African Journal of Biotechnology Vol. 9(40), pp. 6733-6739, 4 October, 2010
Available online at http://www.academicjournals.org/AJB
DOI: 10.5897/AJB10.910
ISSN 1684–5315 © 2010 Academic Journals

Full Length Research Paper

Distribution of biomass and diversity of *Stipa bungeana* community to climatic factors in the Loess Plateau of northwestern China

Cheng Jie[1], Hu Tian-Ming[1], Cheng Ji-Min[1,2*] and Wu Gao-Lin[1,2*]

[1]College of Animal Science and Technology of Northwest A and F University, Yangling, Shaanxi 712100, P. R. China.
[2]State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau of Institute of Soil and Water Conservation of Chinese Academy of Sciences (CAS) and Ministry of Water Resource (MWR), Yangling, Shaanxi 712100, P.R. China.

Accepted 3 September, 2010

Based on 28 year field data of *Stipa bungeana* community in arid, semi-arid, semi-humid areas of the Loess Plateau of Northwestern China, we studied species diversity and above ground biomass of *S. bungeana* community, analyzed the responses of above ground biomass to climate in different areas, and built a model of relationship between biomass and climatic factors. Results showed that there were significant differences for species diversity and above ground biomass among different sampling area. The species diversity range of *S. bungeana* was from 8.5 - 30.8 (ind/m^2), and above ground biomass range was from 407.3 - 817.3 (g/m^2) among studied area. The optimal distribution altitude range for *S. bungeana* is 1400 - 2000 m in arid area, 1200 - 1900 m in semi-arid area, and 600 - 1600 m in semi-humid area. Results also showed that the growth of *S. bungeana* was affected by different climatic factors, with rainfall as the major factor. Meanwhile, there was a close relationship between monthly biomass and rainfall during the growth stage. The models of monthly biomass and climate were built to compare the results and reveal the relationship between climatic factors and the growth of *S. bungeana* community.

Key words: *Stipa bungeana* community, biomass model, species diversity, climatic factor, Loess Plateau.

INTRODUCTION

Stipa bungeana community is distributed in typical steppe in semi-arid areas that belong to warm temperate and temperate zones. From the 1970s - 1980s, *S. bungeana* appeared as the accompanying species or dominant species in west arid and semi-humid areas of China, with rarely concentrated distribution (Li, 1990; Zhang, 1994; Nature reserve management office of Yunwu Mountain in Ningxia, 2001). From 1990s, the ecological amplitude of *S. bungeana* community gradually expanded due to human activity, climate changes and climatic factors, and it has become important wild forage and grazing grassland with high production value (Xie et al., 1994; Zhou and Xue, 2007).

Before the rainy season, the growth cycle of *S. bungeana* is completed, the post-fruiting period begins, and the tillering branches increase. *S. bungeana* has a medium palatability and its growth is always mixed with *Clestogenes sqarrosa*, *Aneurolepidium dasystachys*, *Lespedeza dahurica* and *Thymus mongolicus*. In grazing, it is preferred by sheep, goats, and cattles. *S. bungeana* is a main wild forage in northwest natural grassland of China, and it has low water content and loses water quickly. It is useful for the stabilization and conservation of grassland because of its fibrous roots and highly developed root system. *S. bungeana* plays an important role in the maintenance of soil and water, because it can quickly form community and become the dominant and constructive species with its strong ability to compete for growth.

Many studies focus on species and community diversity along an elevation gradient when reviewing literatures (Rahbek, 1995; Vetaas and Grytnes, 2002; Carpenter,

*Corresponding authors. E-mail: gaolinwu@gmail.com, gyzcjm@ms.iswc.ac.cn

Table 1. Sampling sites distribution, location, altitude (m), mean annual rainfall (mm), mean annual temperature (℃), aridity, annual ≥10℃ accumulated temperature (℃), species diversity (numbers m^{-2}) and aboveground biomass (g m^{-2}) of *Stipa bungeana* community in different climate area.

Sampling area	Location	Altitude	Rainfall	Average temperature	Aridity	≥10℃ accumulated temperature	Species diversity	Aboveground biomass
The eastern Qinghai region in Loess Plateau	N36°43′25″,E101°26′30″	2237	254.2	7.2	2.3	2506.2	$8.5±1.51^{aA}$	$412.3±115.4^{aA}$
The windy desert area in Ordos	N39°38′41″, E110°6′21″	1450	343.6	5.5	2.0	2499.7	$12.2±1.55^{abAB}$	$407.3±75.8^{abA}$
The stony slop land in Inner Mongolia	N39°38′04″,E110°36′23″	1550	397.7	7.3	2.0	3118.4	$15.4±1.27^{abA}$	$549.5±37.6^{aA}$
The northern Shannxi region in Loess Plateau	N37°19′20″,E108°16′23″	1360	440.8	8.5	1.6	3391.9	$19.6±1.21^{abAB}$	$678.5±21.7^{aA}$
The western Shanxi region in Loess Plateau	N37°15′44″,E113°36′4″	1450	462.3	8.8	1.7	3367.0	$22.3±0.84^{abA}$	$681.3±49.5^{abA}$
The southern Ningxia region in Loess Plateau	N35°46′42″,E106°12′21″	1850	478.2	6.7	1.5	2259.7	$27.3±2.1^{abAB}$	$721.5±59.3^{aA}$
The eastern Gansu region in Loess Plateau	N36°01′43″,E106°21′18″	1650	537.4	8.7	1.4	3224.0	$26.8±0.75^{abA}$	$753.9±42.5^{aA}$
The weibei Loess-gully type region	N35°12′36″,E108°10′23″	1250	584.1	10.5	1.1	3029.1	$30.8±2.81^{aA}$	$817.3±36.7^{aA}$

The lowercase shows that the significance was at the level of 0.05; capital letter shows that it was very significant at the level of 0.01.

2005). However, elevation gradient, like latitude, is not an environmental variable (Kerr, 2001). Elevation is a proxy term for numerous variables of climatic factors that change with elevation in disparate ways (Carpenter, 2005; Cheng et al., 2010). To our knowledge, no study has been done to research the relationship of the diversity and biomass distribution of *S. bungeana* community and climatic factors. In this study, we studied distribution response of species diversity and above ground biomass of *S. bungeana* community along with climatic factors in arid, semi-arid, and semi-humid areas of northwestern China, and analyzed the responses of aboveground biomass to climate in different areas, and built a model of relationship between biomass and climatic factors. It will provide scientific basis for future studies on the ecological distribution of *S. bungeana* comunity and population dynamic of *S. bungeana*.

MATERIALS AND METHODS

Study sites

The study was conducted on eight sites, which represent the arid, semi-arid and sub-humid areas in the Loess Plateau (Table 1). These study sites belong to the warm temperate and temperate zones with drought and semi-humid climates. It has an altitude range of 600 - 2300 m, an average temperature of 6.7℃, and an average annual rainfall of 440.71 mm. There was a seasonal variance of precipitation distribution and 7 - 9 months' rainfall accounts for 65 - 85% of the annual precipitation. The study area's ≥10℃ accumulated temperature is 2259.7 - 3391.9℃. Its annual sunshine hours are 2300 - 2500 h. The annual average frostless period is 112 - 142 d, and its aridity is 1.0 - 2.3. Atmospheric rainfall is one of the main supplements to the soil water, and the ground water table was about 70 - 100 m.

S. bungeana community is the most widely distributed in temperate grasslands of the Loess Plateau. *S. bungeana* community is distributed in the semi-arid areas of typical steppe, as a result of large-scale cultivation since the 1970s. Virgin *S. bungeana* grassland is patch-mosaic distributed in the sunny slope or half-sunny slope of mountains and abandoned lands. As shown in Table 1, the distribution of *S. bungeana*, which is controlled by climate, gradually expanded and its distribution was concentrated. It moved southward from semi-arid areas to sub-humid areas (Weibei Loess-gully type region) by 120 km, and changed from an accompanying species to the dominant species. *S. bungeana* prefers light, tolerates drought, and is sensitive to soil water. The green-returning stage is in the beginning of July, seed maturation is in the end of May, and the post-fruiting period is in the beginning of the rainy season, when the blades have vigorous growth and high productivity.

Experimental sampling

In this study, we selected the *S. bungeana* communities as study objects in these eight study sites. In studied communities, dominant herbs species was *S. bungeana*, and companion species include *Stipa grandis*, *Stipa breviflora*, *Artemisia sacrorum*, *Potentilla acaulis*, *Androsace erecta*, *Heteropappus altaicus*, *Artemisia frigida*, *Agropyron dasystachys*, and so on.

Eight study areas contain regions of eastern Qinghai Province, eastern Gansu Province, southern Ningxia Municipality, northwestern Shaanxi Province in Loess Plateau, and windy desert area in Inner Mongolia and Weibei Loess-gully type region. Four sampling blocks (about 30 x 30 m) were set in each study site which has been fenced to exclude grazing since 1982. And, five diagonal sampling quadrats (1 × 1 m) in each block were investigated at each year. Based on periodic investigation and long-term experiments, the aboveground biomass and species diversity of *S. bungeana* community was measured monthly, during 20th - 25th of April to October of 1981 - 2008. Climate data was obtained from local weather stations. Biomass was measured by fresh weight with the stubble height of 0 cm. Plant species diversity was determined by number of species sampled per sampling quadrat within a community.

Data analysis

Data is expressed as mean ± standard error of mean. To assess the effects of study sites on species diversity and biomass, Least Significant Difference (LSD) (P < 0.05) test were conducted with one-way analysis of variance (ANOVA) of General Linear Model (GLM). Regression analysis was conducted to assess correlations between aboveground biomass of *S. bungeana* community and climatic factors among seven months. All statistical analyses were performed using the software program of the Statistical Package for the Social Sciences (SPSS), ver. 13.0 (SPSS Inc., Chicago, IL, USA).

RESULTS

Variation of diversity and aboveground biomass for *S. bungeana* community

ANOVA results showed that there were significant difference for species diversity (P < 0.01) and aboveground biomass (P < 0.05) among different sampling area. The species diversity range of *S. bungeana* was from 8.5 - 30.8 (ind/m^2), and aboveground biomass range was from 407.3 - 817.3 (g/m^2) among studied area (Table 1). Results showed that *S. bungeana* had significantly different species diversity in different areas. The optimal distribution altitude range for *S. bungeana* in arid area was 1400 - 2000 m, and the average species diversity was 7.6 ± 2.0 (ind/m^2, Figure 1A). The optimal growth and reproduction altitude for *S. bungeana* in semi-arid area was 1200 - 1900 m, and the average species diversity was 20.6 ± 5.1 (ind/m^2, Figure 1B). In both arid and semi-arid areas, climate of high altitude of over 2000 m was not suitable for *S. bungeana*'s growth. The optimal growth and reproduction altitude for *S. bungeana* in semi-humid area was 600 -1600 m, and the average species diversity was 23.6 ± 5.2 (ind/m^2, Figure 1C).

Above ground biomass model of *S. bungeana* community based on climatic factors

Table 2 shows that there were significant differences in the growth stage under different climatic factors. April was the early growth period, when all growth indexes varied greatly. The biomass formation were influenced by most climatic factors but showed no significant correlation, and the growth needed more water and the shallow soil water played important roles. After the drought condition in May, deep soil water showed significant effects on biomass. In June, the climate indexes gradually became normal. The average temperature and rainfall had a significant effect on biomass, and the correlation between biomass and climate indexes reached extremely significant level. From July - September, when the post-fruiting period begins and the blade vigorously grew, rainfall was a major factor for the biomass formation, and the average temperature was the second important factor. The growth was arrested in October and the following factors affecting biomass were ranked as rainfall>deep soil water>average temperature>sunlight hours>hallow soil water.

DISCUSSION

Distribution of *S. bungeana* community along altitude

Our results showed the optimal altitude distribution range for species diversity within *S. bungeana* community. It is basically consistent with results of previous study of Wang (1991), they reported that the optimal growth altitude for *S. bungeana* community in middle (semi-arid area) and eastern (semi-humid area) Loess Plateau is 600 - 1500 m. However, our results in south Ningxia area showed that the highest value of altitudes of growth distribution of *S. bungeana* community is up to 1900 mm.

In the southern Ningxia region in Loess Plateau, *S. bungeana* community in middle-low mountains had been enclosed for 10 -15 a. The growth range of the population thereupon expanded and the adaptability was enhanced. As a result, *S. bungeana* changed from the accompanying species to the dominant species or constructive species. The maximum area of the concentrated *S. bungeana* community was 6700 hm^2 (Nature reserve management office of Yunwu Mountain in Ningxia, 2001), species diversity was 27.3 (ind/m^2), and biomass reached 721.5 (g/m^2). Under the optimal conditions with 1250 - 2237 m of altitude, 254.2 - 584.1 mm of average annual rainfall, 5.5 - 10.5℃ of average temperature, 1.0 - 2.3 of aridity, 2259.7 - 3391.9℃ of ≥10℃ accumulated temperature, *S. bungeana* community grew very well and restored its high biodiversity and biomass. Being influenced by climatic changes, the growth and structure of *S. bungeana* community in different zones had significant variation characteristics: (1) With the changes of community structure, native constructive or dominant species gradually decreased or declined but the perennial grass increased, invasive species such as *S. bungeana,* became dominant (Zhang, 2004; Zhou and Xue, 2007); (2) in the grassland community of semi-arid areas, the growth of natural grass, the production of

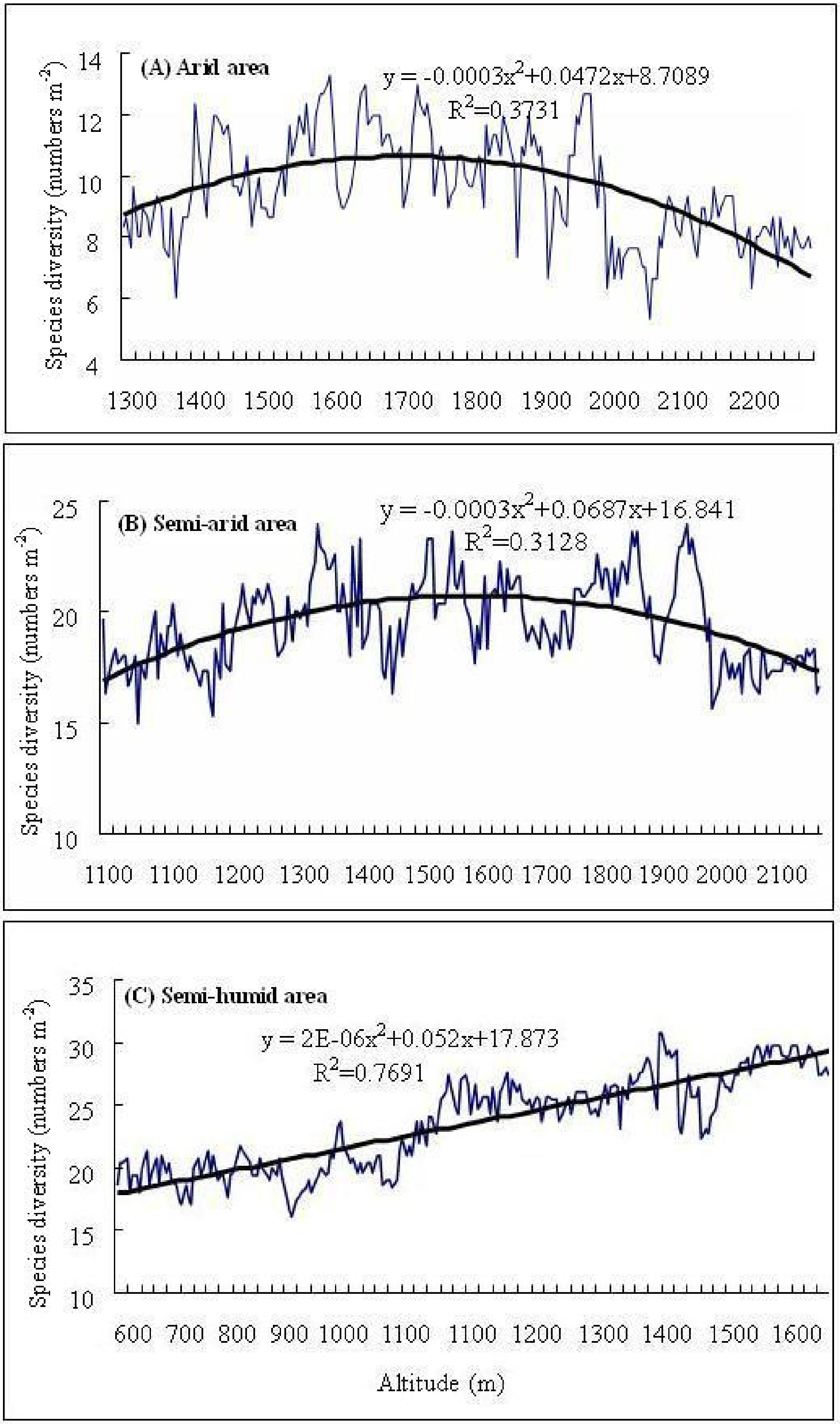

Figure 1. Mean species diversity (numbers m^{-2}) of *Stipa bungeana* communities in arid area (A), semi-arid area (B) and semi-humid area (C) in this study.

Table 2. Regression analysis results of the aboveground biomass of *S. bungeana* community with climate factors for seven months.

Month	Regression model	R^2	*F*-value	*P*-value
April	$Y_4=1.187X_1-0.451X_2-0.085X_3+2.529X_4+0.139X_5+40.681$	0.144	0.738	0.603^{ns}
May	$Y_5=5.106X_1-0.180X_2-0.105X_3-2.934X_4+1.205X_5+184.703$	0.205	1.138	0.370^{ns}
June	$Y_6=0.566X_1+1.534X_2+0.064X_3-4.100X_4-22.905X_5+263.081$	0.590	6.319	0.001
July	$Y_7=10.173X_1+0.996X_2-0.168X_3-1.424X_4-3.875X_5-62.308$	0.479	4.040	0.009^{-}
August	$Y_8=17.348X_1+0.455X_2+0.175X_3+9.095X_4-2.925X_5-333.545$	0.472	3.931	0.011^{-}
September	$Y_9=14.443X_1+0.603X_2-0.135X_3-11.225X_4+3.150X_5-36.650$	0.424	3.239	0.024^{-}
October	$Y_{10}=3.079X_1+0.588X_2+0.278X_3+0.561X_4+1.581X_5-59.514$	0.326	2.125	0.100^{ns}

Y_i is the *i*-th month's biomass (g/m^2); X_i is the monthly rainfall (mm); X_2 is the monthly average temperature (^{o}C); X_3 is the sunshine hours (h); X_4 is the hallow soil water (0 - 50 cm) (%); X_5 is the deep soil water (50 - 100 cm) (%); **P < 0.01, *P < 0.05.

esculent herbage, and the grazing capacity all decreased, and at the same time, the viability and the sexual and asexual reproduction capacity of *S. bungeana* were enhanced; (3) S. *bungeana* showed retarded growth when the environment was worsened (usually caused by soil drying, soil salinization, deterioration of soil's physical and chemical properties, and serious Patchy bare ground); (4) the mounds formed by grassland rodents were beneficial to *S. bungeana*'s seed germination, because the loose soil structure enhanced tillering ability by helping the development of root system.

Along with global warming, the species distribution range has been remarkably changed (Root et al., 2002; IPCC, 2007). The grassland ecosystem is one of the biggest natural land ecosystems, and under environmental changes and human destructions, the species diversity and distribution have become an important object of study (Ma and Qian, 1998). In northwest China, there are arid and semiarid climate, the moisture content has dropped to the lower limit of moisture content required for dry agricultural planter (Rong et al., 2001). Through natural selection, the *S. bungeana* community has become the habitat of semi-arid regions of typical steppe zone. However, over the past 30 years with rising temperatures and declining rainfalls, the distribution range of *S. bungeana* community have gradually expanded to the arid zone. The trend shows that in arid zone, *S. bungeana* has changed from the rare species to associated or dominant species, moving northward by about 75 km. In the semi-humid zone, *S. bungeana* has changed from the accompanying species to dominant or constructive species, moving southward by about 120 km. Overall, the area of forest steppe zone has been reduced, the typical steppe zone has gradually expanded, and the biodiversity of desert steppe zone continued to increase. Global warming and human disturbance get together to exacerbate the loss of biodiversity. The complex interaction between those two factors makes it really difficult to predict the future changes in biodiversity. Climate change can alter ecosystem's species composition and community structure, and it has both positive and negative impacts on biodiversity. Species migrating from low-elevation towards higher elevation tends to increase alpine biodiversity and species diversity (Gaur et al., 2003). Impacted by the climate and environment in the Loess Plateau, *S. bungeana* community's distribution has changed dramatically. In semi-humid area, its species diversity increased to 30.8 species/m^2, and the biomass became 817.3 g/m^2; in the semi-arid regions, where its distribution is concentrated, its species diversity increased to 27.3 species/m^2, and the biomass was 721.5 g/m^2; in the arid zone, the species diversity was 12.2 species/m^2, and the biomass was 407.3 g/m^2. Therefore, a great deal of measures should be taken to protect *S. bungeana* community and avoid human disturbance on biodiversity in order to prevent global warming and climate change that would lead to species extinction and migration.

It is widely known that the high latitude and altitude areas are the most significant ecological systems affected by global warming (Parmesan and Yohe, 2003). When compared to the hilly and gully region that is controlled by low temperature, the high latitude and altitude areas' response to climate warming is particularly sensitive, and are also the ideal places to monitor and study global warming. Therefore, scientists have been paying much attention to the distribution of species, the migration channels, and the biodiversity response to global climate change and adaptation in the sensitive areas. This is of great significance to monitor global climate change.

This study monitored the changes of typical species distribution within the altitude gradient in the Loess Plateau. Elevation gradient had significant effects on the distribution of *S. bungeana*, the indicator plant. In semi-humid areas, the optimal elevation gradient for *S. bungeana*'s growth and reproduction is 600 - 1600 m; in semi-arid regions, it is 1200 - 1900 m; in arid areas, it is 1400 - 2000 m. When the elevation gradient was over 2000 m, S. *bungeana*'s reproduction was very low because of the low temperature, although it could still grow. Overall, because of the climate warming, the distribution of S. *bungeana* was gradually expanded, and the growth of elevation gradient was also largely increased. It indicates that the migration of S. *bungeana* species along the altitude is more rapid than that along the latitude, which is conducive to the formation of species diversity (Chapin and Körner, 1995).

Above ground biomass and climatic factors

Biomass is one of those basic parameters to characterize an ecosystem. Studies on the dynamic changes of the above-ground biomass of grassland species may greatly help understand the circulation of materials and the energy flow in grassland ecosystem. Furthermore, people can apply this important theory in the management of lawns (Huang et al., 2001). The above-ground biomass is formed under certain conditions of ecological climate and plant growth. The rainy and sunny condition has profound influence on plant's photosynthesis and above-ground biomass production (Pan and Dong, 1995); drought can significantly impact on vegetation dynamics in steppe (Shinoda et al., 2010).

The relationship between vegetation characteristics and climate had been reported in many studies (He et al., 2008; Liu et al., 2008; Cheng et al., 2010). With the desert or semi-desert pale climates, rainfall is a critical factor restricting net primary underground productivity of the natural grassland (Zhang and Liang, 1999; He et al., 2008) and community biomass fluctuates among years (Chen et al., 1994). The drier the climate, the lower the benefit of transpiration, and the water cycle of the ecosystem directly affects grassland productivity (Chen and Xie, 2004; Liu et al., 2008). Huang et al. (2001) had reported that sunlight hours had no significant effects on biomass in other months, but water was indeed the most significant impacting factor in every growth stage. Frank and Bauer (1991) pointed out that there was high correlation among the cool-season forage productivity, the rainfall in growing season, and the soil water in the earlier growing season. Some studies showed that the rate of biomass growth is proportional to the rainfall in growing season; annual variations of biomass and rainfall were correlated in a liner regression (Huang et al., 2001a, b; Gaur et al., 2003), especially in arid and semi-arid areas.

In summary, based on 28 years of monitoring in Loess Plateau's typical grassland, we established a month by month regression model between the biomass of *S. bungeana* community and climatic factors. We discovered that the biomass growth of *S. bungeana* was not significantly changed by climatic factors. In June, the growth season of plants, various climate-indexes gradually became normal, and the average temperature and rainfall had remarkable effects on the biomass. From July - September, *S. bungeana* grew well. During this period of time, mainly influenced by rainfall and temperature, the biomass reached a remarkable level with a variety of climatic factors. Overall, rainfall is the most important factor followed by the temperature affecting the biomass of *S. bungeana* for each month.

ACKNOWLEDGEMENTS

The study was supported by projects of important direction of the Chinese Academy of Sciences (No.KZCX2-YW-441), and a subproject of national high-tech investigation and development "973" (No.2007CB106803), national sci-tech tackle of China (No.2006BAD09B08); natural science foundation of China (No.40730631) and special fund in dissertation supervisition of national forest state and State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau (10502-Z8, 10502-Q5).

REFERENCES

Carpenter C (2005). The environmental control of plant species diversity on a Himalayan elevation gradient. J. Biogeog. 32: 999-1018.
Chapin FSIII, Körner CE (1995). Arctic and Alpine Biodiversity: Patterns, Causes and Ecosystem Consequences, p.113. Springer-Verlag, Berlin.
Chen YJ, Li SL, Li LM, Jia SH (1994). Analysis on the correlationship between soil water capacity and annual highest biomass of *Stipa grandis* grassland. Grassland China 8: 29-34.
Chen YY, Xie YZ (2004). Review of studies on vegetation in process of deteriorated grassland instauration. J. Ningxia Agr. Univ. 25: 21-24.
Cheng J, Hu TM, Cheng JM (2010). Responses of vegetation restoration to climate change during the past 30 years in enclosed grassland of Yunwu-Mountain in semi-arid region of the Loess Plateau. Acta Ecol. Sin. 30: 2630-2638.
Frank AB, Bauer A (1991). Rooting activity and water use during vegetative development of crested and westen wheatgrass. Agr. J. 83: 906-910.
Gaur NU, Raturi GP, Bhatt AB (2003). Quantitative response of vegetation in glacial moraine of central Himalya. Environmentalist, 23: 237-247.
He YF, Zhao MX, Wang JX, Zhang HS (2008). Response of grassland productivity to climate change in the farming pasturing interlocked area of Inner Mongolia: a case study of Duolun County. Arid Meteorol. 26: 84-89.
Huang FX, Fu DS, Liu ZD (2001a). Study on the relationship between aboveground biomass of the *Artemisia phaerocephala-Stipa bungeana* community and climate variables at sandy grassland Erdos Plateau. Acta Agrestia Sin. 9: 148-153.
Huang FX, Gao Q, Fu DS, Liu ZD (2001b). Relation between climate variables and the aboveground biomass of *Thymus mongolicus-Stipa bungeana* community in steppe of Ordos Plateau, Inner Mongolia. Acta Ecol. Sin. 21: 1339-1346.
IPCC (2007). Climate change 2007 the physical science basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge and New York.
Kerr J (2001). Global biodiversity patterns: from description to understanding. Trend Ecol. Evol. 16: 424-425.
Li B (1990). Study on natural resources and environment on the Ordos plateau, Inner Mongolia. Science Press, Beijing, pp. 97-102.
Liu DY, Fu N, Fan JL (2008). Dynamic change of vegetation cover and its reponse to climate change in recent 20 years in Tianjin area. Ecol. Environ. 17: 798-801.
Ma KP, Qian YQ (1998). Biodiersity conservation and its research progress. Chin. J. Appl. Environ. Biol. 4: 95-99.
Nature reserve management office of Yunwu Mountain in Ningxia (2001). Collected works of scientific investigation and management of Nature reserve on Yunwu Mountain in Ningxia. Ningxia People Press, Yinchuan.
Pan RC, Dong Y (1995). Plant Physiology. Higher Education Press, Beijing. pp. 106-111.
Parmesan C, Yohe G (2003). A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421: 37-42.
Rahbek C (1995). The elevational gradient of species richness: a

uniform pattern? Ecography, 18: 200-205.
Rong YP, Han JG, Wang P, Huo CJ, Yan GZ, Wu DP (2001). Effects of different grazing intensities on the regrowth characteristics of the Herbage. Acta Agrestia Sin. 9: 92-98.
Root TL, Price JT, Hall KR, Schneider SH, Rosenzweig C, Pounds JA (2003). Fingerprints of global warming on wild animals and plants. Nature, 421: 57-60.
Shinoda M, Nachinshonhor GU, Nemoto M (2010). Impact of drought on vegetation dynamics of the Mongolian steppe: A field experiment. J. Arid Environ. 74: 63-69.
Vetaas OR, Grytnes JA (2002). Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. Global Ecol. Biogeog. 11: 291-301.
Wang YF (1991). Vegetation resources and rational utilization in Loess Plateau region. Science and Technology Press of China, Beijing.
Xie HS, Chen ZX, Zhao YX (1994). Study on the characteristics of climate and the dynamics of climate-plants growth index and sheep husbanorial production in the ecotone on the Ordos plateau. Acta Ecologica Sin. 14: 355-365.
Zhang N, Liang YM (1999). Comparative studies on above ground numerical characteristics and their relationships with soil moisture of two kinds of natural grassland in Loess hilly region. Acta Bot. Boreali-Occidentalia Sin. 19: 494-501.
Zhang XS (1994). Principles and optimal models for development of Maowusu sandy grassland. Acta Phytoecol. Sin. 18: 1-16.
Zhang ZT (2004). Studies on the grassland resources. Symposium of Zhang Zutong. Press of University of Inner Mongolia, Hohhot.
Zhou W, Xue SM (2007). A review of studies on effects of grazing on the succession of vegetation community on artificial grassland. J. Yunnan Agr. Univ. 22: 251-254.