmental change and sustainability (Turner II et al., 2007). Wetland covers 8.6% of the global land area according to a "tentative minimum" of $12.8\times10^6$ $km^2$ by the estimate of Finlayson et al. (1999). It is always characterized by high biomass, high humidity, high loss rate and large area uncertainty combining with irreplaceable value of biodiversity support, water quality improvement, flood control and carbon sequestration for human beings (Meyer and Turner II, 1994; Zedler and Kercher, 2005). However, some studies have reported that wetland has been lost annually to agricultural use or seriously degraded (Zedler and Kercher, 2005; An et al., 2007) by water shortage,

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excessive vegetation harvest or reclamation (Hartig et al., 1997; Ladhar, 2002; Wang et al., 2011a). In China, wetland lost from reclamation may account for 82% of the total wetland loss (An et al., 2007).

Shortsighted reclamation practice is the most important factor in soil carbon (C) loss and makes soil susceptible to accelerated erosion (Lal, 2004; Qi et al., 2012). Soil C pool is altered by the interaction of biogeochemical cycles. From 1850 to 2000, 136–156 Pg C had been released due to land use change and management, accounting for approximately half of the C emission from combustion of fossil fuels (Watson et al., 2000; Houghton, 2003). Wetland is a primary land cover type of both soil C and nitrogen (N) pools (Maltby and Immirzi, 1993; Zedler and Kercher, 2005). The distribution of soil organic carbon (SOC) and total nitrogen (TN) in wetland relies on soil clay content, plant litter input and water table (Bai et al., 2005). In China, land conversion from swamps to croplands alone has caused an estimated C storage loss of 4.58 Tg/a, equivalent to 0.6% of China's C emission in 2000 (Liu and Diamond, 2005). Thus, land cover is a necessary and effective perspective to explain the temporal and spatial variability of wetland soil properties, especially SOC and other nutrients (Moreno-Mateos et al., 2008; Wang et al., 2011b).

Horqin Sandy Land lies in the semiarid area of southeastern Inner Mongolia, China. The primitive landscape is tree-scattered (*Ulmus pumila* and *Quercus mongolica*) grassland characterized by dunes interlocked with gently undulated lowland areas. The human population in Horqin has increased rapidly within the last 50–100 years and the environment was influenced by long-term and excessive fuel wood gathering, overgrazing and land reclamation. Horqin grassland, therefore, has become one of the most severely desertificated regions in Northern China (Zhu and Chen, 1994). Over the past decade, both literature information (Zhao et al., 2009a) and field surveys have confirmed that a large area of wetlands was lost and characterized by the drying-up of rivers and lakes from downstream to upstream in Horqin Sandy Land. The objective of this study was to estimate the effects of agricultural conversion and continuous cultivation on soil properties through an analysis of the reclamation history of Shelihu wetland from 1985 to 2011. We formulated three hypotheses: (1) reclamation in Shelihu was a comprehensive result of regional water shortage and economic development; (2) soil properties varied significantly before and after cultivation due to different land cover types; and (3) long-term and continuous cultivation resulted in soil degradation under local land management in Horqin.

## 1 Materials and methods

### 1.1 Study area

This study was conducted in Naiman county (42°55′N, 120°42′E; 360 m asl) at the southern edge of the Horqin Sandy Land, Inner Mongolia, China. Horqin has a temperate continental semiarid monsoon climate. The mean annual precipitation is 360 mm, about 75% occurring in the growing season from June to September. The mean annual potential evaporation is 1,935 mm. The annual mean temperature is 6.4°C, with a minimum monthly mean of –13.1°C in January and a maximum of 23.7°C in July. The annual average wind speed is in the range of 3.2–4.1 m/s and the prevailing wind direction is northwestward in winter and spring and southwest-southward in summer and autumn (Zhu and Chen, 1994). Soils are of three different types: marsh soil in wetland and flood plain grassland, meadow soil in meadow habitat and sandy soil in sandy dune habitat (Liu et al., 1996).

Shelihu is in a shape of a footprint and about 15 km long from west to east between Laoha River and Jiaolai River in the southwest of Naiman county. It was formed in 1965 for irrigation, water conservation and flood control. Shelihu has shown a mosaic pattern of lake, wet meadow (Typhaceae) and cropland (maize), particularly massive mobile and semi-mobile dunes located on both its north and south sides.

### 1.2 Experimental design

Landsat satellite images taken in July or August (1985, 1995, 2000, 2002, 2005, 2008 and 2010) were selected to exclude the disturbance of irrigation and rainy season on the spatial extent of water body within a given year. Land cover information for 1985, 1995, 2000, 2005 and 2010 in an area of 2,819 $hm^2$ (water body area in 1985) in Shelihu was analyzed by means of field work and visual interpretation of images. Information for 2011 was based on field investigation. The land conversions between four land cover types (water body, wet meadow, cropland and sandy land) were calculated by overlay analysis in Geographical Information System (GIS). Three sampling lines, 13 km each, were established in the north, middle and south of Shelihu for 2010 and 2011 (section under water) by ArcGIS 9.3 and MapSource 6.5 under the guidance of reduced spatial extent of water body (Fig. 1) from 1985 to 2011 (depleted). Nineteen sampling sites were selected at 700–800 m intervals from west to east for each line, giving a total of 57 sites. The land cover types of the sampling sites were wet meadow (CL0, long-term submerged, drained in 2011 and to be reclaimed), sandy land (SL, abandoned cropland) and cropland (CL). According to the reclamation time of land, soil sampling sites of CL were divided into CL10 (reclaimed during 1995–2000), CL5 (reclaimed in around 2005) and CL1 (wet meadow in 2010 and cultivated in 2011). In each site, three quadrats (1 m×1 m) were randomly selected and samples were collected at 0–10, 10–20, 20–40 cm soil depths within each quadrat using a 3-cm diameter auger, and samples obtained from the three quadrats at the same depth were pooled. In the laboratory, soil samples were air-dried and sieved through a 2-mm mesh to remove roots and litter for physical and chemical properties determination.

Soil texture, according to the international and USDA classification systems, was determined by the wet sieving method (ISSCAS, 1978). SOC was measured by $K_2Cr_2O_7$-$H_2SO_4$ oxidation method of Walkley and Black (Nelson and Sommers, 1996), TN by Kjeldahl procedure (KJELTEC 8400, Foss, Denmark), and total phosphorus (TP) by $H_2SO_4$-$HClO_4$ digestion (SmartChem Discrete Analyzer 200, Westco Scientific Instruments Inc., Brookfield, CT, USA) (ISSCAS, 1978). Soil pH was determined in a 1:2.5 soil-water slurry (SARTORIUS PB-21, Germany) and electrical conductivity (EC) in a 1:5 soil-water aqueous extract (Multiline F/SET-3, Germany), respectively.

### 1.3 Data analysis

Land cover information was processed by spatial analysis tools in ArcGIS 9.3. Soil properties were statistically processed by SPSS 16.0. We used data

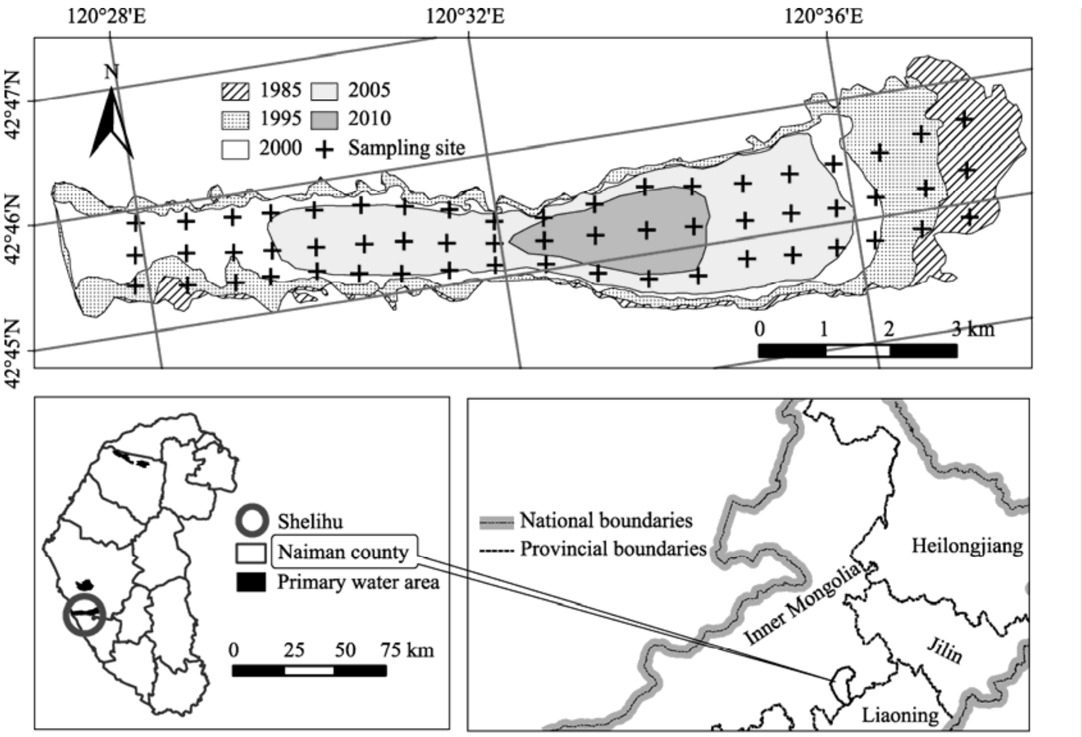


**Fig. 1** Location of the study area and the change of water body in Shelihu

transformation (ln-transformation and square root transformation) for those variables not passing the normality test (Kolmogorov-Smirnov test) at the 0.05 significance level. Multiple comparisons of one-way ANOVA (Duncan's method) were conducted to test differences of soil properties. Figures were drawn by OriginPro 8.0 and ArcGIS 9.3.

## 2 Results

### 2.1 Land cover changes in Shelihu wetland

Land cover changes observed in Shelihu showed three distinct stages: 1985–1995, 1995–2010 and 2011 (Table 1). Water body was the major cover in 1985 (2,819 $hm^2$) and only 11.4% was transformed to cropland (55 $hm^2$), sandy land (49 $hm^2$) and wet meadow (217 $hm^2$) in 1995. During the stage of 1995–2010, water body area drastically declined by 87.8% from 2,498 to 305 $hm^2$; in contrast, there had a steady increase in cropland (1,588 $hm^2$) and most of it came from the reclamation of water body (1,267 $hm^2$) and wet meadow in 1995. The area of wet meadow in 2010, as potential land to be reclaimed, was more than twice that in 1995. Sandy land in 1995was cultivated and another 346 $hm^2$ was desertified in 2010. In 2011, the water body, about 305 $hm^2$, was completely drained and the land was reserved for a new round of reclamation. The 580-$hm^2$ wet meadow in 2010 was replaced by cropland.

### 2.2 Effects of land cover changes on soil properties

SOC, TN and TP contents were decreased with changed land cover types from wet meadow to cropland and sandy land (Table 2) and the differences were significant between CL and SL at 0–40 cm. Compared with CL0, SOC, TN and TP contents were decreased in SL and CL at 0–10, 10–20 and 20–40 cm, respectively. However, C:N ratios were obvious higher in CL than in CL0 and SL, without significance. EC indicated that water-soluble salt content was getting lower in SL than in CL and significantly increased in CL0. Soil pH values in SL ranged from 8.89 to 9.08 and decreased significantly in CL and CL0. Soil texture became coarser in SL, and silt and clay fractions were below 15.87% while in CL0 were above 95.55%. Thus, agricultural conversion showed obvious effects of two varying degrees on soil properties in Shelihu.

### 2.3 Effects of cultivation age on soil properties

The rate of reclamation activity in Shelihu was obviously accelerated (Table 3). The rate during the stage of 1995–2000 increased to 102.2 $hm^2$/a, and decreased to 79.6 $hm^2$/a during 2000–2005, and then increased again to 124.8 $hm^2$/a during 2005–2010. In 2011, Shelihu gained a newly cultivated area of 580 $hm^2$ and cropland area occupied more than three quarters of the total area of 2,819 $hm^2$.

As indicarted in Fig. 2, SOC and TN contents were decreased gradually from CL0 to CL10 and the differences were significant at 10–20 cm between CL1

**Table 1** Conversion matrix of land cover types from 1985 to 2011

| 1985 | 1995 | | | |
|---|---|---|---|---|
| | Water body | Wet meadow | Cropland | Sandy land |
| Water body | 2,498 | 217 | 55 | 49 |
| **1995** | **2010** | | | |
| | Water body | Wet meadow | Cropland | Sandy land |
| Water body | 305 | 580 | 1,267 | 346 |
| Wet meadow | 0 | 0 | 217 | 0 |
| Cropland | 0 | 0 | 55 | 0 |
| Sandy land | 0 | 0 | 49 | 0 |
| **2010** | **2011** | | | |
| | | Wet meadow | Cropland | Sandy land |
| Water body | | 305 | 0 | 0 |
| Wet meadow | | 0 | 580 | 0 |
| Cropland | | 0 | 1,588 | 0 |
| Sandy land | | 0 | 0 | 346 |

Note: the unit for all the values of each land cover type is $hm^2$.

and CL10; in addition, the contents at 0–20 cm were higher than at 20–40 cm in all groups. The variations in TP content and silt and clay fractions were not steadily correspondent to cultivation age as we supposed. They showed diverse and fluctuant tendencies at each depth while no significant effects were observed among CL1, CL5 and CL10. However, TP content decreased as the depth increased in CL5 and CL10 groups. Substantial decrease in EC from CL1 to CL10 was 79.7%, 76.3% and 51.0% at 0–10, 10–20 and 20–40 cm, respectively. The alkalinity of soil was strengthened with the increase of cultivation age and the differences were significant between CL1 and CL5 at 0–20 cm and between CL1 and CL10 at 0–40 cm. All soil properties except silt and clay fractions were significantly different between CL0 and CL10 at 10–40 cm layer and the SOC, TN and TP contents in CL0 increased with the increase of soil depth.

## 3 Discussion

### 3.1 Rapid agricultural conversion occurred in Horqin

Soil restoration and degradation is generally and intensively related to land use/cover change (Meyer and Turner II, 1994). However, stimulated by economic opportunities, human beings conducted their activities at the expense of environmental damage (Lambin et al., 2001). The studies in West Songnen Plain (Wang et al., 2011a) and Sanjiang Plain (Wang et al., 2011c)

**Table 2** Soil properties of different land cover types

| Sampling depth (cm) | Soil properties | Wet meadow (CL0) | Cropland (CL) | Sandy land (SL) |
|---|---|---|---|---|
| 0–10 | SOC (g/kg ) | 10.125±0.166a | 8.678±0.444a | 1.957±0.304b |
| | TN (g/kg) | 1.195±0.027a | 1.009±0.051a | 0.233±0.045b |
| | TP (mg/kg) | 367.15±3.20a | 262.18±22.49a | 23.45±8.08b |
| | C/N | 8.48±0.05 | 8.66±0.17 | 8.44±0.61 |
| | pH | 8.23±0.04b | 8.46±0.03b | 9.08±0.11a |
| | EC (μS/cm) | 1,305.5±133.2a | 516.5±59.9b | 108.0±47.1b |
| | SC (%) | 97.16±0.56a | 67.21±3.75a | 8.77±2.41b |
| 10–20 | SOC (g/kg) | 9.970±0.319a | 8.234±0.439a | 2.150±0.641b |
| | TN (g/kg) | 1.210±0.041a | 0.957±0.049a | 0.263±0.064b |
| | TP (mg/kg) | 390.51±19.18a | 248.26±18.37a | 8.59±3.60b |
| | C/N | 8.24±0.09 | 8.58±0.15 | 8.13±0.71 |
| | pH | 8.24±0.02b | 8.48±0.03b | 8.89±0.30a |
| | EC (μS/cm) | 1,000.5±105.1a | 398.1±39.1b | 168.7±92.1b |
| | SC (%) | 95.55±0.33a | 65.96±3.71a | 5.87±8.54b |
| 20–40 | SOC (g/kg) | 10.185±0.153a | 7.214±0.483a | 0.930±0.143b |
| | TN (g/kg) | 1.253±0.028a | 0.818±0.052a | 0.140±0.006b |
| | TP (mg/kg) | 429.86±16.61a | 194.26±18.87b | 2.24±0.48c |
| | C/N | 8.14±0.18 | 8.73±0.21 | 6.74±0.99 |
| | pH | 8.29±0.02b | 8.61±0.04b | 9.08±0.19a |
| | EC (μS/cm) | 558.3±55.0a | 272.1±21.4b | 105.3±41.4b |
| | SC (%) | 96.88±0.20a | 64.88±4.32a | 5.27±1.35b |

Note: SOC, soil organic carbon; TN, total nitrogen; TP, total phosphorus; C/N, carbon and nitrogen ratio; EC, electrical conductivity; SC, silt and clay (<0.05 mm). Values are mean±SE. Different letters marked for values within rows indicate significant difference among land cover types ($P$<0.05).

**Table 3** Dynamics of reclamation in Shelihu wetland

| Year | Cropland area ($hm^2$) | Proportion (%) | Stage | Newly cultivated area ($hm^2$) | Annual reclamation rate ($hm^2$/a) |
|---|---|---|---|---|---|
| 1995 | 55 | 2.0 | 1985–1995 | 55 | 5.5 |
| 2000 | 566 | 20.1 | 1995–2000 | 511 | 102.2 |
| 2005 | 964 | 34.2 | 2000–2005 | 398 | 79.6 |
| 2010 | 1588 | 56.3 | 2005–2010 | 624 | 124.8 |
| 2011 | 2168 | 76.9 | 2010–2011 | 580 | 580.0 |

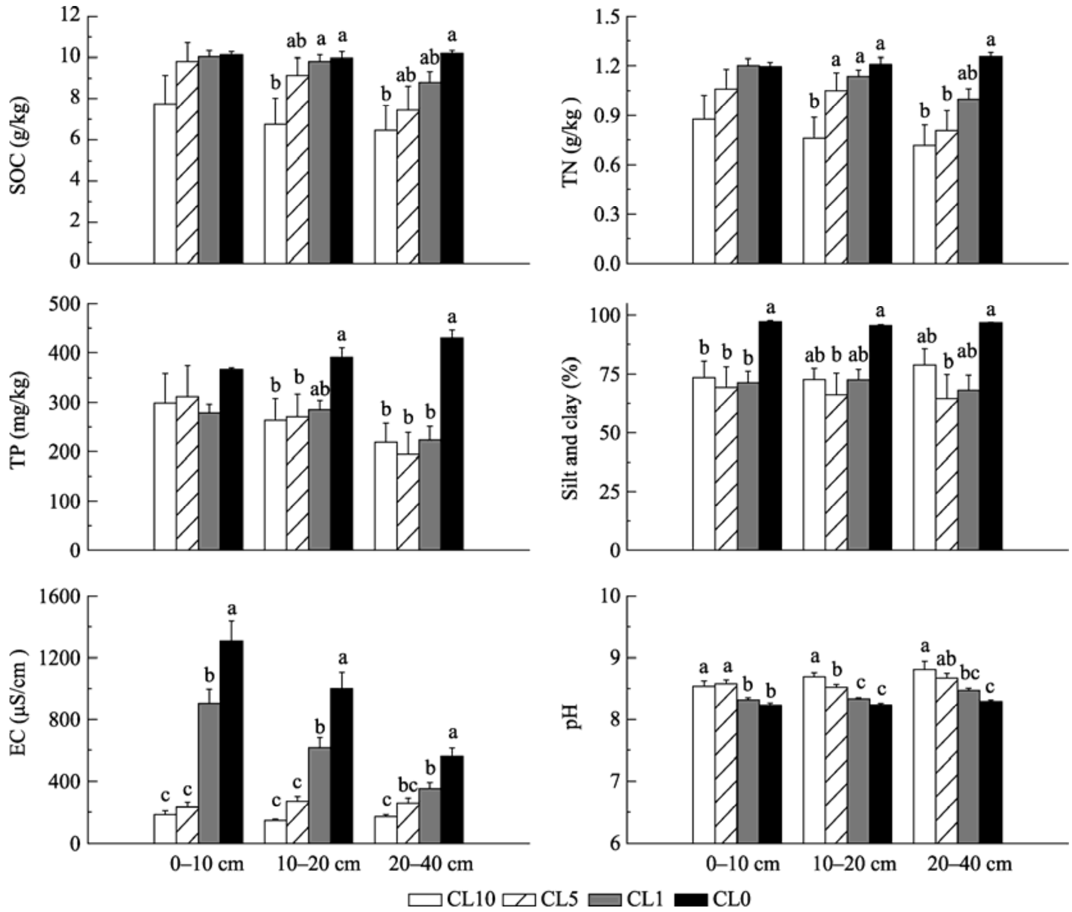


**Fig. 2** Multiple comparison for SOC, TN, TP, silt and clay fractions, EC and pH with the increase of cultivation age at each sampling depth. Values are mean±SE. Different letters marked for bars indicate significant difference at each depth (*P*<0.05).

in Northeast China suggested that the decease of wetland area was largely attributed to land reclamation. In this study, wet meadow was a transitional type of land cover between water body and cropland. Local people reclaimed it when water body was lost. Precipitation in growing seasons was the primary limiting factor to rainfed agriculture. According to data records, Shelihu was reclaimed at a mean annual rate of 132.1 $hm^2/a$ (equivalent to 4.7% per year) after 1995; over the past decades, precipitation shortage was frequently encountered according to observational records and China meteorological data sharing service system (Fig. 3) (Lian et al., 2012), and there were intense competitions for water resource in Horqin Sandy Land. Both local people and the government had the demand and capability to increase the number of dams and deep wells driven with electric power or diesel engines (Zhao et al., 1999). This directly enhanced the process of transformation from rainfed cropland to irrigated cropland and induced the drying-up of rivers and lakes; and water table declined with an alarming annual rate. Thus, wetland reclamation was not only a result, but also a part of the reason for water body loss in the semiarid Horqin Sandy Land.

### 3.2 Impacts of wetland reservation and sand invasion on soil properties

Soil properties, especially SOC content, may be used to measure soil quality threshold, below which agricultural yields decline and accelerated erosion may result in further soil fertility loss and land degradation (Celik, 2005). Previous results indicated that land desertification in Horqin driven by wind erosion caused a significant depletion of nutrients because silt and clay were blown away (Zhao et al., 2009b). Sandy soil is susceptible to wind erosion because of its loose texture, uncovered soil surface and low moisture. In this study, SL was located at the leeward side of mas-

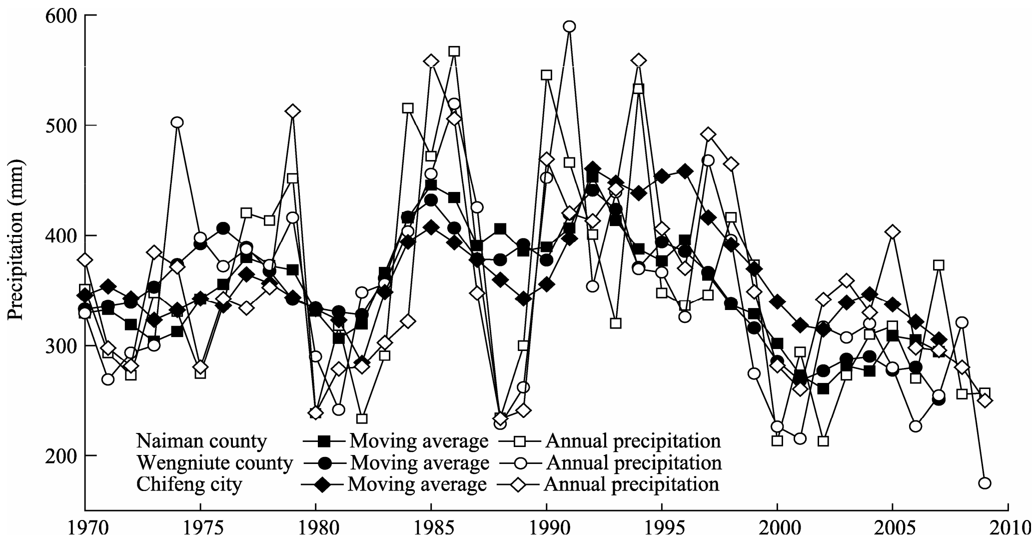


**Fig. 3** Precipitation and its moving average in Horqin Sandy Land. Chifeng city and Wengniute county are at the upstream of Naiman county.

sive mobile and semi-mobile dunes in the windy season, which suggested that the initial soil in SL was influenced by sand invasion from wind eroded dunes year by year and the soil was degraded and somewhat similar to aeolian sand, leading to much lower SOC, TN, TP, water-soluble salt, and silt and clay contents than in CL and CL0.

Accumulation of soil organic matter in wetland depends on local hydrological regime. The results of Bernal and Mitsch (2008) showed that permanently flooded soil provided better conditions to carbon accumulation than pulsing hydrology. This may be explained by that anaerobic conditions suspend organic matter in decomposition time (Davidson and Janssens, 2006) and highlight an export perspective. On the other hand, high biomass import in wetland soil is another important factor that enhances the accumulation of organic matter. CL0 represented anaerobic environment and accumulated materials of fine texture in a long period, while CL1 was intermittently oxidized from 2005 to 2010. Our results were supported by previous research (Zhang et al., 2007) which reported that the presence of wetlands improved organic matter content and facilitated soil restoration, while sand invasion led to degradation.

### 3.3 Impacts of continuous cultivation on soil properties

Soil properties are sensitive to human activities. Continuous cultivation can degrade SOC and nutrients under inappropriate land use practices and management strategies (Juo and Lal, 1977; Grieve, 2001; Zhao et al., 2005). According to the soil survey report of Naiman county in the early 1980s, the mean content of SOC, TN and TP in marsh soil at 0–16 cm was 23.66 g/kg, 1.91 g/kg and 457 mg/kg, respectively (Soil Survey Staff, 1984), higher than in all groups at 0–10 cm. The research in Northern China revealed that more SOC and nutrients were lost during the first decade of cultivation (Zhao et al., 2005). Our results were consistent with previous studies and indicated that continuous cultivation resulted in wetland soil degradation. In Horqin Sandy Land, uncontrolled reclamation usually occurred in places with better water and vegetation conditions, such as lower land where surface water can be more easily collected. Vegetation clearing, plowing and harvesting for both grains and residuals directly left the bare topsoil or plough horizon in an accelerated wind erosion rate; a substantial proportion of organic materials and nutrients were exported from soil to the atmosphere in the windy spring and winter (Zhao et al., 2009b) year after year. At the same time, continuous cultivation also interrupted the accumulation of SOC and nutrients from the original ecosystem, which significantly improved the soil physical and chemical properties in CL0. Thus, land abandonment or fallow regime should be considered seriously in Horqin for their effects on soil restoration. In addition, EC in CL0 and CL1 at soil surface may, to a certain extent, be magnified by concentrated water-soluble salts in shrinking water body.

## 4 Conclusions

The conversion of Shelihu wetland to agricultural use in Horqin Sandy Land was driven by the key factors of precipitation reduction, economic development and increasing irrigation amount. These factors directly lead to flow reduction from the upstream and, coupled with the increase in local water demand, resulted in water body loss. In the conversion process, a small part of reclaimed wetland degraded into SL with very low SOC and nutrient contents and EC while very high pH values. Due to a long-term submerged status under which organism input was greater than decomposed, soil in CL0 accumulated a significant amount of SOC, TN and TP in fine particle materials. Cultivation decreased SOC, TN contents and EC at 0–40 cm soil depth while pH value increased as cultivation age advanced. Conservational tillage and improved land management, especially the fallow method and wetland restoration, should be introduced for local decision making in Horqin.

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