

Research Article

Responses of Plants' Phenology to Climate Warming in the Desert Area in Northwestern China

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Abstract: With climate warming, plants' spring phenology has advanced while autumn phenology has delayed. How does the phenology of desert plants respond to climatic variation? To reveal it, this study analyzed the phenological data of 22 desert species growing in the Minqin Desert Plants Botanical Garden located in the typical desert area in northwest China. The data was observed during the year 1974-2009. Results revealed that comparing with the literatures available, the temperature in the study area since 1974 rose more significantly and plants' growing periods were longer. Both the advance of arbor's spring phenology and the delay of herb's autumn phenology were obviously greater than that reported in available literature. The starting date of spring phenology advanced markedly. From 1974 to 2009, the starting date of spring phenology, the ending date of autumn phenology and plants' growing duration experienced 6 stages. The phenological changes in different stages were closely related to temperature variation.

Keywords: Climate warming, desert plants, minqin, plant phenology, response

INTRODUCTION

With global warming, the response of plant phenology to climate change has currently become a hotspot in phenological research. The studies abroad are mainly concentrated on the response of plants phenology to climate warming, dealing with issues like advance of spring phenology, delay of autumn phenology and lengthening of plants' growing periods (Menzel, 2002; Matsumoto *et al.*, 2003; Badeck *et al.*, 2004).

Studies on the correlation between climate and growing season variation were mostly conducted in Europe, with almost the same results. In the mid-latitude areas, plants' spring phenology depends on temperature changes (Chmielewski and Homas, 2001). In Europe, with the temperature rising by 1°C in early spring, the growing period had advanced by 7 days; and with the mean annual temperature rising by 1°C, the growing period had lengthened by 5 days (Frank *et al.*, 2001; White *et al.*, 1999). The American scholars concluded that since 1990s, the flowering period in southwestern America and northwestern Mexico had advanced with consecutive temperature rising (Janice, 2007). Plants cannot survive without favorable temperature and only under certain accumulated temperatures can they complete their living circle (Menzel, 2000).

Israeli researchers reported that water stress will not impact the phenology of annual desert plants but will slightly impact the flowering period. Water stress can accelerate plants' degeneration (Aronson *et al.*, 1992). El-Ghanif (1997) studied desert plants' phenology in Saudi Arabia. Ghazanfar (1997) studied the desert plants' phenology in the wadi in northern Oman. The results indicated that the start of flowering and the flowering period were closely correlated with precipitation and its duration; the total rainfall will not impact the flowering period of phanerophyte and chamaephyte, but will impact the start of flowering of annuals and hemicryptophyt.

In China, research on plant phenology is also focused on the correlation between phenology and climate warming (Zheng *et al.*, 2002; Ge *et al.*, 2003; Bai *et al.*, 2009). In recent decades, the spring phenology in high-latitude and mid-latitude areas has advanced to some extent, which ideally indicated the global warming trend and the regional differences (Ge *et al.*, 2010). The flowering dates of the 48 woody species in Beijing during 1990-2007 advanced by 5.4 days in contrast to that during 1963-1989. Among the 48 species, 70.8% advanced by 7 days, excepting one species with rather later flowering (Bai *et al.*, 2010). Climatic variation has obviously changed the vegetative growth and multiply phenology of many species (Xia *et al.*, 2012).

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The 17th International Conference on Biology & Climate held in German in 2005 suggested: the methods of phenology research are becoming diversified, more and more attention was paid to the study on the comparison of regional phenological variations (Dai *et al.*, 2006). The responses of desert climate to the global warming are diversified. Many ecological issues in the desert area may closely related to temperature rising (Hu *et al.*, 2001). However, there are few research findings concerning the phenology of desert plants.

Desert plants are a kind of important species. They are at a significant position in the desert ecosystem. The climate in the Minqin desert area is sensitive to global warming (Zhu and Chang, 2011). Research on the phenology of desert plants is one of the indispensable components in the study on the response of plants to global warming. With global warming, how do desert plants respond to climate change? Which species are more sensitive? Are there any differences among plants with different life-forms and eco-types in responding to climate change? This study attempts to answer these questions.

MATERIALS AND METHODS

Study site: The study was conducted at the Minqin Desert Botanical Garden (Fig. 1), which is located at the western fringe of the Tengger Desert in northwest China (102° 59'E, 38° 34' N), with an average elevation of 1378 m, annual mean temperature of 7.76°C, yearly average precipitation of 16.36 mm and annual average evaporation of 2383.7 mm. Mean aridity is 5.85 and annual average wind speed is 2.4 m/s. There are 27.4 days within a year during which wind velocity is bigger than 17 m/s. It is characterized by typical droughty desert climate. In Han dynasty (2200 years ago), there was a large area of water. However, desertification appeared since then and the environment was gradually degraded. Currently, the land is covered by undulating sand dunes, with a water table of 16-20 m. The natural

Table 1: Main species observed in Minqin desert botanical garden of desert plants

Family	No.	Species
Salicaceae	1	<i>Populus alba</i> var. <i>pyramidalis</i>
	2	<i>Populus gansuensis</i>
Rosaceae	3	<i>Prunus armeniaca</i>
Ulmaceae	4	<i>Ulmus pumila</i>
Leguminosae	5	<i>Robinia pseudoacacia</i>
	6	<i>Amorpha fruticosa</i>
	7	<i>Caragana korshinskii</i>
	8	<i>Caragana intermedia</i>
	9	<i>Medicago sativa</i>
	10	<i>Glycyrrhiza uralensis</i>
	11	<i>Sophora alopecuroides</i>
Rhamnaceae	12	<i>Ziziphus jujuba</i>
Oleaceae	13	<i>Forsythia suspense</i>
	14	<i>Syringa oblata</i>
	15	<i>Syringa oblata</i> var. <i>alba</i>
Tamaricaceae	16	<i>Tamarix elongata</i>
Solanaceae	17	<i>Lycium ruthenicum</i>
Chenopodiaceae	18	<i>Nitraria tangutorum</i>
Asteraceae	19	<i>Artemisia arenaria</i>
Chenopodiaceae	20	<i>Haloxylon ammodendron</i>
Ranunculaceae	21	<i>Paeonia suffruticosa</i>
	22	<i>Paeonia lactiflora</i>

vegetation is dominated by xerophytic shrub, semi-shrub and herb.

Materials: Minqin Desert Botanical Garden was listed as a site of national phenology observation network by the Institute of Botany, Chinese Academy of Sciences in 1974. Since then, 108 species (20 arbor, 68 shrub and 40 herb) were observed, 15 phenophases for each. During the observation, some species were added later while some disappeared. In this study, 22 species (8 species of arbor or small arbor, 10 species of shrub or semi-shrub and 4 species of herb) with complete observational data (Table 1) were selected for analysis. The observational data collected during 1974 -2009 was used in this analysis.

Among the species, *Artemisia arenaria* and *Nitraria tangutorum* are the representative species of the natural shrubs in local area. *Artemisia arenaria* is widely distributed from the middle to lower parts of semi-fixed and mobile sand dunes, as well as

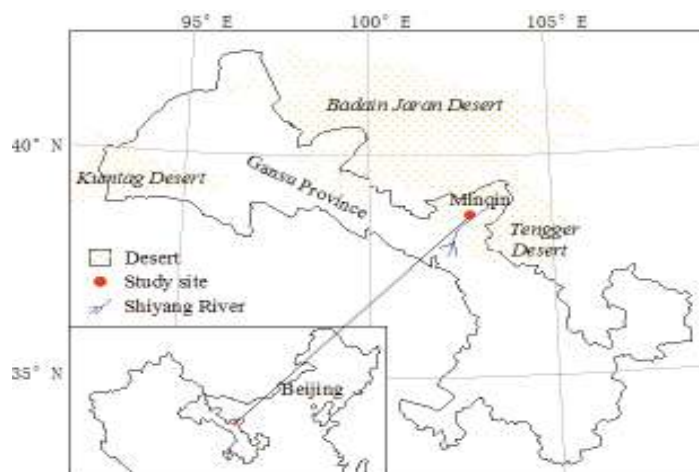


Fig. 1: Location of the study site

Table 2: Average dates of phenophases appearance of 22 species

Phenophases	Sequence	Avg. date	S.D.
Bud-expansion	1	Apr. 1	3.18
Bud-opening	2	Apr.11	2.73
Beginning of leaf extension	3	Apr. 23	2.36
Leaf flourishing	4	May 2	2.27
Flower-bud appearance	5	May 2	2.56
Beginning of flowering	6	May 14	2.27
Flower flourish	7	May 22	1.94
End of flowering	8	Jun. 3	2.20
Fruit maturity	9	Jul.26	1.27
Beginning of fruit drop	10	Aug. 5	0.87
End of fruit drop	11	Aug.22	0.98
Beginning of leaf-discoloration	12	Sep.28	2.89
Full leaf-discoloration	13	Oct.15	2.54
Beginning of leaf fall	14	Oct.11	2.26
End of leaf fall	15	Oct.28	2.30

Avg.: Average; S.D.: Standard deviation

inter-dune depressions. Statistics show that there was $6.642 \times 10^4 \text{ hm}^2$ of *Nitraria tangutorum* in the study area in 2002. *Haloxylon ammodendron* is the pioneering sand-fixation species in local area and currently there is $4.4 \times 10^4 \text{ hm}^2$ of artificial *Haloxylon ammodendron* forests in Minqin County.

Methods for observation and analysis: Phenological observation was carried out in accordance with the “Chinese phenological observation standard” (Wan and Liu, 1987). It was done once two days during the growing period, with 3-5 individuals for each species as replication. The observation covered 15 phenophases (Table 2). Bud expansion is the starting point while the end of leaf-fall is the ending point of phenology. The meteorological data was derived from the ground weather station installed in the Minqin Integrated Desert Control Experiment Station (1.5 km away from the study site). The observation was done following the meteorological observation standards formulated by the Chinese State Meteorology Bureau.

The variations of both the starting dates of growing periods and the total growing periods were expressed in *Julian days*. Spring phenology refers to the duration from bud expansion to the end of flowering and autumn phenology refers to the duration from leaf-discoloration to the end of fruit-drop. Bud expansion is the starting of spring phenology and the end of leaf-fall is the ending of autumn phenology. Growing period refers to the duration from bud expansion to the end of leaf-fall. Data was analyzed using SPSS 13.0 software. Linear equation with one unknown quantity was applied in analyzing the variation trends of the air temperature, growing period, precipitation and air humidity. The correlation between air temperature, precipitation, air humidity and phenology was expressed with the Pearson correlation coefficient. The differences of phenological variations of plants with different ecotypes and life-forms were analyzed using the one-way ANOVA.

Ninety five percent confidence level was used for significance tests of regression trend and relevant coefficients, as well as for variance test.

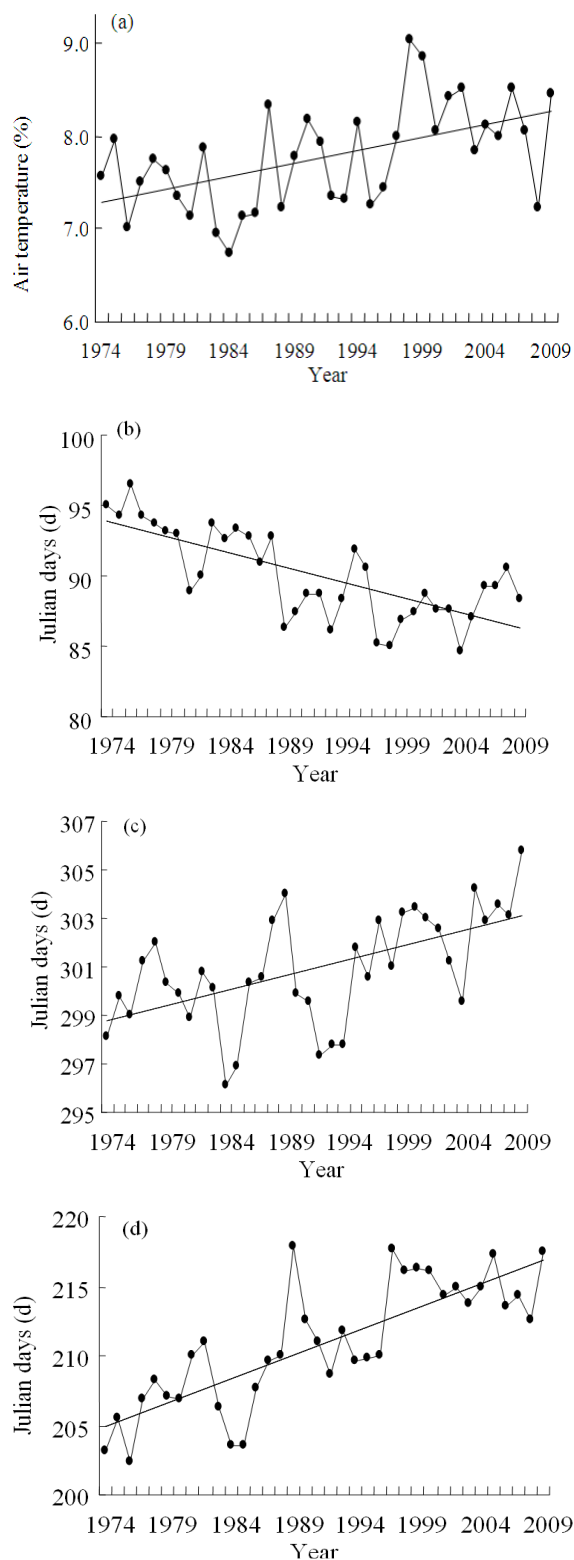


Fig. 2: (a) Variation trend of annual mean temperature during 1974-2009, (b) variation trend of the starting date of spring phenology during 1974-2009, (c) variation trend of the ending date of autumn phenology during 1974-2009, (d) variation trend of the growing duration during 1974-2009

RESULTS AND ANALYSIS

During the period of 1974 -2009, the temperature in the study site showed a clearly increasing trend ($p < 0.01$) (Fig. 2a) at the rate of $0.27^{\circ}\text{C}/10\text{a}$; in terms of monthly average temperature, the high increasing rate can be found in March, February, April, May, June, July and December, whereas the temperatures in January and August showed a decreasing trend. Only in March, April, May and July did the temperature showed an evidently increasing trend ($p < 0.05$).

From 1974 to 2009, the starting dates of spring phenology (starting from the bud expansion, the same hereinafter) showed a clearly advance trend ($p < 0.01$) (Fig. 2b), advanced by 7.57 days in 36 years. The ending date of autumn phenology (the end of leaf-fall, the same hereinafter) displayed a noticeable delay trend ($p < 0.01$) (Fig. 2c), 4.33 days delayed in 36 years. The growing period showed an obvious lengthening trend ($p < 0.01$) (Fig. 2d), 11.9 days lengthened in 36 years.

Phenological variation of plants with different ecotype:

As for mesophyte during 1974-2009, the growing period showed a lengthening trend ($p < 0.01$) at a rate of 0.36 days/a, lengthened by 12.60 days in 36 years; the starting date of spring phenology presented an advance trend ($p < 0.01$) at the rate of -0.26 days/a, advanced by 9.17 days in 36 years; the ending date of autumn phenology showed a delay trend ($p < 0.01$) at the rate of 0.10 days/a, delayed by 3.44 days in 36 years. As for xerophyte, the growing period showed a lengthening trend ($p < 0.01$) at a rate of 0.36 days/a, lengthened by 10.89 days in 36 years; the starting date of spring phenology presented an advance trend ($p < 0.01$) at the rate of -0.15 days/a, advanced by 5.26 days in 36 years; the ending date of autumn phenology showed a delay trend ($p < 0.01$) at the rate of 0.16 days/a, delayed by 5.62 days in 36 years. Mesophyte's growing duration was significantly longer than xerophyte's ($p < 0.01$) (Fig. 3a and b).

The spring phenology of mesophyte advanced more days than that of xerophyte, whereas the autumn phenology delayed fewer days than that of xerophyte. The ANOVA significance test showed the bud-expansion, bud-opening and the beginning of leaf extension of mesophyte advanced significant more days than those of xerophyte ($p < 0.01$), whereas the end of fruit drop, beginning of leaf-discoloration, full leaf-discoloration, beginning of leaf fall and end of leaf fall of mesophyte delayed significant less days than those of xerophyte ($p < 0.01$).

Phenological variation of plants with different life-form:

As for arbor during 1974-2009, the growing period showed a lengthening trend ($p < 0.01$) at a rate of 0.34a^{-1} , lengthened by 11.86 days in 36 years; the starting date of spring phenology presented an advance trend ($p < 0.01$) at the rate of -0.25 days/a, advanced by

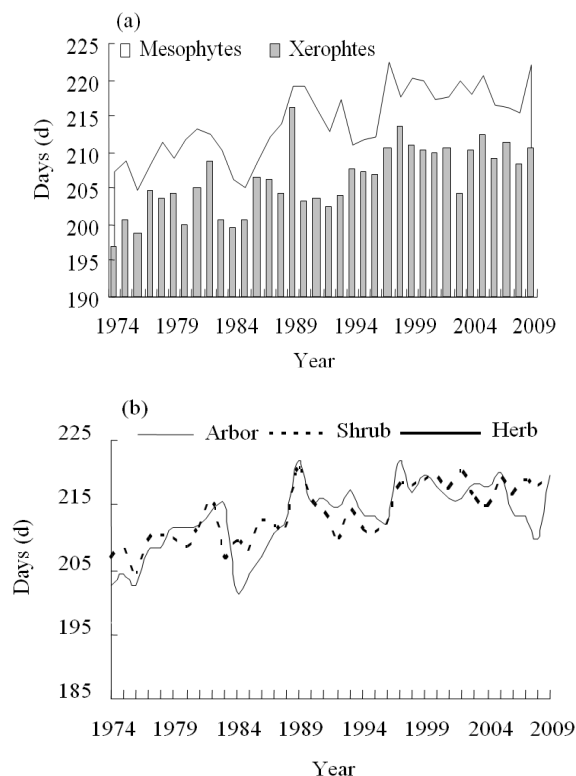


Fig. 3: (a) Differences of the growing duration between mesophyte and xerophyte during 1974-2009, (b) differences of the growing duration among arbor, shrub and herb during 1974-2009

8.58 days in 36 years; the ending date of autumn phenology showed a delay trend ($p < 0.05$) at the rate of 0.09 days/a, delayed by 3.29 days in 36 years. As for shrub, the growing period showed a lengthening trend ($p < 0.01$) at a rate of 0.34 days/a, lengthened by 12.02 days in 36 years; the starting date of spring phenology presented an advance trend ($p < 0.01$) at the rate of -0.20 days/a, advanced by 7.15 days in 36 years; the ending date of autumn phenology showed a delay trend ($p < 0.01$) at the rate of 0.14 days/a, delayed by 4.87 days in 36 years. As for herb, the growing period presented a lengthening trend ($p < 0.01$) at the rate of 0.33 days/a, lengthened by 11.68 days in 36 years; the starting date of spring phenology displayed an advance trend ($p < 0.01$) at the rate of -0.19 days/a, advanced by 6.59 days in 36 years; the ending date of autumn phenology showed a delay trend ($p < 0.05$) at the rate of 0.15 days/a, delayed by 5.09 days in 36 years.

The growing duration of arbor and shrub the average advance duration of spring phenology of arbor was longer than those of shrub and herb; whereas its delay duration of autumn phenology was shorter than those of shrubs and herbs. Both the advance days of spring phenology and delay days of autumn phenology of shrubs were slightly longer than that of herbs. Analysis from ANOVA showed the advance durations

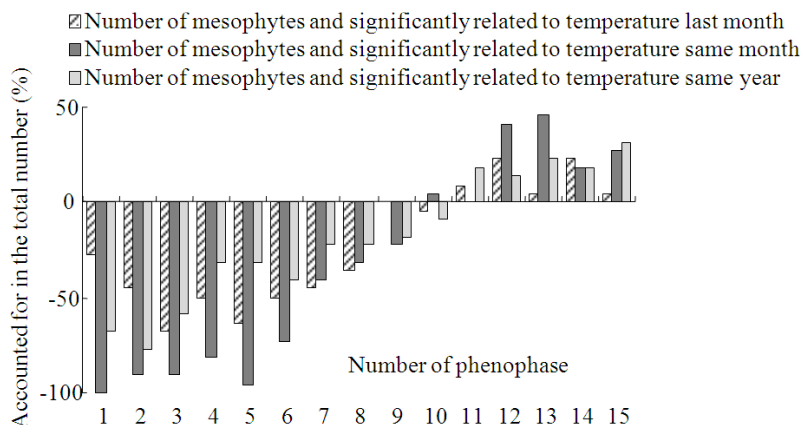


Fig. 4: Percentage of plants whose phenological variations are significantly correlated to air temperature

of bud-opening, the beginning of leaf-extension, the beginning of flowering and the end of flowering of arbors were significantly longer than those of shrubs ($p < 0.01$); whereas, the delay durations of full leaf-discoloration and the beginning of leaf-fall of arbors were significantly shorter than those of shrubs ($p < 0.01$), the difference of the beginning of flowering of shrubs was significantly smaller than that of herbs ($p < 0.01$).

Sensitive phenophases correlated to air temperature:

In the 15 phenophases of 22 species, the advance of bud-expansion of 100% of the species (22 species) were significantly negatively correlated with temperature rising in the current month ($\alpha < 0.05$); the advance of flower-bud appearance of 95.5% of the species (21 species) were significantly negatively related to temperature rising in the current month ($\alpha < 0.05$); the advance of bud-opening and the beginning of leaf-extension of 90.9% of the species (20 species) were significantly negatively related to temperature rising in the current month ($\alpha < 0.05$), the advance of leaf flourishing of 81.8% of the species (18 species) were significantly negatively related to temperature rising in the current month ($\alpha < 0.05$); the advance of the beginning of flowering of 72.7% of the species (16 species) were significantly negatively related to temperature rising in the current month ($\alpha < 0.05$). The variation of remaining phenophases of less than 50% of the species was significantly related to temperature rising in the current month. The delay of the beginning of leaf-coloration, full leaf-discoloration, the beginning of leaf-fall and the end of leaf-fall were positively correlated with temperature rising in the current month (Fig. 4).

The correlation between phenological variation and climatic variation are characterized as:

- The negative correlation between the phenology advance and temperature rising in current month from high to low was: bud-expansion, flower-bud appearance, bud-opening and the beginning of leaf extension, leaf flourish, the beginning of flowering,

flower-flourishing, the end of flowering, fruit maturity, the beginning of fruit-drop; the positive correlation between phenology delay and temperature rising in current month from high to low was in an order as: full leaf-discoloration, the beginning of leaf-discoloration, end of leaf-fall, the beginning of leaf-fall.

- In early spring after bud expansion, the positive correlation between phenology advance and temperature rising in the current month became weak gradually.
- The effect of air temperature on plant phenology from high to low was in an order as: the average air temperature in the current month, the average air temperature in the current year, the average air temperature in the preceding month.

DISCUSSION

Since 1974, the temperature in the study area showed a significant rising trend and the duration of temperature rising was longer than that reported in literatures available. During 1974-2009, plants' growing duration was longer in contrast to the findings in the literatures available. But both the advance days of mesophyte's and arbor's spring phenology and the delay days of xerophyte's and herbs autumn phenology were longer than those reported in the literatures available.

The advance of phenophase with temperature rising was ranked from earlier to later as: bud-expansion, bud-opening, beginning of flowering, beginning of leaf-extension and leaf flourish, flower-bud appearance, flower flourishing, end of flowering, fruit-maturity. The delay of phenophase with temperature rising was ranked from later to earlier as: full leaf-discoloration, beginning of leaf-fall, beginning of leaf-discoloration, end of leaf-fall. There are more phenophases in spring as the temperature rises more quickly in spring. Therefore, the impact of temperature rising in spring on plants' phenology was greater than that of temperature rising in autumn.

From 1974 to 2009, the starting date of spring phenology, the ending date of autumn phenology and the growing duration of local plants experienced 6 stages. The growing duration showed a lengthening trend during 1974-1982, a shortening trend during 1982-mid 1987, a lengthening trend during 1987-1991, a shortening trend during 1991-1996, a lengthening trend during 1996-2002 and a shortening trend since 2002. The periodic phenological change was closely related to temperature variation.

Air temperature exerts a significant short-term impact on plants' phenology.

The advance days of mesophyte's spring phenology were longer than xerophyte's, whereas the delay days of mesophyte's autumn phenology were shorter than xerophyte's. Mesophyte is more sensitive than xerophyte to temperature rising in spring and also to temperature dropping in autumn.

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REFERENCES

- Aronson, J., J. Kige, A. Shmida and J. Klein, 1992. Adaptive phenology of desert and mediterranean populations of annual plants grown with and without water stress. *Oecologia*, 89: 17-26.
- Badeck, F.W., A. Bondeau, K. Böttcher, D. Doktor, W. Lucht, J. Schaber and S. Sitch, 2004. Responses of spring phenology to climate change. *New Phytol.*, 162: 295-309.
- Bai, J., Q.S. Ge and J.H. Dai, 2009. Response of woody plant phenophases to climate change for recent 30 years in Guiyang. *Geograph. Res.*, 28(6): 1606-1614.
- Bai, J., Q.S. Ge and J.H. Dai, 2010. The response of first flowering dates to abrupt climate change in Beijing. *Adv. Atmosph. Sci.*, Doi: 10.1007/s00376-010-9219-8.
- Chmielewski, F.M. and R. Homas, 2001. Response of tree phenology to climate change across Europe. *Agric. Forest Meteorol.*, 108(2): 101-112.
- Dai, J.H., J.Y. Zheng and Q.S. Ge, 2006. Current hotspot of study on international bio-meteorology. Proceeding of the 17th International Conference on Bio-meteorology Held in Garmisch: Partenkerchen in German. *Acta Geographica Sinica*, 61(2): 223.
- El-Ghanif, M.M., 1997. Phenology of ten common plant species in western Saudi Arabia. *J. Arid Environ.*, 35: 673-683.
- Frank, M., F.M. Chmielewski and R. Thomas, 2001. Response of tree phenology to climate change across Europe. *Agric. Forest Meteorol.*, 108(2): 101-112.
- Ge, Q.S., J.H. Dai and J.Y. Zheng, 2010. The progress of phenology studies and challenges to modern phenology research in China. *Chinese Acad. Sci.*, 25(3): 310-316.
- Ge, Q.S., J.Y. Zheng, X.X. Zhang and Z.X. Hao, 2003. Study on the variations of climate and plant phenology in China in the past 40 years. *Prog. Nat. Sci.*, 13(10): 1048-1053.
- Ghazanfar, S.A., 1997. The phenology of desert plants: A 3-year study in a gravel desert wadi in northern Oman. *J. Arid Environ.*, 35: 407-417.
- Hu, R.J., Z.L. Fan, Y.J. Wang, Q. Yang and Y.Y. Huang, 2001. Assessment about the impact climate change on environment in Xinjiang since recent 50 years. *Arid Land Geograp.*, 24(2): 97-103.
- Janice, E.B., 2007. Has climatic warming altered spring flowering date of Sonoran desert shrubs? *Southwestern Natur.*, 52(3): 347-355.
- Matsumoto, K., T. Ohta, M. Irasawa and T. Nakamura, 2003. Climate change and extension of the *Ginkgo biloba* L. growing season in Japan. *Global Change Biol.*, 9: 1634-1642.
- Menzel, A., 2000. Trends in phenological phases in Europe between 1951 and 1996. *Int. J. Biometeorol.*, 44(2): 76-81.
- Menzel, A., 2002. Phenology: Its importance to the global change community. *Climate Change*, 54: 379-385.
- Wan, M.W. and X.Z. Liu, 1987. The observation methods of phenology in China. Science Press, Beijing.
- White, M.Z., S.W. Running and P.E. Thornton, 1999. The impact of growing season length variability on carbon assimilation and evapotranspiration over 88 years in the eastern US deciduous forest. *Int. J. Biometeorol.*, 42(3): 139-145.
- Xia, F.C., C.F. Pan and X.H. Zhao, 2012. Plants phenological response to climate change of temperate deciduous forest. *Ecol. Environ.*, 21(5): 793-799.
- Zheng, J.Y., Q.S. Ge and Z.X. Hao, 2002. Impacts of climate warming on plants phenophases in China for the last 40 years. *Chinese Sci. Bull.*, 47(20): 1582-1587.
- Zhu, S.J. and Z.F. Chang, 2011. Temperature and precipitation trends in Minqin desert during the period of 1961-2007. *J. Arid Land*, 3(3): 214-221.