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Effects of Plant Types on Physico-chemical Properties of Reclaimed Mining Soil in Inner Mongolia, China

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Abstract: A field experiment was conducted in Jungar Banner, Inner Mongolia, China to study the effects of plant types on the physical structure and chemical properties of open-cast mining soils reclaimed for 15 years, and to analyze the triggering factors of the soil formation. Results indicate that plant types affect soil-forming process especially in the upper layer (0–20 cm), and the spatial structure of reclaimed plant is the main reason for variability of the soil-forming process. In the upper soil layer at the site reclaimed with mixed plants, the concentrations of soil organic matter (SOM) and soil organic carbon (SOC) are the highest, and they were significantly higher at the sites reclaimed with *Leymus chinensis*, *Caragana sinica*, which is mainly due to a large amount of litter fall and root exudation in herbages and shrubs. However, the concentrations of SOM and SOC in the soils at the reclaimed sites are quite low comparing with those in local primary soil, which indicates the importance of using organic amendments during the ecological restoration in the study area.

Keywords: open-cast coal mining; mining reclamation; soil physico-chemical property; soil organic matter; soil organic carbon

1 Introduction

During open-cast coal mining in the Inner Mongolia, China, overlying soil material above the coal layer is removed and deposited in heaps. The excavated materials come from a depth of 0–200 m and may vary substantially in chemical and physical properties, such as water holding and absorption capacities, nutrient content and availability, soil bulk density, buffering capacity, *etc*. (Sourkova *et al*., 2005b). Typically, soil material does not contain organic carbon derived from recent plant material, but may contain various amounts of fossil carbon. Adverse properties of soil materials such as sensitivity to erosion, toxicity, unsuitable water regime and nutrient deficiency may reduce plant growth in some post-mining landscapes (Piha *et al*., 1995), and reclamation of mined land with heavy machinery can result in soil compaction. The high bulk density and reduced infiltration in such compact profiles reduce the water movement, which leads to high resistance to root penetration, and thus reduces crop productivity (Chong and Cowsert, 1997).

One of the most important issues for restoration of ecosystem function in post-mining landscapes is soil formation, and accumulation of soil organic matter (SOM) and soil organic carbon (SOC) in the surface layers is a crucial factor (Bradshaw, 1997), which results in changes of physical and chemical properties of soil (Allison, 1965; Lorenz and Lal, 2007; Moreno-de *et al.*, 2009). During mining process, SOC loses in various ways. Soil erosion during stripping, storing, spreading and accumulating, rain eroding and wind eroding can lead to the loss of great amount of SOC (Anderson *et al*., 2008). In addition, a reduction in above and below ground litter also contributes to a decline in SOM and SOC. As a nutrient pool and the source of labile sub-

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strates, SOM plays an important role in determining water holding capacity, macrospore formation and micronutrient adsorption, so the loss of SOM and SOC can lead to serious consequences in the semi-arid and arid soils.

Soil formation and organic carbon accumulation in post-mining landscapes depend on the growth of vegetation cover and the mineralization of plant debris, which are obviously limited by the contents of nitrogen (N) and phosphorus (P) of soils (Gildon and Rimmer, 1993; Sourkova *et al.*, 2005b). Nitrogen accumulation is controlled by organic carbon input and N_2 fixation, and phosphorus content is determined by the organic matter, pH of the soil substrate and weathering process. Therefore, integrating organic carbon accumulation with nitrogen and phosphorus contents is important for soil formation and ecosystem restoration. However, little is known about the rate of soil formation and SOC accumulation after restoration or during primary succession in post-mining landscapes due to inconsistent available data with great differences. Moreover, researches are mainly focused on the SOC accumulation with little attention to other nutrients (Akala and Lal, 2001; Paterson *et al.*, 2003; Sourkova, 2005a; Ussiri *et al.*, 2006; Anderson *et al.*, 2008).

This study was conducted to evaluate the accumulation of organic carbon, N and P in soil substrates reclaimed by different plant types in post-mining areas in Inner Mongolia, China. The aim is to analyze the effects of different plant types on physico-chemical properties of soils, compare the differences of SOM and SOC in reclaimed soil and in undisturbed soil, and provide the appropriate botanical reclamation method for surface coal mines in the study area.

2 Materials and Methods

2.1 Study area

The study area (39°25′–39°59′N and 111°10′–111°25′E) was located in eastern Jungar Banner, Ordos City, Inner Mongolia Autonomous Region, China, where land surface was mined for coal and subsequently reclaimed. The study area represents a semi-arid and continental climate with a frost-free period of about 140 days. The mean annual temperature ranges from 5.3℃ to 7.6℃, the annual precipitation is 230–460 mm, and the annual potential evapo-transpiration is approximately three times as much as the mean annual precipitation. The primary soil in the study area was loessial soil typically. Due to the development of mining, the main ingredients in the below soil layer were sandstone and siltstone deriving from the mine. The ground surface had been replaced by topsoil during the initial stage of reclamation, which varied from 15 cm to 30 cm. The topsoil replaced was derived from the original topsoil before the mining, which had been piled up during mining and then covered the ground during reclamation. Owing to high coarse fragment percentage, bulk density, pH and electrical conductivity of the topsoil were lower than those of the soils at below layer.

2.2 Sampling sites

The study area had been reclaimed since 1992. Six plant types, i.e., three arbor species, two shrub species and one herbage, were selected. The study area was plotted out into nine sampling sites including eight sites and a check site (CK) (Table 1). In the eight sites, six single plant species and two mixed plant species were planted, and the check site was bare soil in the vicinity of the reclaimed sites. The sampling sites were reclaimed to original terrain by grading overburden materials, spreading the stored topsoil and establishing plant cover. The study area was composed of four terraces (Fig. 1). The site 1 (the CK site) was arranged in the first terrace, and the sites 2 and 3 were in the second terrace in which *Pinus tabulaeformis* (PT) and *Caragana sinica* (CS) were planted, respectively. The sites 4, 5 and 6 were arranged in the third terrace. In sites 4 and 6 *Populus simonii* (PS) and *Leymus chinensis* (LC) were planted respectively, and in the site 5 mixed plant species consisting of *P. tabulaeformis*, *Salix matsudana* and *Hippophae rhamnoides* (PT×SM×HR) were planted. In the fourth terrace, the sites 7 and 8 were arranged, where mixed plant species of *P. simonii* and *H. rhamnoides* (PS×HR) and *H. rhamnoides* (HR) were planted respectively. The site 9 was placed in orchard in the vicinity of the second terrace, where many fruit trees (FT) were planted.

Soil samples were collected in August 2007. In each site, seven plots of 5 m×5 m were randomly established, and five sampling points were selected in each plot. At each sampling point, soil samples at depth of 0–20 and 20–40 cm were collected. In each plot, the five individual soil samples collected from the corresponding layers were mixed in the same weight ratio.

Table 1 Sampling site description

Site	Plant species	Altitude (m)	Reclaimed year	Canopy coverage	Plant height (m)
1	CK	1240	–	–	0.2
2	PT	1220	1992	0.8	9.5
3	CS	1220	1992	0.7	1.1
4	PS	1195	1992	0.7	11.2
5	PT×SM×HR	1195	1992	0.6	10.2
6	LC	1195	1992	0.9	0.4
7	PS×HR	1180	1992	0.7	11.6
8	HR	1180	1992	0.7	0.9
9	FT	1220	1992	0.7	2.8

Notes: CK (the check site), bare soil; PT, *Pinus tabulaeformis*; CS, *Caragana sinica*; PS, *Populus simonii*; SM, *Salix matsudana*; HR, *Hippophae rhamnoides*; LC, *Leymus chinensis*; FT, Fruit trees consist of grape, plum and almond

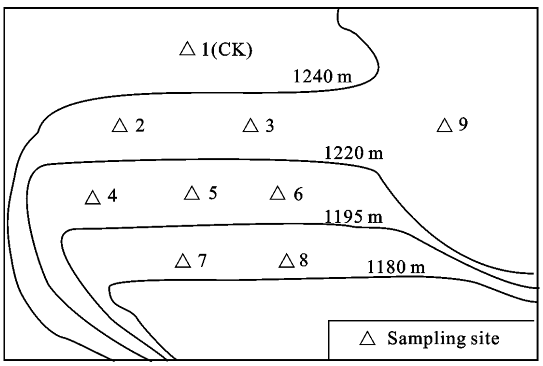


Fig. 1 Location sketch of sampling sites

2.3 Analysis methods

Bulk density (BD) of the soil samples was measured with stainless Kopecky cylinders, then the samples were oven-dried at 105℃ for 48 h, and the ratio of weight and volume of the soil was calculated (Lorenz and Lal, 2007). Specific gravities (SG) were measured with pycnometer (BSY-110, China). And 10 g oven-dried soil passed through a 0.25-mm sieve was added to the pyconometer, and distilled water was added till the solution surface reached the mark on the pyconometer, then the specific gravities was obtained after 10 min. Porosity (Po) was calculated as:

$$Po = (1 - BD / SG) \times 100\%$$

For chemical analyses, air dried soil samples were ground to pass through a 1-mm sieve. Soil organic matter was determined with the Walkley-Black method (Allison, 1965) and the concentration of total organic carbon (TOC) was analyzed with a high-temperature combustion method with a Shimadzu 5000 TOC Analyser (Kyoto, Japan). Total nitrogen (TN) was determined with a Kjeltec 2300 Analyzer Unit (Foss Tecator AB, Sweden), and total phosphorus (TP) was determined with the molybdenum blue method (Olsen and Sommers, 1982). The samples analyzed for available nitrogen (AN) were extracted in 1 M KCl with a Kjeltec 2300 Analyzer Unit (Olsen and Sommers, 1982). Following the Olsen bicarbonate extractable P method (Olsen *et al*., 1954), available phosphorus (AP) was extracted from 5 g soil sample with 100 ml 0.5 M sodium bicarbonate at pH 8.5. Mixtures were shaken end-to-end on a reciprocating shaker (L510019, China) at 200 cycles/min for 30 min and filtered through pore size 2.5 m. Colorimetric determination of phosphate in solution was carried out with molybdate-ascorbic acid method (Murphy and Riley, 1962).

2.4 Statistical methods

Among-site differences in measured parameters were tested by SPSS 10.0 for Windows (SPSS, Chicago, IL, USA). Analysis of variance (ANOVA) and Tukey's multiple comparison tests were used to determine the statistical significance at 0.05 levels between plant treatments and soil depths. In order to analyze the direct impact of SOM and SOC on soil physico-chemical parameters, Spearman's R correlation coefficients were calculated.

3 Results

3.1 Effect of land reclamation on soil bulk density, specific gravity and porosity

After 15-year reclamation, bulk densities range from 1.34 g/cm^3 to 1.65 g/cm^3, and do not differ between both depths except for 20–40 cm at the site 5 which is covered with mixed plant types, although soil bulk densities among all sites present significant differences (Table 2). Owing to the representation of shrub HR, the values of soil bulk densities at the sites 5 and 8 are lower than those at the other sites in both depths. Furthermore, the value for 0–20 cm depth at the site 3, which is covered with shrub plant (CS), is lower compared to those at other sites. The change of soil specific gravity is similar to that of bulk density for both depths and species.

The values of porosity range from 38.35% to 50.19%, and they are relatively high in the upper soil layer at the sites 3, 5 and 8 with shrub treatment (CS and HR) or mixed shrub and tree treatment (PT×SM×HR), while the lower values at the sites 1 and 4 (the CK site and woodland covered with PS, respectively) are observed. In the below soil layer, the highest value of porosity appears at the site 5, which is similar to bulk density, whereas the low values at the CK site and the site 9.

3.2 Effect of land reclamation on total and available nitrogen and phosphorus

Total nitrogen (TN) concentration decreases with increasing soil depth except for the sites 3, 6 and 8, and the differences among other sites are negligible. The TN concentrations are higher in 0–20 cm depth at the sites 3, 6 and 8 (0.46 g/kg, 0.43 g/kg and 0.45 g/kg, respectively, Fig. 2a), while those at the CK site is the lowest (0.19 g/kg). In the below soil layer, the TN concentrations are similar among the sites 3, 5, 6 and 8, and are higher than those at the other sites. For all reclaimed sites, the total phosphorus (TP) concentrations in 0–20 cm depth are higher than those in 20–40 cm depth (Fig. 2b). The TP concentrations of the soils at the CK site and the site 9 are higher in both depths, and lower values appear at the sites 2, 4, 5 and 8 at the upper soil layer. In below soil layer, no difference is observed at all reclaimed sites.

Similar to the TN, for both depths, higher available nitrogen (AN) concentrations are observed at the sites 3, 5, 6 and 8 (Fig. 2c). For the upper soil layer, the AN concentrations at the sites 3, 5, 6, 8 and 9 are higher than those at the other sites. In both depths, the available phosphorus (AP) at the CK site is higher than those at the other sites, and the differences of the other sites are negligible (Fig. 2d).

3.3 Effect of land reclamation on soil organic matter and soil organic carbon

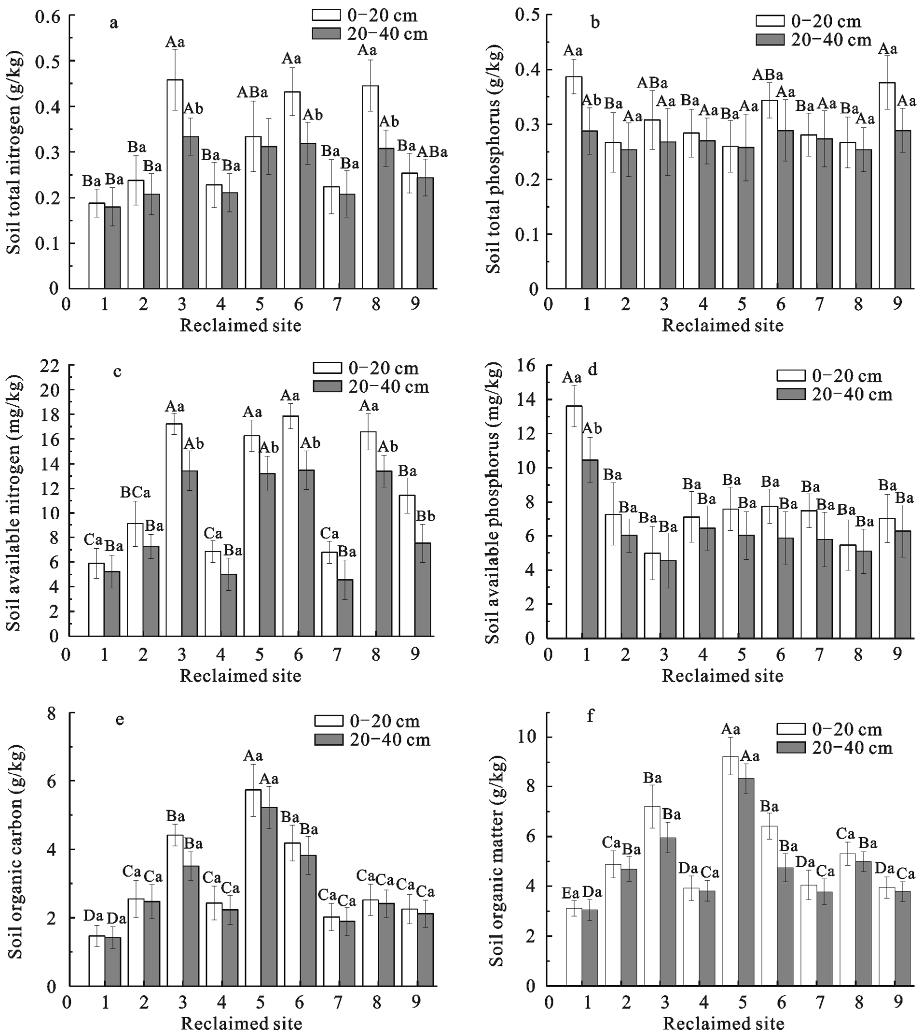
There is the same trend for SOC concentrations in both soil layers, however, SOC concentrations in the upper soil layer are higher than those in the below layer. The SOC concentrations at the site 5 are the highest in both depths (5.73 g/kg in the upper layer and 5.22 g/kg in the below layer, respectively, Fig. 2e), followed by those at the other sites. The lowest SOC concentration appears in the CK site in both depths (1.47 g/kg in the upper layer and 1.41 g/kg in the below layer, respectively). Due to reclamation with mesquite and herbage species, SOC concentrations of the sites 3 and 6 are significantly higher than those at the other sites.

The SOM differs significantly among the sites, and decreases with the soil depth (Fig. 2f). Except for the site 3, there is no significant difference in SOM between both depths. At the site 5, the highest concentration of SOM is observed (9.23 g/kg). In contrast, SOM concentrations are very low at the sites 1, 4, 7 and 9 (3.11 g/kg, 3.92 g/kg, 4.05 g/kg and 3.95 g/kg, respectively). In the below soil layer, once again, the highest concentration of SOM is observed at the site 5, and those at the other sites are relatively lower.

Table 2 Values of soil bulk density, specific gravity and porosity in reclaimed soil (Mean ± S.E.)

Site	Bulk density (g/cm^3)		Specific gravity		Porosity (%)	
	0–20 cm	20–40 cm	0–20 cm	20–40 cm	0–20 cm	20–40 cm
1	1.65±0.12 Aa	1.59±0.15 Aa	2.68±0.54 Aa	2.70±0.38 Aa	38.35±2.66 Aa	40.11±2.22 Aa
2	1.50±0.14 Ba	1.48±0.08 Ba	2.66±0.48 Aa	2.71±0.55 Aa	43.63±1.88 Ba	45.39±2.31 Ba
3	1.38±0.09 Ca	1.45±0.11 Ba	2.66±0.64 Aa	2.68±0.46 Aa	47.48±2.32 Ca	45.90±2.67 Ba
4	1.57±0.13 Aa	1.55±0.15 Aa	2.66±0.24 Aa	2.64±0.81 Aa	40.92±1.98 Aa	41.29±1.54 Aa
5	1.40±0.08 Ca	1.34±0.20 Cb	2.65±0.71 Aa	2.69±0.55 Aa	46.94±2.06 Ca	50.19±1.97 Cb
6	1.48±0.10 Ba	1.49±0.15 Ba	2.63±0.64 Aa	2.66±0.65 Aa	43.55±2.35 Ba	43.98±1.88 Ba
7	1.47±0.11 Ba	1.48±0.11 Ba	2.64±0.67 Aa	2.67±0.55 Aa	44.55±2.01 Ba	44.57±3.01 Ba
8	1.35±0.10 Ca	1.40±0.15 Ca	2.62±0.55 Aa	2.62±0.71 Aa	47.17±1.82 Ca	46.56±2.15 Ba
9	1.49±0.11 Ba	1.46±0.15 Ba	2.65±0.44 Aa	2.53±0.54 Aa	43.71±2.44 Ba	42.29±1.84 Aa

Notes: Means not sharing a common capital letter are statistically different among species, ANOVA, Student-Newman-Keuls test, $P < 0.05$; means for each species not sharing a common lowercase letter are statistically different among depths, Mann-Whitney U-test, $P < 0.05$ ($n = 7$)



Means not sharing a common capital letter are statistically different among land uses, ANOVA, Student-Newman-Keuls test, $P < 0.05$; means for each land use not sharing a common lowercase letter are statistically different among depths, Mann-Whitney U-test, $P < 0.05$ ($n = 7$)

Fig. 2 Concentrations of soil total nitrogen (a), soil total phosphorus (b), soil available nitrogen (c), soil available phosphorus (d), soil organic carbon (e), and soil organic matter (f) in reclaimed soil under different plant types

4 Discussion

4.1 Triggering factors of soil formation

The differences in the change of physical structure and chemical properties in the studied mining soils mainly respond to the differences in the amount of SOM and SOC accumulated (Table 3). Similarly, the accumulation of organic matter and organic carbon in mining soils has been previously recognized as the key factor for the activation of soil biological processes (Lorenz and Lal, 2007). It is well known from the undisturbed site that the formation of SOM is important to the sustainable development of soil ecosystem especially in sandy substrates where SOM serves as important storage component for water, nutrients and energy. In this way, increased SOM were associated with enhanced organic carbon, which results in overall increase in microbial activity of soil (Powlson *et al*., 1987). The development of these active microbial populations had direct impact on the activation of vital processes for element cycling leading to transformation of organic compounds and releasing inorganic forms of N and P that are directly available to growing plants (Moreno-de las Heras, 2009).

Table 3 Correlation coefficients between SOM, SOC and soil physical and chemical parameters

	BD	SG	Po	TN	TP	AN	AP
0–20 cm							
SOM	–0.48*	0.21	0.43*	0.62**	0.40*	0.77***	0.60**
SOC	–0.45*	0.33	0.47*	0.60**	0.44*	0.69***	0.52**
20–40 cm							
SOM	–0.35	0.24	0.40*	0.46*	0.37	0.55**	0.42*
SOC	–0.38	0.25	0.37	0.44*	0.40*	0.52**	0.45*

Notes: SOM, soil organic matter; SOC, soil organic carbon; BD, soil bulk density; SG, specific gravity; Po, porosity; TN, total nitrogen; TP, total phosphorus; AN, available nitrogen; AP, available phosphorus; * Significant at $P < 0.05$; ** Significant at $P < 0.01$; *** Significant at $P < 0.001$

Other factors related to soil texture can also influence both enzyme and microbial activity (Thomsen *et al.*, 2003). In fact, little variations in the proportion of silt and sand particles in clay and clay-loam textured soils could improve water circulation and soil aeration and thus, enhancing biological soil processes (Moreno-de las Heras *et al.*, 2009), which could explain the positive correlation between soil chemical parameters and porosity, as well as the negative correlation between some of these parameters and soil bulk density in this study (Table 3). The differences observed in soil aggregation (soil bulk density, specific gravity and porosity) are mainly caused by the variation in organic matter content since organic matter is the main soil bonding agent (Bronick and Lal, 2005). These bonding factors were associated with the coarsening of soil aggregates by reducing the proportion of microparticles and increasing macroparticles (Moreno-de las Heras *et al.*, 2008). Similarly, the direct association was found between the stability of soil physical parameters and SOM (Table 3), which is the result of the cementing effect of the organic compounds and the stimulation of soil microorganisms (Cerdà, 1998; Six *et al.*, 2004).

Although the impact of SOM and SOC upon soil bulk density and soil porosity is significant, it is generally weaker than that upon soil chemical parameters (Table 3). This is probably because that soil chemical parameters respond rapidly to the changes in soil conditions by changing plant community structure, biomass and decomposed SOM from topsoil (Schloter *et al.*, 2003). Menounos (1997) found a statistically significant relationship between SOM and bulk density. The effect of the increasing SOM on the bulk density became clearer if we consider the possibility that the SOM is highly hydrated. The modification of soil physical traits (i.e. soil specific gravity) is generally detected when soil conditions undergo really drastic changes (Gil-Sotres *et al.*, 2005). Therefore, it is necessary to integrate the soil chemical parameters with the physical parameters during assessing soil function especially when rapid changes in soil environment happen.

4.2 Variability of soil physico-chemical properties

The physical and chemical properties of the soil in the study area reclaimed in 1992 varied with land use. In particular, pasture management-related vehicular traffic contributed to higher soil bulk density, such as those at the CK site and the site 4. Despite of the above mentioned differences in soil texture, soil physico-chemical properties (excluding specific gravity, TP and AP) were rather homogeneous between the sites (Table 2, Fig 2), which indicated that there were other factors influencing the soil-forming process. Such differences have been generally attributed to variations in plants since plants determine the amount of SOM by means of litter fall and root exudation (Sourkova *et al.*, 2005a). Moreover, the plant type also affects the physico-chemical properties due to different quantity, quality and dynamics of litter production. In this study, the concentrations of SOM and SOC are significantly higher at the sites reclaimed with herbages and shrubs (such as LC, CS and HR) than those at the sites reclaimed with woodland.

In fact, the contribution of growing plant to SOM and SOC has been crucial for the activation of soil-forming process in the study area, where no organic amendments were carried out. The spatial variability of soil resources (water, nutrients, *etc.*) and soil-forming process are intimately linked to vegetation pattern and structure (Puigdefábregas *et al.*, 1999). It might be the reason why in this study the highest concentrations of SOC and SOM are observed at the site 5, which is reclaimed by PT×SM×HR plant type (Fig. 2e, f). Topsoil and overburden parent material, and root biomass are primary sources of TN, TP, SOM and SOC in reclaimed sites

(Rasse *et al.*, 2005). Coal impurities may also contribute to the total C pool. Furthermore, plant type also contributed to TN and AN concentrations at 0–20 cm depth in the sites 5 and 8 (reclaimed by PT×SM×HR, and HR, respectively), and in the site 3, the reclamation of mesquite CS can increase TN and AN concentrations markedly at the upper layer. At the sites 1 and 9 (bare soil covered with annual plant and reclaimed site covered by fruit trees, respectively), extremely high TP and AP concentrations are observed, which is caused by the addition of pesticide that contains phosphorus. The TN and AN concentrations were stratified by soil depth at the sites 3, 6 and 8, whereas stratification of AP and TP was observed only at the site 1, with the higher concentrations observed in the 0–20 cm depth.

The lack of input of fresh biomass is responsible for the low SOC and SOM at the CK site. The SOC and SOM at the site 5 (reclaimed by PT×SM×HR) are still dominated by highly decomposed soil organic compounds from upper soil and the overburden parent material. At the sites 3 and 6, a reductin in SOM decomposition with depth might contribute to the decrease in the contents of SOC and SOM with depth (Batjes, 1996). In 0–20 cm depth, the SOC and SOM concentrations at the sites 3, 5 and 6 (reclaimed by pure herbage and mixed plant types) were higher than those in the other sites reclaimed by pure woodland. These differences in soil properties are probably resulted from different response to plant types and species compositions to defoliation. Defoliation is known to affect plants growth and soil-forming process in many ways, and it can also affect the quality and quantity of carbon entering the soil (Paterson *et al.*, 2003) that leads to alterations in the content of SOM and SOC. Owing to more defoliation at the mixed plant sites, such as the site 5, the high concentrations of SOM and SOC are observed. This result is in agreement with previous research (Mikola *et al.*, 2001). It indicates that plant type and species compositions can affect the soil-forming process, and mixed plant types have the high potential for SOC sequestration (Ussiri and Lal, 2005).

4.3 Impact of different plant types

In fact, restored plant, which is the only source of soil organic carbon in the artificial reclaimed sites, is affected by accelerated soil erosion processes through a reduction in water availability. The final result of such erosion-related primary productivity limitations is the restriction of organic carbon inputs into the soil (Pimentel *et al.*, 1995). However, differences of plant types may also have direct effects upon soil erosion, which was evaluated by the contents of organic matter and organic carbon. Indeed, low vegetation cover is involved in the removal of the light and fine soil fractions, decreasing the soil organic matter and the most fertile layer of the soil profile (Marqués *et al.*, 2008). As a result of the significant accumulation of soil organic matter and organic carbon, which is basic for the activation of soil- forming process, soil development processes in the study area reclaimed with mixed plant types can be considered appreciable after reclamation.

The lack of spatial complexity of plant types in the site reclaimed with single woody plant (such as the sites 2 and 4) also limited the soil-forming process. In fact, homogeneously bare surfaces with some scattered individuals of woody plant are dominant in these sites, where spontaneous colonization and plant differentiation by ecological succession is severely constrained (Moreno-de las Heras *et al.*, 2008). On the contrary, owing to a dynamic process of vegetation succession, spontaneous colonization may happen in the sites reclaimed with mixed plant types, and soil is covered by vegetation patches with different composition and density, which leads to different levels during the development of physical and chemical properties.

It was observed that concentrations of SOM were lower than 1% even at the sites with the highest density reclaimed plant, which indicates that the importance of using organic amendments during the ecological restoration in the study area, as the accumulation rate of soil organic matter driven by growing vegetation are particularly low in temperate zone (García and Hernández, 1997).

5 Conclusions

The concentration of SOM and SOC is the main trigger for the change of soil physical structure and chemical properties in the study area, which play an important role in stabilising soil aggregates and conditioning the activation of basic element cycling processes. The species and spatial structure of reclaimed plant types have an significant effect on soil-forming process because growing plants determine the accumulation rates of

SOM and SOC. The spatial simplification of plant types can bring obvious inhibition to soil physical structure and biological function. Even at the site reclaimed by mixed plant types, the concentrations of SOM and SOC are still quite low comparing with that in local primary soil, which indicates that the importance of using organic amendments during the ecological restoration in the study area.

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