ANALYSIS ON RESPONSE OF VEGETATION INDEX IN ENERGY ENRICHMENT ZONE TO CHANGE OF HYDROTHERMAL CONDITION AND ITS TIME LAG IN THE NORTH OF SHAANXI, CHINA

QIANG LI[1*], CHONG ZHANG[2] AND ZHIYUAN REN[1]

Environment and Resource Management Department, Shaanxi Xueqian Normal University, Xi'an-710100, Shaanxi, China

Key words: Time lag, Cross correlation method, Hydrothermal condition, Energy enrichment zone

Abstract

Time lag cross correlation method is adopted to conduct analysis on intra-annual time lag response of vegetation coverage to hydrothermal condition based on ten-day average air temperature, precipitation data and Systeme Probatoire d'Observation de la Terre - normalized difference vegetation index (SPOT-NDVI) data in energy enrichment zone in the north of Shaanxi from 1999 to 2010. The vegetation coverage in the south of energy enrichment zone was better, characterized by high degree of correlation between ten-day NDVI (TN), ten-day mean temperature (TT) and ten-day precipitation (TP), correlation coefficient of more than 0.9, rapid response, lag time being 10 to 20 days. The windy sand grass shoal area in the south end of Mu Us desert was characterized by low degree of correlation between TN with TT and TP, correlation coefficient from 0.75 to 0.85 and longer response time, lag time for 30 to 50 days in most part of the zone, indicated that the zone with better hydrothermal condition was higher in degree of correlation and rapid in response speed and that the zone with poor hydrothermal condition was lower in degree of correlation and slow in response speed. Level of influence of Intra-annual change of air temperature on NDVI of vegetation is on the decrease from south to north. The response of vegetation to intra-annual precipitation was similar to temperature. The research finding may offer theoretical basis for optimization of type of vegetation planted in energy enrichment zone in the north of Shaanxi.

Introduction

Influence and feedback of climate change on ecological system of land surface are main content in global climate change research in current period. The vegetation and climate had also become a focus of attention in global climate change research in recent years (Xin *et al.* 2008, Salim *et al.* 2008). Change of surface vegetation in temporal and spatial scales has drawn attention from scholars both in China and abroad in their research. Research finding shows that global vegetation activity is gaining momentum and that the increase of vegetation in high latitude area in northern hemisphere is of extremely distinctive significant (Zhang *et al.* 2011), and that of America and Africa have become focus of attention in research (Paruelo *et al.* 1998, Anyamba *et al.* 2005). Scholars both here and abroad have conducted research on correlation between time series NDVI data and meteorological factor. The result shows that meteorological factor has greater influence on NDVI (Dai *et al.* 2010, Weiss *et al.* 2004,). In recent years, more research of spatial distribution, time difference and their relation with climate change related to vegetation coverage changes on various space and time scales has been conducted (Liu *et al.* 2007, Han *et al.* 2011) and less research of NDVI change pattern for various vegetation types has been made. More attention has been paid to research based on inter-annual relation and less attention paid to research of response of vegetation coverage to climate condition including hydrothermal factor

*Author for correspondence. <liqiangis@163.com>. [1]College of Tourism and Environment, Shaanxi Normal University, Xi'an-710119, Shaanxi, China. [2]Shaanxi Key Laboratory of Disaster Monitoring and Mechanism Modeling, Baoji University of Arts and Sciences, Baoji-721013, Shaanxi, China.

based on seasonal variation. Vegetation under the influence of climate factor shall generate lag effect to a certain effect, at the same time, change of vegetation shall also give feedback about climate (Hou *et al.* 2012, Zhang *et al.* 2005). Previous researches have mainly been based on zero time lag, in the present work time lag cross correlation method had been taken as entry point to conduct research of correlation between seasonal aspect of vegetation and hydrothermal condition and ten-day NDVI in energy zone in the north of Shaanxi, China so as to offer basis for promotion of ecological construction in energy enrichment zone.

Materials and Methods

The research area is located in the north of Shaanxi Province (35°21′-39°34′N, 107°28' - 110°31' E), including two prefecture-level cities, namely Yulin and Yan'an , with maximum cross distance from east to west of 385 km and width from south to north of 500 km and total area of about 80607 km^2 with four distinctive seasons and abundant sunshine. Since it is in inland with middle latitude, the north and north-west of the area is semiarid monsoon climate, its middle and south are warm temperate semiarid monsoon climate.

Data contain every ten-day mean temperature and precipitation data in energy enrichment zone from 1999 to 2010, 10-day maximun synthesized data, SPOT-NDVI data from 1999 to 2010, administrative map for the north of Shaanxi. TT and TP from 1999 to 2010 are obtained by IDW (Inverse Distance Weighted) interpolation based on 15 complete meteorological stations screened out in the north of Shaanxi and its surrounding region in Shaanxi Province, with the possibility of loss and error in record and acquisition of precipitation and air temperature data due to human factor taken into consideration.

Time lag cross correlation method is adopted to research the correlation between TT and TP and TN to determine actual effect of climatic factor on NDVI. Supposing time series of climatic factor and NDVI are $^x t$ and $^y t$, then they correlate with any time lag K, their cross correlation is expressed as:

$$r_k(x,y) = \frac{c_k(x,y)}{\delta_x \delta_{y+k}}$$

(1)

where, the covariance $C_k(x, y)$ and mean square deviation $^\delta x$, $^\delta y+k$ of sample is

$$\begin{cases} c_k(x,y) = \dfrac{1}{n-k} \sum_{t=1}^{n-k} \left(x_t - \overline{x_t}\right)\left(y_{t+k} - \overline{y_{t+k}}\right) \\[2ex] \delta_x = \sqrt{\dfrac{1}{n-k} \sum_{t=1}^{n-k} \left(x_t - \overline{x_t}\right)^2} \\[2ex] \delta_{y+k} = \sqrt{\dfrac{1}{n-k} \sum_{t=1}^{n-k} \left(y_{t+k} - \overline{y_{t+k}}\right)^2} \end{cases}$$

(2)

The mean value in equation is

$$\begin{cases} \overline{x_t} = \dfrac{1}{n-k}\sum_{t=1}^{n-k} x_t \\ \overline{y_{t+k}} = \dfrac{1}{n-k}\sum_{t=1}^{n-k} y_{t+k} \end{cases} \qquad (3)$$

where, n is sample number of series, k is lag time, k is positive value based on the practical situation mentioned in the paper. According to experience, time lag k shall be smaller than n/4. Since the research is to discuss intra-annual relation, and n is ten days, accordingly, n = 36, then the maximum of k is 9, take k =1, 2,…, 9.

Results and Discussion

Time lag cross correlation method is adopted to calculate correlation coefficient between TT, TP and TN of NDVI at all lattice points when every time lag k(k = 1, 2,…, 9) within research area (1 km × 1 km), the maximum correlation coefficient and its corresponding lag time between TT and TN as well as TP and TN are calculated in Cell Statistic and Highest Position tool in ArcGIS9.3, the spatial distribution result is as shown in Fig. 1.

It is observed from Fig. 1(a1) that the maximum cross correlation coefficient between TN and TT shows distinctively regional difference. On the whole, the degree of correlation between TN and TT in research area is relatively high, with correlation coefficients in every zone being more than 0.72, and correlation coefficients in Yulin city (Yuyang district), part of Shenmu County, Fuxian County and east of Huangling County, south of Wuqi County, large part of Luochuan County, east of Yijun County, middle of Yanchang County, middle of Yanchuan County, north-east of Yichuan County, south-east of Baotai District are more than 0.96. On the whole, the south is slightly higher than the north in terms of correlation. It is observed from Fig. 1(a2) that the zones with time lag between TT and TN for fewer than ten days are mainly distributed in southeast of Fuxian County, north of Huangling County, south central of Huanglong County and south of Yichuan County and that the zones with time lag for 20 days are mainly distributed in southwest of Shenmu County, north-west and south-west of Yulin City, Ganquan County and large part of Luochuan County, south of Yan'an City, north and east of Fuxian County, southeast and north of Huanglong County and that the zones with time lag for 40 days are mainly distributed in southwest of Dingbian County, Zizhou County and Suide County, large part of Mizhi County, north and east of Qingjian County and south of Jiaxian County. The time lag for other zones is 30 days by and large.

It is observed from Fig. 1(b1) that the correlation between TN and TP in energy enrichment zone in the north of Shaanxi is higher by and large, except that the correlation coefficients between TP and TN in several zones in Yulin City, small part of Huangling County, north-most part of Luochuan County, south-east of Huanglong County and several zones in south of Yichuan County are from 0.81 to 0.85 and that the correlation coefficients in other zones are above 0.85.

It is observed from lag time shown in Fig. 1(b2) that the zones without time lag are mainly distributed in six counties in the south of Yan'an region, south of Yan'an City, north of Jingbian County, north-west and south-west of Yulin City and north-west of Shenmu County and the zones with time lag for ten days are mainly distributed in Shenmu County, Fugu County, Dingbian County, Jingbian County and large part of Zhidan County, Wuqi County and Hengshan County and Mizhi County, east of Yulin City and west of Jiaxian County; the lag time in other zones is 20 days.
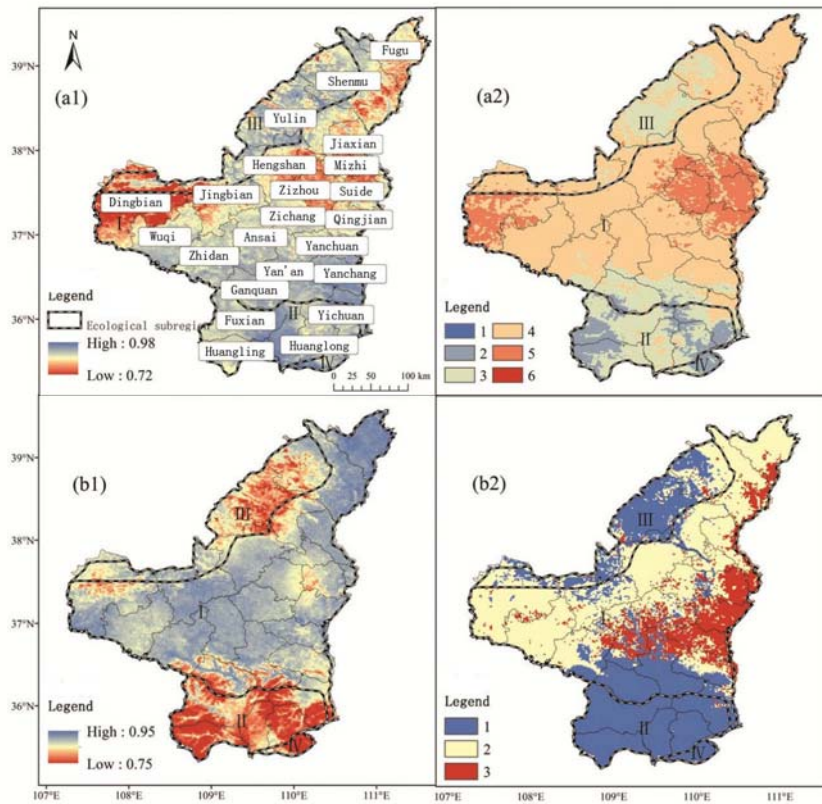
Fig. 1. The spatial distribution pattern of the the maximum correlation coefficient (1) and lag-time (2) between TN and TT(a), TP(b) and the distribution of ecological subregions.

Region I is loess hilly gully soil erosion ecological subregion which extremely sensitive in central and southern Shanbei-Shanxi west; Region II is rainfed agriculture ecological subregion in beam gullies loess tableland area of Shaanxi; Region III is typical grassland ecological subregion in the eastern Ordos plateau; Region IV is agricultural ecological subregion in the Wei river basin.

The entire research area is divided into four sub-ecotopes based on ecological feature, importance of service function of ecological system and sensitivity to ecological issue therein (Fig. 1) in relation to maximum cross correlation coefficient and maximum lag time in every sub-ecotope. The results are as shown in Table 1. It was observed that the difference in maximum correlation coefficient between TN and TT in every ecotope is insignificant, value being above 0.92, but there was difference in corresponding response time to a certain extent. The response time of TN to TT in loess hill and ravine sub-ecotope (zone 1) extremely sensitive to soil and water loss in the north of Shaanxi and central south of the west of Shanxi was 40 days. The response time of TN to TT in typical grassland sub-ecotope in the east of Erdos Plateau (zone II) is 30 days, the response time of TN to TT in dry farming sub-ecotope in ravine in the middle and loess tableland of Shaanxi was 30 days. The response time in agricultural sub-ecotope (zone IV) in Weihe Basin was the rapidest, being only 20 days.

Table 1. Average annual temperature and precipitation, maximum cross correlation coefficient (Rmax) and lag time (D-time) in different ecological subregions between TN and TT/TP.

Ecological sub-regions	Average annual temperature (ºC)	Average annual precipitation (mm)	Rmax		D-time(ten-day)	
			TT	TP	TT	TP
I	9.98	436.53	0.921	0.925	4	2
II	10.52	576.85	0.951	0.875	3	1
III	9.64	390.22	0.932	0.902	4	1
IV	10.40	608.91	0.954	0.864	2	1

It is observed from mean values (Table 1) of air temperature and precipitation from 1999 to 2010 in every sub-ecotope based on further analysis that the four zones have been insignificant in annual mean temperature difference for years, being about 10ºC, zone II and zone IV are agricultural ecotopes, with annual precipitation being above 550 mm for years and ample precipitation and correlation coefficient between vegetation index and air temperature greater than the correlation coefficient between vegetation index and precipitation, therefore, the intra annual change in vegetation coverage in the two zones is mainly subjected to the influence of air temperature and the response of vegetation to hydrothermal factor is faster. However, the precipitation in zones 1 and 2 is lower than 450 mm, being equivalent in terms of correlation coefficient between vegetation index and air temperature and correlation coefficient between vegetation index and precipitation, indicating that the intra annual growth of vegetation in the two zones is subjected to common influence of air temperature and precipitation, with slow response to water and heat.

Maximum correlation coefficient between NDVI and TT as well as NDVI and TP of various vegetations and their response time are subjected to statistics, respectively according to Fig.1, the result is as shown in Table 2. The degree of correlation between TN and average temperature of various vegetations including evergreen coniferous forest, deciduous broadleaved forest, dense scrub, hilly grassland, desert grassland and pasture is higher and higher than that of TN and precipitation. In plain grassland, the degree of correlation between precipitation and vegetation index is higher than these of precipitation and average temperature, the degree of correlation between arable land vegetation index and average temperature and the degree of correlation between arable land vegetation index and precipitation are equivalent by and large.

Precedence of ordering for maximum correlation coefficient between average temperature and vegetation index: Dense scrub, deciduous broadleaved forest, evergreen coniferous forest, arable land, hilly grassland, pasture, plain grassland, desert grassland, desert, indicating that average temperature exerts the greatest influence on dense scrub in energy enrichment zone in the north of Shaanxi and that it has weaker influence on desert grassland and desert therein and that the precedence ordering for maximum correlation coefficient between precipitation and vegetation index: arable land, hilly grassland, pasture, desert grassland, dense scrub, deciduous broadleaved forest, evergreen coniferous forest, desert, indicating that precipitation exerts the greatest influence on arable land and that it has weaker influence on desert and that the growth of vegetation is subjected to combined influence of air temperature and precipitation, it is observed from spatial distribution that correlation is on the decrease from south to north.

Zones with high degree of correlation between TN and TT in energy enrichment in the north of Shaanxi contain Fuxian County, east of Huangling County and north-east of Yichuan County. The zones with low degree of correlation between TN and TT included Dingbian County, Jiaxian County and Hengshan County. The zones with short lag time between TN and TT included

southeast of Fuxian County, north of Huangling County, Huanglong County and Yichuan County. The zones with long lag time between TN and TT included south of Dingbian County and Zizhou County and Suide County. The zones with high degree of correlation between TN and TP included Yanchang County, Ancai County. The zones with low degree of correlation between TN and TP included northmost part of Luochuan County and south-east of Huanglong County. The zones with short lag time between TN and TP included six counties in the south of Yan'an Region. The zones with long lag time between TN and TP included Qingjian County and Wubu County. The south and south-east of the north of Shaanxi is higher in degree of correlation between TN and TT as well as TN and TP, with short response time. The north of the north of Shaanxi is lower in degree of correlation between TN and TT as well as TN and TP, with long response time.

Table 2. Maximum cross correlation co-efficient (a) and lag time (b) between TN and TT, TP in different vegetation types.

Vegetation type	Rmax		D-time (ten-day)	
	TT	TP	TT	TP
Evergreen coniferous forest	0.941	0.857	3	1
Deciduous broadleaved forest	0.942	0.869	2	1
Dense scrub	0.947	0.883	3	1
Hilly grassland	0.927	0.919	4	2
Plain grassland	0.916	0.921	4	2
Desert grassland	0.911	0.901	4	2
Pasture	0.926	0.913	4	2
River	0.943	0.928	4	2
Desert	0.902	0.853	4	1
Arable land	0.926	0.926	4	2

It is observed from analysis of the influence of hydrothermal factor on TN change in energy enrichment zone based on division of sub-ecotopes in the north of Shaanxi that the energy enrichment zone in the north of Shaanxi was higher in degree of correlation between TN and TT, being above 0.92 and that the basin and loess tableland ravine zone was faster than loess hill ravine sub-ecotope and typical grassland sub-ecotope in terms of response to temperature but with distinctive difference in degree of correlation between TN and TP and that basin and tableland ravine zone was lower than grassland and loess hill ravine zone in degree of correlation and that four sub ecotopes were rapid in the response to precipitation. On the whole, basin and loess tableland ravine zone were higher in the degree of response to hydrothermal factor.

The dense scrub was in the first place in degree of influence of change in air temperature on NDVI of vegetation; deciduous broadleaved forest and evergreen coniferous forest were in the next place and desert grassland and desert were in the last place, showing trend of gradual decrease in correlation between TN and TT from south to north in spatial distribution. The arable land was in the first place in degree of influence of change in precipitation on NDVI of vegetation, grassland was in the next place, evergreen coniferous forest and desert were in the last place. Every sub-group of the same type of vegetation was different in its response time to water and heats indicating that deciduous broadleaved forest was higher than evergreen coniferous forest in correlation with ten-day mean temperature and precipitation, deciduous broadleaved forest was faster than evergreen coniferous forest in response to temperature.

Basin and loess tableland ravine zone was faster than loess hill ravine sub-ecotope and typical grassland sub-ecotope in speed of response to temperature, this result was in accordance with the conclusion drawn by Zhang *et al.* (2011) in his research. The vegetation coverage in energy enrichment zone in the north of Shaanxi mentioned in the paper was in arid and semiarid region, the growth of vegetation in agricultural sub-ecotope was subjected to influence of human and natural irrigation, with more complex correlation between NDVI and precipitation and higher uncertainty, indicating that there were many restrictive factors for vegetation coverage and that change in vegetation coverage was an alternating process, the paper only involved relation between vegetation coverage change and climatic factor by calculation, without considering human activity, which should be taken into full consideration in follow-up research so as to further research characteristic of response of vegetation coverage to hydrothermal factors, from now on, in-depth research and analysis should be carried out based on sensitivity of time to start growing season and time to end growing season together with length of growing season to seasonal fluctuation in hydrothermal condition.

Acknowledgements

Reference

Anyamba A and Tucker CJ 2005. Analysis of sahelian vegetation dynamics using NOAA-AVHRR NDVI data from 1981-2003. J. Arid Environ. **63**(3): 596-614.

Dai SP, Zhang Bo and Wang HJ 2010. Analysis of temporal and spatial variation trend of grassland vegetation in Qilian Mountain based on SPOT NDVI. Adv. Geogr. Sci. **29**(9): 1075-1080.

Han JX, Wang ZM and Mao Dehua 2011. Analysis of correlation between dynamic change of vegetation and climatic factor from 1982 to 2010. Chin. J. Agrometeorology **32**(3): 430-436.

Hou GL, Zhang HY and Guo R 2012. Temporal and spatial change in NDVI in vegetation growing season and its sensitivity to climatic factor in Changbai Mountain. Adv. Geogr. Sci. **31**(3): 285-292.

Liu LL and Xu HM 2007. Main vegetation types in Yellow River Valley, NDVI change pattern and their relation with meteorological factor. Chin. J. Agrometeorology **28**(3): 334-337.

Paruelo JM and Lauenroth WK 1998. Interannual variability of NDVI and its relationship to climate for North American shrublands and grasslands. J. Biogeogr. **25**(4): 721-733.

Weiss JL, Gutzler DS and Coonrod JEA 2004. Long-term vegetation monitoring with NDVI in a diverse semi-arid setting, central New Mexico, USA. J. Arid Environ. **58**(2): 249-272.

Xin ZB, Xu JX and Zheng W 2008. Spatio-temporal variations of vegetation cover on the Chinese Loess Plateau (1981-2006): impacts of climate changes and human activities. Sci. in China Seri D: Earth Sci. **51**(1): 67-78.

Zhang C, Ren ZY and Yuan X 2011. Northwest, Response of NDVI to intra-annual change in hydrothermal condition and its space feature. Resour. Sci. **33**(12): 2356-2361.

Zhang WJ and Gao ZQ 2005. Research of response of vegetation coverage to hydrothermal condition in middle east of Qinghai-Tibet Plateau. Adv. Geogr. Sci. **24**(5): 13-22.