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ORIGINAL ARTICLE

Soil properties as indicators of desertification in an alpine meadow ecosystem of the Qinghai–Tibet Plateau, China

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Abstract The objective of this study was to examine the variation of time and space and the effects of alpine meadow desertification, and the study area was selected at the Qinghai–Tibet Plateau of China. The sampling locations were categorized as the top, middle, bottom of the slope and flat in front of the slope, and the sites were classified as alpine meadow, light desertified land, moderate desertified land, serious desertified land, and very serious desertified land according to the level of alpine meadow desertification. This study examined spatial and temporal variability in soil organic carbon (SOC), total nitrogen (TN), pH, and soil bulk density due to wind erosion and documents the relationship between soil properties and desertification of alpine meadows. Desertification caused decreases to soil organic carbon and total nitrogen and increases to pH and soil bulk density. Soil properties were greatly affected by the level of alpine meadow desertification with the changes being attributed to overgrazing. The middle portion of slopes was identified as being the most susceptible to desertification. Carbon and nitrogen stocks were found to decrease as desertification progressed, the SOC stocks were 274.70, 273.81, 285.26, 196.20, and 144.36 g m^{-2} in the alpine meadow, light desertified land, moderate desertified land, serious desertified land and very serious desertified land, respectively; and the TN stocks were 27.23, 27.11, 28.35, 20.97, and 17.09 g m^{-2} at the top 30 cm soil layer, respectively. To alleviate desertification of alpine meadow, conservative grazing practices should be implemented.

Keywords Desertification · Alpine meadow · Qinghai–Tibet Plateau · Soil properties

Introduction

Soils are the largest carbon pool in terrestrial ecosystems, containing more than 1,500 Pg C (Raich and Schlesinger 1992; Eswaran et al. 1993). Grasslands, one of the terrestrial ecosystems, account for 40 % of the total land area in China. However, by the end of the 20th century, 90 % of this grassland experienced degradation as a consequence of a rapid expansion of livestock numbers and economic reforms initiated in the 1980s (Wang et al. 2004). As a result of reclamation, overgrazing of grasslands, wind erosion, and desertification, the soil carbon of China has become a carbon source (Li 2000). Soil organic material [SOM, which is 1.724 times the soil organic carbon (SOC)] plays a major role in nutrient cycling and soil quality, and, ultimately, has critical implications for the management of ecosystems and physical stability of soil erosion resistance (Su and Zhao 2003; Zhao et al. 2006).

Lowery et al. (1995) and López (1998) noted that soil coarseness is caused by selective erosion on soil clays and very fine sands. Even if supplemental carbon is added, soil mineralization becomes very weak with the occurrence of

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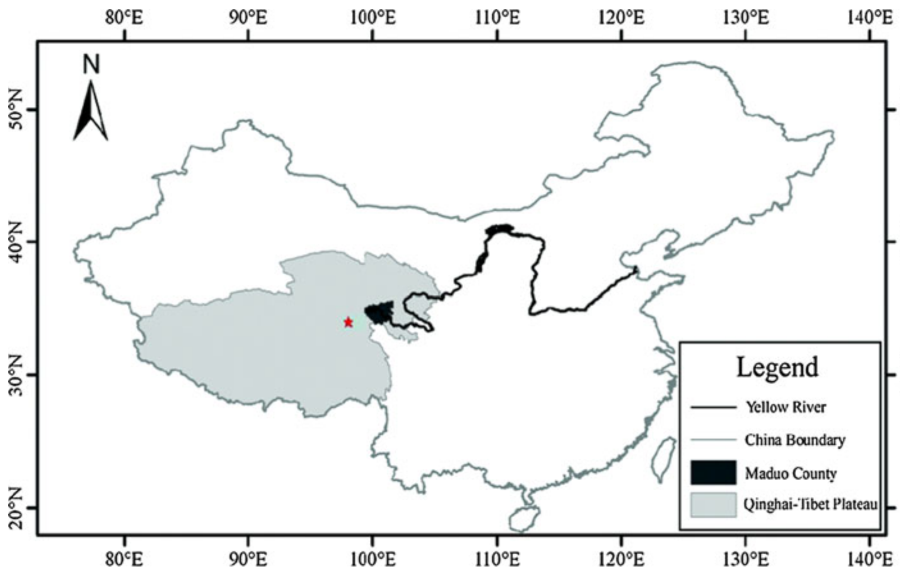
desertification because the soil substrate on which soil microorganisms depend has deteriorated (Su et al. 2004). As a result, the soil becomes susceptible to wind erosion (Arianoutsou-Faraggitaki 1985). Serious wind erosion leads to loss of surface soil, exposing the calcium carbonate-rich subsurface to the air. As the carbon oxidizes, CO_2 can be released (Lal 2003).

Studies by McPherson (1995) and Wondzell and Ludwing (1995) indicate that livestock overgrazing and increasing aridity are the major causes of grassland desertification, although the complex interactions of many factors may contribute to desertification (Humphrey 1958; Reynolds et al. 1999). Desertification not only results in soil degradation and severe losses to land productivity (Gad and Abdel-Samie 2000), but fosters atmospheric emissions of soil C and N as greenhouse gases (Tan and Lal 2005). Since SOM can be associated with different soil chemical, physical, and biological processes, it is considered one of the most important indicators of environmental quality. Soil C and N have been used to assess the effects that different management options have on soil quality (Silveira et al. 2009). The C/N ratio can be used not only as a sensitive index, but can also affect the cycle of SOC and N (Ren et al. 2006). Soil organic material serves as an important storehouse of nutrients, drives the nutrient cycle, maintains soil structural stability, aids the infiltration of air and water, promotes water retention, and reduces soil erosion (Gregorich et al. 1994). For these reasons, the effect of desertification on soil C and N have become a concern in recent years (Johnson and Curtis 2001; Breuer et al. 2006; Qi et al. 2008). The maintenance of adequate levels of SOM should be an integral component of soil management strategy, because SOM is essential to ecosystem productivity and regeneration (Chan et al. 2002).

During the recent decades, high altitude soil has attracted more attention in the debate on the potential impact of environmental change on the global C cycle (Beniston et al. 1997; Diaz and Bradley 1997; Goulden et al. 1998; Christensen et al. 1999; Oechel et al. 2000). With an average elevation above 4,000 m, the Qinghai–Tibet Plateau is called the roof of the world. Wang et al. (2002) and Zeng et al. (2003) have shown that high altitude soil in alpine meadow (AM) ecosystems on the Qinghai–Tibet Plateau has exhibited significant degradation due to natural and human disturbance factors. Decreased vegetation has led to a lower supply of organic material and a reduction in SOM, decreased infiltration capacity, increased runoff, and accelerated soil erosion (Gamougoun et al. 1984; Evans 1998; Trimble and Mendel 1995).

The current study examined spatial and temporal variability in SOC and other related soil properties near Maduo County (33°50′–35°40′N, 96°50′–99°20′E) on the Qinghai–Tibet Plateau, and Maduo County (Fig. 1) is the source region of the Yellow River in the northeastern region of the Qinghai–Tibet Plateau, where desertification has restricted the development of livestock husbandry. The objectives of this study were to (1) evaluate differences in soil properties within and among sites that transition from hilltops to level areas, and (2) determine the effects of desertification on the physical and chemical properties of soil. This work studied the changes to SOC, total nitrogen (TN), pH, and soil bulk density (SBD) from the upslope areas to level areas at the bottom of slopes due to wind erosion, and documented the relationship between soil properties and desertification of AM. The working hypothesis is that, as desertification advances, SOC and TN will decrease, and pH and SBD will increase.

Fig. 1 Study area



Materials and methods

Study area

The area of Maduo County is about 26,267 km^2, and its elevation ranges from approximately 4,200 to 4,800 m above sea level. The region is characterized by low mountains, numerous lakes, and wide valleys. A warm season occurs from June to September and a long cold season runs from October to May. The annual average air temperature is −4.1 °C and there is no absolute frost-free season. The annual precipitation is about 303.9 mm, with 86 % of the precipitation mainly occurring from May to September, in the form of snow or heavy rain. The annual potential evaporation is about 1,264 mm, and the maximum wind speed is 26 m/s. Vegetation consists largely of high-cold meadow and high-cold steppe species.

Experimental design

An experimental plot was selected on which livestock grazing occurred during the cold season (from October to May). Different sub-plots were selected at the top, middle, and bottom of an approximately 30° slope, and a level area at the base of the slope with altitudes of 4,320, 4,275, 4,238 and 4,227 m, respectively. Land desertification was classified based on the criteria developed by Xue et al. (2009) as shown in Table 1: lightly desertified land (LDL), moderately desertified land (MDL), seriously desertified land (SDL), and very seriously desertified land (VSDL). In addition, a non-degraded alpine meadow was also selected as a control (Xue et al. 2009).

Table 1 Grassland grading for different desertification levels in Maduo County in Qinghai Province, China

Classification	Characteristics of grassland
LDL	Vegetation coverage greater than 80 % and yield of grassland is slightly reduced. Plant population change is not obvious
MDL	Vegetation coverage is 50–80 %, and yield of grassland is decreased by 20 %. Plant population change is not obvious although weeds are apparent in the grassland. Soil wind erosion is not obvious
SDL	Vegetation coverage is 20–50 %, and grassland yield is decreased by 75 % or edible rate of grassland is less than 30 %. Native vegetation is greatly reduced and weeds, which have poor palatability and low feeding value, obvious. Poisonous plants thrive. Wind erosion is serious with bare land and shifting sand
VSDL	Vegetative coverage is less than 10 %, and edible forage is non-existent. Native vegetation has completely disappeared; and is replaced by weeds with poor palatability and little feeding value. Poisonous and harmful plants are obvious. Wind erosion is very serious

For each land classification, soil samples were collected from each plot in 10 cm increments, representing 0–10, 10–20, and 20–30 cm depths. Each sample was oven-dried at 105 °C for over 24 h, weighed on an electronic balance (±0.01 g), and analyzed for TN using the Walkley–Black method (Nelson and Sommers 1982). The Walkley–Black method (Allison 1965) was also used to determine SOC, except that a 0.33 M solution of $K_2Cr_2O_7$ was used instead of a 0.17 M solution, enabling a larger subsample to be used in the analyses. SBD and pH were also measured for each sample. Soil pH was determined in a suspension of soil and water (soil:water ratio was 1:5) using a glass electrode. The results of each sample from all three depths were averaged. Reported results represent averages of three replicates from each site.

Statistical analysis

The calculation of C and storage in the soil was based on the method of Li et al. (2005a, b) as follows: SOC or TN in soil = (soil area) × (soil depth) × (average SBD) × (average SOC or TN content). All statistical analyses were performed using SPSS 10.0 (SPSS for Windows, Version 10.0, Chicago, IL, USA).

Results

Soil properties

In the 0–30 cm depth range, SOC was the highest in the AM soils (26.61 g/kg), followed by LDL (25.65 g/kg), MDL (25.08 g/kg), SDL (15.51 g/kg) and VSDL soils (10.90 g/kg) (Fig. 2).

Soil organic carbon generally decreased as desertification increased upslope and downslope; the decrease in SOC was most pronounced at the bottom of the slope. SOC generally increased as desertification increased from AM to MDL, then decreased from MDL to VSDL (Fig. 2). As desertification increased, SOC decreased significantly ($p < 0.05$) (Table 2).

In the 0–30 cm depth range, TN was highest in the AM soils (2.641 g/kg), followed by LDL (2.54 g/kg), MDL (2.49 g/kg), SDL (1.66 g/kg) and VSDL soils (1.29 g/kg).

Total nitrogen decreased with increasing desertification at the upper and lower portions of the slope, with this tendency being more pronounced at the bottom. TN increased with increasing desertification from AM to MDL with this tendency being more pronounced in the level areas. TN decreased from MDL to VSDL (Fig. 3).

Fig. 2 SOC in different desertified lands

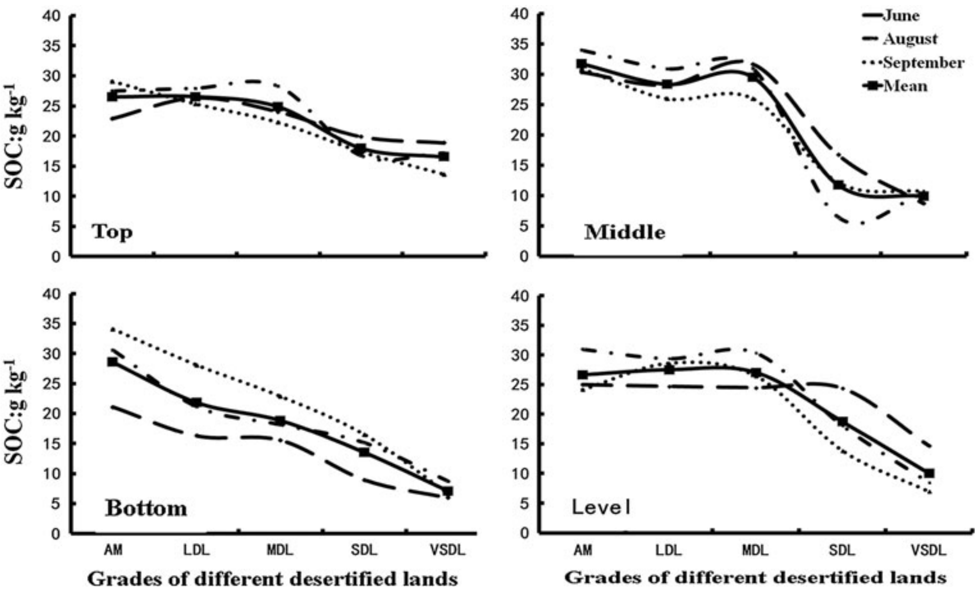


Table 2 *T* test among soil properties in the different desertified lands

	SOC	TN	pH	SBD
AM and LDL	1.788	0.098	−0.005	−0.033
AM and MDL	2.363	0.146	0.079	−0.103
AM and SDL	11.932*	0.978*	0.041	−0.234*
AM and VSDL	16.545*	1.343*	−0.168	−0.290*
LDL and MDL	0.575	0.048	0.084	−0.071
LDL and SDL	10.143*	0.880*	0.046	−0.202*
LDL and VSDL	14.757*	1.246*	−0.163	−0.258*
MDL and SDL	9.568*	0.832*	−0.038	−0.131*
MDL and VSDL	14.182*	1.198*	−0.248	−0.187*
SDL and VSDL	4.613	0.366	−0.209	−0.056

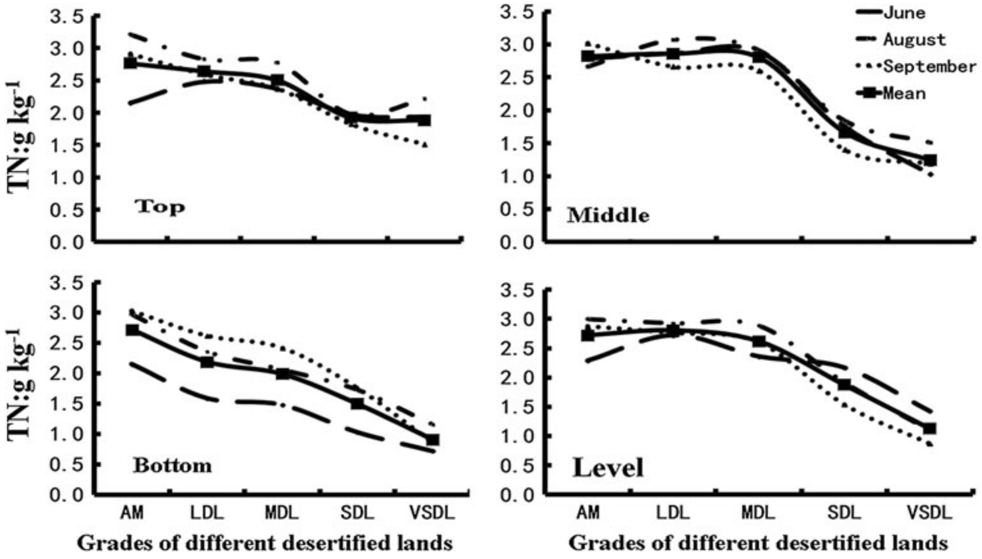
* $p < 0.05$

The pH levels (Fig. 4) were the lowest in the MDL soils (8.01), followed by SDL (8.05), AM (8.09), LDL (8.09), and VSDL soils (8.26).

With increasing desertification, pH may increase or decrease from AM and LDL to MDL, but it always increases from MDL and SDL to VSDL regardless the position on the slope. As desertification proceeds from AM to VSDL, pH tends to increase. For example, when compared with AM soils, the pH in VSDL increased 2.80, 0.25, 2.20 and 3.16 %, respectively at the top, middle, bottom, and level areas, with the pH values being highest at the bottom, followed by level, middle, and top areas (Fig. 4).

As shown in Fig. 5, SBD increased significantly with increased desertification. The mean SBD increased in downslope samples and increased from June to September, SBD was the lowest in the AM soils (1.03 g/cm^3), followed

Fig. 3 TN levels in different desertified lands



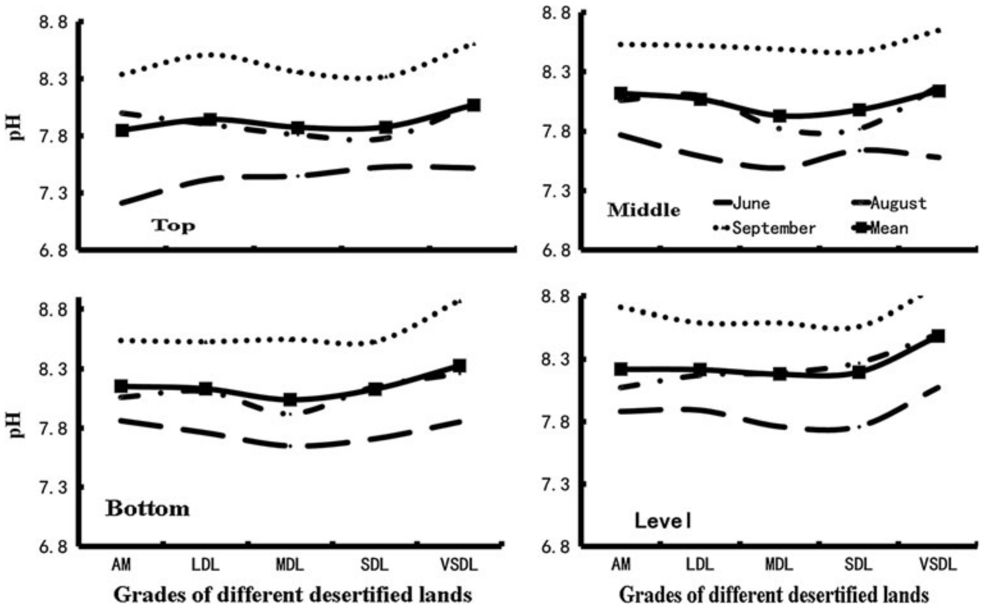


Fig. 4 pH levels in different desertified lands

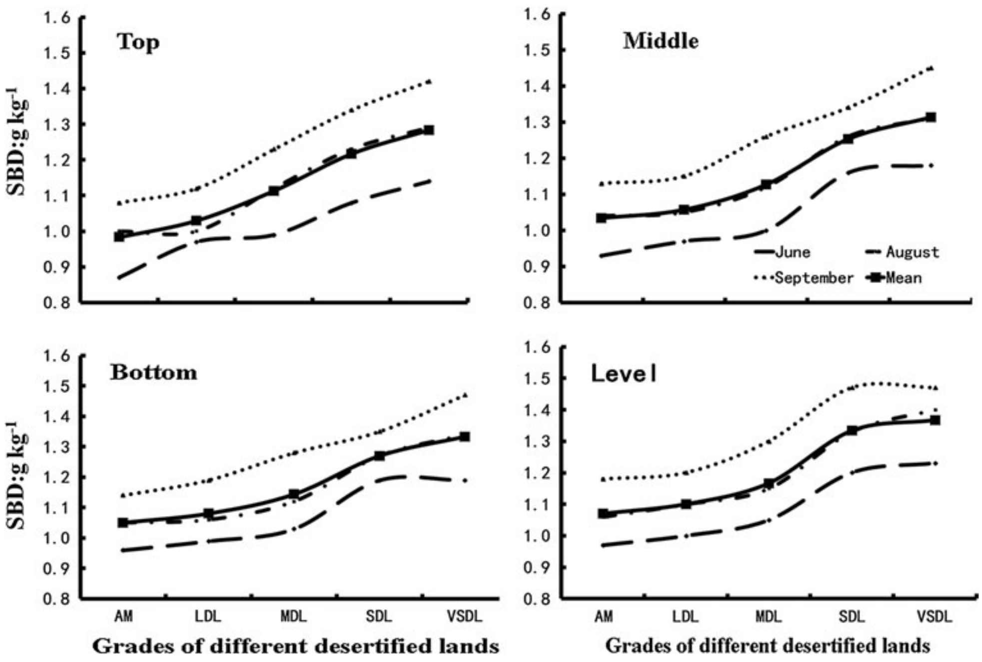


Fig. 5 SBD in different desertified lands

by LDL (1.07 g/cm^3), MDL (1.14 g/cm^3), SDL (1.27 g/cm^3) and VSDL soils (1.33 g/cm^3). Generally, the changes were greater in the level area than in the other positions of slope. SBD increased with increasing desertification regardless of where it was located on the slope (Fig. 5).

T tests show that samples from AM, LDL, and MDL are not significantly different. Similarly, samples for SDL and VSDL are not significantly different, regardless of SOC, TN, and SBD. There are significant differences between samples from AM, LDL, and MDL and samples for SDL and VSDL for SOC, TN, and SBD. There are no significant differences in pH (Table 2).

C/N ratios

There was positive correlation between SOC and TN at all slope positions (Table 3).

As desertification increases from AM to VSDL, the C/N ratio (the actual ratios are 10 times of the ratios which are shown in the figures) increases at the top, middle, bottom

Table 3 Relationship between SOC and TN ($n = 16$)

Variance	Fitting equation	P	R^2
AM	$Y = -0.003X^2 + 0.253X - 1.660$	<0.01	0.896
LDL	$Y = -0.000X^2 + 0.138X - 0.462$	<0.005	0.917
MDL	$Y = -0.001X^2 + 0.173X - 0.633$	<0.005	0.954
SDL	$Y = -0.002X^2 + 0.160X - 0.140$	<0.005	0.971
VSDL	$Y = -0.001X^2 + 0.127X + 0.059$	<0.01	0.897

of an approximately 30° slope, and a level area at the base of the slope. Moreover, the land deteriorates from AM to LDL, the C/N ratio increases slowly. With increasing degradation from MDL to SDL, and from SDL to VSDL, the C/N ratio increases rapidly.

Generally, if the decomposition rate of C is faster than that of N, the C/N ratio will be lower. Not much change in the C/N ratio is evident from AM and LDL to MDL; however, the more pronounced change in the ratio from MDL to SDL and from SDL to VSDL indicates that N losses are greatest in SDL and VSDL (Fig. 6).

Changes to the coefficient of variation

At all slope positions, the largest coefficient of variation was for SOC followed by TN, SBD, and pH (Table 4).

The largest coefficient of variation for SOC illustrates C losses with increases in desertification and the differences were quite pronounced ($p < 0.05$) (Table 2). The coefficient of variation for SOC is generally highest in September, except for that in the middle of the slope in August. The coefficient of variation is high for SOC and TN in the middle of the slope and there was no pronounced change for pH and SBD at any position on the slope (Table 4).

Discussion

Effects of desertification on soil properties

Soil chemical and physical properties decline under heavy grazing as desertification progresses from AM to VSDL. In particular, SOC and TN levels decrease and SBD and pH levels increase significantly. This indicates that soil properties are severely affected by desertification, and is consistent with the results of Zhao et al. (2007) and Su and Zhao (2003). Increases in SBD and decreases in SOC enhance the likelihood of wind erosion on soils (López 1998), lowering land productivity as soils become coarser and leaner. This ultimately leads to vegetative degradation and land desertification.

Soil erosion by wind is the main cause for changes in soil particle composition (He et al. 2004); in addition, trampling by animals promotes the loss of top soil (Huang et al. 2007). During the transformation of the soil from AM to VSDL, SOC content generally decreases (Fig. 2). Huang et al. (2007) state that overgrazing affects soil nutrient losses by (1) reducing vegetative growth and exposing the soil surface to erosion which leads to direct soil nutrient losses; and (2) reducing the return of litter to the soil. During the process of desertification from AM to MDL, some positions on the slope, especially the level base areas, show a tendency to accumulate SOC (Fig. 2). Moderate grazing can contribute to this accumulation. Productivity and soil fertility improve as a result of residual litter and livestock excrement being returned to soil (Wang et al. 2008); however, as a desertification progress, SOC decreases are evident. Fu and Chen (2004) and Dormaar et al. (1990) claim that an important manifestation of heavy grazing is the reduction of SOC. The soil environment,

Fig. 6 C/N ratios in different desertified lands

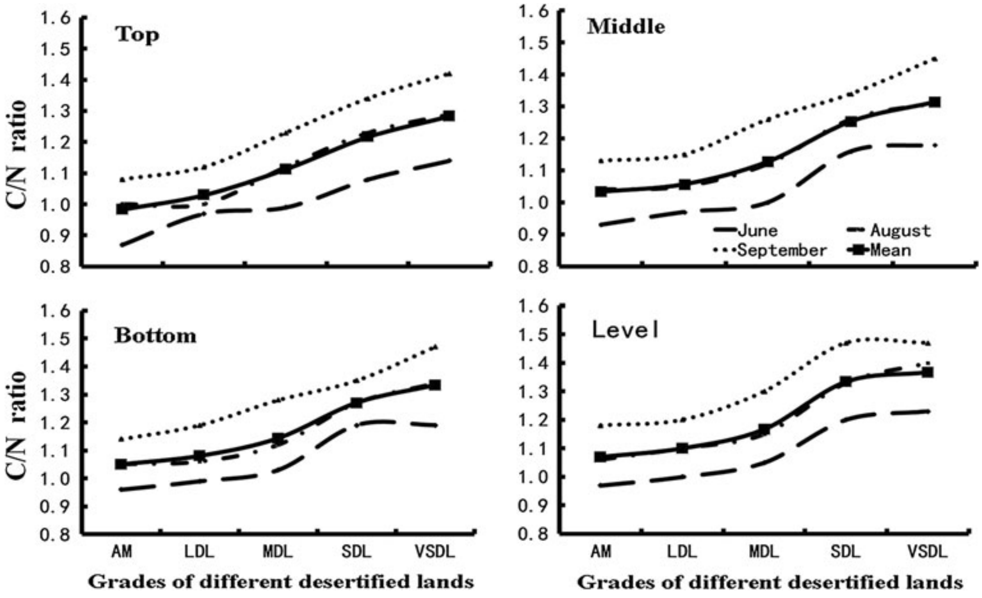


Table 4 Coefficient of variation for various slope locations during the field study season

Parameter	Position	June	August	September	Mean
SOC	Top	0.14	0.26	0.29	0.21
	Middle	0.43	0.56	0.43	0.46
	Bottom	0.45	0.43	0.49	0.45
	Level	0.26	0.42	0.46	0.33
TN	Top	0.11	0.19	0.25	0.18
	Middle	0.37	0.45	0.38	0.39
	Bottom	0.39	0.33	0.40	0.37
	Level	0.26	0.35	0.40	0.29
SBD	Top	0.10	0.12	0.12	0.11
	Middle	0.11	0.11	0.11	0.10
	Bottom	0.10	0.11	0.10	0.10
	Level	0.11	0.12	0.11	0.11
pH	Top	0.02	0.02	0.01	0.01
	Middle	0.01	0.02	0.01	0.01
	Bottom	0.01	0.02	0.02	0.01
	Level	0.02	0.02	0.02	0.02

including both soil quality and soil stability of AM, gradually degrades (Wang et al. 2008). In addition, while clays can retain SOC, the decreases in SOC were affected by the development of bare surfaces and wind erosion, which reduce the clay content of the soil (Lynch and Cotnoir 1956).

The TN content of the soil also decreases significantly with the development of desertification (Fig. 3). Under heavy grazing, the output of N and inorganic N increases due to frequent livestock feeding, which means more N is transported out of the system by plants (Li et al. 2005a, b). This leads to N decrease in the soil (Fig. 3), similar to results found by Guan et al. (1997). Although the decrease in TN is not pronounced, it is likely that soil properties are weakened by soil buffering capacity (Wang et al. 1998).

Owing to the dominating upward (i.e., toward the soil surface) direction of water movement in the soil profile, soluble salts in the groundwater move upward and accumulate in topsoil. The desert soil in northwestern China is naturally saline (Institute of Soil Science, Academia Sinica 1978), a fact that was confirmed in the present work. Figure 4 shows that pH increases with greater desertification from 7.21 to 8.71. The increase in pH may be due to an increase in the ion circulation rate that the results from the soils receiving a large amount of livestock wastes and/or an increase in salt accumulation caused by the higher evaporation of soil surface water that resulted from decreased vegetative coverage and floor litter (Zhou et al. 2005). The increases in soil pH may affect the bioavailability of nutrients, thus influencing the growth, development, and absorbing functions of plants and resulting in aggravated desertification.

During the study, SBD increased from June to September. Although the experimental plots were subjected to grazing only in winter, lower rainfall may have led to increased soil compaction, which causes SBD to increase. From AM to VSDL, SBD decreased as desertification increased (Fig. 5). The SBD increase is usually accompanied by a reduction in porosity during the process of grassland desertification (Wang et al. 2004). Therefore, SBD can be used as an indicator to monitor soil degradation and to estimate the degree of soil desertification. This phenomenon is similar to that noted by Greenwood et al. (1997) and Rong et al. (2001), who stated that SBD had a cumulative effect.

The C/N ratio of the soil is an indicator for assessing the C and N nutrition balance and is significant in that it reflects the carbon and nitrogen cycling of the soils (Qi et al. 2008). The C/N ratio of soils decreased from 10.14 to 8.36 as desertification increased because the soil carbon declined more rapidly relative to the decrease in nitrogen (Fig. 6). As desertification increases, the decrease in the C/N ratio results in enhanced microbial activity that accelerates the rate of decomposition and mineralization of the SOM and TN, and reduces the capacity of the soils to fix organic carbon. As such, more inorganic N is released from the soil, negatively affecting the environment. Moreover, additional inorganic N is released by the mineralization of organic matter (Li et al. 2006). Inorganic N does not accumulate readily, in part because of leaching and denitrification (Franzluebbers et al. 1996; Vanlauwe et al. 1996; Lupwayi and Haque 1998), which may also contribute to the pollution of groundwater and surface water.

T tests on SOC, TN, and SBD in the sample plots showed significant differences (Table 2) and allow differentiation between the different grazing intensities on AM lands and the state of vegetative growth. The *T* test can be used as an index to evaluate the health of AM lands (Zhou et al. 2005). Based on the changes to the coefficient of variance (Table 4), the middle portions of the slope are more easily desertified, assuming similar grazing conditions, thus the middle portion of the slope should receive additional attention.

Soil carbon and nitrogen storage

Using satellite images of desertified areas from (Xue et al. 2009), the SOC and TN contents of the soil in Maduo County were calculated for depths of 0–30 cm (Table 5).

The storage of SOC and N for the different land classifications are shown in Table 6. The soil profile (0–30 cm depth) in this region stored 5.04×10^{11} kg C and 5.07×10^{10} kg N. The AM soil had the highest SOC and N stocks, 1.78×10^{11} kg C and 1.77×10^{10} kg N,

Table 5 Areas of desertified land types and alpine meadow in Maduo County (km^2)

	1987	1994	2000	2006
AM	7,501.7	6,759.1	4,861.4	6,491.5
LDL	4,270.3	3,459.7	3,971.1	5,003.7
MDL	4,229.2	5,114.2	5,219.4	3,988.4
SDL	3,846.6	4,873.5	5,549.7	3,375.2
VSDL	481.5	1,073.1	1,590.6	609.8
Total areas	20,329.3	21,279.6	21,192.2	19,468.6
Total desertified land	12,827.6	14,520.5	16,330.8	12,977.1

respectively, which was more than 20 times that of the VSDL SOC stocks and 1.6 times that of the VSDL N stocks. The results given by Xue et al. (2009) showed that desertification of AM land had expanded from 12,827.6 km^2 in 1987 to 12,977.1 km^2 in 2006 (Table 5). Determining the total stocks of SOC and TN for each land classification provides an estimate of the stock lost due to desertification (Table 6). The difference in SOC and TN stock noted for AM and VSDL lands indicate that the process of desertification caused the loss of 130.34 g/m^2 of SOC and 10.14 g/m^2 of TN.

Large losses of SOC and TN indicate substantial environmental degradation. As C and N are lost from the soil, land productivity deteriorates, and the atmospheric release of greenhouse gases contributes to global climate change (Duan et al. 2001). Saggar et al. (2001) and Su et al. (2002) have indicated that land use/cover and land management are two primary factors influencing soil nutrient content. These results show that land use/cover had significant effects, not only on the soil SOC and TN contents, but also on the amounts of these nutrients lost in the land desertification process. On the one hand, high quality grassland, which not only had higher moisture content and levels of nutrients, but also suffer less from wind erosion. On the other hand, soils subjected to overgrazing and trampling by livestock not only decrease vegetation height and cover, but also destroy the soil crust and intensify wind-induced soil erosion (Zhao et al. 2007). Thus, AM lands begin with better soil quality and nutrient content and have more SOC and TN available for loss through desertification. In addition, SOC and N storage capacity were lost more rapidly during the later stages of desertification than in the initial stages. More than likely, the loss of nutrients led to a decline in vegetative coverage, and desertified land expanded quickly due to overgrazing and wind erosion in the later stages of desertification.

Conclusions

Desertification of AM has increased on the Qinghai–Tibet Plateau during the last century, mainly because of climatic changes and anthropogenic activities. The natural climate effects of the AM on the growth, but unreasonable human activities aggravate the AM to the desertification development.

Through the experimental plot was selected and then different sub-plots were decided at the top, middle, and bottom of an approximately 30° slope, and a level area at the base of the slope. Therefore, land desertification was classified based on the criteria. This study concentrates on SOC, TN, SBD and pH at different desertified alpine meadow. Analysis of the results of this work show that (1) AM desertification in the Qinghai–Tibet plateau is driven by overgrazing and has resulted in significantly increased SBD and pH and significantly decreased SOC and TN; (2) under similar grazing conditions, SOC and TN was more easily lost in the middle portion of a 30 % slope and, accordingly, the middle portion of the slope should be given priority for protection; (3) desertification affected SOC much more than it affected TN, pH, and SBD; (4) the C/N ratio increased and the rate of N decomposition increased as desertification increased, which led to environmental pollution and river eutrophication; and (5) soil carbon storage and nitrogen storage were lost more rapidly during the later stages of desertification than in the initial stages.

Soil bulk density has been shown to be closely related to the degree of soil degradation. This study has shown that soil properties and vegetation succession changes significantly as AM go through a desertification process as a result of overgrazing. AM desertification was found to be

Table 6 SOC and TN storage in desertified land types and alpine meadow in Maduo County (2006) at depth 0–30 cm

	AM	LDL	MDL	SDL	VSDL
Areas (km^2)	6,491.5	5,003.7	3,988.4	3,375.2	609.8
SOC (g/kg)	26.61	25.65	25.0775	15.51	10.90
SOC (kg)	1.78×10^{11}	1.37×10^{11}	1.14×10^{11}	0.66×10^{11}	0.09×10^{11}
SOC (g/m^2)	274.70	273.81	285.26	196.20	144.36
TN (g/kg)	2.64	2.54	2.49	1.66	1.29
TN (kg)	1.77×10^{10}	1.36×10^{10}	1.13×10^{10}	0.71×10^{9}	0.10×10^{9}
TN (g/m^2)	27.23	27.11	28.35	20.97	17.09

accompanied by severe soil erosion, declining soil nutrition, and losses of species diversity. This information can provide a useful baseline to better understand the AM desertification process in Qinghai–Tibet Plateau.

Currently, overgrazing is one of the primary causes of AM degradation and desertification in the Qinghai–Tibet Plateau. Therefore, reduce grazing intensity, which is the most cost-effective method of preventing AM from desertification, is to relieve grazing intensity and implement reasonable grazing systems, give vegetation some time for rehabilitation and then recovering the update and propagate abilities. First, reduce grazing intensity. The coverage and height of the AM and biomass of the upper and underground increased significantly after taking this method. Increasing the height and coverage of AM can make ground more rough. It not only reduces wind erosion, but also deposits quicksand. Meanwhile, the underground biomass increasing enhances the ability of consolidating soils by grass roots to play a great role in combating desertification. The second take reasonable grazing systems. Rotational grazing can give AM a short-term rehabilitation time to ensure its update and better growth. It is very necessary to carry out fencing policy rapidly to control the spread of sand disasters before moderate desertification.

Above all, conservative grazing methods can alleviate pressures on AM grasslands and lead to a healthier AM on the Qinghai–Tibet Plateau.

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References

Allison LE (1965) Organic carbon. In: Black CA (ed) Methods of soil analysis, Part 2—chemical and microbiological properties. American Society of Agronomy, Madison, pp 1367–1378

Arianoutsou-Faraggitaki M (1985) Desertification by overgrazing in Greece: the case of Lesvos is land. J Arid Environ 9:237–242

Beniston M, Diaz HF, Bradley RS (1997) Climatic change at high elevation sites: an overview. Clim Change 36:233–251

Breuer L, Huisman JA, Keller T, Frede HG (2006) Impact of a conversion from cropland to grassland on C and N storage and related soil properties: analysis of a 60-year chronosequence. Geoderma 133:6–18

Chan KY, Heenam DP, Oates A (2002) Soil carbon fractions and relationship to soil quality under different tillage and stubble management. Soil Tillage Res 63:133–139

Christensen TR, Jonasson S, Callaghan TV, Havström M (1999) On the potential CO_2 release from tundra soils in a changing climate. Appl Soil Ecol 11:127–134

Diaz HF, Bradley RS (1997) Temperature variations during the last century at high elevation sites. Clim Change 36:253–279

Dormaar JF, Smoliak S, Willms WD (1990) Distribution of nitrogen fractions on grazed and ungrazed fescue grassland Ah horizons. J Range Manage 43:6–9

Duan ZH, Xiao HL, Dong ZB, He XD, Wang G (2001) Estimate of total CO_2 output from desertified sandy land in China. Atmos Environ 35:5915–5921

Eswaran H, Berg EVD, Reich P (1993) Organic carbon in soils of the world. Soil Sci Soc Am J 57:192–194

Evans R (1998) The erosional impact of grazing animals. Prog Phys Geogr 22:251–268

Franzluebbers AJ, Arshad MA, Ripmeester JA (1996) Alterations in canola residue composition during decomposition. Soil Biol Biochem 28:1289–1295

Fu H, Chen YM (2004) Organic carbon content in major grassland types in Alex, Inner Mongolia. Acta Ecologia Sinica 24:469–476

Gad A, Abdel-Samie AG (2000) Study on desertification of irrigated arable lands in Egypt. II–salinization Egypt. J Soil Sci 40:373–384

Gamougoun ND, Smith RP, Wood K, Pieper RD (1984) Soil, vegetation, and hydrologic responses to grazing management at Fort Stanton, New Mexico. J Range Manage 37:538–541

Goulden ML, Wofsy SC, Harden JW, Trumbore SE, Crill PM, Gower ST, Fries T, Daube BC, Fan SM, Sutton DJ, Bazzaz A, Munger JW (1998) Sensitivity of boreal forest carbon balance to soil thaw. Science 279:214–217

Greenwood KL, MacLeod DA, Hutchinson KJ (1997) Long-term stocking rate effects on soil physical properties. Aust J Exp Agric 37:413–419

Gregorich EG, Carter MR, Angers DA, Monreal CM, Ellert BH (1994) Towards a minimum data set to assess soil organic matter quality in agricultural soils. Can J Soil Sci 74:367–385

Guan SY, Chang SB, Jia SH, Li SL, Chen YJ, Wang YF (1997) The properties of soil and its change regularities in the degraded succession of dark chestnut in *Leymus chinesis* steppe. Grassl China 3:39–43

He WQ, Gao WS, Tuo DB, Zhao PY (2004) Study on some factors influencing soil erosion by wind tunnel experiment in North Ectone between agriculture and pasture. J Soil Water Conserv 18:1–8

Huang D, Wang K, Wu WL (2007) Dynamics of soil physical and chemical properties and vegetation succession characteristics during grassland desertification under sheep grazing in an agro-pastoral transition zone in Northern China. J Arid Environ 70: 120–136

Humphrey RR (1958) The desert grassland: a history of vegetational change and analysis of causes. Bot Rev 24:193–252

Institute of Soil Science, Academia Sinica (1978) Soils in China. Science Publishing Press, Beijing (in Chinese)

Johnson DW, Curtis PS (2001) Effects of forest management on soil C and N storage: meta analysis. For Ecol Manage 140:227–238

Lal R (2003) Soil erosion and the global carbon budget. Environ Int 29:437–450

Li KR (2000) Land use change, greenhouse emission and carbon cycle in terrestrial ecosystem. Weather Press, Beijing (in Chinese)

Li MF, Dong YS, Qi YC, Geng YB (2005a) Effect of land-use change on the contents of C & N in temperate grassland soils. Grassl China 1:1–6

Li YQ, Zhao HL, Zhao XY, Zhang TH, Yi XY, Zuo XA (2005b) Characteristics of soil carbon and nitrogen during desertification process in Horqin sandy land. J Soil Water Conserv 19:73–182

Li ZP, Zhang TL, Chen BY (2006) Changes in organic carbon and nutrient contents of highly productive paddy soils in Yujiang county of Jiangxi Province, China and their environmental application. Agric Sci China 5:522–529

López MV (1998) Wind erosion in agricultural soils: an example of limited supply of particles available for erosion. Catena 33:17–28

Lowery B, Swan J, Schumacher T, Jones A (1995) Physical properties of selected soils by erosion class. J Soil Water Conserv 50:306–311

Lupwayi NZ, Haque I (1998) Mineralization of N, P, K, Ca and Mg from *Sesbania* and *Leucaena* leaves varying in chemical composition. Soil Biol Biochem 30:337–343

Lynch DL, Cotnoir LJ (1956) The Influence of clay minerals on the breakdown of certain organic substrates. Soil Sci Soc Am Proc 20:367–370

McPherson GR (1995) The role of fire in desert grassland. In: McClaran MP, Van Devender TR (eds) The desert grassland. University of Arizona Press, Tucson

Nelson DW, Sommers LE (1982) Total carbon, organic carbon and organic matter. In: Page AL, Miller RH, Keeney DR (eds) Methods of soil analysis. American Society of Agronomy, Madison

Oechel WC, Vourlitis GL, Hastings SJ, Zulueta RC, Hinzman L, Kane D (2000) Acclimation of ecosystem CO_2 exchange in the Alaskan Arctic in response to decadal climate warming. Nature 406:978–981

Qi YB, Huang B, Gu ZQ, Zhao YC, Sun WX, Wang ZG, Yang YF (2008) Spatial and temporal variation of C/N rations of agricultural soils in typical area of Yangtze delta region and its environmental significance. Bull Mineral Petrol Geochem 27:50–56 (in Chinese)

Raich JW, Schlesinger WH (1992) The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. Tellus 44:81–99

Ren SJ, Cao MK, Tao B, Li KR (2006) The effect of nitrogen limitation on terrestrial ecosystem carbon cycle: a review. Prog Geogr 25:58–67 (in Chinese)

Reynolds JF, Virginia RA, Kemp PR, de Soyza AG, Tremmel DC (1999) Impact of drought on desert shrubs: effects of seasonality and degree of resource island development. Ecol Monogr 69:69–106

Rong YP, Han JG, Wang P, Mao PS (2001) The effects of grazing intensity on soil physics and chemical properties. Grassl China 23:41–47 (in Chinese)

Saggar S, Yeates GW, Shepherd TG (2001) Cultivation effects on soil biological properties, microfauna and organic matter dynamics in Eutric Gleysol and Gleyic Luvisol soils in New Zealand. Soil Tillage Res 58:55–68

Silveira ML, Comerford NB, Reddy KR, Prenger J, Debusk WF (2009) Soil properties as indicators of disturbance in forest ecosystems of Georgia, USA. Ecol Indic 9:740–747

Su YZ, Zhao HL (2003) Losses of soil organic carbon and nitrogen and their mechanisms in the desertification process of sandy farmlands in Horqin sand land. China Agric Sci 2:890–897 (in Chinese)

Su YZ, Zhao HL, Zhang TH, Li YL (2002) Processes and characteristics of soil degradation in rainfed farmland in the Horqin sandy land. J Soil Water Conserv 16:25–28 (in Chinese)

Su YZ, Zhao HL, Li YL, Cui JY (2004) Carbon mineralization potential in soils of different habitats in the semiarid Horqin sandy land: a laboratory experiment. Arid Land Res Manage 18:39–50

Tan ZX, Lal R (2005) Carbon sequestration potential estimates with changes in land use and tillage practice in Ohio, USA. Agric Ecosyst Environ 111:140–152

Trimble SW, Mendel AC (1995) The cow as a geomorphic agent—a critical review. Geomorphology 13:233–253

Vanlauwe B, Nwoke OC, Sanginga N, Merckx R (1996) Impact of residue quality on the C and N mineralization of leaf and root residues of three agroforestry species. Plant Soil 183:221–231

Wang YF, Chen ZZ, Tieszen LT (1998) Distribution of soil organic carbon in the major grasslands of Xilinguole, Inner Mongolia, China. Acta Phytoecologica Sinica 22:545–551 (in Chinese)

Wang GX, Qian J, Cheng GD, Lai YM (2002) Soil organic carbon pool of grassland soils on the Qinghai–Tibetan Plateau and its global implication. Sci Total Environ 291:207–217

Wang K, Lu JY, Shao XQ (2004) Measures of restoring and rebuilding desertified grassland. Acta Agrestia Sinica 3:240–245 (in Chinese)

Wang CT, Long RJ, Wang QL, Cao GM, Shi JJ, Du YG (2008) Response of plant diversity and productivity to soil resources changing under grazing disturbance on an alpine meadow. Acta Ecologica Sinica 28:4144–4152 (in Chinese)

Wondzell S, Ludwing JA (1995) Community dynamics of desert grasslands: influences of climate, landforms, and soil. J Veg Sci 6:337–390

Xue X, Guo J, Han BS, Sun QW, Liu LC (2009) The effect of climate warming and permafrost thaw on desertification in the Qinghai–Tibetan Plateau. Geomorphology 108:182–190

Zeng YN, Feng ZD, Cao GC (2003) Land-cover change and its impacts on environment in the upper reaches of the Yellow River, northeast Qinghai–Tibetan Plateau. Mt Res Dev 23:353–361

Zhao HL, Zhou RL, Su YZ, Zhang JY, Yi XY (2006) Effects of desertification on soil and crop growth properties in Horqin sandy farmland of Inner Mongolia. Soil Tillage Res 87:175–185

Zhao HL, Zhou RL, Su YZ, Zhang JY, Yi XY (2007) Processes and mechanisms of soil desertification in semiarid areas, Northern China. J Soil Water Conserv 21:1–5 (in Chinese)

Zhou LY, Wang MJ, Han GD, Wu ZY (2005) Effects of different grazing intensities on community and soil physical and chemical characteristics in *Stipa baicalensis* steppe. J Arid Land Resour Environ 19:182–187 (in Chinese)