Study on Estimating Rice Yield by Using Chinese Satellite Images

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ABSTRACT: Being taken Xinghua County, Dafeng County and Yandu County in Jiangsu Province, China as example, monitoring and forecasting of rice production were carried out by using Chinese HJ-1A satellite remote sensing images. The handhold GPS machines were used to measure the geographical position and some other information of these samples such as areas shapes. The GPS data and the interpretation mark were used to correct HJ-1 image, assist human-computer interactive interpretation, and other operations. The test data had been participated in the whole classification process. The accuracy of interpreted information on rice planting area is more than 90%. By using the leaf area index got from the Normalized Difference Vegetation Index inversion, and the biomass got from the ratio Vegetation Index inversion, combined with the rice yield estimation model, the rice yield was estimated. Further the thematic map of rice production classification was made based on the rice yield data. According to the comparison results between measured and fitted values of yields and areas of sample sites, the accuracy of the yield estimation have been more than 85%. The results suggest that HJ-A/B images could basically meet the demand of rice growth monitoring and yield forecasting, and could be widely applied to rice production monitoring.

China is one of the biggest rice cultivation countries, it is very important significance for crop structure adjustment and food policy to monitor and forecast rice production timely and accurately. In the early 1990s, Chinese Academy of Sciences and other units, organized by the Ministry of Science & Technology, used Landsat / TM and NOAA / AVHRR images data to estimate the planting area and production of rice, wheat, corn in the key grain-producing area. The rice was conducted in Hubei and Jiangsu province and the prediction accuracy was above 85%. They had preliminarily mastered the main methods and technology system of crop yield assessment by use of remote sensing data (e.g. Xia Deshen et al.,1996, Lobell D B et al.,2003, Chen shenbin et al.1997). As our land resources satellite, environmental mitigation satellite, meteorological ocean satellite and many other series, many kinds of satellites were successfully launched, China has made great progress in the sensor field of multi-spectral and even hyperspectral, Using our own satellites data to carry out relate rice yield estimation studies has become an inevitable trend of crop yield estimation methods development. In recent years, some domestic researchers have make some crop yield estimation research based on our satellites data and achieved better results (e.g. Qi La et al., 2008, Qin Yuanwei et al., 2009), but few reports about the rice yield estimation. Taking the main rice producing region of Jiangsu province central as study area, this paper used HJ-A / B images and carried out the related exploratory and experimental research on remote sensing yield estimation combining with rice yield estimation model to monitor and forecast exactly the rice planting area and production, which provide the information for rice quantitative management and macro-control. (e.g. Yang Wude et al., 2009).

1. MATERIALS AND METHODS

1.1 Research regional overviews

Being taken Xinghua County, Yandu County and Dafeng County in Jiangsu Province, China, where as the study area, the region locate at 119°43 ' E ~120°56 ' E, 32°40 ' N ~33°36 ' N with temperate zone monsoon climate and four distinct seasons. It has an annual frost-free period of about 204 days, an average annual temperature of 14℃, an average annual precipitation of 940mm and average annual sunshine ranging between 2130 and 2430 hours , which are better climate and the soil condition. In sync with satellite transit time, we established 28 sample points for the difference GPS fixed-point investigation and sample that included the leaf area index and the biomass. The dry matter was processed at 105℃ heating for 20 min firstly, at 75℃ drying afterward, and finally taking the oven-dry weight. The leaf area index was measured by the proportion method. The grain yield was got by field surveys, which took samples by 50m×50m type frame according to the field block diagonal line 5 points, $1m^2$ grain at every sampling point and 5 m^2 grain altogether, withered naturally(approximate 13% water content) and weighed. The meteorological data were provided by the county Meteorological department.

1.2 Data source

The satellite in this paper is Chinese environment disaster reduction satellite, the HJ-1 satellite for short, which include the A star and the B star with the orbital altitude of 650 km. CCD camera covers the earth every 4ds (HJ-1A and HJ-1B satellite network revisit cycle is 2ds over the global), spectrum scope covers blue light (0.43~0.52μm), green light (0.52~0.60μm), red (0.63~6.9μm) and near-infrared (0.76~0.9μm), the subsatellite resolution is 30m, the single CCD camera's breadth is 360 km (two ones' breadth is 710 km).

The HJ-1A satellite transit time was on August 26, 2009, when the region rice was in the heading stage. It was sunny and cloudless, so the satellite image quality was good. Geometric correction was first roughly made using 1:100 000 topographic maps, and then accurately carried out by the GPS route recording and ground truth data to make sure the alignment error within one pixel. According to the experience linear transformation, the atmospheric radiation correction and reflection conversion were obtained by using the actual reflectivity of ground calibration body and the corresponding primitive DN value of satellite images.

1.3 Remote sensing yield estimation model of Rice

In the sun radiation energy only the visible part (350~700nm), accounting for about 47% to 48%, can be used for plants photosynthesis. The ability of rice daily conversion from visible light into organic light is called solar contract efficiency (also called daily increase in above-ground biomass weight, DABW). Daily increase in aboveground biomass weight calculation refered to Gao Liangzhi's (Gao et al. 1992) simulation algorithm, the indication is the type:

$$\Delta DABW_i = \frac{B}{K \times A} \times Ln\left(\frac{1+D}{1+D \times Exp(-K \times LAI_i)}\right) \times DL \times \delta$$

$$D = A \times 0.47 \times (1-\alpha) \times Q_i / DL \qquad (1)$$

Where $\triangle DABW_i$ (kg ·hm^{-2} ·d^{-1}) is the *i-th* day of the daily increase in above-ground biomass weight, K is the group extinction coefficient; LAI_i is the *i-th* day of the leaf area index; D is the middle variable; $\alpha$is the rice group reflection(%); *Qi* is the daily global solar radiation (MJ/m^2); *B*、*A* is the experiment coefficient, the value is 22 and 4.5 respectively ; δis the conversion coefficient of CH_2O and CO_2 with 0.68 value; *DL* (h) is the day length. And LAI_i in heading period can be computed by the model ($Y=2.8339\times e^{1.3655NDVI}$ (Li Weiguo, et al., 2008)). NDVI is the Normalized Difference Vegetation Index, $NDVI = (R_{B4} - R_{B3})/(R_{B4} + R_{B3})$, R_{NIR} for is the near infrared reflectance (the fourth band of HJ-1A satellite), R_{RED} is the red reflectance (the third band of HJ-1A satellite).

Daily increase in above-ground biomass weight removing the plant growth respiration and its maintenance consumption is the plant daily net assimilation (also called the above-ground biomass weight). Its algorithm is as follows:

$$\Delta ABW_i = \left(\Delta DABW_i - RG_i - RM_i\right) \times \min\left(TF_i,\ NF\right) \qquad (2)$$

Where RG_i and RM_i are the photosynthesis assimilation amount (kg·hm^{-2} ·d^{-1}), growth breath consumption (kg ·hm^{-2}·d^{-1}) and maintenance breath consumption (kg·hm^{-2}·d^{-1}) of the *i*-th day respectively. TF_i and NF are influence factor of above ground biomass accumulation from air temperature and soil nitrogen respectively. Its algorithm is described in Li Weiguo's article (e.g. Li Weiguo, et al., 2008).

In the rice growing period, Above-ground Biomass Weight is the sum of dry matter accumulation. ABW_i is the total above-ground dry biomass accumulation (kg·hm^{-2}) of the *i-th* day from the first emergence day to harvest. $\triangle ABW_i$ is the increment in *i*-th day of the above-ground dry biomass weight (kg·hm^{-1}·d^{-1}) and described as follow:

$$ABW_i = \sum_{i=1}^{n} \Delta ABW_{\mathrm{i}} \qquad (3)$$

Where *n* (d) is the total days of crop growth period; ABW_1 (the first emergence day of above-ground biomass) is half of sowing seeds weight. And ABW_i of rice heading period can get through the inversion model (y=741.76×RVI+4253.2); RVI is the ratio vegetation index, $RVI = R_{B4}/R_{B3}$

The rice yield refers to the harvest of economic product organ(rough rice or unpolished rice), which is the product of above-ground biomass of mature stage and harvest index; the algorithm is as follows:

$$Y = [ABW_i/(1+\beta)] \times HI \qquad (4)$$

Where *i* (d) is the number of days from sowing to maturity time, which equals the total days of period of duration, and$\beta$is the root shoot ratio of rice mature stage, generally between 0.05~0.08, the value is 0.06 in the model. The parameter information of rice yield estimation model (Table 1) .

Table.1 The parameters of rice materials

Rice materials	Seeding rate/ (kg·hm^{-2})	Growing period /(d)	Harvest Index	k
Huaidao5	150	130	0.41	0.61
Ningjing4	150	140	0.43	0.66
Xudao9	150	152	0.45	0.68

2. RESULTS AND ANALYSIS

2.1 Leaf area index and biomass forecast and confirmation

We firstly extracted RVI, NDVI and that of 28 sample points information separately through ERDAS and ENVI software, and then calculated the LAI and biomass of every points by inversion model, The rice LAI values from inversion was lower in Figure 1, their root mean square prediction error (RMSE) was 0.38, which indicated the data was comparatively consistent with relative error range between 1.0% and 10.3% and the average error of 4.72%. The studies showed that the LAI inversion model could be used for the current rice LAI because of reliable results. In Figure 2 the actual biomass values were a bit higher than the model inversion ones with the RMSE of 464.14 kg ·hm^{-2}, the relative error range between 1.57% and 7.57%, the average error of 4.96%, which stated the biomass inversion model could be used to estimate current rice biomass.

2.2 Rice sampling point data and estimation model precision confirmation

According to design features of rice yield estimation model, rice yield of study area was predicted based on rice variety parameters, meteorological data and remote sensing information. The rice actual yield was between 6915～10868 kg·hm^{-2}, with the average yield of 8929.96 kg·hm^{-2}; the estimated value was between 6450～10443 kg ·hm^{-2}, with the average value of 8859.96 kg·hm^{-2}.

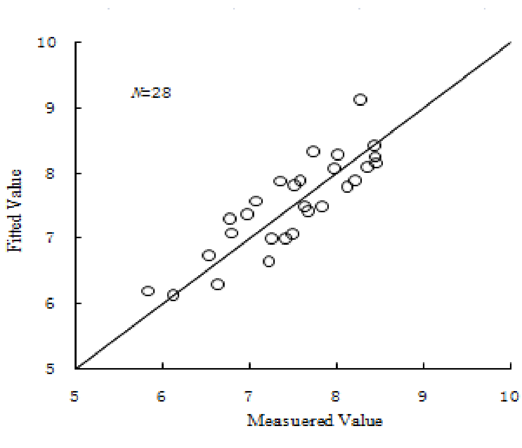

Fig.1 Comparison of fitted values with measured rice LAI

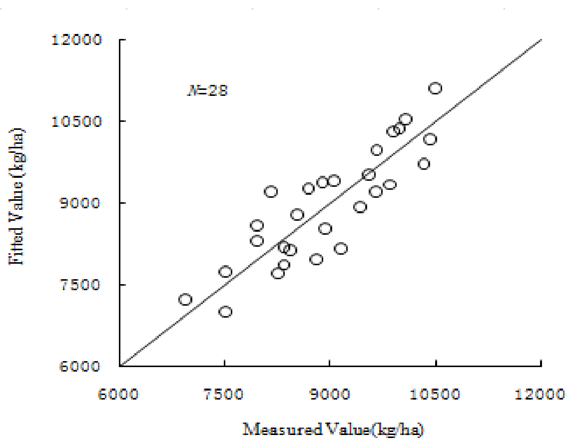

Fig.2 Comparison of fitted values with measured rice biomass

Figure 3 demonstrated 1: 1 the relations of different sampling points between rice actual yield values and the estimation values, its standard deviation RMSE was 482.5 kg·hm^{-2}, the relative error was in 1.01%~8.90% range, with the average of 4.90%. The model accuracy test, between the estimation values and the actual values, showed the precision was over 85%, which indicated that it was possible to estimate the regional rice yield combining heading stage biomass and leaf area index through rice yield estimation model.

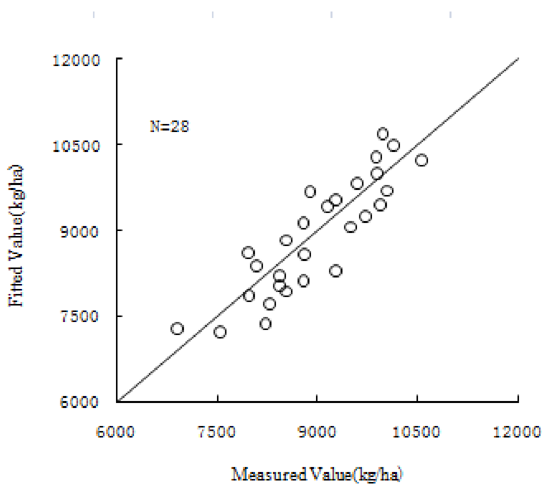

Fig.3 Comparison of fitted values with measured rice yields

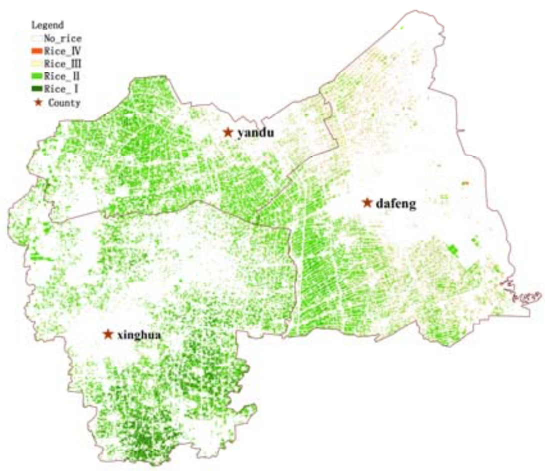

Fig.4 Gradation monitoring and forecasting chart of rice yield

2.3 rice planting area extraction and levels of production forecast figure

Accurate extraction of rice planting area by remote sensing was very important preparatory work for rice production estimation. We made the county AOI documents by existing administrative boundary vector, cut out the experimental region from HJ-A images, and generated the interpretation base image choosing 4, 2, 1 bands combination. After the classification and interpretation process, rice planting area of the sample cities and counties in 2009 year was 173652.2 hm^2, while the actual area was 162641.1 hm^2, so the interpretation accuracy was over 90%,which proved the result was much more reliable.

GIS software was used to get the regional production information map based on linear transformation between sample points yield data from rice yield estimation model and NDVI image. According to the rice single-production, the rice fields were divided into 4 types: the most high-yield field (≥9750 kg·hm^{-2}), the high-yield field (8250~9750 kg·hm^{-2}), the middle-yield field (6750~8250 kg·hm^{-2}) and the low-yield field (<6750 kg·hm^{-2}). Monitoring and stage prediction thematic map of rice production in the region was gained by overlay the actual sample points rice production data (Figure 4).

Table 2 showed the area distribution of various rice yield ranks, from which we can conclude that each county's rice extraction area precision was above 85% and the area extraction result was comparatively reliable. The rice yield

Table 2 The distribution of rice area at different yield level after classification

County	Planting area /（hm^2）	Interpretation area / (hm^2)	Interpretation accuracy /(%)	Rice-I /（hm^2）	Rice-II /（hm^2）	Rice-III /（hm^2）	Rice-IV /（hm^2）
Xinghua	90152.45	94114.67	95.79%	15720.64	53976.76	17485.56	6931.71
Yandu	42313.41	45833.42	92.32%	2798.97	33130.64	7863.33	2040.48
Dafeng	30175.27	33704.08	89.53%	1276.57	15082.61	9213.18	8131.72
Total	162641.1	173652.17	93.66%	19796.18	102190	34562.07	17103.91

Note: Actual rice planting area data was provided by the local agricultural management department. Rice-I, II, III, and IV represent the area of field, in which the yield is higher than 9750 kg/hm^2, 8250-9750 kg/hm^2, 6750-8250 kg/hm^2, and lower than 6750 kg/hm^2, respectively.

grade area in different county was different, the Dafeng County was mostly low-yield field, but the most high-yield field and the high-yield field had a much bigger proportion in Xinghua County. The most rice high-yield field in 3 counties occupied 11.4% of total rice area, the high-yield field and middle yield field accounted for 78.75% of the total rice area, while the low-yield field was only 9.85% of the total rice area. The rice was in the heading period at the sample time, which was an important rice production phase, so it was time to strengthen the field management for these low-yield fields: for example, head sprouting fertilization and reasonable irrigation, which can increase the rice later production and make the low-yield field developing to middle-yield field. Similarly the middle-yield field can conduct some scientific management and reasonable regulation based on soil characteristic to reach a high yield field.

3 . CONCLUSIONS AND DISCUSSION

Xinghua County, Yandu County and Dafeng County, in the middle of Jiangsu Province, have the undulating topography and complex planting structure. the lower spatial resolution satellites (for example, NOAA, MODIS and so on) cannot satisfy the accuracy requirement of crop growing and yield estimation, particularly for precise monitoring in plant area (for example, the regions with complex terrain and diverse farming system). This research has selected HJ-1A satellite images with 30m spatial resolution, which can satisfy the accuracy requirement for monitoring crop growing in the study area. Moreover, HJ-1 satellite, after combining A star with B star, can revisit the same place in 2 days and much better satisfied the time precision for rice long-term dynamic monitoring.

On the rice yield remote sensing monitoring and forecasting, most previous research always focused on the basis of analyzing the relationship between spectral information of images with rice LAI and biomass or yield by establishing a regression model.(e.g. Cheng Qian et al., 2006, Liu Liangyun et al.,2004, Tang Yanlin et al.,2004). Although this yield estimation model was simple, it was strongly empirical and less universal. Remote sensing images can obtain rice instantaneous growing information of a certain growth stage, but only by which it always had a large deviation to predict the maturity yield. Because in the prediction period the climate conditions (temperature, light, water status etc.) were constantly changeable that had a great influence on rice production. It can play a "point" and "surface" complementary effect by combining crop growth model's continuous and dynamic feature and remote sensing's instantaneous and wide-area advantage.

This research used rice yield estimation model which coupled with remote sensing data and the growth model, integrated remote sensing inversion information and made yield estimation through assimilation. The estimated yield and actual values had a high consistency with more than 85% yield prediction. The research in this study indicated that the estimation model can be effectively used to estimate the rice yield, which had a good theatrical value and practical prospect because of improving yield estimation accuracy and strengthening remote sensing yield estimation mechanism. In addition, the rice yield remote sensing classification forecasting map in this study had a better practicability for primary agricultural technicians to guide the field production management and planting division.

It has still existed to the mixed pixel problem in HJ-A / B satellite images. Hereafter, if we can unify the high resolution images(for example, SPOT, QUICKBIRD and so on) and use image fusion technology to display the advantage of multiple source and multi-temporal remote sensing images (e.g. Chen J Y *et al*., 2006, Zhang hao *et al*., 2008). It can not only greatly improve the classification and interpretation precision, but also enhance the rice growing trend graduation monitoring accuracy. What's more, this research studied the new rice yield remote sensing estimation model with some innovation. But some individual sample points had bigger deviation, which may be the effect by model parameters or environmental factors. In the future, we need validate it in a more wide area to further clarify the boundary conditions of this yield estimation model.

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