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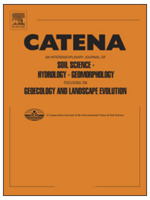

Alpine grassland degradation in the Qilian Mountains, China — A case study in Damaying Grassland

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ABSTRACT

Degradation of semiarid grassland and efforts to control that degradation have become pressing issues. However, the inherent characteristics of the grassland and the intertemporal nature of the problem complicate the analysis of degradation issues, and consequently, the search for more appropriate rangeland policies. Using the Damaying Grassland as a case study, we assessed alpine grassland on the north slopes of the Qilian Mountains by means of in situ samples using vegetative cover, biological diversity, forage productivity, soil bulk density, and soil nutrients as the main evaluation indices. The forage yields on high, moderate, and low coverage rangeland exhibited decreases of 20.2%, 20.8% and 56.4%, respectively, from 1982 to 2012. Due to the lower basal cover of rangeland in poor condition, soil nutrient and organic matter content decreased with rangeland degradation. Increased soil compaction appears to lead to lower basal cover of rangeland The soil bulk density in high, moderate, and low coverage rangelands was found to be 0.8 $g \cdot cm^{-3}$, 1.1 $g \cdot cm^{-3}$, and 1.2 $g \cdot cm^{-3}$, respectively. The soil nutrient levels and organic matter contents indicate that the rangelands experienced degradation over the 30-year period. Organic matter and available nitrogen decreased significantly over time, while available phosphorus and available potassium increased significantly. Overall, our results show that the Damaying Grassland is in a period of rapid degradation, and that mitigation and remediation measures are needed to protect the rangelands.

1. Introduction

The effects of recent climate variability and human disturbance on the degradation of arid or semiarid rangeland has made this issue increasingly topical in agricultural economics research (Dean and Macdonald, 1994; Dodd, 1994; Milton et al., 1994; Chan et al., 1995; Snyman and du Preez, 2005; Wessels et al., 2007; Akiyama and Kawamura, 2007; Spottiswoode et al., 2009; Harris, 2010; Rutherford and Powrie, 2010). Grassland degradation is the overall reduction in grassland productivity as a consequence of human activities and natural processes and may be induced through overgrazing, cropland misuse, and unregulated collection of plants for fuel and medicinal purposes. Such degradation may be manifested as reductions in the extent and density of grass cover and output of forage, as increases in unpalatable grass species, or even as denudation of underlying soil. In China, degradation of semi-arid rangelands, especially in regions such as the Qinghai–Tibet Plateau and Inner Mongolia, is a serious and pressing concern (Li et al., 2000, 2005, 2006; Liu et al., 2004; Tong et al., 2004; He et al., 2005; Su et al., 2005; Zhou et al., 2006). Degradation is a reversible process; however, rangeland degradation proceeds in steps that are increasingly difficult and costly to reverse. Severely degraded rangelands may not return to their original state, even when rested for decades (Westoby et al., 1989; O'Connor, 1991).

The Qilian Mountains lie in a remote northeastern corner of the Qinghai–Tibet Plateau. An important region for ecological environment research (Li et al., 2007; Tang et al., 2011; Wang et al., 2013), the north slope of Qilian Mountains is a natural ecological barrier between the Gobi desert and the Qinghai–Tibet Plateau and an important base for stock breeding in China. These mountains are the source of numerous, mostly small, rivers and creeks that flow northeast, enabling irrigated agriculture in the Hexi Corridor to the north of Qilian Mountains (Chen, 1996; Shen et al., 2001; Qin et al., 2013).

The Chinese government has paid increasing attention to the problems of degradation in the Qilian Mountains. The government's *Major Function-Oriented Zone Planning in China* (http://www.gov.cn/zwgk/2011-06/08/content_1879180.htm) has declared the Qilian Mountains to be an important glacial and water source conservation region. In particular, alpine grasslands on the north slopes constitute a fragile ecosystem. The natural environment is extremely harsh and the soil is generally quite thin. Once the alpine grassland vegetation is disturbed or degraded, recovery of the grassland is difficult. Under the dual influences of a harsh natural environment and increased human pressures, large areas of the alpine grassland in this region have become severely

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degraded (Zhao et al., 2004a, 2004b; Cheng et al., 2008; Wu et al., 2008; Yan et al., 2010; Huang et al., 2011). The inherent characteristics of the rangeland and the intertemporal nature of the problem complicate the analysis of degradation issues and the search for appropriate rangeland policies.

In this study, we mapped and quantified the extent of rangeland degradation and identified the driving forces of degradation at the local level. We assessed the grassland degradation index in the alpine grasslands and trends in degradation in relation to human activities and natural factors in this fragile and strategically important ecosystem. The results of this contribute scientific and technical evidence and support for adapting to future climate changes, sustainable use, and improved management of alpine grasslands.

2. Methods

2.1. Study area

Located between the Qilian Mountains and the Yanzhi Mountains, the Damaying Grassland (37°57′–38°23′N, 101°02′–101°22′E) is an important area on the north slopes of the Qilian Mountains pasturing area (Fig. 1), ranging from 2450 m to 3200 m above sea level. The Damaying Grassland is characterized by piedmont fans and alluvial plains inclined at 1–2° to the north and northwest. The thickness of the soil layer in the grasslands ranges from about 0.5–2.0 m. Highly susceptible to wind erosion, the light-yellow, loosely structured soil consists mainly of very fine sand and silt and is classified as silty clay (chestnut soil). The climate of the area is semi-arid with a mean annual precipitation of 364 mm (Fig. 2), 65.8% of which occurs in the growing season (May–August). Under the influence of atmospheric circulation and topography, precipitation increases from north to south as the elevation increases. The annual evaporation is 1700 mm. Annual mean temperatures (1980–2011) are 0.9 °C with monthly mean temperatures in the growing season ranging from 7.9 °C to 14.1 °C. The annual frost-free period is 110 days, with higher altitude areas characterized by a very short growing season. Shandan Horse Farm has a long history of raising horse and 2058 horses, 34 066 Cattles, and 29 632 sheep were raised in 2008 (Table 1). However, the Damaying Grassland was reclaimed in order to more economic benefits since 1941and the cultivated area reached 51 029 ha in 2012.

The vegetative cover exhibits distinct belts based on altitude and can be divided into four main types: temperate steppe (low coverage), alpine typical steppe (moderate coverage), alpine meadow-steppe (high coverage), and alpine shrub steppe (Table 2). There are 51 families, 155 genera, and 342 species of grassland plants, most of which fall into the Gramineae, Cyperaceae, Compositae, and Leguminosae families.

Grasslands at altitudes between 2500 m and 2700 m fall in the temperate steppe zone and are characterized by herbs dominated by *Artemisia abrotanum*, *Achnatherum splendens*, and *Stipa capillata*. The alpine typical steppe zone (2600 m to 2900 m) is dominated by *A. splendens*, *S. capillata*, *A. abrotanum*, *Agropyron cristatum*, *Leymus secalinus*, *Roegneria kamoji*, *Elymus dahuricus*, *Poa annua*, *Festuca rubra*, and *Carex tristachya*. Between 2900 m and 3200 m, a mixed belt of alpine meadow-steppe is dominated by *Polygonum viviparum*, *Kobresia*

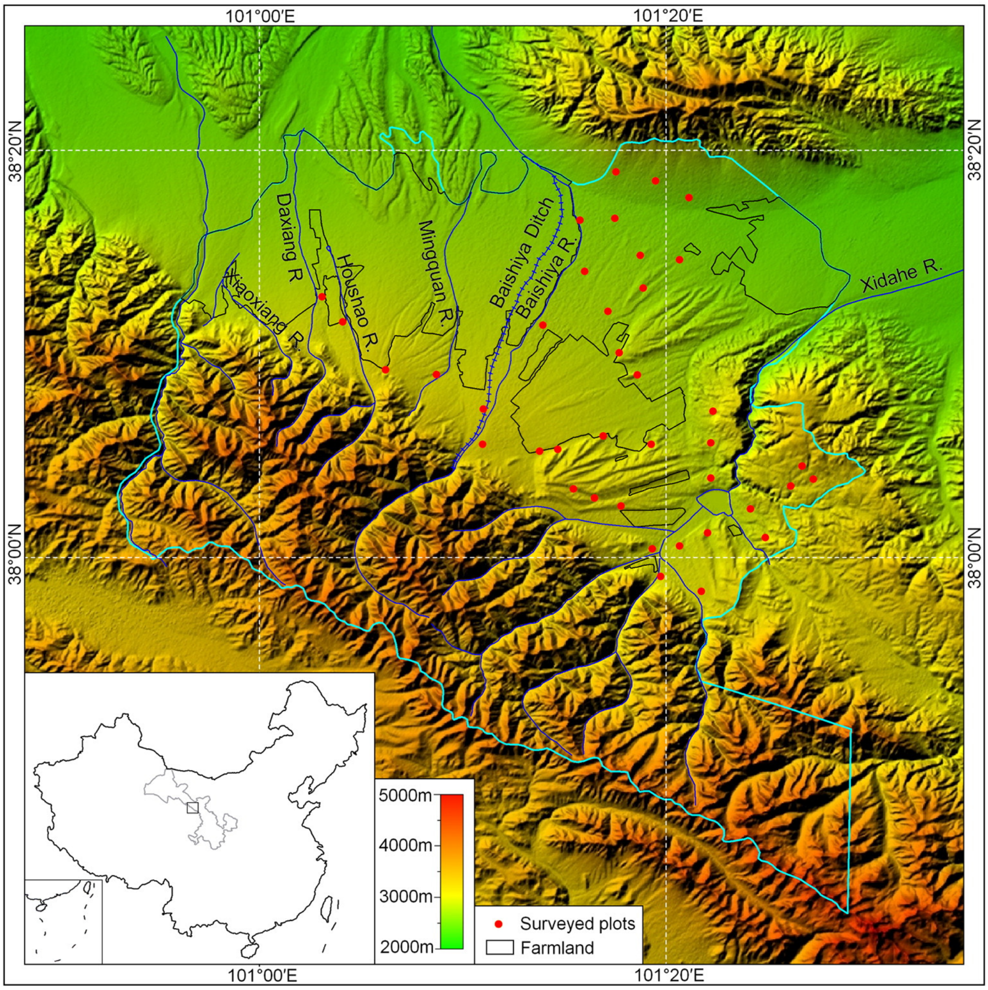

Fig. 1. Location of the Damaying Grassland at north slope of Qilian Mountains; the outline is the borderline of Shandan Horse Farm. The dots showing the position of the surveyed plots which are served as winter and spring pastures, for grazing only after September.

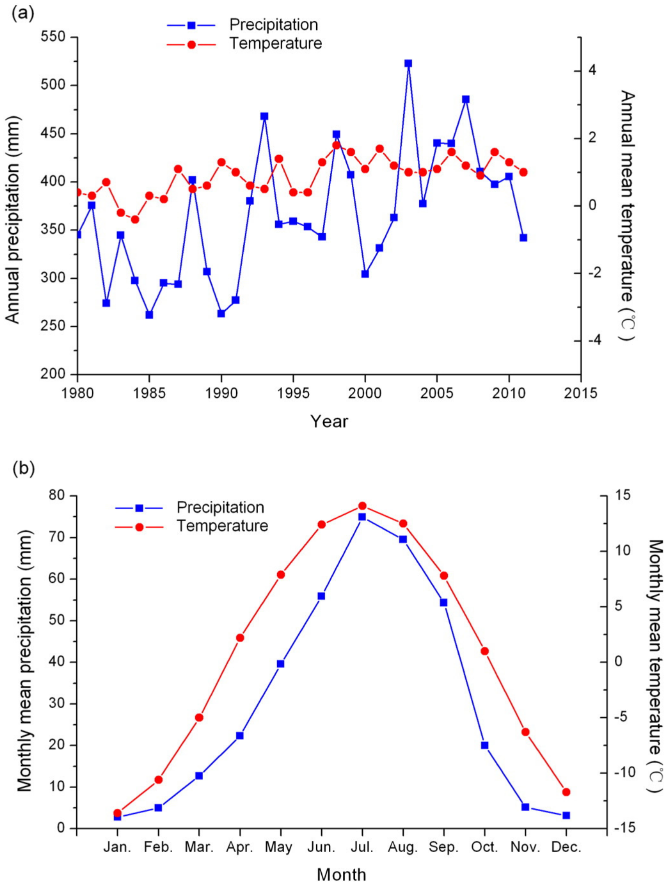

Fig. 2. Climate conditions in Damaying Grassland. A, annual precipitation and annual mean temperature. B, monthly distribution of precipitation and mean temperature.

myosuroides, and *C. tristachya*. Rangelands of temperate steppe, alpine typical steppe, and alpine meadow-steppe are served as winter and spring pasture. Above 3200 m, the alpine shrub steppe is dominated by *Salix cupularis*, *Potentilla fruticosa*, *Spiraea alpina*, and *Caragana jubata*. Alpine shrub steppe rangeland is served as summer and autumn pastures. At elevations above 4500 m, vegetation is very sparse and is dominated by cushion plants such as *Androsace* spp. on stable soils amidst boulders and scree. Because of sufficient moisture from snow melt and mist, grass cover between 3200 and 4100 m generally exceeds 85%, while above 4100 m vegetation cover is generally less than 60% for low temperature.

2.2. Methodology

Since 2001, rangelands have been allocated by the government to individual families. The allotted portions of these rangelands were subsequently fenced and managed by graziers. We used the grazier-managed rangeland plots as sampling plots for the study and sampled from rangeland artificially maintained in three of the four rangeland conditions: high vegetative coverage, moderate coverage, and low coverage. Our fieldwork was undertaken in September 2012. We selected 39 sampling plots (each 0.25 m^2) and visually estimated percent grass coverage within each plot by two experienced rangers whose estimates were within 5% of one another. All the surveyed plots are served as winter and spring pasture, for grazing only after September. We then clipped and immediately weighed the grass within each plot, first for unpalatable grass species and then for all remaining species. We determined the precise location of each plot using a Garmin International portable global positioning system (GPS) receiver (Garmin etrex Vista C)with a horizontal accuracy of 10 m and analyzed the plant diversity and plant spatial patterns at each site. We evaluated changes in the spatial structure of vegetation as a way to characterize the parameters that govern the dynamics of those spatial patterns based on the information fractal dimension and correlation analyses in September 2012. This approach provides a quantitative procedure to assess organizational change in plant communities undergoing succession.

We assessed forage diversity using the Shannon–Wiener diversity index H (Spellerberg and Fedor, 2003):

$$H = -\sum_{i=1}^{S} P_i \ln P_i \tag{1}$$

where P_i is the proportion of characters belonging to the ith type of letter in the string of interest. In ecology, P_i is often the proportion of individuals belonging to the ith species in the dataset of interest. The Shannon entropy quantifies the uncertainty in predicting the species identity of an individual that is taken at random from the dataset. This Shannon–Wiener diversity index takes into account both the number of species (species richness) and how evenly these species were distributed in the pasture.

Table 1
Livestock number increases in Damaying Grassland, 1958 to 2008.[a]

	1958		1965		1982		2008	
	Head	Sheep unit	Head	Sheep unit	Head	Sheep unit	Head	Sheep unit
Horse	10 158	60 948	13 640	81 840	10 275	61 650	2058	12 348
Cattle	3076	15 380	7231	36 155	15 596	77 980	34 066	170 330
Sheep	34 228	34 228	36 925	36 925	31 273	31 273	29 632	29 632
Total		110 556		154 920		170 903		212 310

[a] Livestock number of 1958, 1965, and 1982 come from Comprehensive Agricultural Regionalization Report of Shandan Horse Farm (1982, unpublished). Data of 2008 come from Comprehensive Development Planning of Shandan Horse Farm, 2009–2020 (2009, Unpublished).

Table 2
Rangeland coverage and Shannon–Wiener diversity index in Damaying Grassland.

Rangeland coverage	Rangeland type	Altitude (m)	Coverage (%)	Shannon–Wiener diversity index		
				Range	Mean ± SD	P
High	Alpine meadow steppe	2900–3200	80–95	1.2–2.1	1.7 ± 0.2	<0.001
Moderate	Alpine typical steppe	2600–2900	40–80	1.1–1.8	1.5 ± 0.3	<0.001
Low	Temperate steppe	2500–2700	20–65	0.8–1.5	1.1 ± 0.3	<0.006

In the field, we packed the harvested material in plastic bags; oven dried the material at 65 °C for 72 h in the laboratory; and combined the dry weight of all species to obtain total biomass estimates. In all the sampling plots, we collected topsoil from 0 to 5 cm depth for analysis of soil bulk density using a soil sample ring (stainless steel core sampler 52 mm high, 70 mm internal diameter, 200 cm^3 volume) and placed the soil samples in sealed plastic bags and transported the samples to the laboratory. In the laboratory, we weighed each sample prior to and after oven drying for 24 h at 105 °C. Organic carbon, pH, and soil nutrient analysis was performed by the Key Laboratory of Ecohydrology of Inland River Basin, Chinese Academy of Sciences. Organic matter content was estimated by contrasting loss of weight at 105 °C and 360 °C. Soil pH is usually measured potentiometrically in slurry using an electronic pH meter. For available phosphorus, the Olsen sodium bicarbonate method (0.5 M $NaHCO_3$ solution) and Mo–Sb anti-spectrophotography is used. The available potassium is measured by analyzing the filtered extract on an atomic absorption spectrometer set on emission mode at 776 nm. Automated colorimetric techniques using continuous flow analyzers are used for determination of available nitrogen. In 1982, the Shandan Horse Farm made a comprehensive investigation of land use, agriculture, grassland resources, and soil in the Damaying Grassland. The data of forage productivity and soil nutrients come from unpublished Grassland Resources Survey Report and Soil Survey Report of Shandan Horse Farm. Their investigation was based on the relevant national standards. Although the National standards have updated but the method of determined soil nutrition has no change.

3. Results

3.1. 2012 grass coverage

Based on our 2012 field survey, grass cover in high coverage rangeland was 80–95% and the Shannon–Wiener diversity index was 1.2–2.1. In the moderate coverage rangeland, the grass cover was 40–80% and the Shannon–Wiener diversity index was 1.1–1.8. In low coverage rangeland, the grass cover was 20–65% and the Shannon–Wiener diversity index was 0.8–1.5 (Table 1, Fig. 3).

From 1982 (Grassland Resources Survey Report of Shandan Horse Farm, 1982, Unpublished) to 2012 the species richness declined with grazing pressure in the Damaying Grassland. The borderlines of high coverage grassland were shrunk to south about 10 km in the west part and about 4 km in the east part. Total area of high and moderate coverage grassland was decreased 101.9 km^2 and 103.1 km^2, respectively (Fig. 4). However, the characteristics of the vegetative coverage in the southern areas, especially at the foot of the Qilian Mountains, remained unchanged. In the southern part of the study area, most areas with extreme loss of vegetation were agricultural areas where the loss could be attributed to land expansion for subsistence agriculture. However, the substantial loss of vegetation in the northern and northwestern areas was attributed to over grazing.

3.2. Forage productivity: comparison of 1982 to 2012

Four factors—precipitation, temperature, soil characteristics, and plant residue—largely control forage productivity and seasonal species composition. Precipitation and temperature control the timing and characteristics of four distinct phases of forage growth: break of season, winter growth, rapid spring growth, and peak forage production (George et al., 1985). Human factors, such as grassland management, also can affect forage productivity. For complex climate and weather condition, the forage productivity varies greatly.

The total grass productivity declined significantly from 1982 to 2012. In 1982, a maximum fresh biomass of 4950 $kg \cdot ha^{-1}$ was provided by high coverage rangeland, followed by moderate coverage rangeland (2520 $kg \cdot ha^{-1}$) and low coverage rangeland (1515 $kg \cdot ha^{-1}$) (Grassland Resources Survey Report of Shandan Horse Farm, 1982, Unpublished). In 2012, we found that the forage production of high coverage, moderate coverage, and low coverage rangeland decreased

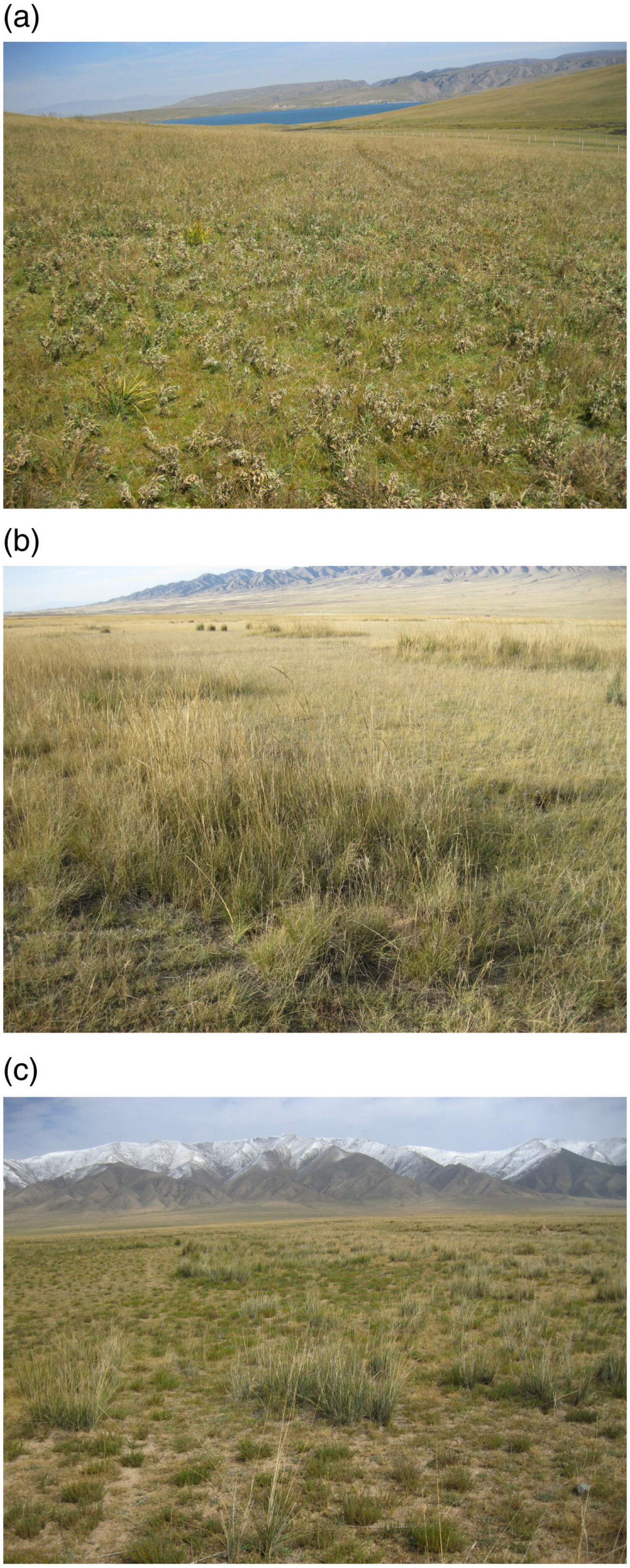

Fig. 3. Grass community response to livestock grazing. A, high coverage rangeland, about 2936 m. *Stellera chamaejasme* flourishes in this rangeland. B, moderate coverage rangeland, about 2639 m. C, low coverage rangeland, about 2669 m.

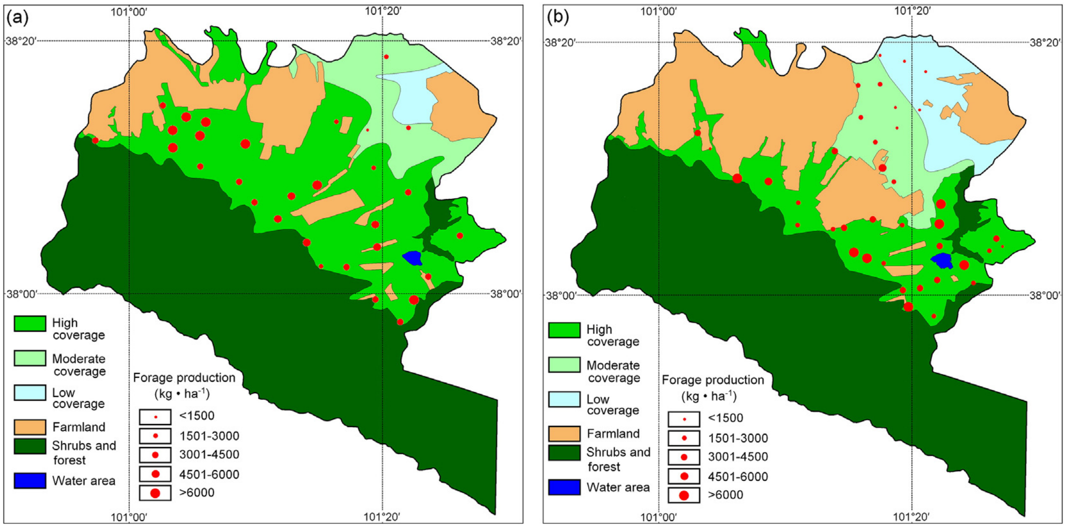

Fig. 4. Forage production. **A,** 1982. B, 2012.

by 1002 kg·ha^{-1}, 525 kg·ha^{-1}, and 855 kg·ha^{-1}, respectively, representing decreased production of approximately 20.2%, 20.8%, and 56.4%, respectively, from 1982 production levels (Table 3) (Fig. 4).

3.3. Soil bulk density

Bulk density is a measure of the compaction of the soil. The major effect of compaction is an increase in bulk density as soil aggregates are pressed closer together, resulting in a greater mass per unit volume. Compaction reduces the soil pore volume, resulting in less space for air and water in the soil. Most importantly, the large pores, responsible for much of the gas and water movement, are destroyed. Increased bulk density and reduced pore volume also reduce water infiltration into the soil. Less rainwater can move into excessively compacted soils, increasing the potential for runoff and erosion. Water may remain on the soil surface longer, especially in depressions and wheel tracks.

The mean soil compaction in high, moderate, and low coverage rangeland was 0.8 ± 0.02 g·cm^{-3} ($P < 0.001$), 1.1 ± 0.1 g·cm^{-3} ($P < 0.001$), and 1.2 ± 0.02 g·cm^{-3} ($P < 0.05$), respectively. Rangeland degradation significantly corresponded to increased soil compaction. Soil compaction remained relatively constant in rangeland in high and moderate coverages. In low coverage rangeland, soil compaction even showed a slight increase. In contrast to adjoining cropland, in the high and moderate coverage rangelands, the rangeland soil bulk density was 20.2%, 11.5% higher than that in the cropland.

Our study showed that the soil organic matter content has a negative correlation the soil bulk density (Fig. 5).

3.4. Soil nutrients

Organic matter is widely recognized to be an important aspect of soil fertility, fulfilling various functions such as improving soil structure, aggregate stability, and water-holding capacity. Dead plant material, animal remains, and excreta all contribute to soil organic matter content. Soil nutrition directly affects both plant yield and quality. The availability of required nutrients, together with the degree of interaction between these nutrients and the soil, plays a vital role in crop development. A deficiency in any one required nutrient or a soil condition that limits or prevents a metabolic function from occurring can limit plant growth.

The soil nutrients test results indicated that the site soil was weakly alkaline (pH 7.8 ± 0.4), with low available phosphorus (P_2O_5, 11.7 ± 4.1 mg·kg^{-1}), high available potassium (K_2O, 437.7 ± 169.0 mg·kg^{-1}), and some available nitrogen (337.6 ± 146.6 mg·kg^{-1}). Soil organic matter averaged 91.2 ± 38.3 g·kg^{-1} (Table 4).

For the high coverage rangeland ($n = 27$), the average soil pH was 7.6 ± 0.3, while extractable P, K, and N levels averaged 12.8 ± 4.2 mg·kg^{-1}, 468.9 ± 178.8 mg·kg^{-1}, and 412.6 ± 111.2 mg·kg^{-1}, respectively. Soil organic matter averaged 109.4 ± 29.5 g·kg^{-1}. The soil nutrients in the moderate coverage rangeland ($n = 8$) were significantly lower, with an average soil pH of 8.1 ± 0.4, and extractable P, K, and N levels averaging 9.5 ± 3.0 mg·kg^{-1}, 378.8 ± 102.6 mg·kg^{-1}, and 230.0 ± 70.1 mg·kg^{-1}, respectively. Soil organic matter averaged 57.3 ± 20.2 g·kg^{-1}. The soil nutrients in the low coverage rangeland ($n = 4$) were very low; extractable P, K, and N levels averaged 9.2 ± 3.4 mg·kg^{-1}, 260.0 ± 50.0 mg·kg^{-1}, and 148.5 ± 22.6 mg·kg^{-1},

Table 3
Forage productivity (fresh biomass) (Mean ± SD) decreases Damaying Grassland, 1982 to 2012.

Rangeland coverage	Productivity (kg ha^{-1})		Decrease (kg ha^{-1})	Decrease (%)
	1982 ($n = 31$)	2012 ($n = 39$)		
High	4950 ± 1755**	3948 ± 2078**	1002	20.2%
Moderate	2520 ± 52**	1997 ± 730**	523	20.8%
Low	1515 ± 202**	660 ± 227*	855	56.4%

** $P < 0.001$.
* $P < 0.05$.

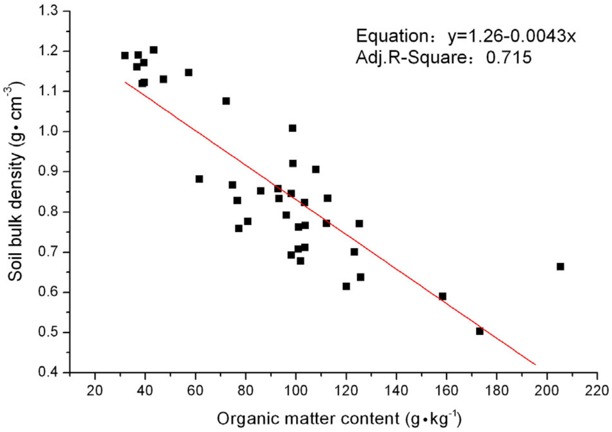

Fig. 5. Relationship between soil organic matter content and the soil bulk density.

Table 4
Soil nutrition (Mean ± SD) of Damaying Grassland, 2012.

Rangeland coverage	pH	Available phosphorus (mg kg^{-1})	Available potassium (mg kg^{-1})	Available nitrogen (mg · kg^{-1})	Organic matter (g · kg^{-1})
Total (n = 39)	7.8 ± 0.4**	11.7 ± 4.1**	437.7 ± 169.0**	337.6 ± 146.6**	91.2 ± 38.3**
High (n = 27)	7.6 ± 0.3**	12.8 ± 4.2**	468.9 ± 178.8**	412.6 ± 111.2**	109.4 ± 29.5**
Moderate (n = 8)	8.1 ± 0.4**	9.5 ± 3.0**	378.8 ± 102.6**	230.0 ± 70.1**	57.3 ± 20.2**
Low (n = 4)	8.4 ± 0.02**	9.2 ± 3.4*	260.0 ± 50.0*	148.5 ± 22.6**	36.4 ± 3.2**

** $P < 0.001$
* $P < 0.05$.

respectively. The pH of these areas was higher averaging 8.4 ± 0.02. Soil organic matter of low coverage rangeland averaged 36.4 ± 3.2 g·kg^{-1}.

A comparison of our results to the 1982 survey show that degradation of the Damaying Grasslands over the 30-year period resulted in significantly lower organic matter and available nitrogen. The results of our study clearly show that decreases in organic matter over the 30-year period was greater in moderate (30.9%) and low (35.5%) coverage rangelands than in high coverage rangeland (8.9%). The decline in available nitrogen showed a similar trend: changes of 9.3%, 24.4%, and 42.4% in high, moderate, and low coverage rangelands, respectively. However, available phosphorus and potassium showed significant increases from 1982 to 2012, especially for high coverage areas. Increases in available phosphorus for high, moderate, and low coverage rangelands were 70.5%, 40.1%, and 27.1%, respectively. The available potassium increases in high, moderate, and low coverage rangelands were 84.4%, 67.4%, and 34.7%, respectively (Fig. 6).

4. Discussion

Natural factors (such as climate, geomorphology, and rodent infestations) and mankind-induced factors (such as grassland reclamation, livestock overgrazing, inappropriate water uses, and collecting herbal medicines) have accelerated vegetative degradation in the Damaying Grassland. This degradation is an increasing concern of rangeland managers and the government.

Overgrazing is a fundamental cause of increasing degradation of grassland in the region. Uncontrolled increases in the number of animals exceed the carrying capacity of the grassland. The development of animal husbandry in this region has resulted in the doubling of animal numbers from 1958 to 2009 (Table 2). This has decreased the carrying capacity of the summer–autumn and winter–spring rangeland by 17.4% and 28.9% respectively.

Intense grazing pressure tends to result in the dominance of a few species highly resistant to grazing; these species increase in abundance with increasing disturbance (Cingolani et al., 2005). Owing to their unpalatability and adaptability, poisonous weeds begin to dominate the constructive species. The noxious weeds in the Damaying Grassland include *Stellera chamaejasme*, *Oxytropis ochrocephala*, *Thermopsis lanceolata*, *Mprzewalskyi roskev*, *Achnatherum inebrians Keng*, and *Aconitum tanguticum*.

Additionally, there is frequent, uncontrolled and destructive grazing by invaded neighboring livestock, particularly in the boundary districts. According to incomplete statistics from 1982 to 2002, 2201 horses, 9547 cattle, and 95 308 sheep (about 156 000 sheep units, almost equal to that present in Shandan Horse Farm) invaded the Damaying Grassland every year. The invading livestock covered about 540 km^2, occupying 43% of the Damaying Grassland.

Poorly-planned reclamation of land for crops, with an emphasis on grain production has further reduced available rangeland. Agricultural reclamation in Damaying Grassland started in 1941 with the conversion of about 38.2 ha of grassland and has continually increased. Large-scale reclamation occurred from 1957 to 1962 and during this period, newly reclaimed lands increased 2440 ha each year. A second large reclamation took place from 1975 to 2000, increasing farmland area 54 244 ha in 2000 (1307 ha per year) (Fig. 7). A loss of rangeland leads to overgrazing which contributes to degradation.

Snowmelt and glacier fed irrigation canals are important sources of soil moisture for agriculture and rangeland productivity. The Baishiya rivulet is the main water resource of the Damaying Grassland with annual runoff of 3.7×10^7 m^3. Constructed in 1965 and rebuilt in 1994, the Baishiya Ditch transfers most of the water to downstream users for irrigating farmland, only allotting 2.6×10^6 m^3 for the Damaying Grassland, about 7.0% of total (Fig. 1). Other rivulets, such as Houshao (1.1×10^7 m^3), Daxiang (6.6×10^6 m^3), and Xiaoxiang (3.8×10^6 m^3) had no water diversion, but their waters were preferentially allotted for irrigating farmland. Due to the lack of natural irrigation, large areas of rangeland suffer from a lack of moisture and are degraded (Comprehensive Agricultural Regionalization Report of Shandan Horse Farm, 1982, Unpublished).

Also affecting large areas, rodent infestations have become important contributors to the degradation of grasslands in the region. The main species of rodents are *Myospalax fontanierii Milne-Edwarda* and *Ochotona curzoniae*. They feed on the roots, stems, leaves, and seeds of

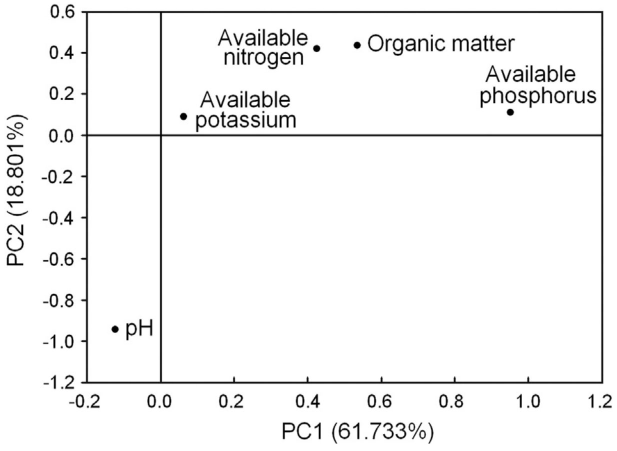

Fig. 6. Principal component analysis of pH, and nutrition of soil (PC1 vs. PC2).

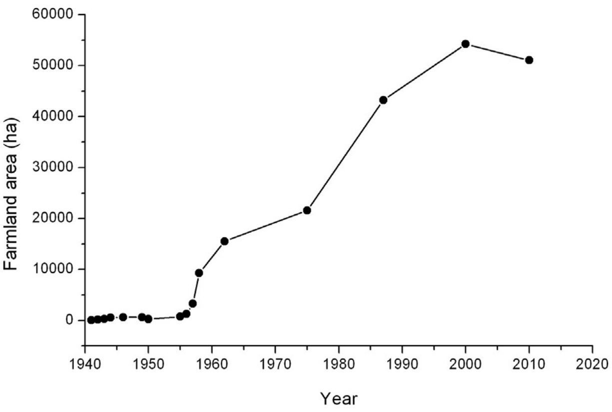

Fig. 7. Changes to farmland area.

the grasses and dig burrows underground, thereby influencing the future reproduction and development of the grasses. Rodent infestations have damaged 82 km^2 of grassland. In severely damaged areas, there were about 36 burrows or mounds in every 100 m^2, with mound diameters reaching 30 cm (Grassland Resources Survey Report of Shandan Horse Farm, 1982, Unpublished).

5. Conclusions

In this study, we have shown the effect of grassland degradation on various soil characteristics and show that the Damaying Grassland is in a rapidly degraded period due to inappropriate human activities and rodent infestations.

The soil–water balance must be emphasized as a factor in all the causes of grassland degradation. Although the Damaying rangeland is located in a semi-arid zone, it was not in a degraded condition in the 1950s and 1960s. Snow melt and glacier melt from the Qilian Mountains was not diverted prior to this time. If all the water from Baishiya, Houshao, Mingquan, Daxiang, and Xiaoxiang rivers were used to irrigate the rangeland, it would be equivalent to rainfall of 100 mm on the high and moderate coverage rangelands. Since water is the prime determinant of plant growth in semi-arid rangelands, reduced vegetative production with degradation can be attributed to the reduction of soil–water content.

We can conclude that Damaying rangeland will only be restored through reasonable use of water resources of the Qilian Mountains. However, under the current situation that includes many interest conflicts (upstream and downstream users, agriculture and stockbreeding), the water allotted to the Damaying rangeland is not expected to be increased. Thus, the only way to restore the Damaying rangeland is through reasonable use of water resources and the introduction of forage species and mechanical inputs.

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