DETECTING CROP ROTATIONS IN CHINA USING AVHRR IMAGERY AND ANCILLARY DATA

J.K. Guo [a], J.Y. Liu [a], G.M. Huang [b], D.F. Zhuang [a], H.M. Yan [a], G.P. Zhang [c]
a Institute of Geographical Science and Natural Resources Research, CAS, 11A Datun Road, Anwai, Beijing, 100101, China- (Guojk, zhuangdf, yanhm)@lreis.cn, liujy@igsnrr.ac.cn
b Chinese Academy of Surveying and Mapping, Beitaiping Road, No.16, HaiDian, Beijing, 100039, China - huang.guoman@163.net
c National Meteorological Center, Zhongguancun South Street, 46, HaiDian, Beijing, 100081, China - zhanggp@cma.gov.cn

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ABSTRACT:

The situation of cropland use in China is very complicated. In many areas, the cropland is used in multi-cropped ways. There is a need for better information on the area and distribution of cropland using in different cropping rotation systems, but it is not easy to get it in traditional census ways. This paper focuses on the methodology of crop rotations detection in China using multitemporal satellites images. Two agricultural regions located in the middle of China were chosen as the study areas. The dataset used here includes 10 days composites NDVI (36 periods) obtained from the NASA Pathfinder AVHRR Land dataset, land-cover dataset derived from TM images, and the ground based agricultural monitoring data. The discrete Fourier transform was applied to the NDVI data set on a per pixel basis for the whole cropland of the study areas and then the additive and the first four harmonics (amplitude and phase) were classified using ISOLATE unsupervised classification algorithm for both regions respectively. Crop information derived from local stations and the Chinese cultivated system regionalization map were used to assess the accuracy of the result. The result of this study showed that the methodology used in this study is, in general, feasible for detecting crop rotations in China.

1. INTRODUCTION

The situation of cropland use in China is very complicated because of huge population and limited cropland. Roughly half of the cropland in China is used in multi-cropped ways—the sequential cultivation of an ordered succession of crops on the same land in a year. The information about the crop rotations in China is very important for assessments of the potential of food production and the impact of multi-cropping on biogeochemical cycling of carbon and nitrogen in agroecosystems. There is a need for better information on the area and distribution of cropland using in different cropping rotation systems but it is not easy to get it in traditional census ways. Remote Sensing has been shown to be very useful for analysis and mapping crop rotations (Panigrahy, 1997; Qiu, 2003).

Time series of Normalized Difference Vegetation Index (NDVI) have been used widely in studies on land cover characteristics and vegetation phenology because of its correlation with green plant biomass and vegetation cover. The cropland used in different kinds of crop rotations exhibit distinctive patterns of NDVI variation in a year so it is feasible to derive the crop rotation information from analysis the temporal change in NDVI values.

Some methods have been used to obtain the characteristics of NDVI time series such as signal decomposition (Moody, 2001) and key NDVI metrics analysis (Reed, 1994). Discrete Fourier transform (DFT) as a signal decomposition method can extract periodic responses through expressing a NDVI time series curve with the sum of an additive term and a series of sinusoidal waves and it has been used in analysis and evaluation land surface dynamics and phonologies (Moody, 2001; Olsson, 1994), land cover classification (Andres, 1994), crop type identification (Jakubauskas, 2001, 2002), and mapping agroecological zones or producing bioclimatological regionalization (Menenti, 1993; Azzali, 2000). It has been shown that the Fourier harmonics are sensitive to seasonal variability in vegetation productivity and discrete Fourier analysis is an objective and concise summarization of the temporal signature that is sensitive to systematic changes in vegetation (Andres, 1994; Moody, 2001).

In this study we detected the situation of crop rotations in two of nine agricultural regions in China using discrete Fourier analysis and unsupervised classification approach with AVHRR time series NDVI and ancillary data.

2. DATA USED

2.1 Study Areas

In this paper, Yellow-Huai-Hai Rivers' Region (HH) and Loess Plateau Region (HT), two of the nine agricultural regions based on the Chinese general agricultural regionalization map (Sun, 1994) were used for the study (Fig.1). Both regions are located in the middle of China and cover the total or part of 12 provinces and metropolis. There is a mix of single and double-cropping in these areas. Single cropped winter or spring wheat, spring maize, cotton, rapeseed and double cropped winter wheat and summer maize (or cotton, rice) are the main crop rotations types in these two regions.

2.2 Data Used

The dataset used in this study includes 10 days composites AVHRR time series NDVI (36 periods), land-cover dataset obtained from TM images, Chinese general agricultural regionalization data, Chinese agricultural cultivated system regionalization map and ground based agricultural phonological observation data.

A time series of 10 days composites NDVI derived from 8km AVHRR using the Maximum Value Composite (MVC) technique were used for analysis crop rotations in study areas. The data were obtained from the NASA Pathfinder AVHRR Land dataset. The 36 10 days composites NDVI which cover the two regions were created by averaging the same period data in 1999 and 2000 to reduce climatic influence, and corresponding average data of 1997 and 1998 were used to instead of missing periods from November to December both in 1999 and 2000. The images which are originally in the Goode's Interrupted Homolosine Projection were reprojected to Albers Equal Area Map Projection before being used in the research.

Cropland grid data with a spatial resolution of 8km were used as a mask to extract NDVI time series for cropland in study areas. The data were aggregated based on the maximum percentage of land cover in each cell from 1km NLCD-1999/2000 (Liu, 2003), which were derived from NLCD-1996 (Liu, 1996) through updating with Landsat TM.

The ground based agricultural monitoring data derived from 96 local stations in year 2000 (Fig.1) including the crop phonological calendar and main crop types planted in the local area were used for evaluation. The Chinese cultivated system regionalization map (Chinese agriculture regionalization committee, 1991) was used as other kinds of dataset to assess the result.

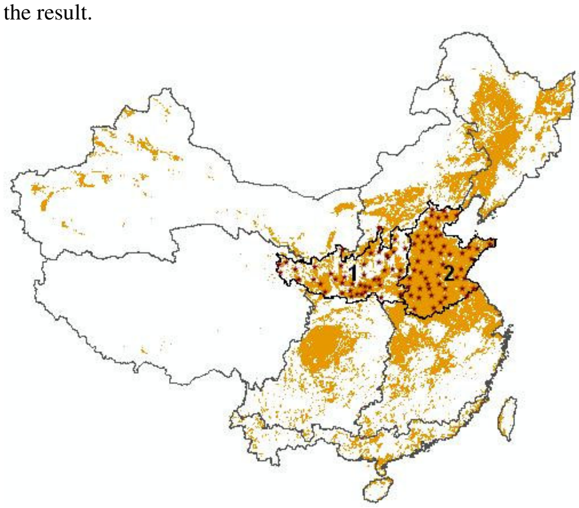

Figure 1. The location of study area in Chinese general agricultural regionalization map, the distribution of cropland in China at 8km resolution and the distribution of 96 local stations. 1. Loess Plateau Region (HT) 2. Yellow-Huai-Hai Rivers' Region (HH).

3. METHODS

3.1 Discrete Fourier Transformation

Discrete Fourier transform (DFT) as a signal decomposition method can decompose discrete temporal data to the frequency domain. The discrete Fourier transform is given by Eq.(1) (Moody, 2001):

$$y_k = \frac{1}{N} \cdot \sum_{k=0}^{N-1} c_k e^{-j2\pi k/N} \tag{1}$$

where N = the number of samples in the time series
k = an index representing the current sample number
i = an imaginary number
c = the kth sample value.

By the DFT a time-dependent periodic phenomenon can be decomposed into a series of constituent sine and cosine functions and can also be converted to the sum of an additive and a series of sinusoidal waves (harmonics, or orders). The additive is the arithmetic mean and each wave is defined by a unique amplitude and phase angle, where the amplitude value is half the height of a wave, and the phase angle (or simply, phase) defines the offset between the origin and the peak of the wave over the range 0- 2π for the first harmonic, 0- 4π for the second harmonic and so on. Successive harmonics are added to produce a complex curve, and each component curve, or harmonic, accounts for a percentage of the total variance in the original time-series data set. The majority of the variance in a data set is contained in the first few harmonics.

In this study the discrete Fourier transform was applied to the 36 10 days composites AVHRR time series NDVI dataset on a per pixel basis for the whole cropland of study areas. Images of the additive, and amplitude and phase angle for each harmonic to the eighteenth harmonic were produced on a per-pixel basis for each pixel in the NDVI dataset. The amplitude and phase were presented in the unit of NDVI and 10 days. Percent variance of each harmonics was computed and then the additive and the first four harmonics (amplitude and phase) were extracted and used for further analysis because about 87% of the variance is captured in the additive and the first four harmonics.

3.2 Classification

Unsupervised classification method was used in this study. Image of the additive, and amplitude and phase for the first four harmonics (13 bands together) was used as input to the iterative ISODATA clustering algorithm, and a convergence threshold of 95% and 10 as the maximum number of iterations were assigned. Twenty spectral clusters were generated for each round and multi-rounds of classification were performed for the image to account for mixed clusters. Clusters were merged and labeled to four crop rotation classes: single cropped for paddy rice and others (non-paddy rice such as wheat, maize, soybean, rapeseed etc.), double cropped for others/rice and others/others, double cropped rice and triple cropped rotations were not considered in this paper because none of these situations occurs in these areas. These four crop rotations classes were assigned based on the analyst's knowledge of agriculture and patterns constructed from the summing of amplitudes and phases mean of first four harmonics and paddy fields data aggregated from NLCD-1999/2000 dataset.

4. RESULTS AND DISCUSSION

4.1 Fourier Analysis for Crop Rotations Detection

Power densities for the first four harmonics in Yellow-Huai-Hai Rivers' Region and Loess Plateau Region were compared with each other (Fig.2). The comparison showed that there is an obvious difference in proportions of the first four harmonics between these two regions, which means the quite different crop rotations patterns in these two regions. In Loess Plateau Region the power in the first harmonic is much greater than the power in successive harmonics, so unimodal pattern, in other words, single growing season and period of peak greenness is the main pattern for crops planted there and single crop rotations is predominantly located in that area. In Yellow-Huai-Hai Rivers' Region the situations is more complicated because the amplitude value of the third harmonic is higher, which means the possibility of much more cropland using in multimodal pattern resulting from muilti-cultivation practices.

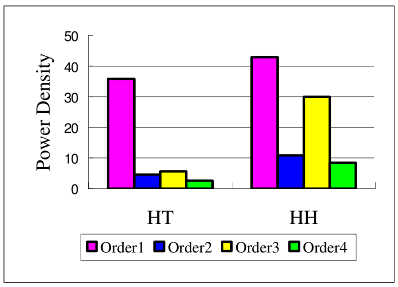

Figure 2. The power density of the first four frequencies in Loess Plateau Region (HT) and Yellow-Huai-Hai Rivers' Region (HH)

The result of the classification (Fig.3) shows that single and double cropped non paddy rice is the main crop rotations types in the study areas. About 39.1% of cropland is single cropped and 60.9% is double cropped. Single crop rotations are predominantly located in the Loess Plateau Region (70.5%), while double crop rotations occurs mainly in Yellow-Huai-Hai River' Region (90.1%).

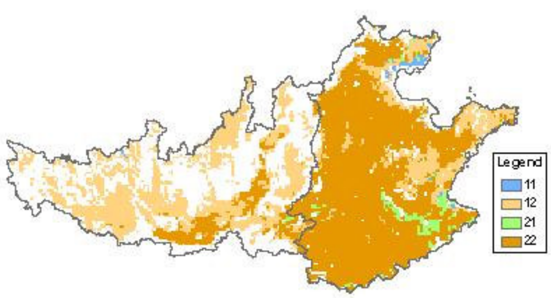

Figure 3. The distribution of single and double crop rotations in Loess Plateau Region and Yellow-Huai-Hai Rivers' Region. 11. rice, 12. others, 21. rice/others, 22. others/others. Here others means non-paddy rice including wheat, maize, rapeseed, soybean, etc.

As shown in Fig. 3, in the Loess Plateau Region nearly 82.1% of the cropland is singled cropped but most of the cropland in Yellow-Huai-Hai River' Region is planted in double cropped ways, and only 17.3% of the cropland is planted in single rotations. The obvious difference of crop rotations pattern between Yellow-Huai-Hai Rivers' Region and Loess Plateau Region derived from classification is consist with the result of the power densities comparison for the first four harmonics.

Crops planted in single crop rotations possess a single distinct growing season, attaining peak greenness during midsummer. This is manifested in the curve constructed from the first four harmonics but mainly depended on the first harmonic (Fig. 4). Since high amplitude values for a given harmonic indicate a high level of variance in temporal NDVI, and the harmonic in which that variance occurs indicates the periodicity of the event ((Jakubauskas, 2002)), the amplitude value in the first harmonic is much higher than the others, and as shown in Table.1, the amplitude values in successive harmonics are in descend order means a unimodal temporal NDVI pattern, in other words, single cropped pattern. The phase angle for the first harmonic (21.363, the beginning of August) (Table. 1) is almost the same as the time for the peak greenness of crops planted in single cropped ways and keeps an agreement with the crop phonological calendar.

Compared with the single crop rotations, curves for double crop rotations constructed from first four harmonics also exhibit the characteristics of double crop rotations (Fig.5), which is the two peak greenness occurred in temporal NDVI curve of one year, and differ from the curve for single crop rotations in that they depend on not only the first harmonic but also the second and third harmonics due to cultivating twice in a year. The high amplitude value in the third harmonic indicates the high variability of NDVI within four months. The phase of the third harmonic keeps an agreement with the time of peak greenness for the crops planted twice a year. In our study areas, winter wheat and summer maize is the main crop rotation. Winter wheat is planted in the fall, sprouts, and goes dormant over winter. In the spring, the wheat greens up and is harvested by May, followed by planting summer maize or cotton, etc. The springtime peak of the curve constructed with first four harmonics emphasizes the strength of winter wheat growing and corresponding time for the summertime peak is consistent with the phonology of summer maize.

Crop rotation	Order	Amplitude	Phase	% Var	Cum. Var
Single	0	153.460			
	1	6.267	21.363	0.69	0.69
	2	1.978	7.184	0.10	0.79
	3	1.457	8.091	0.06	0.85
	4	0.894	4.459	0.02	0.87
Double	0	162.762			
	1	5.658	17.645	0.34	034
	2	2.954	7.067	0.09	0.43
	3	5.536	10.416	0.32	0.75
	4	2.923	3.398	0.09	0.84

Table 1. Amplitudes, phases and variances of the first four harmonics for single crop rotations and double crop rotations in Loess Plateau Region and Yellow-Huai-Hai Rivers' Region.

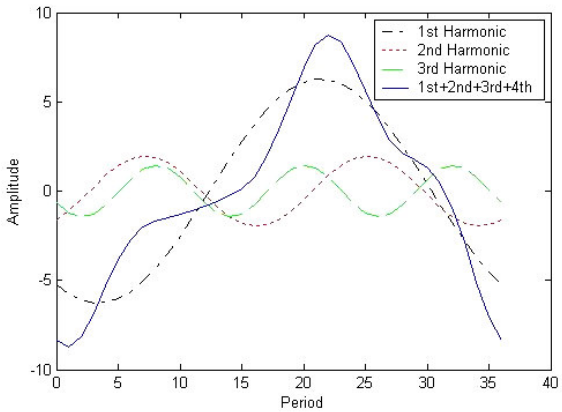

Figure 4. The curve constructed from the first four harmonics for single crop rotations in Loess Plateau Region and Yellow-Huai-Hai Rivers' Region.

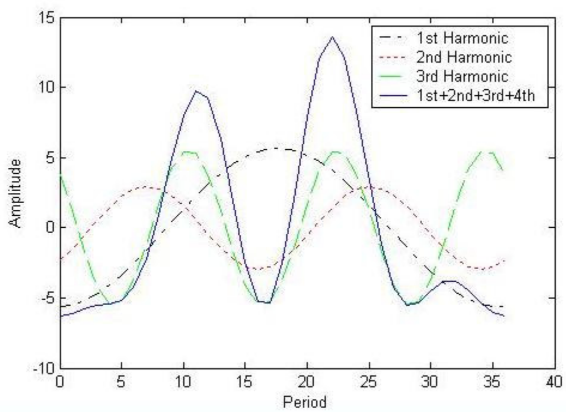

Figure 5. The curve constructed from first four harmonics for double crop rotations in Loess Plateau Region and Yellow-Huai-Hai Rivers' Region.

4.2 Result Evaluation

The results of the crop rotations classification were evaluated in two ways. First, we compared the Fourier based classification with the Chinese cultivated system regionalization map. Second, they were compared with the ground based agricultural monitoring data derived from local stations in year 2000.

The crop rotations map (Fig.3) described above was evaluated first by comparison with the Chinese cultivated system regionalization map, which was georeferenced to the same map coordinate system. The result of the crop rotations classification keeps comparative consistency with the reference map. The high accuracy derived from this comparison is partly due to the coarse description of the Chinese cultivated system regionalization map. But anyway the comparison shows that there are no notable mistakes in the result s of the crop rotations classification.

In addition to the map comparisons, we also evaluated the results with the ground-based observations, which include the information about crop phonological calendar, and main crop types (winter wheat, spring wheat, spring maize, summer maize, rice, rapeseed, cotton, soybean, sorghum and peanut) planted in the local area. There are 96 local stations observations (43 for Loess Plateau Region, 53 for Yellow-Huai-Hai River' Region) in year 2000 in the study areas.

In Loess Plateau Region, double crop rotations were observed in 14 of 43 stations and winter wheat/summer maize (8 stations) and winter wheat/cotton (4 stations) were the main rotations types. From others local stations observations, winter wheat, spring wheat, spring maize and sorghum were known as the main crops planted in single rotations. In Yellow-Huai-Hai River' Region, double crop rotations were observed in 46 of 53 stations, and four of them for double cropped winter wheat/ rice, others for double cropped nor rice crops. Winter wheat/summer maize was the main double crop rotations type in this region since it was observed in thirty local stations. The number of the local stations observations for single or double crop rotations showed the general agreement with the result of the classification.

The accuracy of the crop rotations map evaluated with observations from 96 local stations was shown in Table. 2. The overall agreement between our crop rotations map and ground observations was 85 %.

	Single cropped	Double cropped	User's accuracy (%)
Single cropped	28	6	82.4
Double cropped	8	54	87.1

Table 2. The accuracy of the crop rotations map evaluated with observations from 96 local stations.

5. CONCLUSIONS

In this study we detected the situation of crop rotations in Yellow-Huai-Hai Rivers' Region and Loess Plateau Region, China using discrete Fourier analysis and unsupervised classification approach with AVHRR time series NDVI. The result of this study shows that the methodology used in this study is, in general, feasible for detecting the distributions of single cropped and double cropped rotations in China. Detection of triple crop rotations using discrete Fourier transform will be considered in the further study.

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