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STUDY ON THE INTERACTION BETWEEN NDVI PROFILE AND THE GROWING STATUS OF CROPS

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ABSTRACT: Daily and ten-day Normalized Difference Vegetation Index(*NDVI*)of crops were retrieved from meteorological satellite NOAA AVHRR images. The temporal variations of the *NDVI* were analyzed during the whole growing season, and thus the principle of the interaction between *NDVI* profile and the growing status of crops was discussed. As a case in point, the relationship between integral *NDVI* and winter wheat yield of Henan Province in 1999 had been analyzed. By putting integral *NDVI* values of 60 sample counties into the winter wheat yield-integral *NDVI* coordination, scattering map was plotted. It demonstrated that integral *NDVI* had a close relation with winter wheat yield. These relation could be described with linear, cubic polynomial, and exponential regression, and the cubic polynomial regression was the best way. In general, *NDVI* reflects growing status of green vegetation, so crop monitoring and crop yield estimation could be realized by using remote sensing technique on the basis of time serial *NDVI* data together with agriculture calendars.

KEY WORDS: *NDVI*; profile; growing status, ; crop

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Growing situation monitoring and yield estimation of crops is an important region of agriculture research using remote sensing. Electronic waves reflected or emitted by crops and ground objects pass through atmosphere and reach the surface of sensors onboard satellite. The variation of the waves can be recorded and useful indexes reflecting growing status of crops can be created with proper processing and analysis. Therefore, continuously monitoring of growing status of crops can be carried out successfully(SUN, 1996; XIAO, 1986).

1 VEGETATION INDEXES AND GROWING STATUS OF CROPS

Reflecting values of cropland surface are influenced by many factors including environmental factors (such as solar angle, cloud, aerosol etc.) and inner factors (such as physical condition of leaves, leaf area, geometry structure of canopy, etc.). Giving the same environmental factors, variation of emission lights and reflecting values in certain extent indicate growing status, growing season, and physical condition of crops (CHI, 1995).

With the help of meteorological satellite NOAA AVHRR images (one image a day, with spatial resolution of 1. 1km × 1. 1km) from sowing to harvest, we can find that temporal variation of emission lights and reflecting values have their special character, which demonstrate the process of replacing bare soil by green vegetation (crops) step by step(TIAN, 1990). Spectral vegetation indices, which are integrated data of several bands of satellite images, have been widely used in order to derive useful information of canopies, meanwhile, deduce interference of background(ZHANG *et al.*, 2001)

There are two absorbing zones in the typical spectrum

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profile of green vegetation: one is in blue band and another is in red band. In near infrared spectral region, there is a peak of reflectance. These are caused by pigment and inner structure of leaves(QUARMBY, 1993). The sensors of NOAA AVHRR were just designed to catch these character: the first band CH_1 (0.58 – 0.68μm) was in the absorbing zone of chlorophyl, and the second band CH_2(0.58 – 0.68μm) was in the reflecting zone of vegetation. So the CH_1 and CH_2 are always used together to form vegetation indices. The Normalized Difference Vegetation Index(*NDVI*) is a case in point, which can be calculated with formula as follows(RAMAKRISHNA and STEVE, 1997):

$$NDVI = \frac{CH_2 - CH_1}{CH_2 + CH_1} \qquad (1)$$

where CH_1 and CH_2 represent the reflecting values of the first and second band of NOAA AVHRR.

The normalization algorithm in formula (1) give much help to distinguish vegetation with background soil, meanwhile, it deduces the influences of atmosphere and elevation. *NDVI* is sensitive to the variation of soil, and varies in different land-cover circumstances. It is somewhat larger than bare soil in the case of low cover (vegetation coverage is smaller than 15%); it increases linearly when vegetation coverage increase in the case of middle cover (vegetation covering is between 25% and 80%); and the sensitivity of detecting will decrease when vegetation coverage is larger than 80% (JIANG and WANG, 1999; POTDAR *et al.*, 1993).

In order to deduce the influences of cloud, atmosphere, etc., *NDVI* data may be composed by using proper algorithm in certain time duration. The most popular method is decade composing, which means maximum *NDVI* of a ten-day will be selected to represent the *NDVI* value of this ten-day(PRINCE and GOWARD, 1996; RASMUSSEN, 1998a). In this study, daily and ten-day *NDVI* of the Huang-Huai-Hai Plain in 1999 were all calculated and the *NDVI* database was established as the foundation of further studies.

2 TIME SERIES ANALYSIS OF NDVI

Putting *NDVI* values of a whole growing season into the *NDVI*-time coordination, a dynamic trace profile of crop growing will be achieved. This profile indicates the variation of *NDVI* from sowing to harvest. Different types of crops and different growing condition have different types of *NDVI* profile(JIANG *et al.*, 1999; RASNUSSEN, 1998b). This is why we can detect growing status and even estimate crop yield using time series analysis of *NDVI*(LI and ZHANG, 2001).

The counties with different yield levels were selected as samples in Henan Province. Thresholds for yield division and names of sample counties are as follows (yield here means yield per unit area):

(1) High level(yield≥ 4500kg/ha): Huaxian, Fugou and Yanjin counties, with average yield of 5100, 4650 and 4500kg/ha separately.

(2) Middle level(3000kg/ha<yield<4500kg/ha): Zhenyang, Weishi and Huangchuan counties, with average yield of 3900, 3600 and 3150kg/ha separately.

(3) Low level (yield ≤ 3000kg/ha): Xinyang, Guangshan and Luoshan counties, with average yield of 2700, 2250 and 1650kg/ha separately.

2.1 Typical Character of *NDVI* profiles

NDVI profiles of different yield levels in Henan Province in 1999 were shown in Fig. 1 – 3. Cubic polynomial function was used to simulate temporal variation of *NDVI* profiles, since the scattering plot of *NDVI* data showed a typical "S" shape. The Y axis stands for *NDVI* and the X axis stands for growing times of winter wheat (number of days from January 1, 1999).

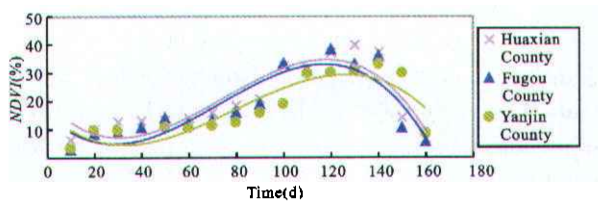

Fig. 1 The *NDVI* temporal profiles of winter wheat with high yields at county level in Henan Province in 1999

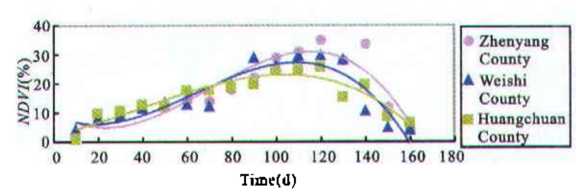

Fig. 2 The *NDVI* temporal profiles of winter wheat with middle yields in at county level Henan Province in 1999

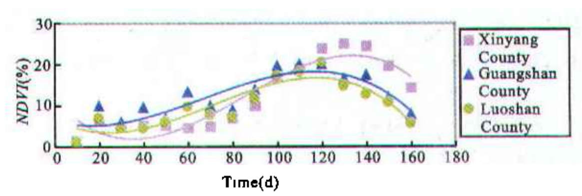

Fig. 3 The *NDVI* temporal profiles of winter wheat with low yields at county level in Henan Province in 1999

Simulating results were shown in Table 1. The expressions for simulation are as follows:

$$NDVI = a \times t^3 + b \times t^2 + c \times t + d \qquad (2)$$

where t is growing time of winter wheat (d); a, b, c are coefficients; d is a constant.

Table 1 Simulating results of the *NDVI* temporal profiles of winter wheats in Henan Province in 1999

Sample counties	Regressive parameters				Coefficients
	a	b	c	d	(r^2)
Huaxian	-8×10^{-5}	0.0185	-0.9009	19.837	0.8059
Fugou	-8×10^{-5}	0.0178	-0.8212	15.836	0.7968
Yanjin	-9×10^{-5}	0.0228	-1.4959	35.009	0.8290
Zhenyang	-7×10^{-5}	0.0140	-0.5465	10.984	0.8483
Weishi	-6×10^{-5}	0.0109	-0.3477	9.270	0.8288
Huangchuan	-2×10^{-5}	0.0027	-0.1562	2.916	0.8583
Xinyang	-4×10^{-5}	0.0113	-0.6452	12.394	0.8546
Guangshan	-3×10^{-5}	0.0053	-0.1587	6.588	0.7531
Laoshan	-3×10^{-5}	0.0071	-0.2932	4.916	0.8156

2.2 Integral Analysis of *NDVI* Profile of Winter Wheat

In North China, growing season of winter wheat is from September (sowing) till June of next year (harvest). Spectral character of winter wheat vary in different growing periods. There are three highlight points on the *NDVI* profiles, which would be the key for understanding the relation between remotely sensed *NDVI* and growing status of crop:

(1) Start-up point (1st or 2nd ten days of March, t = 70 - 80d). Winter wheat begin to grow rapidly from this point on. Since other crops and grasses only germinate at that time, it is easy to distinguish winter wheat from other vegetables. It is the best time for estimating planting area in satellite images.

(2) Peak point (1st or 2nd ten days of May, t = 120 - 130d). Nutritional organs of crops have been fully developed and *NDVI* reached a maximum value ($NDVI_{max}$) accordingly. A large $NDVI_{max}$ always means a good growing status of crops, which often results in high yield level. These were proved quite well by Fig. 1 - 3: $NDVI_{max}$ of the counties with high yield level ranged from 35% to 40%, while in the counties with low yield level, they were lower than 30%. It shows that the value of $NDVI_{max}$ is an important index of crop status.

(3) Valley point (1st or 2nd ten days of June, t = 150 - 160d). *NDVI* profile declined rapidly after peak point and reached a minimum value at the end of growing season. The crop got matured.

3 INTEGRAL NDVI AND ITS RELATION WITH CROP YIELD

It's reported that integral *NDVI* during certain growing period has a close relation with the final biomass (or yield) (WIEGAND *et al*., 1991). In order to approve this interesting principle, 60 counties at different yield level in Henan Province were selected as samples. Integral *NDVI*s were calculated using formula as follows:

$$iNDVI = \int_{t_1}^{t_2} NDVI dt \qquad (3)$$

where *iNDVI* is the integral *NDVI*, t_1, t_2 stand for beginning and ending time for integrating separately (in this case, t_1 = January 1, and t_2 = May 1).

When integral *NDVI* and corresponding crop yields data were all achieved, a scattering plot in yield-*iNDVI* coordinate space could be got as shown in Fig. 4.

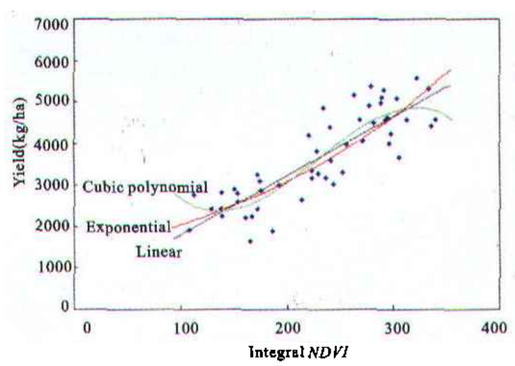

Fig. 4 Imitating results of the relationship between integral *NDVI* and winter wheat yields in Henan Province in 1999

It can be educed from Fig. 4 that there is an obvious positive relationship between integral *NDVI* and winter wheat yields. This relationship can be simulated by regressive functions with different types of methods: linear, cubic polynomial as well as exponential method. The results are shown in Table 2.

Table 2 Imitating results of the relationship between integral *NDVI* and winter wheat yields

Function type	Expressions	Regressive parameters	Coefficients
Linear	$y = a + bx$	$a = 0.995,\ b = 25.997$	0.7316
Cubic polynomial	$y = ax^3 + bx^2 + cx + d$	$a = -5 \times 10^{-5},\ b = 0.04,\ c = -6.78,\ d = 553.96$	0.7341
Exponential	$y = a \cdot e^{bx}$	$a = 90.21,\ b = 0.004$	0.7255

According to the coefficients (r^2), all of the three types of regressive method achieved good results ($r^2 > 0.7$). The cubic polynomial function had been proved to be the best way for describing nonlinear relationship between integral *NDVI* and winter wheat yields, which was consistent with basic cognition of farmland ecosystems. Meanwhile, we would also recognize that the crop yield was affected by many factors. So crop models including multiple factors will work much better than models with single factor. This is one of the important directions of crop models supported by remote sensing technique.

4 CONCLUSIONS

Following conclusions can be drawn according to this study:

(1) During the course of growing season, changes of crop status and growing condition will cause corresponding dynamic variation in temporal profile of *NDVI*. Thus crop status and growing condition could be monitored dynamically with character derived from *NDVI* profile.

(2) The integral *NDVI*, which contains integral information of growing status of crops, has close relationship with crop yield per unit area. Crop yield can be predicted with help of this principle.

(3) For the complexity of farmland ecosystem and uncertainty in transmission process of spectrums, crop monitoring and yield estimation are arduous tasks in recent years. Algorithms and models introduced here were periodical results of our research and should be completed both in larger areas and also in larger time span.

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