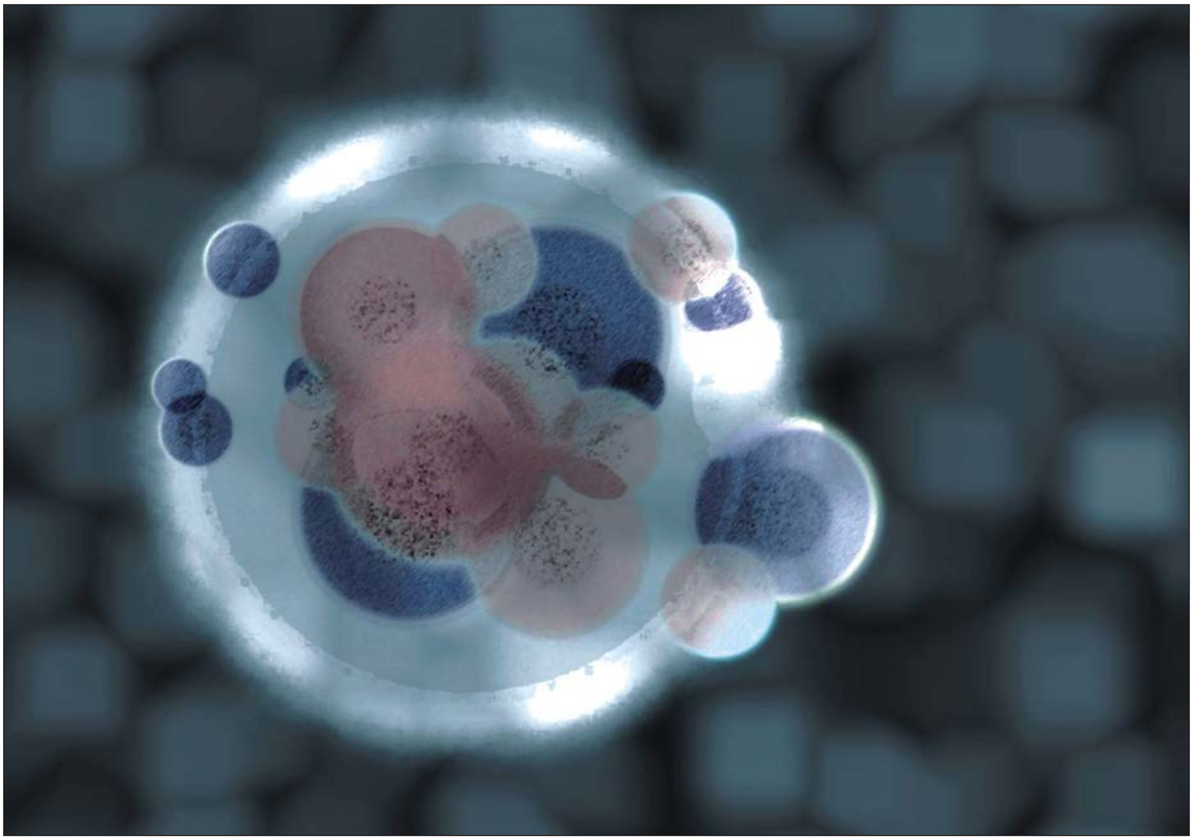

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Relationship between Soil Physicochemical Properties and Herbage Mass of Alpine Rangelands in Southern Qinghai, China from 2004 to 2012

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Abstract: Yak (*Bos grunniens*) are commonly grazed on the alpine rangeland (3970 to 4160 m above sea level) of Yushu, southern Qinghai, China. The rangeland, comprising our research site, experiences a typical continental climate with a mean annual temperature of 4.1°C and annual precipitation of 350 mm. Aboveground herbage Dry Matter (DM) was found to vary among sampling locations, ranging from 40 to 744 g m^{-2} and from 88 to 501 g m^{-2}, in 2004 and 2012, respectively. Over the previous decade from 2004 to 2012, soil pH was observed to decline to near-neutral values (pH 6.5 to 8.2), while available phosphoric acid (Av-P) increased to 36 to 100 mg kg^{-1}. Plant coverage was positively correlated ($p<0.05$) with soil Total Nitrogen (TN) and cation content in 2012. Soil fertility of the site remained constant over the 2004-2012 period in terms of soil pH, electric conductivity, Av-P, TN and total carbon. It is, thus, concluded that the soil fertility of the research site has not been negatively affected by extensive yak-grazing over the previous decade.

Key words: Alpine rangeland, herbage mass, plant coverage, Qinghai, soil physicochemical property

INTRODUCTION

Qinghai alpine rangeland, accounting for one-third of total grassland area in China, is used for continuous grazing by livestock of sheep, goat and yak (*Bos grunniens*), which has great impacts on rangeland health (Cao *et al*., 2013; Li *et al*., 2013b). However, global warming has brought drought and desert conditions to this region (Cui and Graf, 2009; Harris, 2010). This, combined with inappropriate rangeland management resulting in overgrazing and other detrimental practices, has led to fears of deteriorating vegetation, loss of plant diversity and continuous decline in animal production (Foggin and Smith, 1996; Wu and Tiessen, 2002; Liu *et al*., 2004; Gao *et al*., 2007; Klein *et al*., 2007; Cui and Graf, 2009). Monitoring, management and restoring methods for the rangeland degradation were presented including Landsat Thematic Mapper (TM) image (Liu *et al*., 2004; Akiyama and Kawamura, 2007; Wen *et al*., 2010). Qinghai Province is located in the eastern Tibetan Highland (1700-5000 m above sea level), where more than 6 million head of yak are grazed on 31.6 million ha of rangeland. Grass productivity is low due to low precipitation (430 to 820 mm) and low annual temperatures (-2.7 to 3.9°C). Since the current study site is located at the origin of the Yellow, Yangtze and Mekong Rivers, deterioration of the rangeland environment, i.e., change in vegetation and leaching of soil nutrients, may negatively affect not only areas in China but the earth as a whole (Zhou *et al*., 2005; Wang *et al*., 2008; Xu *et al*., 2013). Grazing land often affects the soil's ability to sequester carbon, which is closely related with global warming (Gao *et al*., 2007; Li *et al*., 2013a) and the soil quality was closely correlated with vegetation cover change in the alpine rangeland (Li *et al*., 2010; Li *et al*., 2013c; Xu *et al*., 2013).

The objectives of the current study were to determine what changes have occurred in herbage mass, soil chemical properties and the relationship between the two during the decade from 2004 to 2012. This will serve as basic information for improving rangeland management practices related to yak-grazing in the alpine rangeland of southern Qinghai, China.

MATERIALS AND METHODS

Research site and observations: Observations were conducted at the Yushu National Ranch in Qinghai Province (96°51′E, 33°03′E, 3970 to 4160 m above sea

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level), located 850 km southwest of the Provincial capital Xining. Yak and sheep are grazed continuously throughout the year on Ranch rangeland. Approximately 1,200 yak and 145 sheep were grazed, while 1,050 yak and 145 sheep were grazed in 2004 and 2012, respectively, on the research site, covering 345 ha. Grazing pressure, based on Animal Unit (AU), were 3.47 and 3.05 AU ha^{-1} in 2004 and 2012, respectively.

Mean annual precipitation is 349.6 mm, while mean annual solar duration is 3459.6 h and mean annual temperature is 4.1°C. The plant growth period is 100 to 120 days, from mid-May to early September, even though no lasting frost period occurs.

In August 2004, 9 locations within the site were randomly selected for plant surveys and measurement of soil properties. Aboveground herbage mass was sampled to determine fresh weight by quadrat (1×1 m) in each sampling location. Plant samples were dried by induction oven to determine dry matter weight. After completing the plant sampling, soil profiles were investigated in the same locations as the plant sampling. Soil layers were delineated based on a soil color chart and soil samples obtained from each layer.

In August 2012, 10 locations within the site were again randomly selected for plant surveys and measurement of soil physicochemical properties. Each location comprised a 20×20 m (400 m^2) area. The altitude, longitude and slope of each location was determined. Five quadrats (0.5×0.5 m) were randomly designated in each location. Plant coverage, plant community height and names of plants present were recorded for each quadrat before the fresh weight of herbage mass was determined by cutting plants at the ground surface. After the fresh weight of each plant species was recorded, dry matter weight was determined by drying samples to the constant weight using an induction oven. After completion of the plant sampling, depth of the soil surface layer was measured 5 times in each location using a standard Yamanaka-type Soil Hardness Tester. Five surface soil samples were taken at a depth of 0-15 cm (a total of 50 samples for the 10 locations) using a 100 mL core sampler to determine soil dry weight and bulk density. Soil samples were transferred to Miyazaki, Japan for chemical analysis under the imported permission of Ministry of Agriculture, Forestry and Fishery of Japan.

Soil chemical analysis: Soil pH (H_2O), Electric Conductivity (EC) and available phosphoric acid (Av-P) were determined by the using a glass electrode, platinum-titanium electrode and the method by Truog (Truog, 1930), respectively (ECAMSE, 1997). Soil Total Nitrogen (TN) and Total Carbon (TC) were determined using an NC corder (Model NC-220F, Sumitomo Chemical Center Co. Ltd., Tokyo). Soil samples (0.5 g) were dissolved in 25 mL distilled water and extracted without shaking for 60 min. The suspensions were then passed through membrane filters (0.45 μm) and the filtrate analyzed for cation and anion contents using an ion analyzer (Model IA-200, Toa DKK Co. Ltd., Tokyo).

Statistical analysis: Multiple regression analysis and correlation coefficient were performed using SPSS Statistic Version 20 (IBM Co. Ltd., Tokyo) and $p<0.05$ was used as the critical threshold for signigicance to determine differences in the parameters.

RESULTS

Rangeland herbage mass: Plant species observed in the 9 locations surveyed in 2004 were *Elymus nutans*, *Stipa* and *Poa* spp. in genus *Poaceae*, along with *Kobresia humilis* and *Kobresia pygmaea* in genus *Cyperaceae*. Aboveground herbage dry matter weight (DM) varied widely, ranging from 14 to 744 g m^{-2} in 2004. Invasion of shrub species such as *Patentilla fruticosa* and *Salix cuplaris* tended to increase herbage DM.

Plant species observed in the 10 locations surveyed in 2012 included a total of 78 species, including members of the genera *Poaceae*, *Cyperaceae* and *Fabaceae*. The mean number of plants per sampling location was 19±3.4 species (Mean±standard deviation). Aboveground herbage DM and plant coverage in 2012 ranged from 88 to 501 g m^{-2} and 52.0 to 99.6%, respectively. Mean aboveground herbage DM was 161.3 and 201.1 g m^{-2} in 2004 and 2012, respectively, although these means were not found to differ significantly ($p>0.05$). Grazing pressure in the two years were also comparable, averaging 3.47 in 2004 and 3.05 head ha^{-1} in 2012.

Aboveground herbage DM was positively correlated with altitude ($p<0.05$) in both 2004 and 2012 and in all sampling locations, with the exception of the location experiencing a shrub invasion in 2004 and the location where grazing was prohibited in 2012 (Fig. 1).

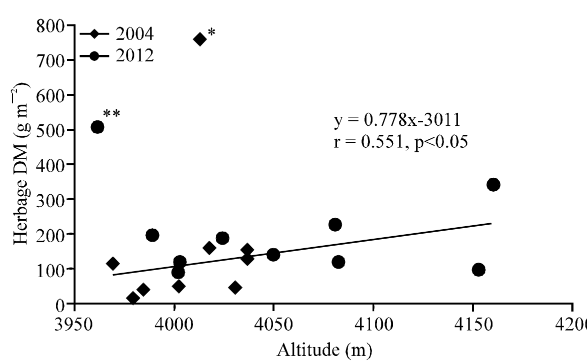

Fig. 1: Relationship between herbage DM and altitude in yak-grazed rangeland, *Site included shrubs, **Site located within a grazing-prohibited area

Soil chemical properties: In 2004, soil pH ranged from 6.6 to 9.2, averaging pH 7.8 (weakly alkali) across all soil layers in all sampling locations. Mean EC and Av-P concentration were 0.19±0.14 mS m^{-1} and 17.2±1.8 mg kg^{-1}, respectively. Soil TN and TC content ranged from 0.8 to 14.4 g kg^{-1} and from 26.5 to 166.4 g kg^{-1}, respectively, with both TN and TC decreasing with soil depth.

In 2012, soil pH ranged from 6.2 to 8.2, averaging pH 7.6 (weakly alkali). Similar to 2004, soil pH tended to increase with soil depth. As in the 2004 sampling, soil chemical properties, including EC, Av-P, TN and TC tended to decrease with soil depth. Av-P content was significantly higher in 2012 ($p<0.05$) than in 2004.

Soil chemical properties were plotted against sampling location altitude using data 2004 and 2012 data (Fig. 2). Significant negative correlation ($p<0.05$) was observed between altitude and EC, while no such correlation was observed between altitude and any other measured soil property.

Soil cation (Ca^{2+}, Mg^{2+}) and anion (SO_4^{2-}, Cl^-) content was plotted against altitude (Fig. 3). Ca^{2+} accounted for 70% of total cation content and was relatively consistent (60 to 80 mg L^{-1}) across sampling locations at different altitudes. Mg^{2+} and SO_4^{2-} content was not significantly correlated with altitude, while Cl^- content, accounting for more than 30-40% of total anion content, was found to be positively correlated with altitude ($p<0.05$).

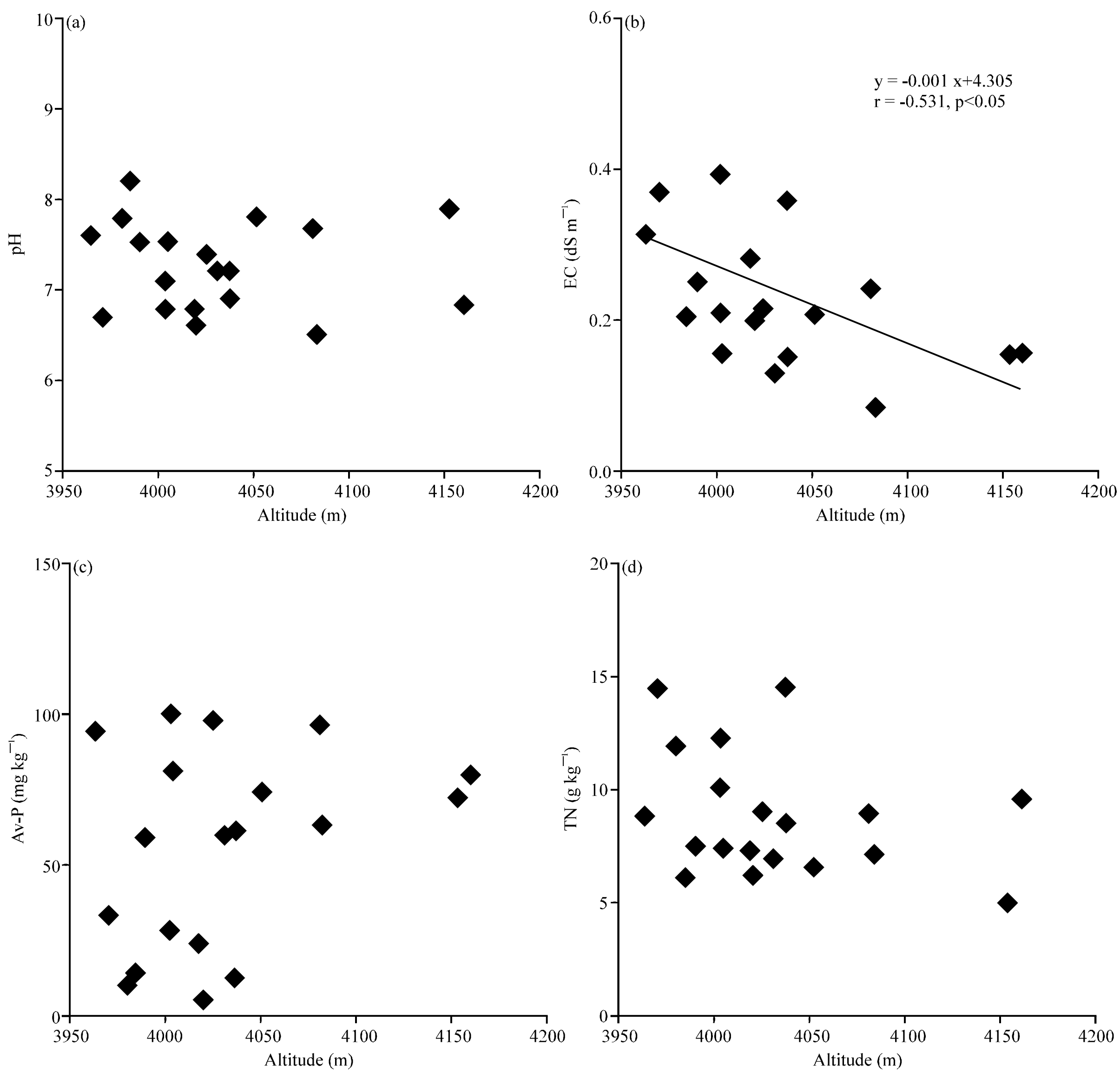

Fig. 2(a-f): Continue

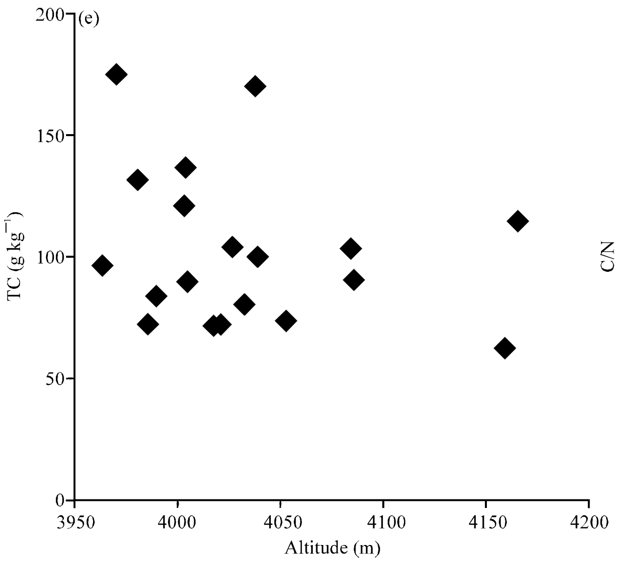

Fig. 2(a-f): Relationship between altitude and surface soil chemical properties in yak-grazed rangeland, in 2004 and 2012: (a) pH, (b) Electric conductivity, (c) Available phosphoric acid, (d) Total nitrogen, (e) Total carbon and (f) C/N ratio

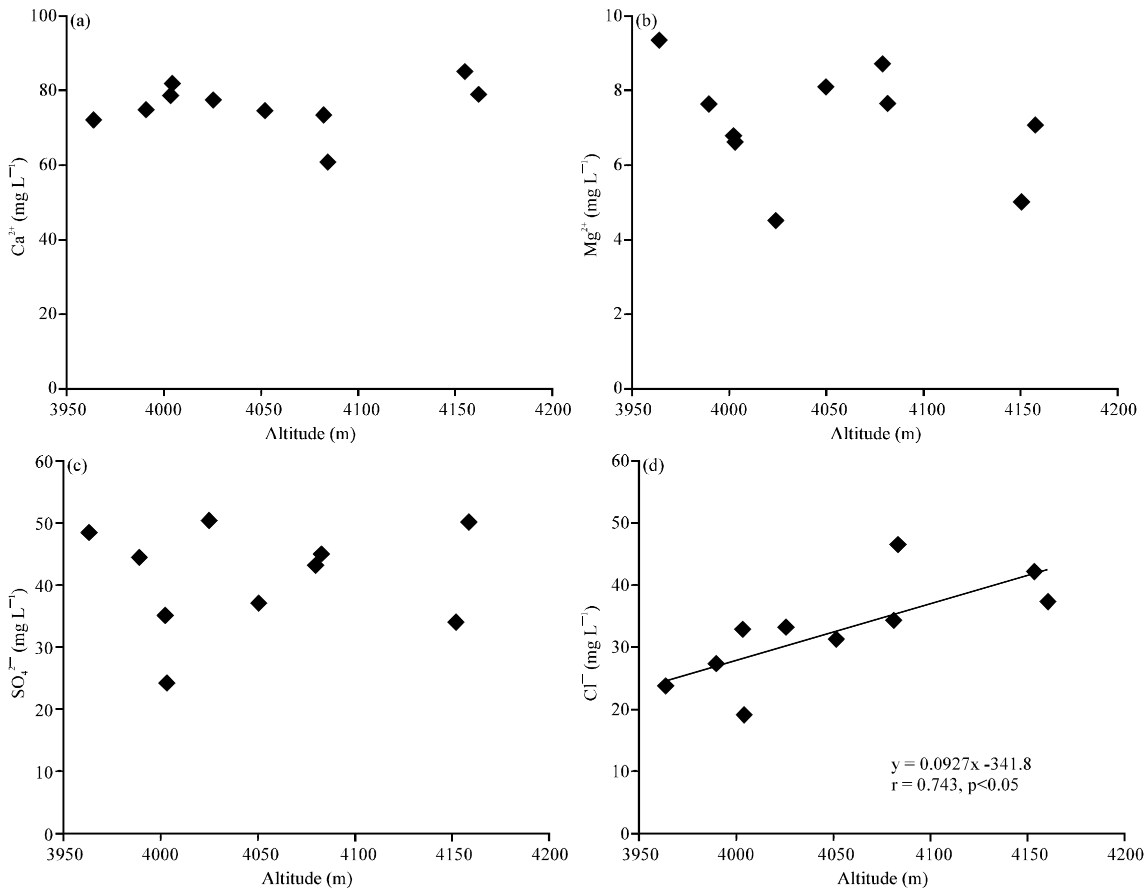

Fig. 3(a-d): Relationship between altitude and soil mineral contents: (a) Calcium (Ca^{2+}), (b) Magnesium (Mg^{2+}), (c) Sulfate (SO_4^{2-}) and (d) Chloride (Cl^-), Data represent means of three soil depths (0-5, 5-10 and 10-15 cm from the surface) in 2012

Soil hardness was ranged from 17 to 22 mm across sampling locations. Soil hardness greater than 21 mm was recorded in 6 sampling locations. Such high soil hardness is expected to inhibit root elongation (Fujiwara *et al.*, 1998). Soil moisture content and bulk density varied widely between sampling locations, ranging from 10.3 to 49.7% and from 0.5 to 1.1 g cm^{-3}, respectively.

DISCUSSION

Changes in soil chemical property: In Yushu, southern Qinghai, where the soil is considered to be deficient in phosphate and nitrogen and, thus, infertile, soil organic content, pH, TN content and soluble phosphate content were found to range from 9.0 to 41.0 g kg^{-1}, 8.3 to 8.7, 0.7 to 2.6 g kg^{-1} and 3 to 9 mg kg^{-1}, respectively. At this location, the cold season also lasts longer and, as a result, soil organic matter decomposition is so slow to the point that the rate of mineralization of soil nutrients is insufficient for plant growth (Yushu Tibetan Autonomous Prefecture, 1991).

Soil pH values determined both in 2004 and 2012 were closer to neutral and soil TN and Av-P was higher than in previous reports (Yushu Tibetan Autonomous Prefecture, 1991). The same trends were observed in the slightly degraded rangeland soils of eastern Qinghai (pH 8.1, TN = 2.7 g kg^{-1}) (Li *et al.*, 2010).

As for changes over the previous decade, pH, EC, TN and TC remained essentially unchanged from 2004 to 2012, while Av-P content increased over the same period. The results indicate no symptoms of degradation with regard to soil chemical properties. Plotting the relationship between sampling location altitude and various soil chemical properties in Fig. 2 revealed negative and positive correlations between altitude and soil EC and Cl^-, respectively.

Relationship between herbage mass and soil chemical properties: No significant correlation was observed between soil chemical properties and aboveground herbage DM in 2004. Based on the correlation coefficients of plant coverage and several soil physicochemical properties shown in Table 1, we see that plant coverage was positively correlated ($p<0.05$) with TN and cation content.

Multiple regression of plant coverage on TN and cation content yielded the following model:

$$\text{Plant coverage} = 44.76\times\text{TN}+2.773\times\text{cation content}+18.14\ (R^2 = 0.834,\ p<0.05)$$

where, the partial regression coefficients of the two explanatory variables were both found to be significant ($p<0.05$).

Similar relationships between plant coverage and soil pH, TN and C/N ratio were observed in rangelands of the northern Loess Plateau in Shaanxi Province, China (Bai *et al.*, 2004). However, in the present study, no significant correlation was obtained between plant coverage and soil pH or C/N ratio (Table 1). In 2012, plant coverage was positively correlated ($p<0.01$) with aboveground herbage DM, which was not found to not be significant correlated with any soil physicochemical properties as in 2004. This lack of correlation is likely due to the fact that aboveground herbage DM is more substantially influenced by the continuous grazing by yak and sheep than by soil physicochemical properties.

In conclusion, in the ranchland studied, pH, EC and TN and TC remained steady from 2004 to 2012 and the aboveground herbage DM did not differ between the two years, despite extensive yak-grazing. These results suggesting that the rangeland has not experienced degradation over the latest decade from 2004 to 2012. In addition, it was demonstrated that, in alpine rangelands under continuous yak-grazing, plant coverage is more strongly correlated to soil physicochemical properties than is herbage DM.

Table 1: Correlation of plant coverage with soil physicochemical properties in 2012

Parameters	Coverage	pH	EC	TN	TC	C/N	Anion	Cation	Hardness	Moisture content
Coverage	1									
pH	ns	1								
EC	ns	ns	1							
TN	0.718*	ns	ns	1						
TC	ns	ns	ns	0.973***	1					
C/N	ns	ns	-0.880***	ns	ns	1				
Anion	ns	ns	0.935***	ns	ns	-0.817**	1			
Cation	0.743*	ns	ns	ns	ns	ns	0.657*	1		
Hardness	ns	ns	ns	ns	ns	0.707	ns	ns	1	
Moisture content	ns	-0.634*	ns	0.789**	0.762*	ns	ns	ns	ns	1

*: $p<0.05$, **: $p<0.01$, ***: $p<0.001$, Soil physicochemical properties: EC: Electric conductivity, TN: Total nitrogen, TC: Total carbon, C/N: Carbon to nitrogen ratio

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