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Full Length Research Paper

MODIS data based NDVI Seasonal dynamics in agro-ecosystems of south bank Hangzhouwan bay

Zhao Hangbin[1], Yang Xiaoping[2]* and Li Jialin[2]

[1]College of Information, South China Agricultural University, Guangzhou 510642, Guangdong, China.
[2]Coastal Resources and Environment Research Center, Ningbo University, Ningbo 315211, China.

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Normalized difference vegetation index (NDVI) is an important index characterizing the growth dynamics of plants. During the growth process of plants, NDVI value gradually increases, reaching its maximum at a certain stage of its growth period and then gradually dwindle. The variation curve of NDVI varies for different plants. Due to its high time resolution, Moderate Resolution Imaging Spectrometer–Normalized difference vegetation index (MODIS-NDVI) data can be applied to the study on the NDVI's variation of agro-ecosystem. The analysis on the NDVI's variation characteristics in different cropping systems of the agro-ecosystem of south bank Hangzhouwan Bay (Southeast Shanghai, China with north latitude of 30°02′ to 30°24′ and east longitude of 121°02′ to 121°42′) was conducted by employing the field investigation data and remote sensing data of 23 time sequences synthesized by MODIS-NDVI 16d in 2002. The results indicate that NDVI curves of different cropping systems are characterized by specific variation law. NDVI feature model extracted from different cropping systems based on MODIS-NDVI data can be used for the analysis of the cropping system of the agro-ecosystem, providing basic data for remote sensing yield estimation.

Key words: MODIS – NDVI, agro-ecosystem, cropping system, seasonal dynamics.

INTRODUCTION

Vegetation is an integral part of the terrestrial ecosystem, with its significant impact on the climate, hydrology and biochemical process of the entire earth system. Satellite remote sensing, which is independent from the constraints of natural and social conditions, can acquire the observed data of earth vegetation extensively, thus becoming an effective approach for studying earth vegetation and its variation. Normalized difference vegetation index (NDVI) is an important index for the characterization of earth surface vegetation (Shi et al., 2000), and its temporal variation is of great significance for revealing the evolution of earth system on regional short scale (Li and Shi, 2000). Therefore, researches related to NDVI have become the hot spot in the study on earth vegetation. Existing researches are mainly focused on vegetation division on varying scales (Sheng et al., 1995; Li and Shi, 1999). Analysis of NDVI characteristics of vegetation and their seasonal variation (Pan et al., 2000; Gao and Liu, 2000; Sun et al., 2003), the vegetation's growth situation and phenological monitoring (Pei and Yang, 2000; Lu et al., 2002; Zhang et al., 2004; Song and Zhao, 2004), the correlation analysis of NDVI and climatic factors(Li and Shi, 2000; Li and Tao, 2000; Tang and Chen, 2003; Mao et al., 2003) and the monitoring of natural disasters (Zhou, 1998), etc.

Since agro-ecosystem is the basic food source for the sustenance of human being, the monitoring of the growth dynamics of the crops and the accurate estimation of the yield is of great significance for maintaining national food security and social stability. As a consequence, the macroscopic monitoring of the growth situation of crops and yield estimation using NDVI and ground monitoring data have also undergone rapid progress. In 1974, US department of agriculture, national oceanic and atmospheric administration, and the commercial department of national aeronautics and space administration (NASA) together formulated the plan for LACIE (large area crop inventory experiment), which turned out to be successful. China's remote sensing yield estimation of crops has also entered the stage of practical operation (Jiang et al., 1999; Huang et al., 2003; Yang et al., 2004). The prerequisite for remote sensing yield estimation of crops

*Corresponding author. E-mail: yxpnb@126.com.

is the acquisition of information concerning the cropping system of agro-ecosystem and the planting areas of each crop, and the method mainly adopted is to obtain the planting percentage of each crop based on ground agricultural sampling. Then the total planting area of each crop is calculated from regional farmland area (Yang et al., 2004; Wu, 2000). In this paper, MODIS-NDVI data with high temporal resolution is used to study the seasonal variation characteristics of vegetation index of principle cropping systems of the agro-ecosystem of south bank Hangzhouwan Bay, with the attempt to offer new idea for the planting area estimation of each crop in remote sensing yield estimation of regional agro-ecosystem.

THE STUDY AREA

South bank Hangzhouwan Bay (referred in particular to Cixi City of Ningbo in this paper) is located at the northeast of Zhejiang Province of the middle part of China's eastern coastal area, or on the southeast of Shanghai, and outside Qiantang Estuary. Lying between north latitude of 30°02′ to 30°24′ and east longitude of 121°02′ to 121°42′, it has a total land area of 1154 km^2, with a total population of 1008.4 thousand. The land area per capita is merely 0.114 hm^2, less than 1/6 of national average.

The climate of south bank Hangzhouwan Bay is north subtropical south rim monsoon climate. The hills, plains, intertidal zones and oceans constitute a stepped topography along the direction from north to south. The zonal vegetation belongs to subtropical evergreen broad-leaved forest, and the original vegetation of hills of Cuiping Mountain in the southeastern region which has basically disappeared is substituted with secondary forest and man-made forest. The natural vegetation of the middle of Binhai sedimentary plain is predominantly herbal, and the crops artificially cultivated are mainly composed of rice, cotton, soybeans, rape, and vegetables. The muddy intertidal zones in the north have a broad beach face, with the vegetation dominated by Spartina Alterniflora, reed and Suaeda community. Within this region, the weather is cool in summer and warm in winter, and the annual sunshine duration and total solar radiation is 2038.4h and 112 kilocalorie/cm^2 respectively with an average precipitation of 1272.8 mm annually. The temporal and spatial distribution of sunshine, heat and water are relatively good, and the climate is warm and humid, with high light-temperature efficiency, abundant rainfall and long period for crop growth.

MATERIALS AND METHODS

MODIS-NDVI data came from MODIS sensor of TERRA satellite of America's earth observation system (EOS). This sensor, as the new-generation optical remote sensing apparatus combining image with spectrum, have 36 spectral channels, distributed in the region of electromagnetic spectrum of 0.4-14 μm. The ground resolution of this apparatus is 250, 500 and 1000m, with a scanning width of 2330 km, and it can acquire observation data of terrestrial synthetic information of 36 global spectral bands twice daily (Liu and Ge, 2000) except the equator. Compared with AHVRR, MODIS is only able to acquire NDVI information from limited wave bands, thus excluding moisture absorption area of infrared wave band which is more sensitive to the absorption of chlorophyll (Wang et al., 2003). In order to counteract the adverse influence of cloud, atmosphere and non-satellite zenith angle observation. Constraint view-maximum value compositing (CV-MVC) for 16d day-by-day image was adopted in this paper in MODIS NDVI, to obtain NDVI value of vegetation (Wang et al., 2003). With the synthetic data of MODIS-NDVI 16d of the research area in 2002, the temporal resolution of the data was 1 km × 1 km, with 23 time sequences included.

The field investigation of current land use was conducted in March, June, August and November of 2002. Six principle planting patterns, that is, vegetables and cotton, cotton, double-cropping rice, vegetable and late rice, vegetables and *Pyrus pyrifolianakai* of agro-ecosystem of south bank Hangzhouwan Bay were selected, as shown in Table 1. For each planting pattern, 5 to 8 monitoring points were chosen for the study of seasonal variation of NDVI, with the monitoring points distributed at areas with large planting areas and little topographic undulation in all kinds of planting pattern for better matching with MODIS data with intermediate resolution. In addition, field interviews of 50 different locations were carried out in December 2002, for the purpose of collection information of the planting pattern of each location from the peasant households to confirm the NDVI feature model of each cropping system. Jaguar 12-frequency handheld GPS produced by GARMIN Company was used in the interviews at the monitoring points and field interview points for geographic coordinate positioning.

Open MODIS-NDVI data of the research area in ENVI 4.0. Since the data had geographical coordinates themselves, NDVI values of 23 time 23 time sequences could then be read by inputting the coordinates of the monitoring points. As NDVI value of each time interval is the synthesized product during the 16 days, these values can be transferred into monthly average NDVI values using the following equation:

$$\overline{NDVI}_j = a \cdot NDVI(i) + b \cdot NDVI(i+16) + c \cdot NDVI(i+32) \qquad (1)$$

Where $\overline{NDVI}_j$ is the monthly average of NDVI, and $j = 1, 2, \cdots, 11, 12$ month; $NDVI$ is the MODIS-NDVI 16d product containing part of the days of jth month; i is the Number for MODIS-NDVI 16d products, and $i = 001, 017, \cdots, 305, 321$; a, b and c is the ratio of the number of days in jth month to the total number of days in jth month of i th, $i+16$ th and $i+32$ th product, respectively.

NDVI value of each monitoring point was calculated according to the above equation, and statistical analysis was then conducted on the average value of NDVI, standard deviation and coefficient of variation of each cropping system (Table 2). Analysis showed that coefficient of variation of monthly average NDVI of each cropping system were mostly below 10.0%, indicating that monthly NDVI value of each monitoring point had relatively good representativeness and that taking the monthly average of NDVI value of each monitoring point as the average level of a specific cropping system was feasible. Accordingly, variation curve of annual NDVI of each cropping system was obtained, with the results shown in Figure 1. Meanwhile, in order to further analyze the variation characteristics of NDVI of each cropping system, NDVI

Table 1. Cropping systems of agro-ecosystem of south bank Hangzhouwan bay.

Cropping system	Types of land use	Basic information
Vegetable and cotton pattern	Dry land	The period for cotton planting is from middle and late April to middle and late November, and the remaining period is for vegetable planting.
Cotton planting pattern	Dry land	Middle and late April is the period for planting, and middle November is the period for harvest, with no crop planting during the remaining period.
Double cropping rice pattern	Paddy field	Early rise is transplanted in the late April, and is harvested in late July; late rice is transplanted in the late July, and is harvest in the middle and late November.
Vegetable and late rice pattern	Paddy field	The period from late July to middle November is for planting late rice, and the remaining period is for planting vegetables.
Vegetable pattern	Dry land and paddy field	Vegetables are planted all the year round, and greenhouse is used in winter.
Pyrus pyrifolianakai pattern	Dry land and paddy field	Early March is the time for sprouting; early April is the time for blossoming; middle August is the time for ripening.

Table 2. Statistical characteristics of monthly average NDVI for variety cropping system.

Cropping system		Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Vegetable and cotton pattern	av.	38.71	41.42	45.23	47.86	40.98	50.10	61.69	64.01	67.91	52.57	38.69	41.67
	Std.	2.41	3.12	3.01	3.61	4.35	4.30	3.71	3.20	3.46	2.13	2.12	3.04
	cv. (%)	6.23	7.53	6.66	7.54	10.61	8.58	6.01	5.00	5.10	4.05	5.48	7.30
Cotton planting pattern	av.	30.92	29.02	31.58	32.33	38.62	48.10	59.19	66.88	70.01	50.57	35.81	31.24
	Std.	3.41	3.07	2.96	4.30	2.16	3.07	3.41	4.01	5.16	4.05	2.37	3.01
	cv. (%)	11.03	10.58	9.37	13.3	5.59	6.38	5.76	6.00	7.37	8.01	6.62	9.64
Double cropping rice pattern	av.	38.74	41.98	44.28	45.7	50.36	67.9	36.45	72.22	76.54	64.94	51.12	46.88
	Std.	3.41	3.24	2.45	3.36	3.64	3.18	4.31	5.01	4.94	3.45	3.21	3.11
	cv. (%)	8.80	7.72	5.53	7.35	7.23	4.68	11.82	6.94	6.45	5.31	6.28	6.63
Vegetable and late rice pattern	av.	41.10	42.00	43.03	45.02	47.30	48.1	40.21	74.02	74.54	66.94	49.72	49.24
	Std.	3.65	3.87	3.24	3.15	3.24	4.01	3.05	4.76	4.30	4.01	3.99	3.06

Table 2. Contd.

	cv. (%)	8.88	9.21	7.53	7.00	6.85	8.34	7.59	6.43	5.77	5.99	8.03	6.21
	av.	40.04	42.84	42.68	41.83	48.78	46.15	45.96	43.84	45.14	46.64	45.00	42.01
Vegetable pattern	Std.	3.46	3.45	3.22	3.55	2.16	1.43	3.65	3.76	3.14	4.41	2.67	3.15
	cv. (%)	8.64	8.05	7.54	8.49	4.43	3.10	7.94	8.58	6.96	9.46	5.93	7.50
	av.	38.87	35.33	36.67	45.69	47.51	49.05	60.97	66.3	63.48	57.15	44.28	40.09
Pyrus pyrifolianakai pattern	Std.	2.78	2.96	2.97	2.56	3.45	3.45	3.24	3.64	3.57	3.04	3.21	2.34
	cv. (%)	7.15	8.38	8.10	5.60	7.26	7.03	5.31	5.49	5.62	5.32	7.25	5.84

Table 3. Grey relational analysis for NDVI curve of ground survey sample and variety cropping system.

Cropping system	ξ1	ξ2	ξ3	ξ4	ξ5	ξ6	ξ7	ξ8	ξ9	ϒ
Vegetable and cotton pattern	0.923	0.897	0.937	0.879	0.946	0.967	0.456	0.903	-	0.864(0.922)*
Cotton planting pattern	0.941	0.931	0.889	0.934	0.921	0.881	0.951	0.926	-	0.92175
Double cropping rice pattern	0.874	0.961	0.944	0.923	0.899	0.907	0.964	0.937	-	0.92613
Vegetable and late rice pattern	0.917	0.934	0.881	0.864	0.861	0.941	0.951	0.927	-	0.9095
Vegetable pattern	0.924	0.916	0.937	0.929	0.869	0.893	0.926	0.931	0.907	0.91467
Pyrus pyrifolianakai pattern	0.911	0.974	0.437	0.419	0.891	0.934	0.929	0.913	0.931	0.815(0.926)*

* The data in parenthesis are the correlation coefficient excluding the influence of three samples which exit some error.

of each cropping system in January was taken as the reference point, and the variation monthly NDVI value was calculate as shown in Figure 2.

RESULTS

Variation characteristics of NDVI of each cropping system

Cotton planting pattern

It has not been very long since south bank Hangzhouwan Bay was reclaimed, an extensive range of reclamation land was once used for cotton planting, with the sowing area accounting for 1/3 of Zhejiang Province, creating a record high yield of lint cotton per area. Since 1980s, the cotton planting area at south bank Hangzhouwan Bay gradually decreased with the adjustment of agricultural planting structure, and only part of the high-yield dry land was reserved for cotton planting. Cotton undergoes five stages with different nature from seed germination and fully grown that is sowing stage, seedling stage, budding stage, blooming stage and boll opening stage. The period from sowing to picking is called the entire growth period which lasts for about 210 days. The cotton is generally planted in middle and late April at south bank Hangzhouwan Bay, and it takes around 120 days to proceed from sowing stage, seedling stage, budding stage to blooming stage, and this period is called growth period. Then it comes to boll opening stage for cotton in late August, which lasts until middle November when the pick is over. During these five growth stages, NDVI which reflects the growth situation of cotton displays corresponding variation law. It can be known from Figure 1 that the variation curve of NDVI of agro-ecosystem with only cotton planted is the unimodal curve in the whole year. From January to early April, no crops were sowed in the field generally, resulting

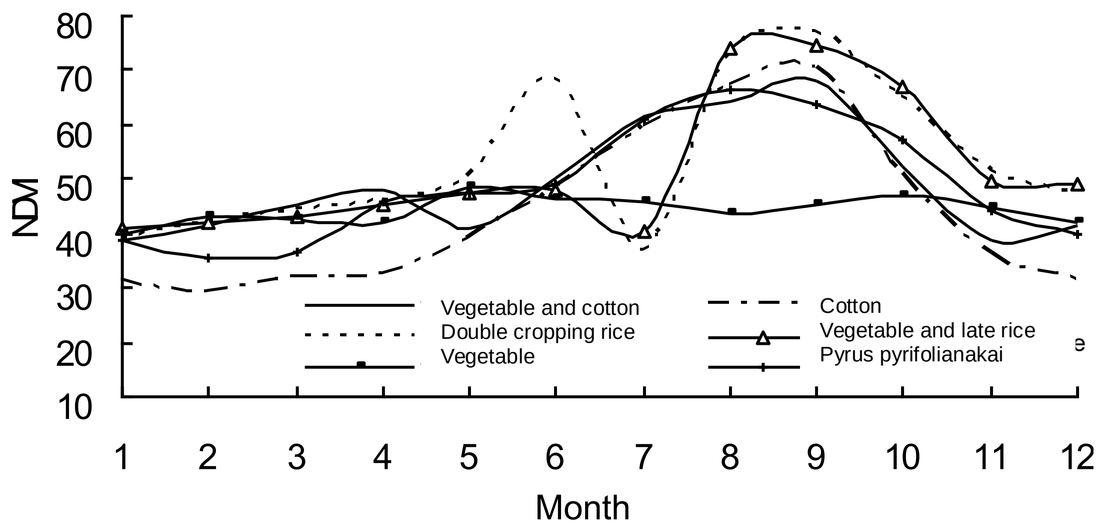

Figure 1. Variation curve of NDVI of each cropping system.

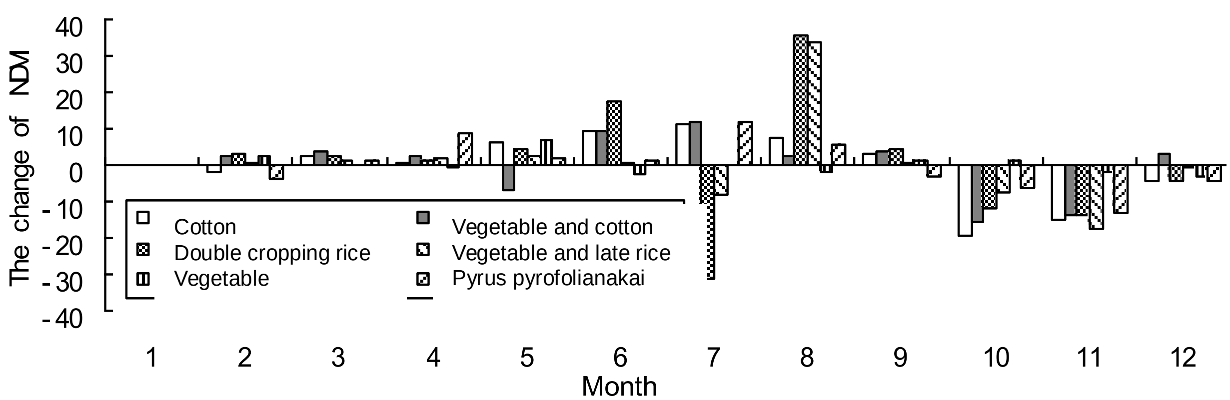

Figure 2. Monthly change of NDVI for variety cropping system.

in a very small NDVI value which was usually 30. Starting from middle and late April when cotton sowing began, NDVI gradually increased. Seedling stage of the cotton started from May, and NDVI value rapidly increased as the cotton seedling grew. June and July were the months for budding, and NDVI further increased. With the approach of blooming stage in August, NDVI value reached its maximum from middle and late August to early September, being 70. Consistent with the increase in NDVI value, the monthly variation of NDVI value from May to September were all positive, with the increment of July being the maximum of 11.09, as shown in Figure 2. Although NDVI value reached its maximum in September, the monthly increment of NDVI value was the minimum of 3.13 during this period. After the cotton entered the boll opening stage, the leaves yellowed, leave pore closed, and the absorption ability of chlorophyll weakened correspondingly. Consequently, the reflectance value of red waveband channel of the senor decreased, while that of infrared waveband gradually decreased, resulting in the reduction of NDVI value. In middle and late November when cotton was harvested and the cotton straw was removed from the cotton field, no vegetation covered the cotton field at this time. Therefore, the information received by MODIS was basically the spectral information of the soil, with NDVI plummeting to the low level at the beginning of spring. It can be known from Figure 2 that from October to December, the monthly variation of NDVI value was all negative, with the reduction of 19.4, 14.8 and 4.6, respectively.

Vegetable and cotton pattern

Vegetable and cotton pattern was mainly distributed in dry land with long time of soil formation and good fertility. During slack season without cotton planting, vegetables were usually planted. The variation process of NDVI of this type of agro-ecosystem was basically consistent with that of cotton pattern during the cotton planting period. Cotton seedling stage started from May, and all the way through the budding stage in June and July, to boll opening stage in August and then to early September, NDVI value constantly increased (Figure1). During this period, the monthly variation of NDVI value was all positive, reaching its maximum of 11.6 in July. In October and November, NDVI value gradually decreased, with the monthly reduction of NDVI value reaching its maximum of 15.3 in October (Figure 2). While during the period from December to April of the following year, NDVI value of this pattern was apparently higher that that of cotton pattern because of vegetable planting, being over 40 normally (Figure 1). The monthly variation of NDVI value during the period from December to April of the following year was positive, ranging between 2 and 4; that in May was negative, with a reduction of 6.9 (Figure 2), as a result of the fact that cotton seedlings were just transplanted after the harvest of vegetables in May, which naturally caused the smaller NDVI value than that in April before the vegetable harvest.

Double cropping rice pattern

Double cropping rice pattern is the traditional cropping system for paddy fields at south bank Hangzhouwan Bay, and an extensive planting area is still retained at present. Early rice is usually transplanted in middle April, and it enters tillering stage in early May, jointing-booting stage in late May, tasseling-blooming stage in middle June, and ripening-reaping stage in early and middle July. Late rice is transplanted right after the reaping of early rice in late July, and it enters tillering stage in middle August, jointing-booting stage in middle and late September, tasseling and blooming in middle and late October, and ripening-reaping in middle November. After the reaping of late rice, some fields are planted with green manure or vegetable, while other fields are left desolated until the cultivation of early rice in April of the following year. During the growth process of double cropping rice, NDVI curve reflecting the growth situation of rice also displayed corresponding variation law.

It can be known from Figure 1 that the variation process of NDVI value of double cropping rice pattern displayed apparent bimodal curve. From January to April, NDVI value was maintained at around 40. With the transplant of early rice seedlings in middle April, NDVI value of paddy field gradually increased. As the early rice entered tillering stage and jointing-booting stage in May, NDVI value rose sharply, reaching the first peak value of 68 at tasseling-blooming stage in June. July was the month for the reaping of early rice and the sowing of late rice. Since no vegetation covered the field after the reaping of early rice and small biomass of late rice seedling transplanted, an apparent low ebb of 36 occurred in July. With the tillering stage and jointing-booting stage of late rice, NDVI value of August kept on increasing, reaching the second peak value of around 76 at the tasseling and blooming stage in September. With the ripening of rice ear, the leaves yellowed and NDVI value decreased correspondingly. After the reaping of rice at the end of November, NDVI plunged to the low ebb for the second time. Seen from the monthly variation of NDVI value, during the growth period of early rice, monthly variation of NDVI value from April to June was positive, increment reaching the maximum of 17.5 in June. NDVI value of July significantly reduced, with the reduction of 31.4. During the growth period of late rice in August and September, the monthly variation of NDVI was all positive, with the increment reaching the maximum of 35.8 in August. The monthly variation of NDVI value from October to December was all negative, reduction reaching its maximum of 13.8 in November.

Vegetable and late rice pattern

Under the influence of adjustment of planting structure as well as supply and demand relation of rice market (structural surplus of rice), the sowing area of food crops tremendously reduced from 1980's. From 1987 to 2000, the proportion of the planting area of food crop in the entire sowing area of crops dropped from 44.34 to 36.78%, a reduction of 7.56% point in 13 years, while as a major aspect of the adjustment of the internal structure of food crops, the proportion of planting area of grains decreased from 34.09 to 16.12%, that of early rice accounting for the greatest portion in the decrease of planting area of rice. Therefore, vegetable and late rice pattern has taken over to become the principle planting pattern of ecosystem of paddy fields at south bank Hangzhouwan Bay. The variation process of NDVI value of vegetable and late rice pattern during the planting of late rice was similar to that of double cropping rice pattern, with large NDVI value in August and September, and a first peak value of 74.6 was reached in September. After this, NDVI value gradually decreased, monthly reduction reaching its maximum of 17.2 in November. From December to July of the following year, due to the vegetable planting in the fields, its NDVI value began to climb slowly but steadily from 41, reaching 48.1 in June. The harvest of vegetables and planting of late rice in July led to the lowest value of 40.2 in the entire year, with the monthly reduction of 7.9 (Figures 1 and 2).

Vegetable pattern

With the construction of Cixi national agricultural science and technology park, facility agriculture and export-oriented agriculture at south bank Hangzhouwan Bay are developing at a rapid speed, with export-oriented vegetable planting being an integral aspect of Cixi national agricultural science and technology park. With Changhe Town where vegetable production base with an area of 8k m2 is located being the core area, the entire demonstration area for vegetable planting extends nearly 70 km2. Large areas of dry land and paddy fields have been converted to vegetable planting, main crop varieties include broad beans and green soybean and other species of vegetable legumes, black maize and waxy corn and other species of vegetable corns, cherry tomato and Japanese wrinkle melon and other species of solanberries, kale and broccoli and other species of leaf vegetables and fruit vegetables, radish and tuber mustard and other species of root vegetables, as well as green Chinese onion and Welsh onion and other species of shallots. As a result of the modification of planting technology, introduction of high-quality varieties and the promotion of greenhouse, the vegetable planting pattern can basically meet the requirement of an evergreen field. Therefore, the yearly variation process of NDVI value was a rather smooth curve, with the average maintaining between 40 and 48 (Figure 1). In terms of the monthly variation of NDVI value, the increment of May when vegetables grew most vigorously reaching as high as 8, while those in other months were below 3 (Figure 2)

Pyrus pyrifolianakai pattern

Ningbo has long been famous as China's hometown of pyrus pyrifolianakai, which enjoys high reputation at home and abroad for its good quality and is an integral component of characteristic fruit production of Cixi national agricultural science and technology park. With its planting area already reaching 30 km2, high-quality pyrus pyrifolianakai can be found mainly in the piedmont paddy fields and dry lands of towns such as Henghe, Zhouxiang and Hangzhouwan Bay, etc. Pyrus pyrifolianakai generally begins to sprout in early March, blooms in early April, fruits in middle August, and defoliates in winter. Since the park for pyrus pyrifolianakai was only built not long ago and the seedlings were greatly spaced. Vegetables are usually inter-planted between pyrus pyrifolianakai of relative young tree age. The variation curve of NDVI value of pyrus pyrifolianakai planting pattern is unimodal curve, and during its defoliation, its NDVI value was less than 40. After March, with the sprout of tree leaves, its NDVI value gradually increased, reaching the maximum of about 66 in August when the fruits ripened. From September on, NDVI value gradually decreased with the decrease of chlorophyll content of the leaves; after November when leaves started to defoliate, NDVI further dwindle, reaching the level of one year ago in December (Figure 1). In terms of monthly variation of NDVI value, the monthly variation of NDVI value was positive during its growth period (March to August), reaching the peak value of 11.9 in July. The monthly variation of NDVI value was negative from September to February of the following year, with the maximum reduction of 12.9 during its defoliation in November (Figure 2).

Confirmation of variation characteristics of NDVI of each cropping system

In order to confirm the applicability of variation characteristics of NDVI in judging different cropping system, the variation curves of NDVI value at each point in different cropping systems obtained via field interview were taken as samples, and discriminant analysis was conducted using grey correlation analysis in grey system theory, with the basic steps listed as follows:

(a) Range transformation of raw data. The objective of conducting range transformation is to eliminate the dimension of raw data so as to make it comparable. The mathematical formula for range transformation is as follows:

$$X'_{ij} = \frac{X_{ij} - X_{j\min}}{X_{J\max} - X_{j\min}} \quad (2)$$

(b) Determine master sequence X_0 and sub-sequence X_i. Variation curve of NDVI of each cropping system is taken as master sequence as in Figure 1 and the sub-sequence is determined with the following method: the point of each cropping system obtained through ground investigation were synthesized into NDVI data with corresponding 16d MODIS-NDVI data acquired. Then, monthly variation curve of NDVI value of each point calculated according to Formula (1) is then taken as the sub-sequence of the variation curve of NDVI value of the corresponding cropping system.

(c) Calculate the absolute value $\Delta_{0i}(t_j)$ of the difference between master sequence and sub-sequence, that is:

$$\Delta_{0i}(t_j) = X_0(t_j) - X_i(t_j) \quad (3)$$

(d) Take the maximum $\Delta_{\max}$ and minimum $\Delta_{\min}$ from $\Delta_{0i}(t_j)$.

(e) Calculate the correlation coefficient between master sequence X_0 and sub-sequence X_i. The calculation formula is as follows:

$$\xi_{0i}(t_j) = \frac{\Delta_{\min} + \rho\Delta_{\max}}{\Delta_{0i}(t_j) + \Delta_{\max}} \quad (4)$$

Where ρ is resolution coefficient, with its value generally selected as 0.5; since the data in correlation analysis intersect with each other after the data transformation, the value of $\Delta_{\min}$ is generally selected as 0.

(f) Obtain the correlation degree from correlation coefficient. The calculation formula is as follows:

$$\gamma_{0i} = \frac{1}{n}\sum_{i=1}^{n}\xi_{0i}(t_j) \tag{5}$$

The results of grey correlation analysis showed that except that the correlation coefficient of Sample No. 7 of cotton planting pattern, Sample No.3 and Sample No. 4 of pyrus pyrifolianakai planting pattern was below 0.5, those of all the remaining samples were uniformly high, and passed the significance test when α = 0.05 (Table 3). In terms of correlation degree index, under the influence of one and two samples with smaller correlation coefficient on cotton planting pattern and pyrus pyrifolianakai planting pattern, respectively, their correlation degree were 0.864 and 0.815, respectively, with those of remaining planting pattern above 0.91. Excluding the influence of these three samples, the correlation degree of cotton planting pattern and pyrus pyrifolianakai planting pattern was 0.922 and 0.926, respectively. Therefore, it can be concluded that the monthly variation curve of NDVI value of each cropping system obtained in this study is of universal significance for south bank Hangzhouwan Bay, and this curve can be used to determine the corresponding planting pattern.

DISCUSSION

The study on the seasonal variation of vegetation of principle agro-ecosystem of south bank Hangzhouwan Bay using MODIS-NDVI data indicates that yearly variation curve of NDVI value displays different characteristics for different cropping system, which can be reflected with variation curve of NDVI value. Grey correlation analysis reveals that this specific curve is of high precision in determining the cropping system o principle agro-ecosystem of south bank Hangzhouwan Bay. Thus, it can provide new idea for the analysis of cropping system of agro-ecosystem and the estimation of the area of each crop in remote sensing yield estimation. However, due to the discrepancies in light and conditions of different regions and climates, certain differences inevitably exist in the growth process of crops. Therefore, the establishment of monthly variation curve of NDVI value of a specific agro-ecosystem should be in compliance with the actual conditions of corresponding regions, in order to obtain the pattern for determining the cropping system and to perform the estimation of planting areas.

Conclusion

Since only a small number of monitoring points were involved for each cropping system in this study and only the variation characteristics of NDVI's monthly average was analyzed, the determination of cropping system might have been affected to some extent. Meanwhile, due to the limited number of field interview locations for confirmation, its precision remains for further testing. In addition, the issue of mixed pixel induced by resolution of NDVI data was not considered in this research, which might have some impact on the coastal areas with fragmented land use, thus it needs further discussion in subsequent studies.

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REFERENCES

Shi PJ, Gong P, Li XB (2000). Land use/ Method and practice of study on plants covering change. Beijing: Science Press, pp. 36-66.

Li XB, Shi PJ (2000). Sensitivity analysis of NDVI dynamic and air temperature, precipitation changes of Chinese vegetation types. China J. Plant Ecol., 24(3): 379-382.

Sheng YW, Chen WY, Xiao QG and Guo L (1995). Macro-classification of Chinese vegetation by using meteorological satellites. J. Chinese Sci. Bull., 40(1): 68-71.

Li XB, Shi PJ (1999). Study on NDVI changes rule of Chinese main vegetation types based on NOAA/ AVHRR. J. Chinese Bull. Bot., 41 (3):314-324.

Pan YZ, Li XB, He CY (2000). General classification study on Chinese vegetation based on NOAA/AVHRR &s Holdridge PE. J. Quat. Res., 20(3): 270-280.

Gao ZQ, Liu JY (2000). Drive-factor analysis and model study on Chinese vegetation index changes based on remote sensing and GIS. J. Clim. Environ. Res., 5(2): 155-164.

Sun L, Guo QX, Wang XC, Zhou XF (2003). NDVI change analysis of vegetation types in the middle and southern tract of Eastern China northern-southern. Chinese J. Appl. Environ. Biol., 9(5): 449-454.

Pei ZY, Yang BJ (2000). Extracting spatial-temporal features and designing plants' growth vigour model of MTVI-NDVI. Int. J. Agric. Biol. Eng., 16(5): 20-22.

Lu L, Li X, Cheng GD (2002). Analysis seasonal features of the Heihe river Basin by using NOAA/ AVHRR vegetation index data. J. Desert Res., 22(2): 187-191.

Zhang F, Wu BF, Liu CL, Luo ZM (2004). Study on monitoring plant phenological methods by using vegetation index in sequence. J. Trans. Chinese Soc. Agric. Eng., 20(1): 155-159.

Song XN, Zhao YS (2004). Study on extraction of plants' temperature & moisture composite index derived from MODIS data. J. Geogr. Geo-Inf. Sci., 20(2): 13-17.

Li BG, Tao S (2000). Correlation analysis of AVHRR-NDVI and climatic factors. J. Acta Ecol. Sin., 20(5): 898-902.

Tang HP, Chen YF (2003). Relation between seasonal change and climatic factors of NDVI in Chinese southern-eastern tract. J. Quat. Res., 23(3): 318-325.

Mao XS, Zhang YQ, Shen YJ (2003). Pre-test on vegetation index change & impact factor of winter wheat. Chinese J. Eco-Agric., 11(2): 35-36.
Zhou YM (1998). Application of NOAA/AVHRR data in drought inspection. J. Quart. J. Appl. Meteorol., 9(4): 496-500.
Jiang D Wang NB, Yang XH (1999). Study on Chinese grain crops assessment based on RS. Chinese J. Nature. 21(6):351-355.
Huang JF, Wang RC, Jiang HX,Yang ZE (2003).The best time-phase choice of Zhejiang Province rice RS-assessment based on GIS. J. Chinese J. Appl. Ecol., 13(23): 290-294.
Yang XH, Zhang XP, Jiang D (2004). Methods on multi-crops cultivated area extracted by MODIS sequential NDVI feature. J. Resour. Sci., 26(6): 17-22.
Wu BF (2000). Functioning RS methods on national farming information monitoring and assessing. J. Acta Geogr. Sin., 55(1):25-35.
Liu C, Ge CH (2000). Characteristics and application of RS data of EOS-MODIS of USA. J. Remote Sens. Inf., 3:45-48.
Wang ZX, Liu C, Huete A (2003). The progress of study on plants index: from AVHRR-NDVI to MODIS-EVI. J. Acta Ecol. Sin., 23(5):979-987.