SIMULATION OF GRASS PHENOPHASES IN INNER MONGOLIA, CHINA

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ABSTRACT
Improved understanding of grass developmental responses to environmental conditions can lead to more reliable predictions of herbage production, and may help in the design of plants that are better matched to their environment. There are modules in most crop growth models to simulate plant phenological development but not to model grass development on natural grassland. An algorithm to quantify the relationship between phenology and environmental factors including temperature, photoperiod and soil moisture was proposed in this paper. A dataset of phenological observation for four natural perennial grass species: *Allium anisopodium*, *Stipa baicalensis*, *Cleistogenes squarrosa* and *Artemisia frigida* from 1995 to 2007 was used to validate the model. The results showed that the model could simulate phenology of the species with acceptable accuracy.

Keywords: simulation, grassland, grass development, phenology

1. INTRODUCTION

The observation of the timing of plant emergence and flowering is a long-standing feature of human societies because plant phenology is a comprehensive reflection of climatological and ecological systems and the indicators of climate change (Leith, 1974; Fang and Yu, 2002; Fitter and Fitter, 2002; Dose and Menzel, 2004). Recently there has been a resurgence of interest in plant phenology because of climate change. Global climate change has increased the length of the growing season in temperate regions by as much as 12–18 d over the last two decades of last century (Zhou et al., 2001). This includes an earlier onset of the growing season (Menzel et al., 2006), as well as an extension of the growing season in the autumn.

Developmental processes are recognised either via changes in the number (not the size) of plant organs, or via the time taken for particular morphological events such as flowering. Thus, plant development may be measured via the number of leaves formed and, as leaves die, plant senescence and the onset of dormancy. Important stages can also be defined that enable estimates of the speed of plant development to be made (Porter et al., 1987). Plant development is heavily dependent on both high and low temperatures for the control of the rate of development and the switch from the vegetative to the reproductive state. The rate of development is affected by temperature in the ways: (1) a period of low temperature early in development hastens progress towards flowering in many temperate plant species and cultivars - this is low-temperature vernalisation; (2) besides vernalisation, progress towards flowering is normally hastened by a temperature increase between a base value and an optimum. Responses across this suboptimal range of temperatures can be modified by photoperiod or vernalisation; and (3) above the optimum temperature further warming causes the developmental rate to decelerate. Although temperature is major dominant element on controlling plant development, there are other environmental factors playing a role in it, e.g. photoperiod and the status of soil moisture in the root zone.

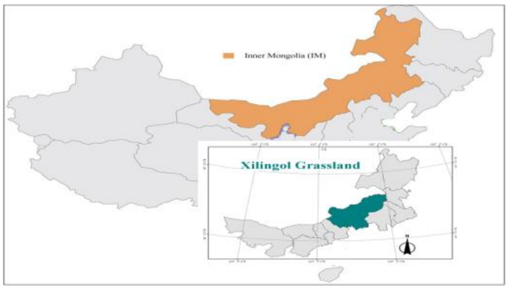

Figure 1: Location of Xilingol Steppe in Inner Mongolia, China

There are modules in most crop growth models to simulate plant phenological development but not to model grass development on natural grassland. The objective of the paper is to describe the algorithm to quantify the relationship between grass phenological development and environmental factors including temperature, photoperiod and soil moisture. A dataset of phenological observation for four natural perennial grass species in Xilingol steppe of Inner Mongolia, China was used to validate the model. The Xilingol steppe located at the latitude of 43°57'N, the longitude of 116°04'E and the altitude of 989.5m above the sea level(Figure 1).

2. MATERIALS AND METHODS

2.1. Climate Change Background

Xilingol steppe not only provides a natural biological defence for northern china, but also is the most important animal husbandry productive place. Xilingol grassland was degenerate since 1980. The serious problem was that the degenerate speed is not being slowly, but accelerated. Some researcher reported that it was caused by over graze in grassland (Qing-feng,L et al, 2002), but others reported that it was caused by climate change (Yang, H et al, 2009).

Dominated by a continental climate, Xilingol grassland has a windy spring and winter, with frequent droughts in spring and summer, sometimes even a long drought period lasting from spring until autumn. The consequence of this is that the ecosystems in the region are fragile and sensitive to a changing climate. As global temperature changes, annual mean temperature in Xilingol also has the tendency to rise (Table 1 and Figure 1). The annual precipitation has the tendency to decrease (Figure 2), and the sunshine hours has also decrease (Figure 3).

Table 1: Annual Climate Change Tendency in Xilingol Grassland

Years	Temp* ℃/10a	Tmax ℃/10a	Tmin ℃/10a	Prec mm/10a	Suns hr/10a
1961-1990	.24	.03	.54	-.13	5.22
1971-2000	.54	.42	.68	7.52	-5.22
1981-2010	.66	.68	.60	-14.13	-6.89

Temp: annual mean temperature

Tmax: annual mean maximum temperature

Tmin: annual mean minimum temperature

Prec: annual precipitation

Suns: annual sunshine hour

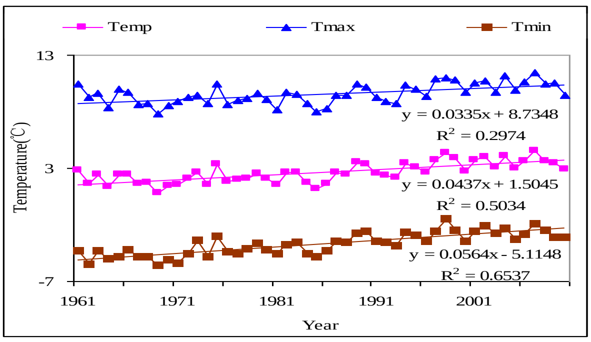

Figure 2: Annual Mean Temperature Tendency in Xilingol Grassland

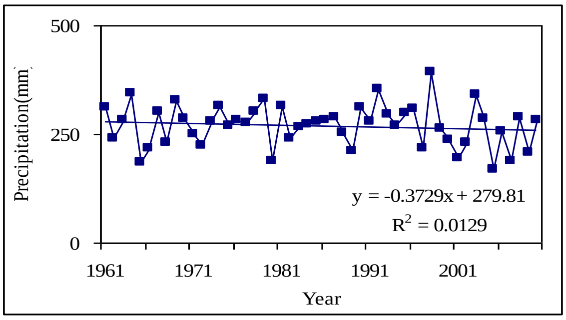

Figure 3: Annual Precipitation Tendency in Xilingol Grassland

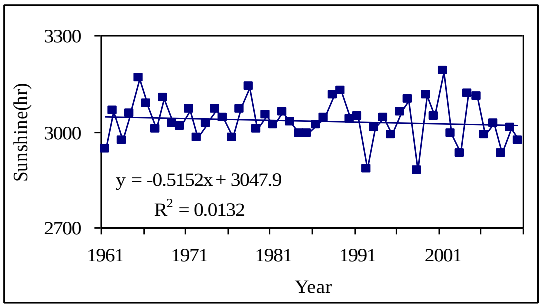

Figure 4: Annual Sunshine Hours Tendency in Xilingol Grassland

Table 2: Climate Change Tendency from Different Season in Xilingol Grassland

season	Years	Temp* ℃/10a	Tmax ℃/10a	Tmin ℃/10a	Prec mm/10a	Sunl hr/10a
Spring	1961-1990	0.2	-0.1	0.5	-1.3	4.4
	1971-2000	0.6	0.5	0.7	3.2	-2.9
	1981-2010	0.5	0.4	0.5	6.7	-18.6
1961-2010		0.4	0.2	0.6	2.4	-6.9
Summer	1961-1990	0.0	-0.1	0.3	-2.2	4.3
	1971-2000	0.4	0.3	0.6	7.5	-5.6
	1981-2010	0.8	0.8	0.6	-19.4	10.3
1961-2010		0.4	0.3	0.5	-6.4	3.5
Autumn	1961-1990	0.3	0.0	0.7	1.7	-2.1
	1971-2000	0.5	0.4	0.6	-4.3	2.4
	1981-2010	0.8	0.8	0.6	-0.6	2.8
1961-2010		0.5	0.4	0.6	-0.4	-1.1
Winter	1961-1990	0.1	0.0	0.3	1.1	7.4
	1971-2000	0.9	0.8	1.1	0.7	0.5
	1981-2010	0.8	0.9	0.8	-1.0	1.2
1961-2010		0.5	0.4	0.6	0.5	3.1
Growing Season	1961-1990	0.0	-0.3	0.4	-2.7	9.5
	1971-2000	0.5	0.3	0.6	7.3	-7.0
	1981-2010	0.7	0.6	0.6	-14.1	-2.5
1961-2010		0.4	0.2	0.5	-4.8	-0.5

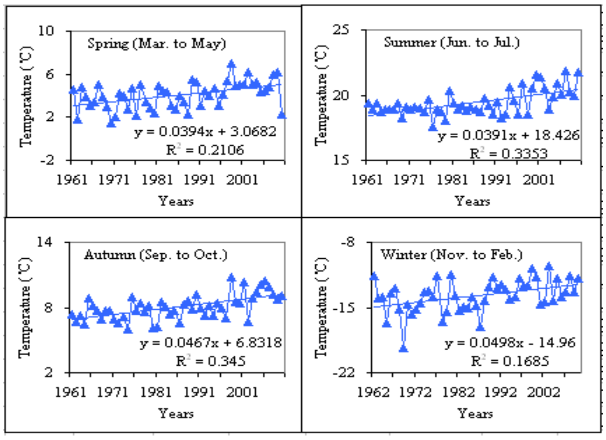

Figure 5: The Seasonal Temperature Change Tendency in Xilingol Grassland

The climate change is different in each season. In the periods of temperature increase, whether it were annual, winter or spring temperatures, mean minimum temperatures increased more than mean temperatures, with the exception of summer and autumn for the later observational period. The spring and winter temperatures (minimum as well average) of 1971 - 2000 increased much faster than those during the baseline period of 1961 to 1990. From the 1981-2010, the summer and autumn temperature increased much faster than those period 1961 to 1990 and 1971 to 2000 (Table 2). Season climate change tendency can be see in figure 4 and figure 5.

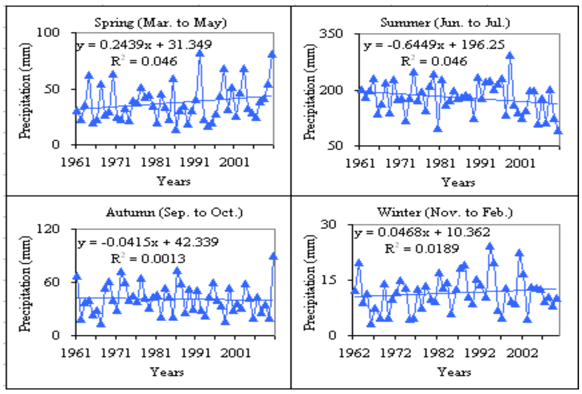

Figure 6: The Seasonal Precipitation Change Tendency in Xilingol Grassland

The spring precipitation tendency is increase and the summer precipitation tendency is decrease. Autumn and winter has no more change.

2.2. Phenological Observation

Phenology of plants is a comprehensive reflection of seasonal climatological and cyclic ecological conditions and may be used as an indicator of climate change (Lieth, 1984; Fang & Yu, 2002; Dose and Menzel, 2004; Li, et al., 2005). The phenological studies based on the European Monitoring Network showed that phenology in spring advanced significantly and events in autumn were extended. The International Phenological Garden (IPG) data gathered from 1959-1993 in European countries revealed that the growing season has extended by 10.8 days since the 1960s while the beginning of spring phenology advanced by 6 days (Roetzer et al., 2000; Estrella and Sparks, 2007).

Similar results were observed from the China Phenology Observing Network. It showed that spring phenology advanced and autumn phenology was delayed in North and Northeast China (Fang and Yu, 2002; Zheng, Ge and Zhao, 2003; Tao, Masyuki, Yokozawa and Xu, 2006; Yurong, W, et al, 2010).

But for natural perennial grass species the result is different from woody and herb plants. All four grass species spring phenology was delayed. Three of four grass species flowering phenology was advanced, and half grass species withered phenology was advanced.

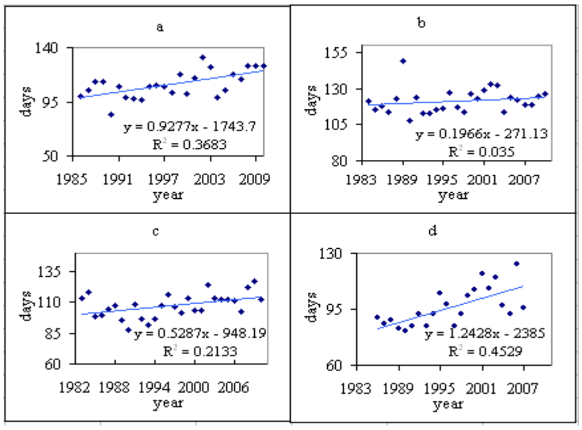

Figure 7: Four Grass Species Regrowth Phenology in Xilingol Grassland (a. *Allium anisopodium* b. *Cleistogenes squarrosa* c. *Stipa baicalensis* d. *Artemisia frigida*)

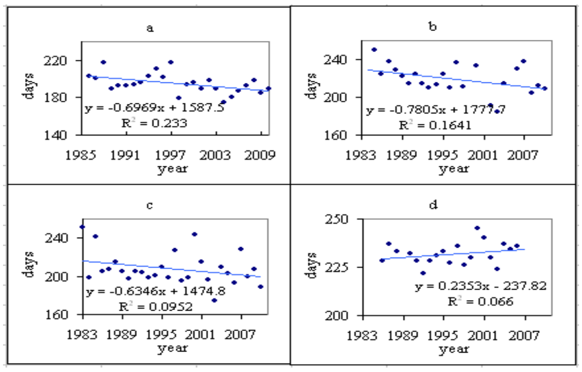

Figure 8: Four Grass Species Flowering Phenology in Xilingol Grassland (a. *Allium anisopodium* b. *Cleistogenes squarrosa* c. *Stipa baicalensis* d. *Artemisia frigida*)

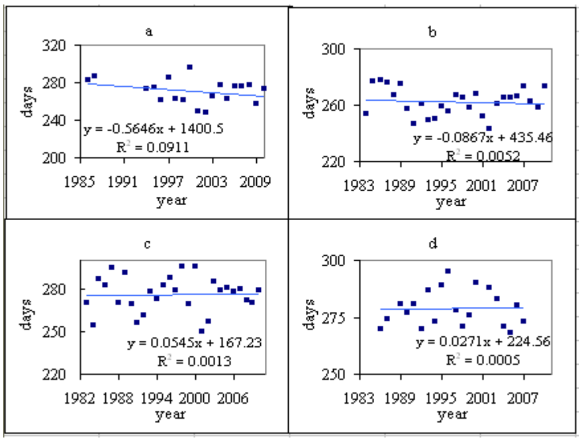

Figure 9: Four Grass Species Withered Phenology in Xilingol Grassland (a. *Allium anisopodium* b. *Cleistogenes squarrosa* c. *Stipa baicalensis* d. *Artemisia frigida*)

2.3. Model development

Plant development is estimated based on its requirement for heat, expressed in degree.days, and threshold temperatures during different stages. It is divided into three periods for perennial grasses: regrowth - flowering, flowering – withered and withered – regrowth (dormancy). The development index is expressed as:

$$Development\ index = \sum \frac{T_{add}}{ADD} \qquad (1)$$

where *ADD* is an required accumulated degree-days for a given period and Tadd is accumulated temperature from the beginning of a given period to the current time of simulation when it is still within the period.

$$T_{add,i} = \begin{cases} T_{a,i} \times \left[1 - e^{kp \times (Dayl_i - photop)}\right] & (T_{a,i} \geq T_c) \\ 0 & \end{cases} \qquad (2)$$

where $T_{a,i}$ is air temperature on the *i* day, $Dayl_i$ is day length (hr) on the *i* day, T_c is threshold temperature for a given development stage below which there is no temperature accumulated. *kp* is a photo-period response control parameter, and *photop* is critical photo-period during vegetative stage (hr). For long-day plants, it is zero when day-length on the day is shorter than pp_c.

The sigmoid function described by Streck et al. (2003) was chosen to be implemented in order to avoid introducing more parameters into the model:

$$f(VD) = \frac{VD^5}{22.5^5 + VD^5} \qquad (3)$$

where *VD* is cumulated vernalisation days since emergence of an over-winter plant. Because of the nature of the sigmoid curve, the function approaches to its maximum value only as VD approaches ∞. It would be possible for plant to have an indefinite period for the process. For simplification, it is assumed the vernalisation process finishes when the function is greater than 0.95.

One VD is attained when the plant is exposed to the optimum temperature for a period of one day. As temperature departs from the optimum, only a fraction of one VD is accumulated by the plant at a given calendar day:

$$VD = \sum_{i=0}^{n} f_{VD,i} \qquad (4)$$

and

$$f_{VD,i} = \begin{cases} 0.0 & (T_i \leq T_{vmin} \ \ or \ \ T_i \geq T_{vmax}) \\ \dfrac{T_i - T_{vmin}}{T_{vopt} - T_{vmin}} & (T_{vmin} < T_i \leq T_{vopt}) \\ \dfrac{T_{vmax} - T_i}{T_{vmax} - T_{vopt}} & (T_{vopt} < T_i < T_{vmax}) \end{cases} \qquad (5)$$

where T_i is daily average temperature at the given day *i*, and T_{vmin}, T_{vopt} and T_{vmax} are minimum, optimum and maximum temperatures that control the response function to air temperature, respectively.

In order to consider the effect of soil water on plant development, a reduction on daily accumulated temperature was made during vegetative and reproductive stages. When the ratio of actual evapotranspiration rate to potential evapotranspiration rate is less than a usr-defined critical ratio value, 30% and 40% of accumulated temperature on that day was reduced during the period of regrowth – flowering and that of flowering – defoliation, respectively.

2.4. Observational data

Phenological data came from the Livestock Meteorological Experimental Station of Xilingol League, Inner Mongolia, located at the latitude of 43°57'N, the longitude of 116°04'E and the altitude of 989.5m above the sea level(Fig.1).

There are two native level livestock meteorological experimental stations in China. Xilingol station is one of them. Except routine weather observation items, the station have other four kind of observation work. One is natural phenology work, which include woody, herb plant and migratory bird phenology. Second is grass growth and developmental, include phenology and biomass. The third is soil moisture. And the last one is livestock gain weight.

Woody plants:*Populus tomentosa*, *Salix babylonica L.* and *Ulmus pumila L.* Herb plants:*Taraxacum mongolicum*, *Plantago asiatica* and *Iris ensata*. Migratory birds:*Anser fabalis serrirostris* and *Hirundo rustica gutturalis Scopoli.*

More than seven grass species are observed phenology and height(Table 1).

Table 1: Observation Grass Species in Xilingol

Chinese name	Latin Name	Data length	Validate Species
Xiyecong	*Allium tenuissimum*	1986-2010	
Chaoyinzicao	*Cleistogenes squarrosa*	1984-2010	*
Mudifu	*Kochia prostrata*	2002-2010	
Aicong	*Allium anisopodium*	1986-2010	*
Keshizhenmao	*Stipa krylovii*	1983-2010	*
Lenghao	*Artemisia frigida*	1986-2007	*
Yangcao	*Leymus chinensis*	1983-2010	

The plot is fixed. Effect on climate change or weather conditions some grass species can not be observed in some years. For example, Due to succession drought *Leymus chinensis* can not be monitor in some years. Sometime it can be monitor the regrowth, but can not be see the flowering. Although it is key constructive species in Xilingol steppe. Therefore, the follow four grass species are choose to validate model. There are *Allium anisopodium*, *Stipa baicalensis*, *Cleistogenes squarrosa* and *Artemisia frigida*
The most three important phenophases of regrowth, flowering and withering of dominated recorded was used from 1995 to 2007.
Weather data are required to simulate phenological development of the species. As the temporal iteration step is daily-time-step-based, daily maximum and minimum air temperatures, wind speed and precipitation (for water cycle) are essential in the weather dataset. Both daily solar radiation above the canopy and net radiation are estimated from other relevant weather elements.

3. RESULTS AND DISCUSSION

Table 1: Comparison Between Simulated (Sim.) and Observed (Obs.) Flowering Dates of Six Perennial Grass Species (The Numbers Within the Table are Days Since the Beginning of a Year. '-' Indicates no Data Available)

Year	*Allium Anisopodium*		*Cleistogenes Squarrosa*		*Stipa Baicalensis*		*Artemisia Frigida*	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
1995	197	-	223	228	229	234	232	236
1996	193	-	219	225	218	235	218	233
1997	194	-	224	-	233	-	237	241
1998	187	187	211	218	207	218	207	232
1999	197	203	224	-	228	235	226	238
2000	188	-	225	240	227	-	231	260
2001	190	207	228	-	222	-	239	-
2002	203	-	233	203	243	-	230	232
2003	202	197	232	193	220	196	228	235
2004	189	186	222	223	227	230	224	246
2005	196	193	228	-	234	-	251	245
2006	197	187	224	230	232	230	262	236
2007	194	193	224	238	230	251	236	236

Simulation results for the dates of flowering and defoliation for those species were compared with observed dates (Table 1 and 2), which showed that the model could simulate the occurrence of phenophases with acceptable accuracy. Apparently there are discrepancies between simulated and observed dates. There may be several reasons contributed to the discrepancies. Firstly the model is a simplified assumption to mimic the dynamics of phenology on which many physiological and chemical processes control. It is necessary to improve the functionality of the model, especially the effect of soil water on them. And secondly actual phenophase could last several days even longer which inevitably causes the errors of observation. Among the species, the estimation for *Artemisia frigida* has the largest discrepancy compared with observed dates in individual years, which it is worth investigating it further.

Table 2: Comparison between simulated (sim.) and observed (obs.) withering dates of six perennial grass species (the numbers within the table are days since the beginning of a year. '-' indicates no data available)

Year	*Allium Anisopodium*		*Cleistogenes Squarrosa*		*Stipa Baicalensis*		*Artemisia Frigida*	
	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.	Sim.	Obs.
1995	246	248	252	250	262	255	283	289
1996	244	252	247	244	250	250	256	295
1997	238	-	252	-	272	-	301	278
1998	238	234	238	244	237	239	244	271
1999	240	237	251	-	255	257	259	276
2000	222	-	253	252	258	-	272	290
2001	233	241	254	-	245	-	269	-
2002	250	-	259	228	271	-	259	288
2003	255	240	267	220	250	243	272	283
2004	238	243	255	252	259	260	270	271
2005	234	246	253	-	256	-	294	268
2006	241	243	250	253	261	261	314	280
2007	239	-	250	-	254	270	268	273

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REFERENCES

Evans, W.A., 1994. Approaches to intelligent information retrieval. *Information Processing and Management*, 7 (2), 147–168.

Dose,V., and Menzel, A., 2004. Approaches to intelligent information retrieval. *Global Change Biology*, 10:259-272.

Fang,X., and W.Yu. 2002. Progress in the studies on the phenological responding to global warming. *Advance in Earth Sciences*, 17:714-719.

Fitter,A.H., and R.S.R.Fitter. 2002. Rapid changes in flowering time in British plants. *Sciences* 296:1689-1691.

Leith,H. 1974. Phenology and seasonality modeling. *Springer-Verlag, New York*.

Menzel,A., T.H.Sparks, N.Estrella, et al. 2006. European phenological response to climate

change matches the warming pattern. *Global Change Biology* 12:1969-1976.
Porter,J.R., E.J.M.Kirby, W.Day, et al. 1987. An analysis of morphological stages in Avalon winter wheat crops with different sowing dates and at ten sites in England and Scotland. *Journal of Agricultural Science* 109:107-121.
Streck,N.A., A.Weiss, and P.S.Baenziger. 2003. A generalized vernalization response function for winter wheat. *Agron. J.* 95:155-159.
Weir,A.H., P.L.Bragg, J.R.Porter, and J.H.Rayner. 1984. A winter wheat crop simulation model without water or nutrient limitations. *J. Agr. Sci.* 102:371-382.
Zhou,L.M., C.J.Tucker, R.K.Jaufmann, D.Slayback, N.V.Shabanov, and R.B.Myneni. 2001. Variations in northern vegetation activity inferred from satellite data of vegetation index during 1981 to 1999. *Journal of Geophysical Research Atmospheres.* 106:20069-20083.
Dose, V. and Menzel, A. 2004. Bayesian analysis of climate change impacts in phenology. *Global Change Biology*, 10, 259-272.
Tao, F., Masayuki, Yokozawa and Xu, Y.2006. Climate changes and trends in phenology and yields of field crops in china 1981–2000. *Agricultural and Forest Meteorology*, 138 , 82–92.
Zheng, J., Ge, Q. and Zhao, H. 2003. Changes of plant phenological period and its response to climate change for the last 40 years in china. *Chinese Journal of Agrometeorology*. 24, 28-33. (In Chinese)
Qingfeng, L, Fusheng, L and Lan, W. 2002. A primary analysis on climatic change and grassland degradation in Inner Mongolia. *Agricultural Research in the Arid Areas*. 20, 98-102. (In Chinese)
Yang, H, Yongfei, B, Yonghong, L and Xingguo, H. 2009. Response of Plant Species Composition and Community Structure to Long-Term Grazing In Typical Steppe of Inner Mongolia. *Chinese Journal of Plant Ecology*. 33, 499-507. (In Chinese)
Yurong, W, Yanfang C, Xuebiao P and Ruiqing G. 2010. The Impact of Climate Change on Phenology of Woody Plants in Inner Mongolia, China. *Proceedings of 2010 Climate Change and Ecosystem Response Conference*, 147-152. July, 2010. Inner Mongolia, China.

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