EXTRACTING CROPPING INDEX VARIATIONS IN NORTHERN CHINA BASED ON *NDVI* TIME-SERIES

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Commission VII, WG VII/5

KEY WORDS: Remote Sensing; Agriculture; Change Detection; Indicators; Multitemporal; Spatial

ABSTRACT:

Multiple cropping system, characterized by cropping index, is of significant importance to Chinese food production and security. Owing to the changing nature conditions and human activity, cropping index could show remarkable inter-annual fluctuations, which in turn reflects arable land use intensity and indicates climate change impacts on agriculture system. *NDVI* (Normalized Difference Vegetation Index) time-series is an effective indicator of vegetation status at regional scale. We developed a new method for extracting cropping index from *NDVI* time-series, and employed it to extract cropping index and its inter-annual variations of northern China from 1982 to 2003. The results show: remotely sensed cropping index is high consistent with statistical data at province scale (R^2=0.9213, P<0.001, slope=1.0775), demonstrating that this method can extract cropping index effectively and correctly. The average cropping index of northern China increased from 87.27 in 1982 to 115.98 in 2003, with an average change rate 1.3275 per year(R^2=0.7955，P<0.001). The areas displayed different changes of cropping index, with Huang-Huai-Hai drainage area experiencing a clear cropping index increase and other regions relatively less cropping index change.

1. INTRODUCTION

Multiple cropping system, characterized by cropping index, is important to Chinese food production, which feeds 22% of the whole world population by using 8.6% arable land of the whole world (Liu, 1992; Ma, 2003). Cropping index refers to the times of sequential crop planting in the same arable land in one year, usually defined as the ratio of the total seeding area to the arable land area (Liu, 1993), which reflects the using efficiency of soil, water, light and other natural resources. Owing to the changing nature conditions and human activity, cropping index could show remarkable inter-annual fluctuations, which in turn reflects the using intensity of arable land and indicates the impacts of climate change on agriculture system. It is desired to extract the cropping index and its change information by remotely sensed data for agriculture sustainable development and assessing the impacts of climate change on agriculture system.

Traditionally, cropping index is calculated by statistical data at local administration unit, which is time-lagged, labor-consuming, poor in creditability, and lack of details of spatial distribution. On the other hand, remote sensing technology has been widely applied to agriculture and crop growing status monitoring (Harris, 2003; Seelan *et al*., 2003). The development of remote sensing technology makes it possible to obtain actual cropping index information efficiently and reliably. Peak of the *NDVI* (Normalized Difference Vegetation Index) time series curve could reveal the time when above ground biomass of crops reaches the maximum and tone of the curve fluctuates with the crops growing processes such as sowing, seeding, heading, ripeness, and harvesting within a year. Therefore, the cropping index could be defined as the number of peaks of *NDVI* time-series per year (Fan and Wu, 2004). However, since *NDVI* data are easy to suffer from cloud and the other poor atmospheric conditions, the curve of *NDVI* time series may include much noise, turning out to be small peaks and valleys in one cycle, which makes it more difficult to extract the cropping index effectively. Some methods have been developed to extract cropping index by reconstructing high quality *NDVI* curve, such as Harmonic Analysis of Time Series (HANTS) (Fan and Wu, 2004) and so on (Yan *et al*., 2005). Nevertheless, these methods depend too much on prior knowledge, and can not get rid of all the disturbing noise effectively.

This study aimed to (1) develop a new method to eliminate the atmospheric effects and other contaminations and improve accuracy of cropping index extracting form *NDVI* time-series and (2) extract the cropping index and the Cropping Index Variation (*VCI*) of 17 provinces of northern China from 1982 to 2003 by using 8km 15-day Maximum Value Composite NOAA/AVHRR GIMMS *NDVI* time-series data.

2. STUDY AREA AND DATA

The cropping index exaction was conducted on the 17 provinces of northern China (Figure.1), of which the arable land area was identified according to Chinese vegetation type map.

The Global Inventory Monitoring and Modelling Study (GIMMS) AVHRR 8 km resolution *NDVI* 15-day composite dataset covering the period of 1982 to 2003 (Tucker *et al*., 2005. Available at http://gimms.gsfc.nasa.gov/) was used to exact the cropping index. This dataset was produced by Maximum Value Composition (MVC) technique which selects the highest value of *NDVI* during every 15-day period for each pixel to remove

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most of the cloudy contamination (Holben, 1986). Beside that, particular efforts were made to the GIMMS dataset including a correction of varying solar zenith angles due to orbital drift of the afternoon NOAA satellites and a correction of volcano aerosols (Vermote *et al*., 1997) emitted by El Chichón from March to April 1982 and Mount Pinatubo in June 1991. It is reported that the GIMMS dataset has high quality (Fensholt *et al*., 2006; Tucker *et al*., 2005).

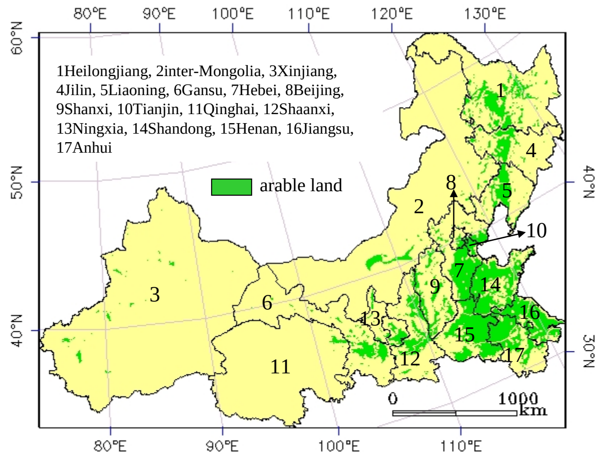

Figure.1 Study area

3. METHORDS

3.1 Definition of the *NDVI* Time-series Based Cropping Index

Based on the fact that the growing length of the mainly crops in China was above 90 days, the definition of one-cropping was "the crop with 3 months growing length and full coverage of the farm" (Liu, 1997). Four parameters were used to characterize the wave of "once cropping" in an *NDVI* curve (Figure.2).

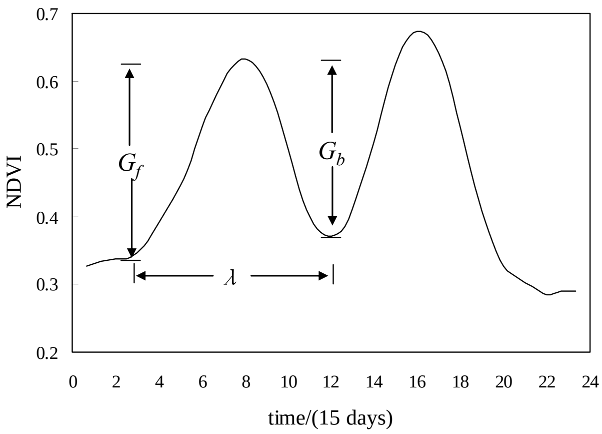

Figure.2 *NDVI* profile of crop

Amplitude P: the difference between maximal *NDVI* and minimal *NDVI* of a certain pixel within one year.
Growing length λ: the interval between the nearest two wave troughs in the *NDVI* curve.
G_f : the difference between a peak value and the nearest backward wave trough.
G_b : the difference between a peak value and the nearest forward wave trough.
Based on above variables, a wave packet meeting equation (1) is identified as "one-cropping". Then the remotely sensed cropping index (*CI*) is defined as the number of peaks of the *NDVI* time-series multiplies 100% which accord with the definition of "once cropping".

$$\begin{aligned} &\lambda \geq 9 \\ &G_f \geq P \times 50\% \\ &G_b \geq P \times 50\% \end{aligned} \tag{1}$$

3.2 The Method of Cropping Index extracting

As presented in Figure.3, the cropping index extracting procedure includes data preprocessing (*step1*, *step2*), false peaks correcting (*step3*, *step4*), and *CI* extracting (*step5*, *step6*).

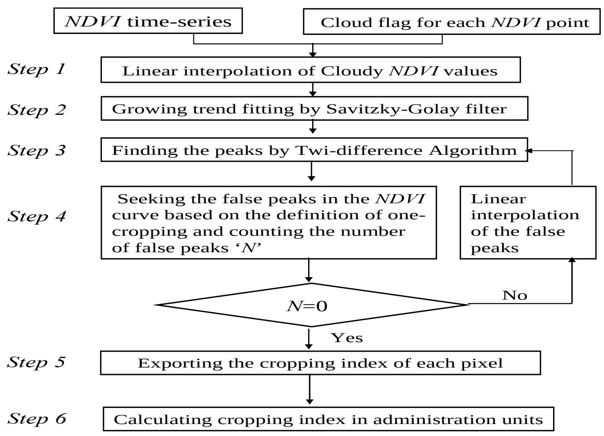

Figure.3 Flowchart of cropping index extracting procedure

***Step 1*: Linear interpolation of cloudy *NDVI* values**
In this study, cloud flag data were used to improve the *NDVI* time-series by linear interpolation of the cloudy *NDVI* values (labelled ● in Figure.4(a)).

***Step 2*: Growing trend fitting by Savitzky-Golay filter**
This step was done exactly as reported in Chen *et al*. (2004). Figure.4(b) shows a growing trend curve obtained using this filter.

***Step 3*: Finding the peaks by Twi-difference Algorithm**
The twi-difference algorithm used in this step is as follows: a new time-series {*S*2} was calculated following equation (2).

$$\begin{aligned} &S1_i = 1, \quad if \;\; NDVI_{i-1} > NDVI_i \\ &S1_i = -1, \quad if \;\; NDVI_{i-1} < NDVI_i \\ &S2_i = S1_i - S1_{i+1} \end{aligned} \tag{2}$$

Where i denotes the ith point in the *NDVI* time-series. Where $S2_i$ equals -2 was recognized as a peak, and 2 a trough.

***Step 4*: Elimination of false peaks in the *NDVI* curve based on the definition of one-cropping and counting the number of false peaks '*N*'**

λ, G_f, G_b of each wave packet can be calculated when all the peaks and troughs were recognized in *step* 3, and then false peaks were identified according to the definition of "one-cropping" and the number of the false peaks (N) was counted .If N is zero, the correcting of *NDVI* time-series will finish (Figure.4(c)), and then do *step5*. Otherwise, replace the false peaks by linearly interpolated values and return to *step3*.

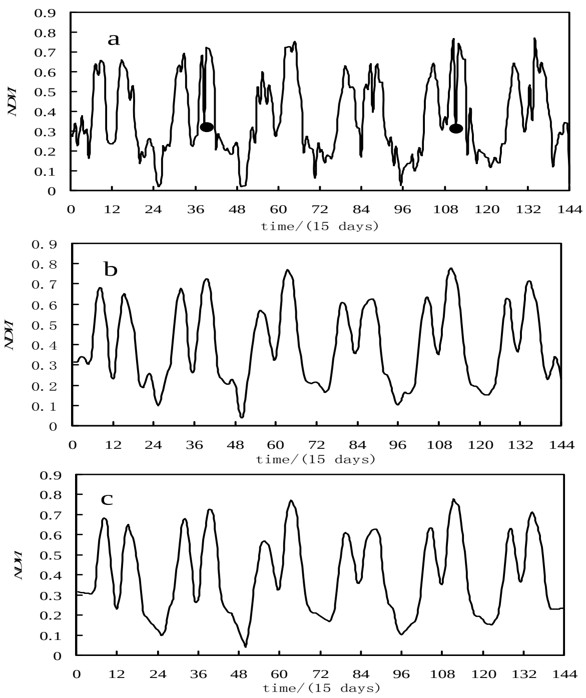

Figure.4 Data processing of *NDVI* time series

***Step 5*: Exporting the cropping index of each pixel**

The cropping index of ith pixel is "$CI_i = M \times 100$", where M is the number of "once cropping" waves.

***Step 6*: Calculating cropping index in administration units**

Average *CI* of certain administration unit can be calculated following equation (3):

$$CI = \frac{\sum_{i}^{n} CI_i}{n} \tag{3}$$

Where n in the above expression is the number of the total arable land pixels in the administration unit.

3.3 The Method of Cropping Index Variation Extracting

Since cropping anomalies often occurred during 1982-2003, the Least Absolute Deviation (LAD) linear regression was employed instead of Ordinary Least Square (OLS) regression to calculate the change trend of cropping index (*VCI*) during 1982-2003. Comparing to OLS, LAD could reduce the sensitivity to outliers effectively and provide a robust and plausible estimate. The detailed information about LAD regression can be found in Powell (1984).

4. RESULTS AND DISCUSSION

4.1 Precision Evaluation

Precision evaluation was carried out as the comparison between the *CI* extracted trough our new method and that calculated from statistical data at province scale. As mentioned above, cropping index is defined as the ratio of the total seeding area to the arable land area. Annual seeding area of every year during 1982 to 2003 is available in "China Agriculture Information Net" (http://www.agri.gov.cn/sjzl/ nongyety.htm). However, there is no available data about arable land area of each year, so the arable land area in 1996 could be approximately regarded as the arable land area from 1996 to 2003 (also available in China Agriculture Information Net). Based on the statistical data above, the annual *CI* of each province was calculated. Generally, the remotely sensed cropping index shows high accordance with statistical data at province scale (R^2=0.9213, P<0.001, slope=1.0775) (Figure.5), suggesting the reliability of the proposed method.

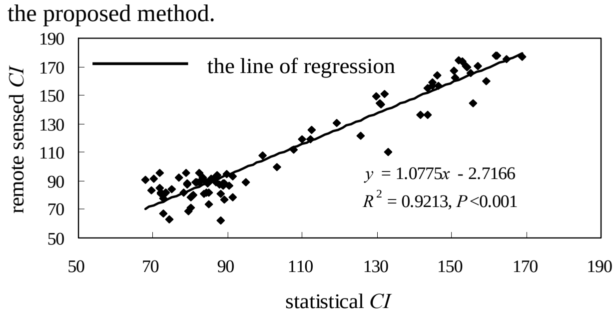

Figure. 5 Correlation of remotely sensed CI and statistical CI

4.2 Spatial Pattern of Cropping Index

The 22-year average *CI* varied evidently among different provinces (Table 1), with Hebei, Shandong, Henan, Jiangsu, Anhui exhibiting high values, and Heilongjiang, inter-Mongolia, Xinjiang, Gansu, Shanxi, Qinghai, Ningxia exhibiting relatively lower values. As presented in Figure.6, the cropping index shows an increasing trend from northeastern and northwestern provinces (about 100) to southeastern ones (about 200). The spatial distribution of cropping index extracted by the newly proposed method was consistent with the actual Chinese cropping system reported by Shen *et al*. (1983).

Province	Average cropping index from 1982 to 2003
Heilongjiang	88.99
inter-	73.61
Xinjiang	79.56
Jilin	90.43
Liaoning	91.88
Gansu	83.04
Hebei	123.34
Beijing	107.99
Shanxi	87.13
Tianjin	104.68
Qinghai	77.07
Shaanxi	95.32
Ningxia	73.78

Shandong	128.56
Henan	156.79
Jiangsu	143.83
Anhui	140.92
total	**106.83**

Table1. The average cropping index of each province from 1982 to 2003

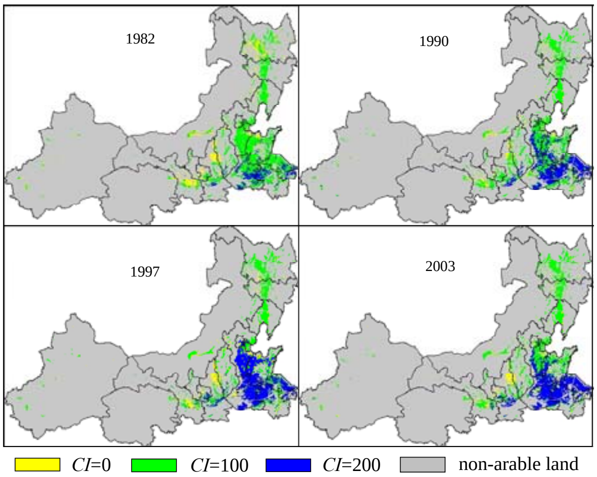

Fig.6 The spatial distribution of the cropping index in Northern China in1982, 1990, 1997, and 2003

4.3 Cropping Index Change Trends

The change trends for cropping index are shown in figure 7, figure 8, figure 9, and table 2. The northern China experienced an obvious cropping index increase, from 87.27 in 1982 to 115.98 in 2003 with an average change rate 1.3275 per year(R^2=0.7955, P<0.001) (Figure 7). Inter-Mongolia, Hebei, Shandong, Henan, Jiangsu, Anhui experienced most significant increase, comparatively, Liaoning, Shanxi, Ningxia no significant increase (Table 2). From the histogram of *VCI* (Figure 8), about 25.95 percent pixels of the whole arable land in northern China had positive values greater than 2, indicating an increase of cropping index. On the contrary, only 2.43 percent had negative *VCI* less than -2, and the rest 71.62 percent falls into the interval [-2, 2]. Figure 9 shows the spatial distribution of *VCI*. During these 22 years, a large increase in *CI* happened in Huang-Huai-Hai drainage area, a large decrease in a small quantity of pixels of Henan and Shanxi provinces, and no visible changes in other regions.

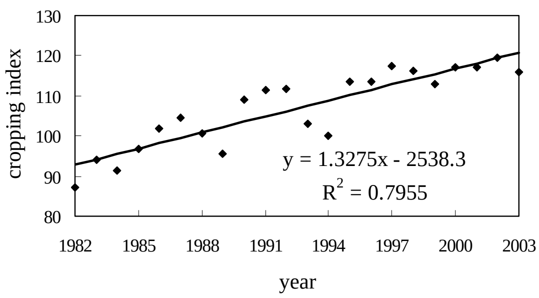

Figure.7 The variation of total northern China cropping index from 1982 to 2003

	Coefficient	R^2	P
Heilongjiang	0.394	0.129	0.100
inter-Mongolia	1.629	0.596	0.000
Xinjiang	0.630	0.567	0.000
Jilin	-0.067	0.115	0.123
Liaoning	0.000	0.000	0.990
Gansu	0.603	0.165	0.061
Hebei	2.686	0.628	0.000
Beijing	1.914	0.375	0.002
Shanxi	0.028	0.001	0.912
Tianjin	1.134	0.375	0.002
Qinghai	0.423	0.127	0.104
Shaanxi	0.617	0.103	0.146
Ningxia	-0.009	0.000	0.977
Shandong	3.044	0.673	0.000
Henan	2.236	0.637	0.000
Jiangsu	2.618	0.462	0.001
Anhui	1.938	0.483	0.000

Table 2. The regression coefficient of each province cropping index from 1982 to 2003

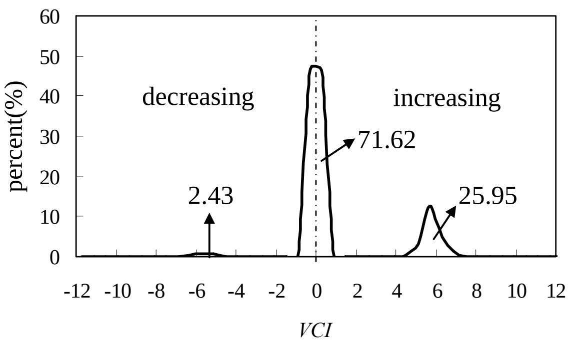

Figure.8 Histogram of cropping index change trends

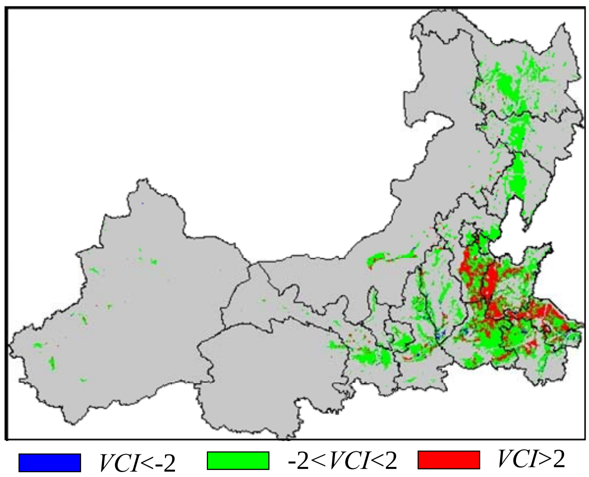

Figure.9 The spatial distribution of cropping index change trend during 1982-2003

5. CONCLUSION

Based on the understanding and definition of cropping index by remote sensing data, this study developed a method for extracting cropping index based on *NDVI* time-series. This method could correct cloud and other contaminations effectively. The most important part of this new method is circular correcting of curve based on the definition of "one-cropping". By applying this new method to GIMMS *NDVI* data, the cropping index of 17 provinces of northern China from 1982 to 2003 was extracted, and then the Cropping Index Variation of every arable land pixel during these 22 years was calculated by the Least Absolute Deviation linear regression method. The high accordance between remotely sensed cropping index data and statistical data suggests that this method could provide an effective way to extract spatial information of cropping index.

Northern China experienced a cropping index increase from 1982 to 2003, and *VCI* varies among different regions, with Huang-Huai-Hai drainage area experiencing a clear cropping index increase and other regions relatively less cropping index change. These results imply that it is possible to improve the food production of limited arable land by enhancing the cropping index. This is of value for regions and countries where food production suffers from arable land decrease along with economic growth.

ACKNOWLEDGEMENTS

This work was supported by the Hi-tech Research and Development Program of China (863 program) under Grant 2006AA12Z103.

REFERENCES

Chen J., Jönsson P., Tamura M., Gu Z., Matsushita B., Eklundh L., 2004. A simple method for reconstructing a high-quality *NDVI* time-series data set based on the Savitzky-Golay filter. *Remote Sensing of Environment*, 91, pp. 332-344.

Fan Jinlong, Wu Bingfang, 2004. A methodology for retrieving cropping index from NDVI profile. *Journal of Remote Sensing*, 8(6), pp. 628-636.

Fensholt, R., Nielsen, T. T., Stisen, S., 2006. Evaluation of AVHRR PAL and GIMMS 10-day composite NDVI time series products using SPOT-4 vegetation data for the African continent. *International Journal of Remote Sensing*, 27 (13), pp. 2719-2733.

Harris, R., 2003. Remote sensing of agriculture change in Oman. *International Journal of Remote Sensing*, 24(23), pp. 4835-4852.

Holben, B. N., 1986. Characteristics of maximum-value composite images from temporal AVHRR data. *International Journal of Remote Sensing,* 7, pp. 1417-1434.

Liu Xunhao, 1992. The view of Chinese Cropping System in 1990s. *Cultivate and Plant*, 2, pp. 1-9.

Liu Xunhao, 1993. *Cropping System in China*. Beijing, Agricultural Press, pp. 12-15.

Liu Xunhao, 1997. Study on potential of multi-cropping index of arable land in China. *Crop Magazine*, 3, pp. 1-3.

Ma Yongxiang, 2003. Multi-cropping index discussion. *Crop Magazine,* 4, pp. 54.

Powell, J. L., 1984. Least absolute deviations estimation for the censored regression model, *Journal of Econometrics*, 25, pp. 303-325.

Seelan, S. K., Laguette, S., Casady, G. M., Seielstad, G. A, 2003. Remote sensing applications for precision agriculture: A learning community approach. *Remote Sensing of Environment,* 88(1-2), pp. 157-169.

Shen Xuenian, Liu Xunhao, 1983. *More Ripeness Cultivation*. Beijing, Agriculture Press, pp. 9-15.

Tucker, C., Pinzon, J., Brown, M., Slayback, D., Pak, E., Mahoney, R., Vermote, E., Saleous N. El., 2005. An extended AVHRR 8-km NDVI dataset compatible with MODIS and SPOT vegetation NDVI data. *International Journal of Remote Sensing*, 26 (20), pp. 4485-4498.

Vermote, E., Saleous N. El., Kaufman Y. J., Dutton E., 1997. Data pre-processing: stratospheric aerosol perturbing effect on the remote sensing of vegetation: correction method for the composite NDVI after the Pinatubo eruption. *Remote Sensing Reviews,* 15, pp. 7-21.

Yan Huimin, Cao Mingkui, Liu Jiyuan, *et al*., 2005. Characterizing spatial patterns of multiple cropping system in China from multi-temporal remote sensing images. *Transactions of the CSAE,* 21(4), pp. 85-90.