Agricultural drought monitoring in Shanxi by using temperature vegetation dryness index

Yue Qi[1,2], Fang Shibo[2*], Wang Runyuan[1]

1. Gansu Key Laboratory of Arid Climatic Change and Reducing Disaster/Key Laboratory of Arid Climatic Change and Disaster Reduction of CMA/ Institute of Arid Meteorology, CMA, Lanzhou

2. Institute of Eco-environment and Agro-meteorology Chinese Academy of Meteorological Sciences, Beijing, China, 100081.

Abstract: Considering the conditions of droughts occurred frequently in recent years, especially the agricultural drought, Shaanxi Province was selected as the study area the NDVI (Normalized difference vegetation index) and LST (land surface temperature) , and to establish for the first time LST-NDVI feature space using the compound MODIS data from in 2014, June through August. Then, the spatial distribution of drought in the Spring Maize at Different Growth Stages were obtained based TVDI (temperature vegetation) , and the variation tendency of the drought in Shaanxi was analyzed. TVDI was verified using the 0-20cm relative soil moisture. The results showed that the drought more serious, and the disaster area is growing, from the spring maize seven-leaf stage to tasseling period. A trend is demonstrated expanding from east to west. The TDVI was validated by using 0-20 cm relative soil moisture data, and it was found that the TDVI and soil moisture had better correlation, at the significance level of 0.01. The TDVI could better reflect the drought status of spring maize at different growth stages.

1. *Introduction*

As the trend in global warming becomes increasingly obvious, more and more areas are becoming drought prone due to the threat posed by a water crisis(Dai *et al*., 2005). The increases of the arid regions and economic loss caused by drought emphasize the importance of strengthening regional drought monitoring and forecasting techniques. Traditional drought monitoring methods use ground-based soil sampling to measure soil moisture in a limited area, which for larger areas interpolation methods are used with limited sampling data(Western and Grayson 1998). However, due to the spatial variability of large areas, it is very hard, or even impossible, to get complete information about soil moisture using ground-sampling methods(Goward *et al*., 2002). Since increase of global temperatures have led to an unprecedented frequency of droughts, and research of the basic factors and trends of these droughts are crucial for China's agricultural production(Piao *et al.* 2010; Yang *et al*. 2013).

Widespread and dynamic monitoring of droughts using traditional monitoring methods is difficult to achieve because of the sacristy of points representing soil moisture content. Remote sensing technology is a feasible method for monitoring droughts on a large scale (Qin *et al*. 2006; Rhee *et al*. 2010), and methods commonly used can be categorized into two types. The first type is based on vegetation indices such as normalized difference vegetation index (NDVI) (Rouse *et al*. 1974), vegetation condition index (Kogan 1995a,b) and standard vegetation index (Qi *et al*. 2004). The second type is based on temperature and includes approaches such as thermal inertia (Price 1985; Yu and Tian 1997), evapotranspiration estimation (Jackson *et al*. 1977a, b; Sui *et al*. 1997)and multitemporal integrated soil moisture statistical model (Xiao *et al*. 1994). However, because of incomplete vegetation cover, use of soil temperature to monitor soil moisture is quite limited (Moran *et al*. 1994), and use of vegetation index to monitor soil moisture is somewhat lag (Sandholt *et al*. 2002). To overcome these problems, Sandholt *et al*.(2002) proposed temperature vegetation drought index (TVDI) based on the relationship between vegetation and land surface temperature (Price 1990; Carlson *et al*. 1995). Because of its definite physical meaning and low requirement to the spectral resolution of remote sensing data, TVDI has been widely applied in the drought monitoring, and its advantages have been verified by a series of studies (Sun *et al*. 2012).

This study selected the TVDI index in Shaanxi province during spring maize growth season to examine drought dynamic change based on the MODIS data. Then for spring maize seven leaf stages, jointing stage and tasseling stage of the soil moisture data of soil moisture sites TVDI index was validatd during the same period.

2. Data and Method

2.1 Datasets

In this study, the southern plain of Shaanxi Province of China was selected as the study area (Fig. 1). The Yulin and Yanan belong to northern Shaanxi area; Tongchuan, Xianyang, Weinan, Baoji and Xian belong to Central Shaanxi area; Hanzhong, Ankang and Shangluo belong to Southern Shaanxi area For the purpose of this research, MODIS-Terra 16-day vegetation indices at 1-km resolution (MOD13A2), daily Ts product at 1000-m resolution (MOD11A1) for 2014, from June to August were used. Data samples from the 52 meteorological stations that measured soil moisture content data for 2014, for the same period serve as validation data.

The MODIS data were obtained from the data sharing infrastructure of earth system science. These data were pretreated by methods of radiation correction, geometric correction, broken line removal, and cloud removal and were then used to calculate the NDVI and land surface temperature. In this study, the three stages of growth of spring maize was chased, such as seven-leaf stage on June 29 representatives, jointing stage on July 15 representatives, and tasseling stage on August 20 representatives.

2.2 Method

TVDI is a simple and effective method that has been widely used in regional drought monitoring. It describes drought conditions using the relationship between LST and soil moisture(Qi *et al*. 2003; Li *et al*. 2006). When soil water is adequate, more energy will be used for evapotranspiration. As a result, LST will be lower. Conversely, low soil moisture results in a decrease of evapotranspiration, making the LST higher. Therefore, LST may be used as an indicator for soil moisture. As well, the TVDI should be considered in drought monitoring. Different vegetation cover can cause a different energy balance for the land surface, thus greatly affecting the LST.

Price (1990) and Carlson *et al*.(1994) found that the scatter plot of LST and VI formed a triangle as shown in Fig.2**.**

Fig.1 Location of the study area in Shaanxi Province

.

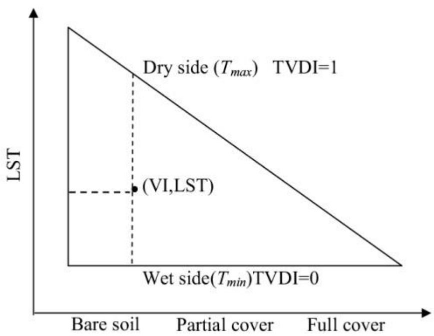


Fig. 2 Vegetation index-land surface temperature feature space in TVDI

Using a spatial query method, the highest (T_{max}) and the lowest (T_{min}) LST under the same NDVI can be found. Combined with NDVI, equations for the dry side and wet side of the feature space can be obtained using a linear fitting method(Sandholt *et al*. 2002):

$$TVDI = \frac{(T - T_{\min})}{(T_{\max} - T_{\min})} \quad (1)$$

$$T_{\max} = a_1 + b_1 \times NDVI \quad (2)$$

$$T_{\min} = a_2 + b_2 \times NDVI \quad (3)$$

Where, Ts is the earth's surface temperature of a given pixel in a featured space; NDVI is the normalization vegetation index value of the pixels; Ts max and Ts min are the surface temperatures of the dry and wet edges corresponding to the NDVI, respectively; and a1, b1 and a2, b2 are the slope and intercept of dry and wet edge equations, respectively, which can be obtained by linear fitting. The calculated of TVDI by using this formula are the normalized values, between 0 and 1. Larger TVDI values indicate low soil moisture and high degrees of drought, whereas smaller TVDI values indicate higher soil moisture and lower degrees of drought.

In order to calculate the TVDI index, we used the maximum value composition to generate daily TVDI data based on daily TVDI data for eliminating the interference of clouds and atmospheric and satellite observation geometry, by the basis of the mean daily TVDI. In this paper, the TVDI classification of drought levels as proposed by Zhang Shun Qian *et al* (Zhang 2007) was adopted(Table 1).

3. *Results*

Spatial and temporal variations of the TVDI in the study area (Fig. 2) show that the drought distributed in seven - leaf stages, the jointing stage and the tasselling stage of spring maize. In seven - leaf stage of spring maize, the drought was mainly distributed in eastern and central region of Northern Shaanxi area, north and central region of Central Shaanxi area, and a few areas of Southern Shaanxi, among them the major drought and extreme drought are mainly distributed in eastern region of Northern Shaanxi area and central region of Central Shaanxi area.

In jointing stage of spring maize, the area of drought expands and becomes more and more serious, resulting in expansion of the major drought and extreme drought areas. The drought is mainly distributed in the northeast of Northern Shaanxi area, most region of Central Shaanxi area, and southwest of Southern Shaanxi.

Tab. 1 The Drought classification

No Drought	Mild Drought	Moderate Drought	Major Drought	Extreme Drought
0-0.67	0.67-0.74	0.74-0.8	0.8-0.86	0.86-1

In tasselling stage of spring maize, the drought appears in most parts of Shaanxi Province while the major drought and extreme drought are mainly distributed in the northern of Northern Shaanxi area, central and eastern of Central Shaanxi area, and most areas of Southern Shaanxi.

Overall from the spring maize seven-leaf stage to tasseling period, drought becomes more and more serious, and the disaster area grows. A trend is demonstrated from east to west expansion. The comparison between the TVDI and 0-20cm relative soil moisture among different growth periods, shows a significant correlation, independent on the growth period. In jointing stage of spring maize, the TVDI and 0-20cm relative soil moisture appear significant correlation and the R2 is 0.328, at the 0.01 significance level. In tasselling stage of spring maize, the TVDI produces better results with more concentrated scatterplots, and the correlation between TVDI and 0-20cm relative soil moisture appears R2 equal to 0.243, at the 0.01 significance level. In jointing stage of spring maize, the TVDI and 0-20cm relative soil moisture forms R2 equal to 0.189, at the 0.01 significance level. Thus it can be seen that the TDVI could better reflect the drought status of spring maize at different growth stages.

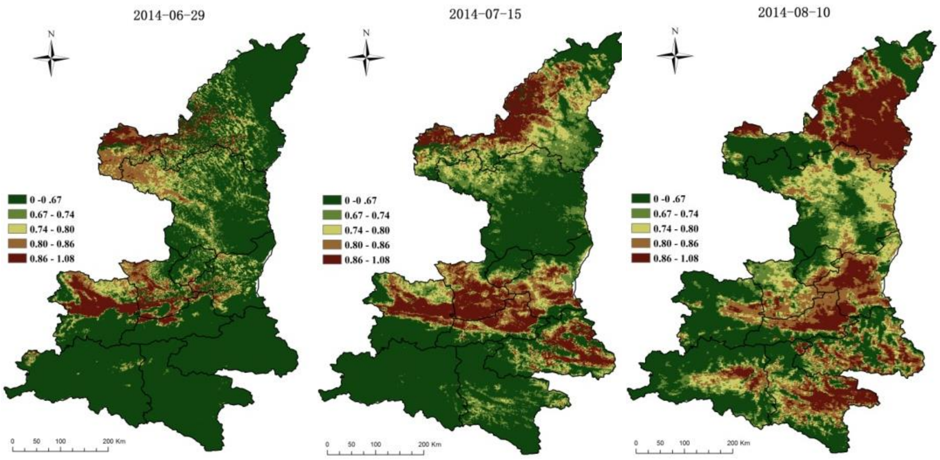
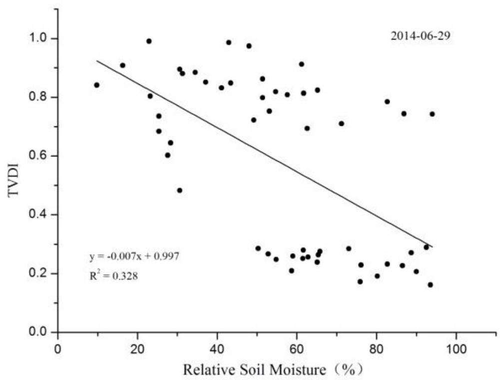


Fig. 2 Distribution of Drought in Spring Maize at Different Growth Stages



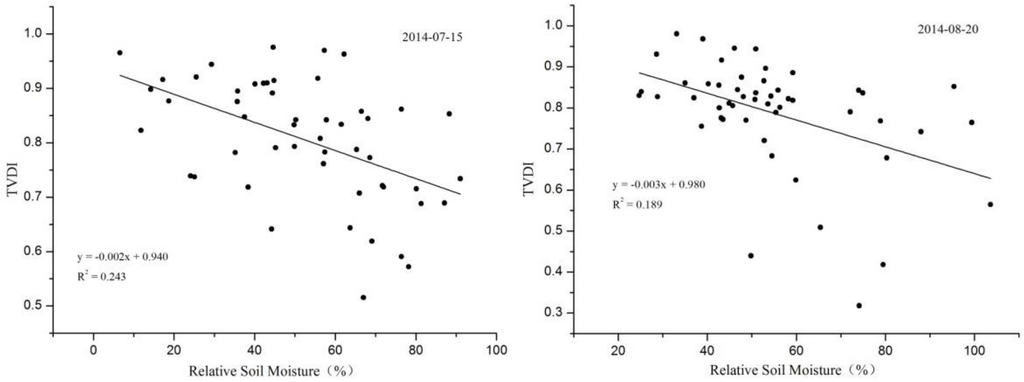


Fig. 3 Scatterplots between the TVDI and 0-20cm relative soil moisture in Spring Maize at Different Growth Stages

4. Conclusions

In this study, the application of the TVDI for drought in Different Growth Stages of Spring Maize in the Shaanxi Province is studied. The relationships between TVDI and 0-20cm relative soil moisture is also analyzed. The results showed that TDVI could better reflect the drought status of spring maize at different growth stages. From the spring maize seven-leaf stage to tasseling period, drought becomes more and more serious, and the disaster area was growing, with a trend from east to west expanding from east to west. The TDVI was validated by using 0-20 cm relative soil moisture data, and it was found there is a good correlation, the 0.01 significance level. It indicated that TDVI can better invert the agricultural drought for drought preventing according to local conditions.

5. Acknowledgements

This research was supported by the National Natural Science Foundation of China (41505098, 41275118), China Special Fund for Meteorological Research in the Public Interest(Major projects) (GYHY201506001-2).

References

Carlson T, Gillies R. and Perry E. 1994. A method to make use of thermal infrared temperature and NDVI measurements to infer surface soil water content and fractional vegetation cover. *Remote Sensing Reviews* **9**:161-173.

Carlson T N, Gillies R R, Schmugge T J. 1995. An interpretation of methodologies for indirect measurement

of soil water content. *Agricultural and Forest Meteorology*, **77**, 191-205.

Dai A, Qian T and Trenberth K. 2005. Has the recent global warming caused increased drying over land. AMS 16th Symposium on Global Change and Climate Variations/Symposium on Living with a Limited Water Supply, pp. 9-13.

Dai A, Qian T and Trenberth K. 2005. Has the recent global warming caused increased drying over land. AMS 16th Symposium on Global Change and Climate Variations/Symposium on Living with a Limited Water Supply, pp. 9-13.

Goward S, Xue Y and Czajkowski K 2002. Evaluating land surface moisture conditions from the remotely sensed temperature/vegetation index measurements: An exploration with the simplified simple biosphere model. *Remote Sensing of Environment* 79:225-242.

Jackson R D, Idso S B, Reginatio R J, Ehrler W L. 1977a. Crop temperature reveals stress. *Crop Solis*, **29**, 10-13.

Jackson R D, Reginatio R J, Idso S B. 1977b. Wheat canopy temperature: A practice tool for evaluating water requirements. *Water Resources Research*, **13**, 651-656.

Kogan F N. 1995a. Drought of the late 1980s in the United States as derived from NOAA polarorbiting satellite data. *Bulletin of the American Meteorological Society*, **76**, 655-668.

Kogan F N. 1995b. Application of vegetation index and brightness temperature for drought detection. *Advanced Space Research*, **15**, 91-100.

Li H, Li C, Zheng L, and Lei Y. 2006. Zonal calculation of drought inspection using remote sensing in large-scale. *Remote Sensing Technology and Application* **21**:137-141.

Moran M S, Clarke T R, Inoue Y, Vidal A. 1994. Estimating crop water deficit using the relation between surface air temperature and spectral vegetation index. *Remote Sensing of Environment*, **49**, 246-263.

Price J. 1990. Using spatial context in satellite data to infer regional scale evapotranspiration. IEEE *Transactions on Geoscience and Remote Sensing* **28**:940-948.

Piao S L, Ciais P, Huang Y, Shen Z H, Peng S S, Li J S, Zhou L P, Liu H Y, Ma Y C, Ding Y H, Friedlingstein P, Liu C Z, Tan K, Yu Y Q, Zhang T Y, Fang J Y. 2010. The impact of climate change on water resource and agriculture in China. *Nature*, **467**, 43-51.

Price J C. 1985. On the analysis of thermal infrared imagery: The limited utility of apparent thermal inertia. *Remote Sensing of Environment*, **18**, 59-73.

Price J C. 1990. Using spatial context insatellite data to infer regional scale evapotran spiration. *IEEE Transactions onGeoscience and Remote Sensing*, **28**, 940-948.

Qi S, Wang C, and Niu Z. 2003. Evaluating soil moisture status in China using the temperature/vegetation dryness index(TVDI). Journal of Remote Sensing **7**:420-427.

Qi S H, Wang C Y, Niu Z, Liu Z J. 2004. SVI and VCI based on NDVI time-series dataset used to monitor vegetation growth status and its response to climate variables. *Progress in Geography*, **23**, 91-99. (in Chinese)

Qin Z H, Li W J, Gao M F, Zhang H O. 2006. An algorithm to retrieve land surface temperature from ASTER thermal band data for agricultural drought monitoring. In: *Proceedings of SPIE 6359*, *Remote Sensing for Agriculture*, *Ecosystems, and Hydrology VIII, 63591F*. Stockhom, Sweden. pp. 63591F1-8.

Rhee J, Im J, Carbone G J. 2010. Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. *Remote Sensing of Environment*, **114**, 2875-2887.

Rouse J W, Hass R H, Schell J A, Deering D W. 1974. Monitoring vegetation systems in the Great Plains with ERTS. In: *Proceedings of the 3rd Earth Resources Technology Satellite-1 Symposium*. NASA SP-351,

Greenbelt, MD. pp. 309-317.

Sandholt I, Rasmussen K, Andersen J. 2002. A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status. *Remote Sensing of Environment*, **79**, 213-224.

Sui H Z, Tian G L, Li F Q. 1997. Two-layer model for monitoring drought using remote sensing. *Journal of*

Remote Sensing, **1**, 220-224. (in Chinese)

Sun H, Chen Y H, Sun H Q. 2012. Comparisons and classification system of typical remote sensing indexes for agricultural drought. *Transactions of the Chinese Society of Agricultural Engineering*, **28**, 147-154. (in Chinese)

Western A and Grayson R. 1998. The Tarrawarra data set: Soil moisture patterns, soil characteristics, and hydrological flux measurements. *Water Resources Research* **34**:2765-2768.

Yang H, Flower J R, Thompson J R. 2013. Sustaining China's water resources. *Science*, **339**, 141-141.

Yu T, Tian G L. 1997. The application of thermal inertia method the monitoring of soil moisture of North China plain based on NOAA-AVHRR data. *Journal of Remote Sensing*, **1**, 24-31, 80. (in Chinese)

Zhang S Q, Qing Q T, Hou M T, Feng J D. 2007. Remote sensing and impact estimation for Sichuan hot-drought based on temperature vegetation dryness index. *Transactions of the Chinese Society of Agricultural Engineering*, **23**:141-146. (in Chinese)