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A Simulative Study on Effects of Climate Warming on Nutrient Contents and *In Vitro* Digestibility of Herbage Grown in Qinghai-Xizang Plateau

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Abstract: The increasing trend of air temperature along with the climate warming has been accepted gradually by scientists and by the general public. Qinghai-Xizang Plateau, a unique geographic unit due to high-altitude climate, is one of the most susceptible regions to climate warming. Its ecosystem is very fragile and sensitive to climate change. In order to get a better understanding of the impacts of climate warming on the nutrient contents of herbage grown in Qinghai-Xizang Plateau, a simulative study was implemented at Daban Moutain by using temperature differences resulted from sites selected at different altitudes and nutrient contents and *in vitro* digestibility were determined for assessing the quality of the grown herbage. There were significant downtrends in crude protein (CP), ether extract (EE) and nitrogen free extract (NFE) contents of herbage along with the increase of temperature. It had a positive correlation between temperature and content of acid detergent fibre (ADF), acid detergent lignin (ADL) in herbage. *In vitro* digestibility of herbage decreased along with the increase of temperature. The results of this study indicated that climate warming significantly influence nutrient contents and *in vitro* digestibility of herbage grown in Qinghai-Xizang Plateau. It is suggested that the future climate warming especially the gradual rise of the night temperature could cause negative effect on herbage quality grown in Qinghai-Xizang Plateau by decreasing CP, EE, and NFE contents and increasing some indigestible ingredients such as crude fibre (CF), neutral detergent fibre (NDF), ADF, and ADL. This, consequently, decreases the ruminant assimilation ability.

Key words: climate warming; Daban Mountain; temperature; herbage; nutrient contents; *in vitro* digestibility

The global surface temperature has increased by about 0.5 ℃ since 1975, and a common view is that the current global warming rate will continue or ever accelerate (James *et al*, 2000). Global air temperature is predicted to increase 1 - 4.5 ℃ over the 21st century, with the greatest increase expected in the Arctic (Houghton *et al*, 1996; Watson, 1999; Zhang and Sun, 1999). Temperature is one of the important factors influencing growth and development of organisms. It is sure that the climate warming affects physiological and ecological features and subsequently causes evident effects on levels of species, population and ecosystem, even whole biosphere (Sun, 1996). Effects of climate warming on herbage species, productivity and quality, and their impacts on livestock production are the research focus of Global Change and Terrestrial Ecosystem (GCTE), one of key projects of International Geosphere-Biosphere Program (IGBP) (Chen and Sun, 1994).

The ecosystem of higher altitude and latitude regions is the most sensitive to climate changes (Houghton *et al*, 1996). With the peculiar topography, Qinghai-Xizang Plateau has a unique climate system and is sensitive to its changes with the air temperature increase at the rate of 0.16 ℃ every ten years (Gong and Wang, 1999; Liu and Hou, 1998). Night temperatures at Qinghai-Xizang Plateau have generally increased more than in daytime (Tang *et al*, 1998; Tang and Li, 1999; Lai *et al*, 2000). Alpine meadow is the dominated vegetation in the Plateau. Most studies on the effects of gradual temperature increase on Qinghai-Xizang Plateau alpine meadow focus on the productivity of grassland and whether ecosystems are carbon sinks or sources (Thornely and Cammell, 1997). When predicting the nutritional quality of herbage, digestibility of the herbage is one of the utmost important parameters (Boisen and Eggum, 1991). Nutrient content is an important factor in assessing herbage digestibility. Effects of climate warming on nutrient contents and *in vitro* digestibility of herbage grown in Qinghai-Xizang Plateau have not been investigated.

In the present study, nutrient contents and *in vitro* digestibility of herbage in Qinghai-Xizang Plateau alpine meadow grown at different altitudes were determined and a simulative study on the effect of climate warming on herbage quality was performed. The results on climate warming on herbage nutrient contents and its *in vitro* digestibility could be useful to predict possible response of Qinghai-Xizang Plateau herbage quality as well as an indicator for future climate warming.

1 Materials and Methods

1.1 Study area

The study was conducted at Daban Mountain (37°

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29′ - 37°45′ N, 101°12′ - 101°23′ E) located in the northwest of Qinghai-Xizang Plateau. The altitude of the mountain ramped from 3 100 m to 4 000 m. The landscape is characterized by large mountain ranges with steep valleys and gorges interspersed with comparatively level and wide intermountain grassland basins. The climate at Daban Mountain is dominated by the southeast monsoon and high pressures from Siberia. It has a continental monsoon type climate, with long and severe winters and short and cool summers. The average air temperature is - 1.7 ℃ with an extreme maximum of 27.6 ℃ and minimum of - 37.1 ℃. During winter months, the average air temperature can drop down to - 15 ℃ or even - 20 ℃ in highland areas. The average precipitation ranges from 426 to 860 mm, 80% of which falls in the short summer growing season from May to September. The annual average sunlight is 2 462.7 h with 60.1% total available sunshine during the growing season (Li, 1998).

1.2 Experimental design and statistical analysis

Four sites at different altitudes of Daban Mountain with various temperatures were selected every 200 m from 3 200 to 3 800 m along northern slope of Daban Mountain. These sites have a similar soil type, vegetation and topography.

Five species of Qinghai-Xizang Plateau herbage, i.e., *Festuca ovina*, *Poa annua*, *Koeleria cristata*, *Kobresia humilis* (stem and leaf) and *Carex alrofusca* (stem and leaf) were selected to determine the soluble contents such as crude protein (CP), ether extract (EE), nitrogen free extract (NFE) and ash. For structured carbohydrates, some studies regarded crude fibre (CF) as a dominant factor that impact herbage digestibility (Liu *et al*, 2001). However, components of herbage CF is complex and unstable, it is difficult to estimate its effect on herbage digestibility. There are some firm chemical bonds between lignin and plant amylose or cell wall protein, tie up into inlaid structure through chemical bonds. Therefore, digestive enzyme hardly contact lignin. Consequently, lignin is an important resistant factor to chemical decomposition (Ensminger and Olentine, 1985; McDonald *et al*, 1992). According to ruminant digestion feature, as for the herbage nutrient components, the dominant factor determining herbage digestibility is herbage lignin content (Tan *et al*, 1994). The lignin content can be attested by the acid detergent fibre (ADF) and acid detergent lignin (ADL) contents that could completely indicate the lignin content. Thus, ADF and ADL contents could predict herbage digestibility more accurately (McDonald *et al*, 1992).

From data of herbage nutrient contents and *in vitro* digestibility, correlations between above-ground and below-ground temperatures versus CP, EE, NFE, ADF, ADL, and *in vitro* digestibility were analysed, respectively. Then, climate warming impacts on herbage quality grown in Qinghai-Xizang Plateau were estimated.

1.3 Methods

1.3.1 Temperatures Outdoor 4-channel external logger (HOBO H8) and temperature sensors made in USA, was used to monitor the temperatures at 5 cm (T_1) and 10 cm (T_2) above-ground, soil temperatures at 5 cm (T_3) and 10 cm (T_4) below-ground at every site. It recorded simultaneous temperatures every 2.5 min by data-log at four levels (T_1, T_2, T_3, T_4) of four sites at 3 200 m, 3 400 m, 3 600 m, and 3 800 m during 14 d (8 - 22, August 2000). The mean temperatures of above-ground (T_{1-2}) and below-ground (T_{3-4}) were derived accordingly.

1.3.2 Nutrient contents K Jeldakl method was employed to measure nitrogen and indirectly the herbage CP content (Zhang *et al*, 1996). EE was determined by Soxtec System HT; samples to be analysed were weighed into thimbles and inserted into the extraction unit. After the solvent addition to the extraction cups, the soluble matter was extracted into the solvent in a two-stage process followed by a solvent recovery cycle. Finally, the extraction cups were dried and weighed. Ash was the residue after burning the samples for 3 h in a muffle at 525 ℃. The leftover amount after subtracting the moisture contents, ash, crude protein, ether extract, and crude fibre is the NFE of the herbage (Ensminger and Olentine, 1985).

Methods of determining ADF and ADL are based on subsequent steps of chemical treatments to solubilize "nonfibre" components and final determination of the residue obtained. ADF is defined as the residue after treatment with an acid detergent solution (cetyl trimethylammonium bromide in sulphuric acid solution). ADL is defined as the residue after initial treatment by the ADF method followed by the removal of the cellulose fraction through extraction using 72% H_2SO_4 (McDonald *et al*, 1992).

1.3.3 *In vitro* digestibility The procedure of *in vitro* digestibility determination is based on the modifications method developed by Weisbjerg and Hveplund (Genizi *et al*, 1990). About 0.5 g of milled sample (1 mm) was weighed into a tube. Ten mL Qinghai-Xizang sheep rumen liquid and 50 mL buffer solution were added to the sample in the tube. The mixture was incubated at 39 ℃ for 48 h with shaking once every 2 h. At the end, the tube was centrifuged and the supernatant decanted. The residue was incubated again with 60 mL pepsin-hydrochloric acid solution (to digest protein) for another 48 h at 39 ℃. This followed by centrifuging, filtering, drying the residues and ashing. Blanks are included to correct for the indigestible dry matter from the rumen liquid.

2 Results

2.1 Temperatures at different altitudes

Above- and below-ground temperatures at four different altitudes represented an evident downtrend with the increase of altitude (Fig. 1). Altitude increasing from 3 200 m to 3 800 m, T_1, T_2, T_3 and T_4 decreased by 1.9 ℃, 1.47 ℃, 1.22 ℃, and 1.25 ℃, respectively. Above-ground (T_{1-2}) and below-ground (T_{3-4}) mean temperatures of four sites were 9.19 ℃ and 8.25 ℃,

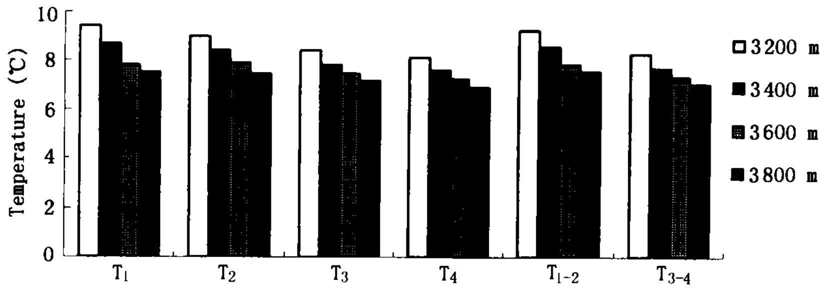

Fig.1. Temperature of different altitudes of Daban Mountain.

Table 1 Correlation coefficients between altitudes and temperatures

	Altitude	T_1	T_2	T_3	T_4	T_{1-2}	T_{3-4}
Altitude	1.000 0						
T_1	-0.982 1	1.000 0					
T_2	-0.997 3	0.992 2	1.000 0				
T_3	-0.984 4	0.982 5	0.992 5	1.000 0			
T_4	-0.995 6	0.988 9	0.999 1	0.996 5	1.000 0		
T_{1-2}	-0.990 4	0.998 5	0.997 2	0.988 3	0.994 3	1.000 0	
T_{3-4}	-0.990 5	0.985 9	0.996 1	0.999 1	0.999 1	0.992 3	1.000 0

8.5 ℃ and 7.69 ℃, 7.84 ℃ and 7.33 ℃, and 7.50 ℃ and 7.01 ℃, respectively.

The correlation analysis of altitudes versus temperatures indicated (Table 1) that negative correlation coefficients between altitudes and temperatures were significant ($P<0.01$).

2.2 ADF and ADL contents

There were positive correlations between T_{1-2}, T_{3-4} and ADF, ADL contents in the herbage (Table 2). T_{1-2} and ADF contents in *P. annua*, *K. cristata* and *F. ovina*, in leaves of *C. alrofusca* and *K. humilis*, and in the stem of *K. humilis* were all significant ($P<0.05$), while it was not significant for the stem of *C. alrofusca* ($P>0.05$). The correlations of T_{3-4} and ADF contents in *P. annua*, *F. ovina*, *K. cristata*, in leaves of *C. alrofusca* and *K. humilis*, in stems of *K. humilis* and *C. alrofusca* were all significant ($P<0.05$). The correlations of T_{1-2}, T_{3-4} versus ADL contents in *F. ovina*, *P. annua*, leaf of *C. alrofusca*, stem of *K. humilis*, leaf of *K. humilis*, *K. cristata* were all significant ($P<0.05$), while it was not significant for stem of *C. alrofusca* ($P>0.05$).

2.3 CP and EE contents

There are negative correlations between T_{1-2}, T_{3-4} and CP, EE contents of the herbage (Table 3). Correlations of T_{1-2} and CP contents of *F. ovina*, stem of *C. alrofusca*, leaf of *C. alrofusca* and leaf of *K. humilis* were all significant ($P<0.05$), but were not significant for *P. annua*, *K. cristata*, and stem of *K. humilis*. Correlations of T_{1-2}, T_{3-4} versus EE contents in *P. annua*, *K. cristata*, stem of *C. alrofusca*, leaf of *C. alrofusca*, stem of *K. humilis* and leaf of *K. humilis*, and *F. ovina* were all significant ($P<0.05$).

2.4 Ash and NFE contents

Correlations of T_{1-2} and ash contents in *F. ovina*, *P. annua*, *K. cristata*, stem of *C. alrofusca*, leaf of *C. alrofusca*, stem of *K. humilis*, and leaf of *K. humilis* were not significant ($P>0.05$). Correlations between T_{3-4} and ash contents in *F. ovina*, *P. annua*, *K. cristata*, leaf of *C. alrofusca*, leaf of *K. humilis* were not significant except for stem of *C. alrofusca* and stem of *K. humilis* where they were significant ($P<0.05$), i.e. there were no regular variations of herbage ash contents along with temperature increased. There were negative correlations between T_{1-2}, T_{3-4} and NFE contents in the herbage (Table 4). Correlations between T_{1-2}, T_{3-4} and NFE contents of *K. cristata*, stem of *C. alrofusca*, leaf of *C. alrofusca*, stem of *K. humilis*, and leaf of *K. humilis* were all significant ($P<0.05$), while were not significant for *F. ovina* and *P. annua* ($P>0.05$).

2.5 *In vitro* digestibility

For *in vitro* digestibility of herbage grown at different altitudes, the correlations with both above-ground and below-ground temperatures were negative (Fig.2). Assessments of the statistical significances suggest that correlations between T_{1-2} and T_{3-4} versus *in vitro* digestibility of *F. ovina*, *P. annua* and *K. cristata*, leaf of *C. alrofusca*, stem of *C. alrofusca*, stem of *K. humilis*, and leaf of *K. humilis* were all significant ($P<0.05$).

3 Discussion

3.1 Effect of temperature on herbage nutrient contents

Herbage grown in alpine climate environment engender a series of adaptive characteristics in physiology and metabolism during the long evolvement process (Grabherr, 1994; Zhang and Ma, 1982). It is evident in some species such as wheat, clover and potato, undergo metabolic changes in protein, carbohydrate, nucleic acid,

Table 2 Temperature and ADF, ADL contents in herbage grown at different altitudes

Species	Altitude (m)	T (℃)		ADF (%) (± *SD*)	ADL (%) (± *SD*)	Correlation analysis			
		T_{1-2}	T_{3-4}			T_{1-2} and ADF	T_{3-4} and ADF	T_{1-2} and ADL	T_{3-4} and ADL
Festuca ovina	3 800	7.50	7.01	35.77 ± 1.27	8.62 ± 0.96	$r = 0.864\,9$	$r = 0.857\,5$	$r = 0.961\,0$	$r = 0.935\,5$
	3 600	7.84	7.33	39.69 ± 1.41	10.17 ± 1.25	$P < 0.05$	$P < 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	41.67 ± 1.63	12.80 ± 1.48				
	3 200	9.19	8.25	41.74 ± 1.45	13.25 ± 1.90				
Poa annua	3 800	7.50	7.01	32.53 ± 1.58	7.60 ± 1.28	$r = 0.963\,9$	$r = 0.958\,1$	$r = 0.991\,9$	$r = 0.969\,4$
	3 600	7.84	7.33	35.12 ± 1.23	8.20 ± 1.28	$P < 0.01$	$P < 0.01$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	37.28 ± 1.22	10.88 ± 1.59				
	3 200	9.19	8.25	38.49 ± 1.24	12.18 ± 0.87				
Koeleria cristata	3 800	7.50	7.01	43.65 ± 1.87	14.72 ± 0.96	$r = 0.954\,9$	$r = 0.914\,9$	$r = 0.906\,5$	$r = 0.873\,5$
	3 600	7.84	7.33	44.39 ± 1.65	16.57 ± 1.39	$P < 0.01$	$P < 0.05$	$P < 0.05$	$P < 0.05$
	3 400	8.56	7.69	47.98 ± 1.33	19.26 ± 1.30				
	3 200	9.19	8.25	48.30 ± 2.36	18.96 ± 1.39				
Stem of *Carex alrofusca*	3 800	7.50	7.01	42.05 ± 1.96	8.53 ± 1.00	$r = 0.749\,4$	$r = 0.814\,7$	$r = 0.710\,1$	$r = 0.687\,3$
	3 600	7.84	7.33	42.90 ± 0.96	11.87 ± 1.61	$P > 0.05$	$P < 0.05$	$P > 0.05$	$P > 0.05$
	3 400	8.56	7.69	41.96 ± 1.07	13.64 ± 0.53				
	3 200	9.19	8.25	45.85 ± 1.77	12.31 ± 1.18				
Leaf of *C. alrofusca*	3 800	7.50	7.01	29.28 ± 1.66	6.38 ± 1.03	$r = 0.868\,4$	$r = 0.860\,7$	$r = 0.926\,6$	$r = 0.937\,0$
	3 600	7.84	7.33	33.22 ± 2.01	7.58 ± 0.90	$P < 0.05$	$P < 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	35.26 ± 1.44	8.01 ± 0.91				
	3 200	9.19	8.25	35.35 ± 1.46	8.53 ± 0.99				
Stem of *Kobresia humilis*	3 800	7.50	7.01	35.70 ± 1.97	9.57 ± 1.06	$r = 0.886\,5$	$r = 0.884\,7$	$r = 0.991\,7$	$r = 0.974\,9$
	3 600	7.84	7.33	39.26 ± 1.79	10.65 ± 0.95	$P < 0.05$	$P < 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	40.88 ± 1.19	12.79 ± 0.61				
	3 200	9.19	8.25	41.36 ± 1.53	13.85 ± 0.99				
Leaf of *K. humilis*	3 800	7.50	7.01	29.00 ± 1.49	5.58 ± 1.18	$r = 0.915\,5$	$r = 0.869\,4$	$r = 0.995\,3$	$r = 0.987\,3$
	3 600	7.84	7.33	30.94 ± 1.49	6.32 ± 1.53	$P < 0.05$	$P < 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	37.08 ± 1.89	7.41 ± 1.06				
	3 200	9.19	8.25	36.43 ± 1.81	8.21 ± 1.42				

$n = 4$, $P_{0.05} = 0.811\,4$, $P_{0.01} = 0.917\,2$.

ADF, acid detergent fibre; ADL, acid detergent Lignin.

and ether extract and participate in physiological processes of resistance against freezing temperatures and then increase their adaptive capability for protection under chilly environment (Han *et al*, 1997). When plants were grown at high altitudes, the increase in protein, ether extract, and some carbohydrates, will cause higher concentration in their cell protoplasm. This consequently decrease its freezing point, and enhance its adaptive resistance capability to cold climate (Zhang and Ma, 1982).

Difference in daytime and nighttime temperatures is obvious in Qinghai-Xizang Plateau. During the growing season the nighttime temperatures (< 10 ℃) are evidently lower than those of daytime (> 20 ℃). There are strong illumination in the daytime, herbage can assimilate a lot of dry matter. Temperature decreases to a lower level during nighttime, so the herbage respires feebly and the dissimilation decreases. Thereby, nutrient accumulation in plants through photosynthesis during daytime exceeds disassimilation during nighttime. In eastern agricultural land of China, disassimilation of wheat plants at night due to respiration accounts for 20% – 30% of photosynthetic products, while wheat plants in Qinghai-Xizang Plateau account for only about 10% (Zhang and Ma, 1982). Different species have different sensitivities to low temperatures during nighttime, but all plants share a common direction, i.e. there is a positive correlation between temperature and herbage respiration with low nighttime temperature restraining herbage respiration (Zhang *et al*, 1987; Levitt, 1980). Herbage respiration mostly consumes some soluble nonstructured carbohydrates and its consumption decreases at low nighttime temperature. Thus, it is propitious to soluble matter accumulation. The increase of soluble matter enhances saturation pressure of plant cell leading to the increase of resistance of cell protoplasm against freezing (Zhang and Ma, 1982). Consequently, this enforces plant resistance against chilly climate.

While low temperature restrains respiration and is favorable to soluble carbohydrate accumulation, some structured carbohydrate contents such as cellulose, hemicellulose and acid detergent lignin decrease. The herbage nutritive value varied with the altitude. Normally, the herbage at higher altitudes has higher protein content and nonstructured carbohydrate. The main reason for this is the low temperature resulted in decreased lignification of plant cell walls. Low temperature also causes slower metabolic activities which increase the pool of metabolites in the cellular content, and also increase nitrates,

Table 3 Temperature and CP, EE contents of herbage grown at different altitudes

Species	Altitude (m)	T (℃)		CP (%) (± SD)	EE (%) (± SD)	Correlation analysis			
		T_{1-2}	T_{3-4}			T_{1-2} and CP	T_{3-4} and CP	T_{1-2} and EE	T_{3-4} and EE
Festuca ovina	3 800	7.50	7.01	9.96 ± 1.35	3.60 ± 1.40	$r = -0.927 4$	$r = -0.961 4$	$r = -0.940 6$	$r = -0.915 8$
	3 600	7.84	7.33	8.97 ± 0.66	3.68 ± 0.20	$P < 0.01$	$P < 0.01$	$P < 0.05$	$P < 0.05$
	3 400	8.56	7.69	8.90 ± 1.46	3.41 ± 0.35				
	3 200	9.19	8.25	7.90 ± 0.73	3.22 ± 0.10				
Poa annua	3 800	7.50	7.01	10.49 ± 1.32	4.17 ± 0.45	$r = -0.700 5$	$r = -0.728 2$	$r = -0.996 3$	$r = -0.993 3$
	3 600	7.84	7.33	8.35 ± 1.40	4.11 ± 1.42	$P > 0.05$	$P > 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	8.48 ± 0.73	3.95 ± 0.55				
	3 200	9.19	8.25	8.27 ± 0.06	3.77 ± 0.25				
Koeleria cristata	3 800	7.50	7.01	8.87 ± 0.48	4.09 ± 0.05	$r = -0.160 6$	$r = -0.138 6$	$r = -0.947 9$	$r = -0.911 9$
	3 600	7.84	7.33	7.13 ± 0.58	3.91 ± 1.01	$P > 0.05$	$P > 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	6.87 ± 0.67	3.45 ± 0.71				
	3 200	9.19	8.25	8.3 ± 1.18	3.43 ± 0.09				
Stem of *Carex alrofusca*	3 800	7.50	7.01	8.34 ± 0.35	4.17 ± 0.42	$r = -0.939 3$	$r = -0.905 2$	$r = -0.996 7$	$r = -0.981 9$
	3 600	7.84	7.33	7.85 ± 0.53	4.12 ± 0.55	$P < 0.01$	$P < 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	6.86 ± 0.85	3.91 ± 0.41				
	3 200	9.19	8.25	6.85 ± 1.05	3.76 ± 0.45				
Leaf of *C. alrofusca*	3 800	7.50	7.01	11.45 ± 2.35	4.33 ± 0.80	$r = -0.887 6$	$r = -0.923 4$	$r = -0.990 4$	$r = -0.998 7$
	3 600	7.84	7.33	9.99 ± 2.72	4.23 ± 0.05	$P < 0.05$	$P < 0.01$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	10.01 ± 2.10	4.14 ± 0.90				
	3 200	9.19	8.25	9.02 ± 2.08	4.00 ± 0.95				
Stem of *Kobresia humilis*	3 800	7.50	7.01	8.21 ± 0.24	4.19 ± 0.50	$r = -0.732 1$	$r = -0.704 7$	$r = -0.975 7$	$r = -0.942 3$
	3 600	7.84	7.33	7.47 ± 0.12	4.16 ± 0.91	$P > 0.05$	$P > 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	6.99 ± 0.98	3.94 ± 0.23				
	3 200	9.19	8.25	7.31 ± 0.70	3.88 ± 0.65				
Leaf of *K. humilis*	3 800	7.50	7.01	11.22 ± 3.49	4.24 ± 0.15	$r = -0.873 2$	$r = -0.808 1$	$r = -0.963 3$	$r = -0.983 9$
	3 600	7.84	7.33	11.38 ± 2.92	4.19 ± 0.41	$P < 0.05$	$P > 0.05$	$P < 0.01$	$P < 0.01$
	3 400	8.56	7.69	9.72 ± 2.28	4.14 ± 0.25				
	3 200	9.19	8.25	9.90 ± 1.61	3.98 ± 0.21				

CP, crude protein; EE, ether extract.

proteins, and soluble carbohydrates, but decrease the structural cell-wall components (Zhao and Zhou, 1999). Han *et al* (1997) studied contents of protein, fat and starch of *K. humulis* grown at different altitudes in Qinghai-Xizang Plateau. They found some biochemical components such as protein, fat, and starch in aboveground and belowground tissues of the plants tended to increase with increasing altitude. In this study, similar results were obtained on CP, EE and NFE in other four species of herbage besides *K. humulis* (Tables 3, 4). In addition, some structured carbohydrate contents such as ADF and ADL, that are dominant factors on herbage digestibility decrease with the increase of altitude (Table 2).

In this study, sites similar in topography, soil type, and vegetation condition, but at different altitudes were selected. Generally, solar ultraviolet radiation (UV), especially ultraviolet radiation B (UV-B) has some negative effects on photosynthetic ability through decreasing the rate of light energy converted into chemical energy and destroying chloroplast structure, reducing chlorophyl content of plants. Synchronously, it increases respiration, so increasing UV-B radiation will decrease the net production of photosynthesis (Li and Yue, 2000). As for lignin, Rozema *et al* (1997) reported that lignin content of plants increased under strong UV-B radiation. However, study on solar UV-B radiation at different evelation regions by Shi *et al* (1999) showed that effects of solar UV-B radiation were not significant at altitudes between 1 800 m and 2 300 m, and Daban Mountain always vestured by cloud and mist for its topography characteristics, plants of the region mostly enclouded by chilliness rather than solar UV-B radiation. Therefore, the solar UV-B radiation difference resulted from 200 m altitude difference had no evident effects on herbage nutrient contents and its digestibility.

Temperature difference resulted from different altitudes is the dominating factor among all kinds of environmental elements. In this study, change in nutrient contents of herbage grown at different altitudes can be deduced as the response of herbage nutrient to temperature differences. Therefore, the difference of herbage CP, EE, NFE, ADF, and ADL contents were primarily influenced by temperature. Evident trend of climate warming in Qinghai-Xizang Plateau during the last 40 years, especially the increase of nighttime temperature would enhance herbage respiration. This is against the accumulation of some soluble matters such as protein, ether extract and nitrogen free extract, and is propitious to accumulation of

Table 4 Temperature and ash, NFE contents of herbage grown at different altitudes

Species	Altitude (m)	T (℃)		Ash (%) (± *SD*)	NFE (%) (± *SD*)	Correlation analysis			
		T_{1-2}	T_{3-4}			T_{1-2} and Ash	T_{3-4} and Ash	T_{1-2} and NFE	T_{3-4} and NFE
Festuca ovina	3 800	7.50	7.01	4.03 ± 1.19	42.69 ± 1.16	$r = 0.3112$ $P > 0.05$	$r = 0.4099$ $P > 0.05$	$r = -0.7389$ $P > 0.05$	$r = -0.6763$ $P > 0.05$
	3 600	7.84	7.33	4.16 ± 1.04	41.39 ± 0.19				
	3 400	8.56	7.69	3.53 ± 0.82	38.35 ± 1.38				
	3 200	9.19	8.25	4.58 ± 0.80	40.05 ± 0.31				
Poa annua	3 800	7.50	7.01	4.17 ± 0.67	43.83 ± 1.31	$r = -0.0519$ $P > 0.05$	$r = -0.1626$ $P > 0.05$	$r = -0.8109$ $P > 0.05$	$r = -0.7703$ $P > 0.05$
	3 600	7.84	7.33	3.54 ± 0.34	44.02 ± 0.70				
	3 400	8.56	7.69	4.21 ± 0.24	41.21 ± 1.09				
	3 200	9.19	8.25	3.82 ± 0.65	41.79 ± 0.36				
Koeleria cristata	3 800	7.50	7.01	4.09 ± 0.71	35.75 ± 1.53	$r = 0.6448$ $P > 0.05$	$r = 0.6908$ $P > 0.05$	$r = -0.9562$ $P < 0.01$	$r = -0.9394$ $P < 0.01$
	3 600	7.84	7.33	3.78 ± 0.32	33.75 ± 1.09				
	3 400	8.56	7.69	3.68 ± 0.51	31.48 ± 0.31				
	3 200	9.19	8.25	5.12 ± 1.12	30.89 ± 1.36				
Stem of *Carex alrofusca*	3 800	7.50	7.01	4.16 ± 0.04	46.12 ± 0.45	$r = 0.8072$ $P > 0.05$	$r = 0.8556$ $P < 0.05$	$r = -0.9736$ $P < 0.01$	$r = -0.9453$ $P < 0.01$
	3 600	7.84	7.33	4.27 ± 0.01	46.24 ± 0.60				
	3 400	8.56	7.69	4.18 ± 0.32	44.26 ± 1.25				
	3 200	9.19	8.25	5.56 ± 0.57	43.27 ± 1.61				
Leaf of *C. alrofusca*	3 800	7.50	7.01	6.39 ± 0.01	46.47 ± 1.86	$r = 0.2717$ $P > 0.05$	$r = 0.3842$ $P > 0.05$	$r = 0.9527$ $P < 0.01$	$r = -0.9783$ $P < 0.01$
	3 600	7.84	7.33	6.90 ± 0.42	44.44 ± 3.32				
	3 400	8.56	7.69	5.99 ± 0.19	43.93 ± 3.06				
	3 200	9.19	8.25	7.09 ± 0.32	41.81 ± 1.87				
Stem of *Kobresia humilis*	3 800	7.50	7.01	4.04 ± 0.16	44.49 ± 0.40	$r = -0.7856$ $P > 0.05$	$r = 0.8261$ $P < 0.05$	$r = -0.9952$ $P < 0.01$	$r = -0.9801$ $P < 0.01$
	3 600	7.84	7.33	3.92 ± 0.06	43.49 ± 2.70				
	3 400	8.56	7.69	3.94 ± 031	41.39 ± 1.89				
	3 200	9.19	8.25	5.63 ± 0.06	40.20 ± 0.96				
Leaf of *K. humilis*	3 800	7.50	7.01	5.87 ± 0.45	46.25 ± 4.06	$r = 0.1213$ $P > 0.05$	$r = 0.1819$ $P > 0.05$	$r = -0.8206$ $P < 0.05$	$r = -0.8827$ $P < 0.05$
	3 600	7.84	7.33	6.82 ± 0.07	45.19 ± 2.50				
	3 400	8.56	7.69	6.33 ± 0.12	45.72 ± 2.93				
	3 200	9.19	8.25	6.29 ± 0.42	43.57 ± 1.67				

NFE, nitrogen free extract.

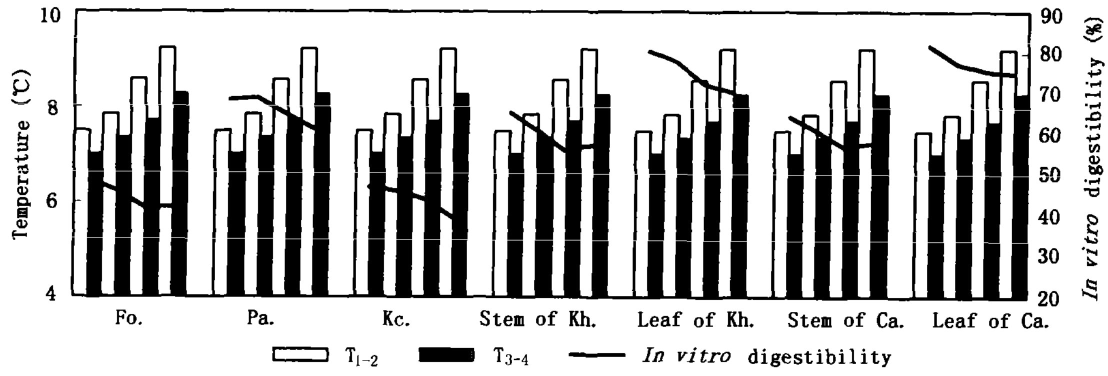

Fig.2. Temperature and *in vitro* digestibility of herbage grown at different altitudes.
Fo., Pa., Kc., Kh., and Ca. were abbreviations for *F. ovina*, *P. annua*, *K. cristata*, *K. humilis*, and *C. alrofusca*. respectively.

unsoluble lignin.

3.2 Temperature and digestibility

The lower digestibility of herbage grown at higher temperature is due to the combination of two main effects. High environmental temperatures result in the increase of lignification in plant cell wall. Higher temperatures also cause more rapid metabolic activities, which decrease the pool metabolites in the cellular conents. Photosynthetic products are thus more rapidly converted to structural components. This activity decreases nitrate, protein, and soluble carbohydrate, and increases the structural cell wall components. In grasses, both leaf and stem qualities decline with increasing temperatures, and more pronounced in tropical grasses (Van Soest, 1994). Leaf quality declines particularly as a result of lignification of the midrib, which contains the major portion of the lignin in grass leaves. Since stems also decline in quality at an equivalent stage, an increase in temperature usually causes an overall decline in grass quality (Van Soest, 1994). Results of this simulative experiment also showed a negative correlation (Fig. 2) between temperature and digestibility of herbage grown in Qinghai-Xizang Plateau.

Results of this study indicated that increasing temperature at various altitudes had the trend of decreasing in protein, ether extract and nitrogen free extract, herbage digestibility, and increasing in structured carbohydrate such as acid detergent fibre and lignin. Temperature as an important factor of all environmental aspects, the future increasing climate warming will bring negative effect on herbage quality in Qinghai-Xizang Plateau.

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气候变暖对青藏高原牧草营养含量及其体外消化率影响模拟研究

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摘要： 全球气候变暖，气温上升的趋势逐步被众人接受，而青藏高原这一独特地理单元的生态系统对气候变暖十分敏感。为更好地了解气候变暖对青藏高原牧草品质的影响，利用大板山北坡 3 200～3 800 m 的海拔梯度，以温度为主要影响因子，用海拔高度不同造成的温差模拟全球变暖带来的升温效应，研究气候变暖对青藏高原牧草营养含量及其体外消化率的影响。针对羊茅(*Festuca ovina*)、早熟禾(*Poa annua*)、 草(*Koeleria cristata*)、矮嵩草(*Kobresia humilis*)和黑褐苔草(*Carex alrofusca*)5种生长在不同海拔梯度的高原牧草中酸性洗涤纤维(ADF)、木质素(ADL)、粗蛋白(CP)、粗脂肪(EE)、无氮浸出物(NFE)、灰分等营养含量及其经绵羊瘤胃液培养后的体外消化率差异，经过1999和2000年两年的测定分析，结果表明：随着温度升高，牧草CP、EE和NFE的百分含量都呈现降低的趋势；牧草ADF和ADL百分含量与温度存在正相关关系，随着温度升高牧草ADF、ADL百分含量都呈增加的趋势；牧草体外消化率与牧草生长的环境温度存在负相关关联，随着温度升高牧草体外消化率呈降低趋势。模拟研究表明，就温度这一重要环境因素而言，未来气候变暖尤其是夜间温度的升高引起青藏高原牧草营养品质的变化，牧草CP、EE、NFE含量的降低，中性洗涤纤维(NDF)、ADL含量的增加，牧草消化率降低，从而不利于反刍动物对牧草的消化利用。

关键词： 气候变暖；大板山；温度；牧草；营养物质；体外消化率

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