Models for estimating the leaf NDVI of japonica rice ~~at the~~ on a canopy scale ~~in Northeast China~~ by combining canopy NDVI and multisource environmental data in Northeast China

Abstract: Remote sensing of rice traits has advanced significantly ~~in~~ with regard to the capacity to retrieve useful plant biochemical, physiological and structural quantities across spatial scales. The rice leaf NDVI [normalized difference vegetation index] has been developed and applied in monitoring rice growth, yield prediction, disease~~s~~ status to guide agricultural management practices. This study combined rice canopy NDVI and environmental data to estimate rice leaf NDVI models. The test site ~~is~~ was a japonica rice experiment located in the eastern city of Shenyang, Liaoning Province, China. This ~~editorial~~ report ~~provides a~~ describes (1) ~~using~~ the use of multiple linear regression to establish~~ed~~ four periods of rice leaf NDVI models with good accuracy (R^2= 0.782–0.903), and (2) ~~determined~~ how the key point of the rice growth period based on these models was determined. This research also presents the techniques for modeling leaf NDVI at the point of ~~canopy~~ remote canopy sensing. The results ~~illustrate~~ indicate that rice leaf NDVI with canopy NDVI and multisource environmental data have a ~~great~~ high correlation. This research ~~established~~ establishes models which may be one efficient method to detect rice leaf growth at the canopy scale in the future.

Keywords: Japonica rice; NDVI; Leaf Models; Canopy scale; Environmental data

1. Introduction

China has the second largest rice-planting area in the world and the largest annual rice output (204 million tons). Rice cultivation in northeast China is ~~mainly~~ based mainly on japonica rice, ~~whose~~ for which the planting area accounts for more than 30% of the total rice area and continues to increase. [1]

The leaf of the rice plant ~~is~~ constitutes its ~~rice~~ photosynthetic vegetative organ~~s~~, ~~leaf~~ the total nitrogen concentration ~~is rice nitrogen~~ with regard to nutrition being an important indicator ~~of~~ for diagnosis. Traditional ~~rice~~ nitrogen-monitoring methods for rice generally rely on ~~plant in~~ field-sampling of plants in the field and subsequent indoor testing. Although the results from such testing ~~is~~ are more reliable, ~~but on~~ the temporal and spatial scales ~~are~~ present difficulties ~~to~~ in meeting real-time, rapid, non-destructive diagnoses of nitrogen requirements. With the development of modern remote sensing technology, ~~remote sensing monitoring~~ this technology ~~for~~ when applied to rice has ~~been involved in~~ included an estimation of the chemical composition of ~~rice~~ nitrogen. ~~and~~ In theory and practice for the evaluation of rice growth and ~~the~~ its physiological parameters, remote sensing ~~provides~~ can guarantee reliable ~~guarantee~~ outcomes.

Applying remote sensing technology to obtain information on rice growth ~~had~~ has rapidly developed in recent years because of its low cost, nondestructive testing processes, and other wide-ranging advantages [2]. The different characteristics of ~~rice~~ the spectral ~~information~~ data on rice ~~are~~ constitute the theoretical basis for using remote sensing technology to obtain information on ~~rice~~ growth through spectral ~~analysis~~ analytical methods to identify and extract the corresponding phenotypic traits ~~of rice information~~ and spectral vegetation indices (VIs). The VIs can reduce the influence of external factors to a certain extent and thus enhance rice-growth information. [3]

In 1999, a group of investigators funded by the NASA Earth Observations Commercialization and Applications Program (EOCAP) pooled their resources ~~and conducted~~ to conduct a nitrogen fertilization experiment aiming to prove ~~the~~ that agricultural crops ~~are required to conduct~~ must undergo dry-matter accumulation during photosynthesis ~~in leaf with~~ of chlorophyll in their leaves.[4] Therefore, ~~leaf~~ leaves need ~~requires~~ a lot of red ~~light~~ and blue light to complete the process of photosynthesis. As rice ~~in~~ is growing, it ~~has~~ exhibits a strong absorption phenomenon in the visible region (VR) of sunlight radiation and weak absorption in the near infrared region (NIR) of sunlight [5]. The spectral bands used by most VIs are concentrated ~~on~~ in the VR-to-NIR (350–1700 nm) range. At present, the VIs of phenotypic traits in rice consist of more than 50 species, such as the ratio vegetation index (RVI), the normalized difference vegetation index (NDVI), the soil- ~~regulate~~ regulation vegetation index (SAVI), the difference vegetation index (DVI), and the enhanced vegetation index (EVI) [6, 7]. Some research has shown good NDVI data for crop production and biomass estimation [8-11]. However, the NDVI ~~do~~ does not reflect rice growth in the internal mechanism process ~~of internal mechanism~~. Although many agronomists and rice NDVI parameters ~~are present~~ have been considered, their models are ~~mostly~~ based mostly on the establishment of statistical methods for remote sensing estimates, frequently with relatively strong empirical models and relatively poor versatility [12-14]. The general remote-sensing method to obtain a rice canopy NDVI takes advantage of ~~the~~ natural light; ~~and~~ therefore, the acquired NDVI is affected by light conditions, the atmosphere, and aerosols, ~~thereby causing~~ all of which contribute to reduced accuracy. ~~The plant type of japonica rice is mainly vertical leaves~~ In Northeast China (Shendao-47, Shendao-525, etc.), the variety of rice known as japonica consists mainly of vertical leaves. A canopy NDVI ~~also~~ can also be affected by soil, water layers, green algae, and other surface features, ~~and these~~ all of which act as interfering factors that greatly influence the accuracy of the NDVI ~~index~~ in a rice canopy.

The objective of this study was to ~~using~~ use ~~the~~ rice canopy NDVI and environmental ~~date~~ data to model~~ing~~ ~~the~~ rice leaf NDVI. The researchers collected different scales of NDVI data (from both canopy and leaves) from the Shenyang Agricultural University experimental rice-breeding ~~experimental~~ fields. The data were acquired during the rice-cultivation period ~~of rice~~ from transplanting to maturity ~~period~~ (~~2015.6–2015.10~~ June 2015-October 2015). The leaf NDVI model of northeast japonica rice was based on ~~fusion~~ remote fusion sensing and environmental factors such as temperature and humidity during the number of growing days, ~~sunshine~~ sunlight hours, and rice-growing microenvironments. [15]

2. Materials and methods

2.1 Testing site

The ~~study~~ testing site was an experimental rice-breeding ~~experimental~~ field at Shenyang Agricultural University (41°49' N, 123°33' E; altitude, 65 m) in Shenyang, Liaoning Province, China.

The japonica rice (Shendao-47) cultivar was transplanted on May 28, 2015. ~~Shendao-47 has robust seedlings, strong tillering features, 350–400 m² plant, height of about 105 cm, semi-erect panicle, compact plant type, erect leaves, about 1.2 to 1.5 million per acre of panicle, ear length of 25 cm, 160 per panicle number of flowers, yellow glume and glume tips, 140 to 200 grains per panicle, and about 90% granulation.~~

The typical properties of Shendao-47 include the following:

- compactness;
- robust seedlings;
- strong tillering features;
- erect leaves;
- yellow glumes and tips;
- semi-erect panicles, numbering about 1.2 to 1.5 million per acre;
- 160 flowers and 140-200 grains per panicle;
- 25-cm ear lengths;
- heights of about 105 cm;
- about 90% granulation;
- 350–400 m^2 planting areas.

China has 10 ~~quality~~ indicators to meet ~~China's~~ its high-quality, high-palatability rice standard. Some varieties ~~have rice resistance~~ are resistant to blasts, lodging, low temperatures, and drought (for the medium-ripe variety). ~~and the growth period is 155–156 days in Shenyang.~~ Shendao-47 is widely cultivated in Shenyang, where the growth period is 155–156 days. Other areas of widespread cultivation include ~~and~~ Liaoyang, Anshan, Yingkou, Panjin, and North China. [16-18]

Data were collected from both leaf and canopy NDVI ~~and canopy NDVI, and the~~ in a circular canopy area ~~was~~ of 0.5 m^2. The average sets ~~have~~ had 15 sampling points for ~~the~~ testing in ~~the~~ a paddy field, as illustrated in Figure 1. The instruments used were a Plant-Pen NDVI-300 (PSI Corporation, Czech Republic) for the leaf NDVI data collection and a SpectroSense2+ (Skye Corporation, UK) for the canopy NDVI data collection. [19-22] Temperature and humidity data were collected by using ~~the~~ a wireless ~~temperature and humidity~~ sensor network. [23] The sensors were distributed inside the plots (at points 1–9) and 2 m above the rice fields at each temperature. The humidity collection point heights ~~was~~ were divided into three sections: the bottom of rice growth (10 cm), mid-area ~~rice~~ growth ~~in the middle~~ (60 cm), and ~~rice~~ the canopy (110 cm). The ~~Rice~~ growth data were collected at different heights, micro-environmental temperatures, and humidity levels.

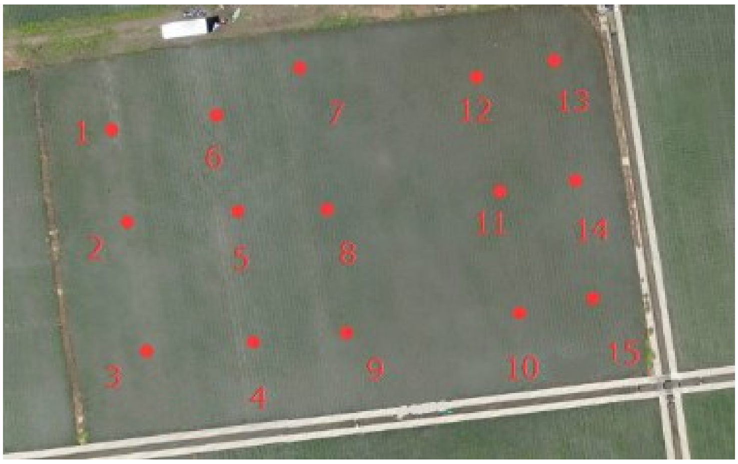

Figure 1. Test site: japonica rice experiment at Shenyang Agricultural University in 2015; points 1~15 ~~was the~~ designate sampling area. (Background: Shendao-47, June 17, 2015, UAV collection)

2.2 NDVI data collection

2.2.1 Leaf NDVI ~~collection~~

Rice leaf NDVI data were collected by using a PlantPen NDVI-300 as ~~an~~ the active light source ~~of NDVI~~ for the measuring instrument. The center of the ~~instrument~~ visible-light wavelength of the instrument was 660 nm (VIS = 660 nm); the near-infrared light-source center wavelength, ~~was~~ 740 nm (NIR=740 nm); and the range, ~~was~~ 620–750nm. [24] The leaf NDVI measurement period was from a week after transplanting ~~after a week~~ (June 4) to harvesting ~~a week before the month's end~~ (October 1). The ~~measuring~~ time for measurement was ~~every day at~~ 10:30H–13:30H daily. On rainy days measurement ~~will be~~ was postponed ~~to after~~ until the rain ended, ~~the latest~~ but not ~~more~~ later than 16:00. Given the ~~relatively~~ relative slenderness ~~leaves~~ of north japonica rice leaves, this study ~~on leaf NDVI measurement~~ included pointed and three-tail leaves, as measured by three NDVI data sets averaged as ~~rice~~ single-leaf NDVI values. For each sample, the number of leaves ~~was~~ collected was considered as an NDVI point for the entire canopy sampling area (0.5 m^2), the area of leaves, and the resulting calculated average ~~NDVI~~. The leaf NDVI ~~in~~ for the region was then obtained. For rice in the tillering stage of rapid growth, the sampling points in the region ~~had~~ included many leaves to ensure accurate data ~~accuracy~~. The rice canopy leaves and rice fields within the main leaf angle blade were averaged for the entire ~~rice~~ sampling area to obtain the average NDVI value of the leaves (not less than 70 leaves).

2.2.2 Canopy NDVI ~~collection~~

Rice canopy NDVI data were very important in this study, for which the canopy-~~NDVI~~ measuring instrument used was a SpectroSense2+ (Figure 2a), which ~~had~~ has a passive light source. The corresponding wavelength of the ~~incident~~ solar radiation incident intensity was measured, and the vegetation canopy of the reflected light was set to be strong ~~based~~ on the basis of the measurement of the corresponding spectral characteristics. [25] To reduce the error caused by the different spectral bands, the selected sensor band was kept consistent with the measurement range of the Plant-Pen NDVI-300 (Figure 2b), ~~and~~ the detection range ~~was~~ being 620–750 nm. The canopy NDVI measurement time was consistent with the leaf NDVI. ~~and~~ Moreover, to reduce human error during the canopy NDVI measurement process, steps were taken to ensure ~~measurement personnel back and the back of the instrument~~ that the backs of the personnel and the instruments ~~was~~ were not measured in the coverage area ~~to reduce human error~~ (Figure 2c).

a) b) c)

Figure 2. Testing instruments: a) SpectroSense2+ for canopy NDVI collection; b) NDVI-300, for leaf NDVI collection; c) canopy NDVI measurements: ~~The~~ center of ~~the instrument~~ visible-light wavelength of instrument, ~~was~~ 660 nm (R = 660 nm); near-infrared light-source center wavelength, ~~was~~ 740 nm (NIR=740 nm).

2.3 Measurement of field environmental parameters

The NDVI ~~is~~ does not represent a physical quantity of rice; thus, the models of NDVI and rice growth show an unclear growth mechanism. ~~The~~ Such models cannot clarify the underlying mechanism of change and its relationship with the NDVI [26-27]. Under ~~the~~ a same-soil condition ~~of the same soil condition~~, the growth of rice ~~was~~ is mainly affected by ~~the~~ environmental factors.

In this study, fifteen wireless temperature and humidity sensor networks were set up in the experimental field, ~~and~~ each sample ~~was~~ being divided into three heights. For each height, temperature and humidity data were ~~detected~~ obtained in the experimental ~~fields~~ field, ~~and the~~ where an external space was also provided with environmental temperature-and-humidity-detection sensors. These wireless sensors ~~network~~ communicated through ~~the~~ a ZigBee network, ~~and~~ the ~~networking~~ modes of which had ~~a~~ star connections. ~~Temperature~~ Sensor data (including information such as temperature, humidity, time, and power) were collected every 10 minutes. The power consumption of the wireless sensor network was low, and the entire experimental process did not require a battery replacement. The sensor used four ~~3A~~ AAA batteries; ~~and~~ the receiver was charged every ~~2~~ two days by using solar panels and a mobile power supply to ensure smooth operation of the entire system. Given that the experimental ~~sites were~~ site was located in the northeast region of China, which ~~had~~ has rainy days in the summer, the ~~study~~ researchers performed waterproof processing for the temperature and humidity tests to ensure that the wireless ~~temperature and humidity~~ sensor network ~~can be~~ is all-weather compatible for temperature and humidity data collection.

2.4 Statistical analyses

Statistical analyses were executed in Microsoft@ Excel@ 2013 and IBM@ SPSS@ Statistics 22.0.0.0. ~~Depending on~~ In accordance with the growth stage of ~~japonica~~ the rice, we analyzed the correlation between the leaf ~~NDVI,~~ and canopy NDVIs, as well as the respective sunshine-exposure ~~time,~~ and growth times of the leaves throughout the entire growth period. [28]

We performed simple linear or exponential regression for leaf ~~NDVI,~~ and canopy NDVIs, environmental temperature and humidity, as well as respective temperatures and humidity levels within the rice canopy, ~~temperature and humidity, temperature and humidity of rice in the middle, and rice bottom temperature and humidity~~ mid-rice and bottom-rice areas. For day-length data, we used multiple linear regression (MLR). [29-30] The following equation was used for the linear model ~~had the following equation~~:

$$y_L = \beta_0 + \beta_1 x_C + \beta_2 x_S + \beta_3 x_D + \beta_4 x_{EHH} + \beta_5 x_{ETH} + \beta_6 x_{MTL} + \beta_7 x_{BTL}$$

where y_L and x_C ~~represents~~ represent the leaf ~~NDVI~~ and canopy NDVIs, respectively; ~~Where~~ x_S and x_D, ~~represents~~ the sunshine- and the growth-days of the rice, respectively; ~~Where~~ x_{EHH} and x_{ETH}, ~~are~~ the highest relative humidity levels and ~~highest~~ temperatures ~~of~~ in the environment, respectively; ~~Where~~ x_{MTL} and x_{BTL}, ~~are~~ the lowest temperatures in the middle and bottom parts of ~~japonica~~ the rice, respectively. The model coefficients (β_0, β_1, β_2, $\cdots$, β_7) were determined for the linear-regression model ~~based~~ on the basis of the calibration dataset.

~~Japonica rice~~ From transplanting to maturity, ~~of~~ the growth process of the rice underwent different ~~growth~~ periods (such as the tillering, jointing, heading, and filling stages), ~~and~~ during each ~~period~~ of which the changes in the rice leaves and canopy ~~was~~ were not the same. Therefore, the different periods ~~of~~ in the rice leaf NDVI model should vary. [31] Accordingly, the ~~Japonica rice~~ leaf NDVI fitting model was divided into four stages: tillering (June), jointing-booting (July), heading and milking (August), and maturity (September) stage models.

3. Results and discussion

3.1 Leaf NDVI modeling ~~of japonica rice~~

The data collection period ~~of~~ for the NDVI fitting model ~~was~~ lasted 118 days, from June 4 to September 30. ~~and the number of days was 118 days.~~ Given that rainy days ~~were~~ are unsuitable for NDVI and humidity data collection, ~~the rain to removal,~~ the effective number of days ~~for~~ was 114 ~~days~~. Because the respective durations of the various growth stages of rice ~~were~~ are not ~~an~~ absolute, ~~time. Thus, to facilitate the future application of the model, we used a monthly modeling process segment, as well as the experimental varieties used in this study and planting time~~[32] we therefore used a monthly modeling process segment, as well as the experimental varieties and planting time in this study, to facilitate future applications of the model. [32] Moreover, because many of the key growth points were at the beginning or end of ~~the~~ a month, ~~so~~ the use of segmentation modeling to improve the accuracy of the model was feasible.

We collected the canopy NDVI ~~of japonica rice~~, sunshine-duration, and ~~rice growth~~ micro-environmental growth data for the rice. The linear-regression model was ~~established~~ created with SPSS software to obtain the tested paddy-leaf NDVI models ~~of~~ for Shendao-47 (Table 1).

Table 1 Shendao-47 leaf NDVI models

Stage	Regression model
Tillering ~~stage~~	y_L=-9.119+0.166x_C+0.633x_S+0.002x_{EHH}
Jointing and booting ~~stage~~	y_L=0.608-0.673x_C+0.051x_S+0.008x_{MTL}-0.009x_{BTL}
Heading to grain-filling ~~stage~~	y_L=0.965-0.285x_C-0.003x_D+0.001x_{ETH}
~~Mature stage~~ Maturity	y_L=-0.705-1.056x_C + 0.176x_S-0.009x_D

Note: y_L=leaf NDVI, x_C=canopy NDVI, x_S= sunshine, x_D=growth days, x_{EHH}=~~the~~ highest relative humidity, x_{ETH}=highest environmental temperature ~~of the environment~~, x_{MTL}= ~~the~~ lowest temperature in ~~the~~ bottom part of ~~japonica~~ rice, x_{BTL}= ~~the~~ lowest temperature in ~~the~~ middle part of ~~japonica~~ rice.

3.2 Model analysis

In this study, the leaf model ~~was~~ included the whole rice leaf ~~of rice~~. The ~~idea~~ objective of this study ~~is~~ was to investigate the effects of environmental factors on the NDVI of the leaves. The experimental area ~~is~~ not being very large, the difference of the soil ~~is~~ being relatively small, and in order to reduce the complexity of the modeling, ~~it is considered that~~ the soil condition ~~is~~ was considered consistent. In the process of ~~model~~ building ~~to~~ the canopy NDVI model as one of the input data, ~~NDVI received~~ the canopy leaf angle, the ~~soil~~ effect of water on the soil and ~~so on~~ other data were input, ~~was~~ resulting in a mixed NDVI value. [Because the removal of interference factors ~~of removal were~~ was a complex process, and in order to facilitate the modeling, ~~did not consider the~~ their effects ~~of these interference factors data~~ were not considered. ~~but~~ However, ~~the~~ in the canopy NDVI data acquisition, ~~through~~ the ~~design of~~ experiment was designed ~~as possible ensures~~ to ensure as much consistency as possible ~~the canopy NDVI~~ with regard to the relative error ~~of consistency~~. [33] ~~This study established~~ The japonica leaf NDVI model established in this study ~~was to try using~~ resulted from an attempt to use canopy NDVI and environmental factors to formulate a quantitative description of the trend in the changes observed in the leaf NDVI ~~change trend~~.] **WHAT are you actually trying to say in this paragraph—especially within your English editor's green brackets? It was a big mess! Hence, these revisions are merely (grammatically correct) educated guesses.**

Table 2 Coefficient of determination (R^2) and root mean square error (RMSE) for regression between observed and predicted leaf NDVI. (RE = relative error).

Stage	R^2	RMSE	RE (%)
Tillering ~~stage~~	0.845	0.511	48.61
Jointing and booting ~~stage~~	0.782	0.131	47.29
Heading to grain-filling ~~stage~~	0.877	0.092	38.36
~~Mature stage~~ Maturity	0.903	0.235	59.67

~~Based~~ On the basis of the results ~~from~~ listed in Table 2, different-stage leaf models were selected for ~~model~~ application in the model. The dataset was divided into ~~a~~ calibration and validation ~~dataset~~ subsets. The validation ~~dataset~~ data consisted of the randomly selected sampling points 1, 5, 9 and 13; ~~while~~ whereas, the remaining sampling points served for the calibration. The calibration models (Table 1) were then applied to the validation ~~dataset~~ data and evaluated by the relationship between the observed and the predicted leaf NDVI. The heading-to-grain-filling stage model had a high fit with R^2 = 0.845 and the lowest error (RMSE=0.092, RE=38.36%).

3.2.1 Tillering stage ~~of leaf NDVI model analysis~~

In June, the Shendao-47 was in its tillering stage. The growth of ~~rice~~ the leaves was related to the maximum relative humidity of the environment and the ~~sunshine~~ duration of sunshine. The coefficient of determination R^2 ~~showed~~ indicated that the maximum relative humidity of the environment for ~~Shendao-47~~ leaf growth had the most obvious effect. ~~and~~ This time, the ~~rice~~ plant height and the leaf area index (LAI) were relatively small [34]; therefore, the relative humidity at different heights was not obvious. ~~and~~ Moreover, the results ~~showed~~ demonstrated that no significant difference existed between the different models (Table 3).

Table 3 Leaf NDVI modeling and analysis of different environmental parameters in tillering stage.
y_L—leaf NDVI，x_C— canopy NDVI, x_S— sunshine, x_{EHH}— ~~The~~ highest relative humidity ~~of~~ in ~~the~~ environment, x_{CHH}— ~~The~~ highest humidity of canopy rice, x_{MHH}— ~~The~~ highest humidity of rice in ~~the~~ middle height, x_{BHH}— ~~The~~ highest humidity of rice in ~~the~~ bottom height

Regression model	***R*²**
$y_L=-9.119+0.166x_C+0.633x_S+0.002x_{EHH}$	0.845
$y_L=-7.032+0.158x_C+0.492x_S+0.002x_{CHH}$	0.839
$y_L=-7.152+0.154x_C+0.5x_S+0.002x_{MHH}$	0.840
$y_L=-6.461+0.179x_C+0.449x_S+0.003x_{BHH}$	0.836

Note: y_L—leaf NDVI，x_C— canopy NDVI, x_S— sunshine, x_{EHH}— ~~The~~ highest relative humidity ~~of~~ in ~~the~~ environment, x_{CHH}— ~~The~~ highest humidity of canopy rice, x_{MHH}— ~~The~~ highest humidity of rice in ~~the~~ middle height, x_{BHH}— ~~The~~ highest humidity of rice in ~~the~~ bottom height **[WHY is this same information repeated from the Table 3 caption (above)? It is redundant. It would be better to leave this Note intact and delete from the caption.]**

Figure 3 ~~was~~ graphs the time series of the canopy ~~NDVI~~ and leaf NDVIs in June. ~~The NDVI of canopy rice and~~ Both NDVIs ~~leaves~~ increased in the tillering stage, but ~~the canopy NDVI~~ the increase was more obvious in the canopy NDVI. After June 26, the canopy NDVI was greater than the leaf NDVI ~~after June 26~~, ~~and~~ this time ~~covered~~ covering the tillering stage ~~of japonica rice growth~~.

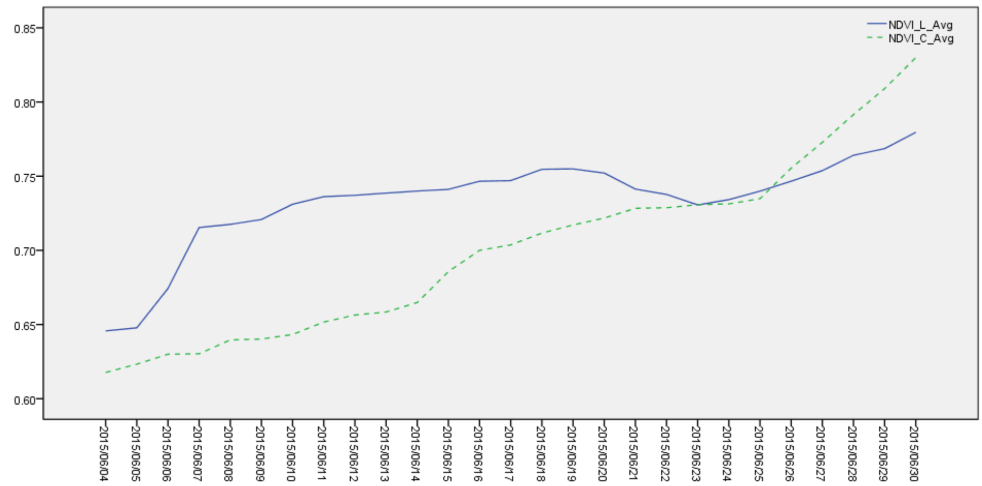

Figure 3 Time-series curves in tillering stage of canopy ~~NDVI~~ and leaf NDVIs of Shendao-47 ~~time-series curve in tillering stage~~ (NDVI_L_Avg—rice leaf NDVI，NDVI_C_Avg— rice canopy NDVI.)

3.2.2 Jointing and booting stages ~~of leaf NDVI model analysis~~

In July, the Shendao-47 was in its jointing and booting stage. The process of achieving accuracy in the NDVI leaf-fitting model ~~accuracy were~~ was lower than that in other periods mainly because, at this stage ~~in the growth of japonica~~, ~~rice~~ vegetative and reproductive growth ensued. Thus, the process was more complex from the ~~point of view~~ perspective ~~on~~ of the model elements. Conversely, ~~by~~ for the canopy NDVI, the long-time illumination, the rice-growing environments, ~~and~~ as well as the accuracy of the middle- and lower-minimum temperatures ~~accuracy~~ of the model were higher than the lowest temperature accuracy of the other model only when actually within the canopy NDVI and in the long-light modeling. Explained at this stage, the ~~rice~~ vertical-middle and lower-ambient temperatures of the rice had important implications for ~~rice~~ growth (Table 4).

Table 4 Leaf NDVI modeling and analysis of different environmental parameters in jointing and booting stage

Regression model	R^2
y_L=0.542-0.664x_C+0.052x_S	0.713
y_L=0.608-0.673x_C+0.051x_S+0.008x_{MTL}-0.009x_{BTL}	0.782

Note: y_L—leaf NDVI，x_C— canopy NDVI, x_S— sunshine, x_{MTL}— ~~The~~ lowest temperature ~~of~~ in ~~rice~~ middle ~~part~~ of rice, x_{BTL}— ~~The~~ lowest temperature ~~of~~ in ~~rice~~ bottom ~~part~~ of rice

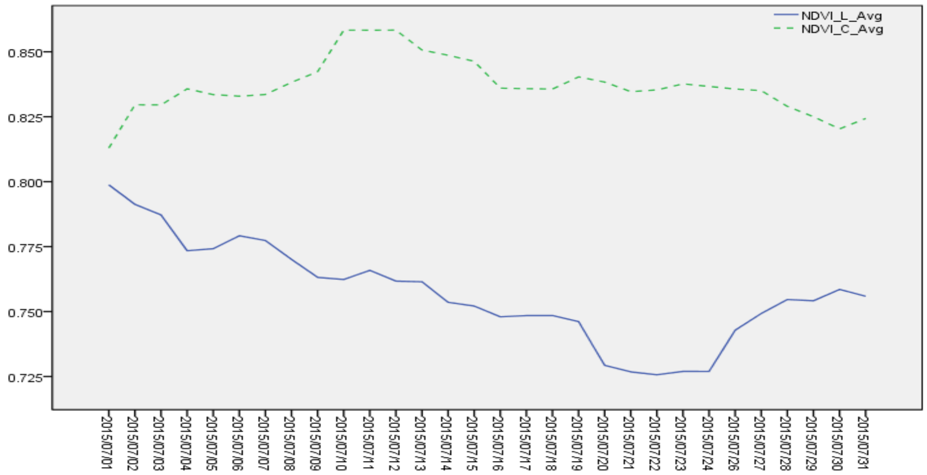

Figure 4 Canopy NDVI and leaf NDVI of Shendao-47 time-series curve in jointing and booting stage (NDVI_L_Avg—rice leaf NDVI，NDVI_C_Avg— rice canopy NDVI.)

Figure 4 ~~shows~~ graphs the time series of the canopy and leaf NDVIs in July. Both ~~canopy and leaf NDVI~~ increased in the tillering stage, ~~whereas~~ but the increase in the canopy NDVI ~~increase~~ was more obvious. After June 26, the tillering stage, the canopy NDVI was greater than the leaf NDVI ~~after June 26, which is the tillering stage of Japonica rice growth~~. ~~Canopy NDVI~~ Having relatively stable data, the canopy NDVI was higher than the leaf NDVI; ~~and canopy NDVI data were relatively stable,~~ whereas, the leaf NDVI data ~~of leaves~~ decreased because japonica rice growth is complete at tillering ~~was complete~~. The LAI increased to the maximum value for the entire growth cycle and ~~after jointing stage it~~ entered the booting and heading process after the jointing stage. ~~Ineffective tillers in~~ During this period, the ineffective tillers gradually died ~~and at the same time,~~ while, concurrently, some nutritional leaf spikes were gradually transferred. [35]

3.2.3 ~~Analysis of~~ Grain-filling stage ~~of leaf NDVI model~~

In August, the Shendao-47 was ~~heading into~~ entering the grain-filling reproductive stage. ~~The rice growth period entered the reproductive stage~~. ~~Shendao-47~~ Its growth was affected by the duration of sunshine, ~~duration and~~ the number of growth days, and the changes in temperature within this period ~~affected rice growth~~. ~~Based~~ On the basis of the fitting accuracy of the model analysis, the ~~height~~ environmental temperature of the height was found to affect ~~rice~~ the growth (Table 5).

Table 5 Leaf NDVI modeling and analysis of different environmental parameters in grain-filling stage.

Regression model	R^2
y_L=0.965-0.285x_C-0.003x_D+0.001x_{ETH}	0.877
y_L=0.942-0.262x_C-0.002x_D+0.001x_{CTH}	0.866
y_L=0.935-0.25x_C-0.002x_D+0.001x_{MTH}	0.861

Note: y_L—leaf NDVI，x_C— canopy NDVI, x_D— ~~Rice~~ growing days, x_{ETH}— ~~The~~ highest temperature ~~of~~ in environment, x_{CTH}—~~The~~ highest temperature of canopy rice, x_{MTH}— ~~The~~ highest temperature ~~of rice~~ in middle ~~part~~

Figure 5 ~~shows~~ graphs the time series of the leaf and canopy NDVIs in August. ~~For rice in~~ During the filling stage, the canopy NDVI data ~~in August 20~~ reached ~~the~~ the highest level on August 20. After the beginning of the rapid decline, the leaf NDVI decreased, resulting ~~in the~~ mainly due to the filling stage, during which leaf nutrients ~~of leaves~~ are continuously transferred to the panicle.

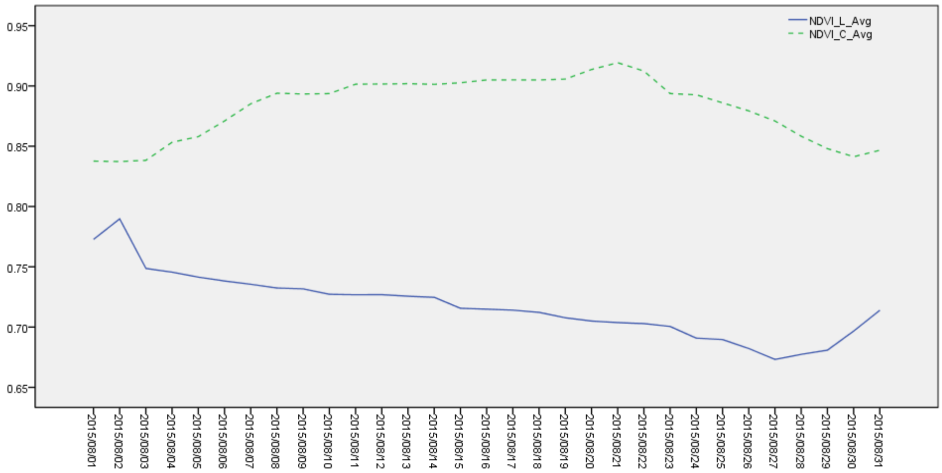

Figure 5 Canopy NDVI and leaf NDVI of Shendao-47 time-series curve ~~in heading to~~ entering grain-filling stage (NDVI_L_Avg—rice leaf NDVI, NDVI_C_Avg— rice canopy NDVI)

3.2.4 Mature stage ~~of leaf NDVI model analysis~~

In September, the Shendao-47 ~~was at the mature stage~~ reached maturity, ~~This period was~~ the last stage of ~~rice~~ growth, ~~in~~ during which ~~rice gradually matured and~~ the leaves ~~turned~~ turn yellow, the canopy ~~NDVI~~ and leaf NDVIs ~~were~~ being ~~really~~ very low and the yield ~~of rice was~~ basically formed. ~~Based~~ On the basis of the established model, this stage of the leaf NDVI fitting model was composed of the canopy NDVI, the duration of sunshine ~~duration~~, and the number of days. The leaf NDVI is not related to the changes in temperature and humidity, which also ~~meant~~ means that changes in the environmental temperature and humidity did not influence the ~~japonica rice~~ final output (Table 6).

Table 6 Leaf NDVI modeling and analysis of different environmental parameters in mature stage

Regression model	R^2
y_L=-0.705-1.056x_C-0.009x_D+0.176x_S	0.903
y_L=1.227+0.424x_C+0.011x_{CTA}+0.176x_{MTH}	0.612
y_L=0.215+0.043x_C-0.094x_{MTL}+0.116x_{BTL}	0.553

Note: y_L—leaf NDVI, x_C— canopy NDVI, x_D— ~~Rice~~ growing days, x_{CTA}— ~~The~~ average temperature of canopy rice, x_{MTH}— ~~The~~ highest temperature ~~of rice~~ in middle ~~part~~, x_{MTL}— ~~The~~ lowest temperature ~~of rice~~ in middle ~~part~~, x_{BTL}—~~The~~ lowest temperature ~~of rice~~ in bottom ~~part~~

Figure 6 ~~shows~~ graphs the time series of the leaf and canopy NDVIs in September. ~~For rice~~ In the mature stage, both ~~leaf and canopy~~ NDVIs decreased, ~~and~~ the canopy

NDVI significantly ~~decreased~~ decreasing. ~~In~~ During this stage, ~~leaf~~ both NDVIs ~~twice~~ intersected twice ~~with canopy NDVI~~. After the second intersection, the leaf NDVI rapidly declined, ~~which indicated~~ thus indicating that the rice was ripe.

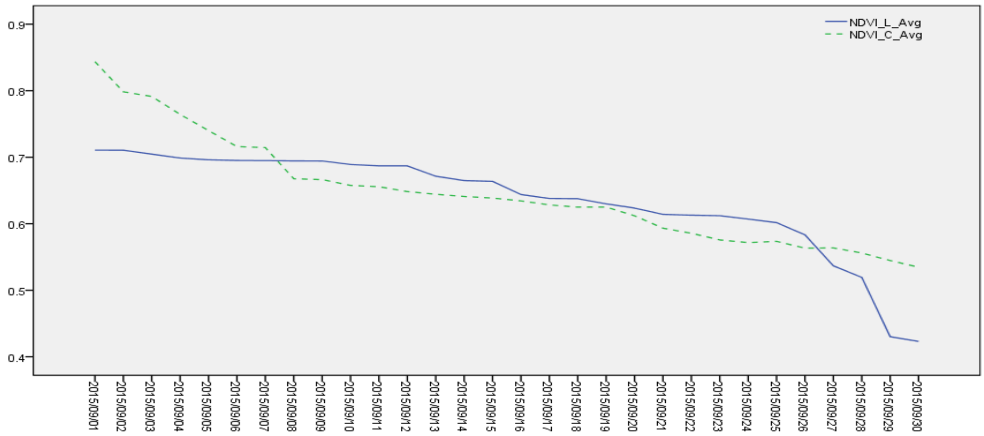

Figure 6 Canopy NDVI and leaf NDVI of Shendao-47 time-series curve in mature stage

(NDVI_L_Avg—rice leaf NDVI，NDVI_C_Avg— rice canopy NDVI.)

3.3 Time-series analysis ~~of japonica rice NDVI~~

~~We collected canopy NDVI and leaf NDVI of japonica rice growing in northeast China.~~ Figure 7 shows the time-series curves ~~with~~ for the leaf and canopy NDVIs of Shendao-47 from transplanting to maturity ~~period~~.

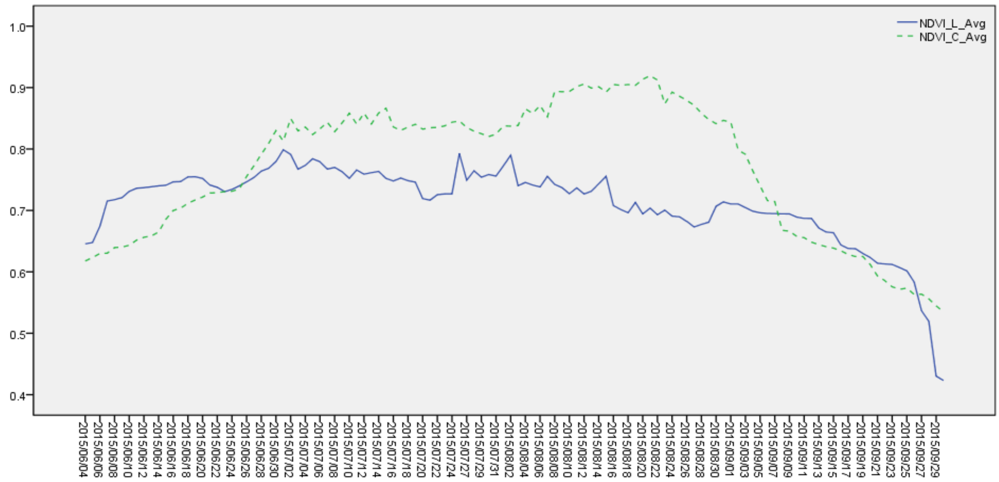

Figure 7 Canopy NDVI and leaf NDVI of Shendao-47 time-series curves

(NDVI_L_Avg—rice leaf NDVI，NDVI_C_Avg— rice canopy NDVI.)

Three intersection points ~~existed~~ exist on the time-series curves of the leaf and canopy NDVIs, ~~and~~ the first ~~intersection~~ point ~~was~~ being on June 27, 2015. Before this period, the leaf NDVI was higher than the canopy NDVI because the LAI was small. The canopy NDVI also contained most of the water layer. At this time, the leaves ~~rapidly~~ grew rapidly; ~~so~~ therefore, ~~in this period~~ the canopy NDVI was smaller than the leaf NDVI during this period. After this period of ~~growing~~ LAI growth, the canopy NDVI was greater than the leaf NDVI; ~~so~~ hence the two curves at the first intersection ~~were~~ represent a sign of ~~rice~~ growth and the tillering stage. [36] The second intersection of the two curves ~~was~~ occurred on September 8, 2015. Before this date, the canopy NDVI was greater than the leaf NDVI. The leaf NDVI was greater than canopy the NDVI after this date because of the continuous growth of ~~rice with~~ the leaves and the stem energy being transferred to the panicle. This phenomenon caused the leaves to turn yellow, this time for the dough-stage node. The third point of the two curves of intersection ~~was~~ occurred on September 27, 2015. Beyond this point, the leaf NDVI rapidly decreased because the rice was ~~basically~~ essentially mature, and ~~Over~~ more than 90% of the leaves ~~became~~ had become yellow. [37] Therefore, predicting the key growth process of ~~japonica~~ the rice ~~was~~ became possible by using the time-series curves ~~of~~ to graph the canopy and leaf NDVIs (Table 7).

Table 7 ~~Using~~ Use of canopy and leaf NDVIs ~~of canopy and leaf~~ to predict key growth period of japonica rice. (Traditional time is ~~the~~ approximate time range)

Prediction time	~~Canopy NDVI and Leaf~~ NDVIs	Period	Traditional time
2015/6/26	Canopy NDVI was greater than leaf NDVI	Tillering stage	2015/6/25
2015/7/1	Leaf NDVI maximum	Jointing stage	2015/7/1–2015/07/05
2015/7/21	~~The~~ Maximum difference between ~~canopy NDVI and leaf~~ NDVIs in July	Booting stage	2015/7/25
2015/8/2	~~The~~ Minimum difference between ~~canopy NDVI and leaf~~ NDVIs in August	Initial heading stage	2015/8/5
2015/8/22	~~The~~ Maximum difference between ~~canopy NDVI and leaf~~ NDVIs	Milk stage	2015/8/24
2015/9/8	Leaf NDVI was greater than NDVI	Dough stage	2015/9/3
2015/9/27	Canopy NDVI was greater than leaf NDVI in September	~~Mature~~ Maturity	2015/10/1

3.4 Discussion

This study ~~analyzes~~ analyzed the relationship ~~of~~ between the canopy and leaf NDVI scales of japonica rice ~~NDVI between canopy scales and leaf scales~~. ~~USDA~~ In a 2013 study the USDA suggested that the crop ~~canopy~~ and leaf canopies of the same vegetation index have different ~~sensitivity~~ sensitivities, and this kind of ~~different~~ difference ~~that~~ affects the accuracy of crop information inversions. [38] The results of this study ~~show~~ indicate that the respective scales of the NDVIs ~~in~~ for different growth periods of rice ~~canopy~~ canopies and ~~leaf~~ leaves ~~of the change of the scale is~~ are different, ~~this is in line with the predecessors'~~ thereby corroborating ~~research~~ the results of previous research. The changes in the leaf NDVI during the growth cycle ~~is~~ were ~~far~~ much less than ~~in the growth cycle~~ the changes in the canopy NDVI; ~~changes, but~~ however, after the filling stage, the changes in both ~~leaf and canopy~~ NDVIs ~~change is~~ were relatively small. ~~while~~ Although ~~the~~ a rapid change in the leaf NDVI

~~of rapid change is~~ was caused by the transfer of leaf energy ~~transfer~~ to the grain, a phenomenon that could reflect ~~the~~ a change in the final stage of ~~rice~~ the crop, it ~~is~~ has been the focus ~~on~~ of fewer problems in ~~the~~ previous research ~~of previous~~ on rice NDVI. This research focused mainly ~~in~~ on the process of ~~the establishment~~ establishing ~~of the~~ a model while ~~takes~~ taking into account the environmental factors and canopy NDVI. ~~From~~ The results indicate that the influence of different parts of rice on the NDVI is different, ~~through~~ by means of the canopy NDVI and environmental ~~date~~ data detection to ~~get~~ obtain the ~~rice~~ leaf NDVI value. ~~But~~ However, this study ~~does~~ did not take into account the influence of soil conditions on the model. ~~and~~ Furthermore, some previous experience is a prerequisite for ~~get~~ obtaining ~~the~~ such a model. ~~of this study need to have some previous experience,~~ Moreover, additional research is needed in the future for ~~the~~ further promotion of the model ~~still needs further research.~~ in future studies, especially from the perspective of a mechanism to further explain the ~~rice~~ relationship between the leaf ~~NDVI~~ and canopy NDVIs.

4. Conclusions

Our studies conducted in Northeast China ~~indicated~~ have demonstrated that the leaf NDVI of japonica rice ~~was able to~~ can be simulated by the canopy NDVI and environmental data ~~in Northeast China~~. The main contributions of this ~~work~~ research are as follows: (1) establishing, with good accuracy (R2= 0.782–0.903), four periods of leaf NDVI models ~~with good accuracy (R2= 0.782–0.903). These models~~ that can predict the key stages ~~of~~ in the rice growth period; (2) ~~By~~ collecting the ~~rice~~ canopy NDVI ~~data~~ and environmental data that can more ~~quickly get~~ efficiently obtain the leaf NDVI information, which ~~is the~~ traditional canopy remote sensing cannot ~~get~~ do; (3) demonstrating that rice leaf NDVIs are influenced by environmental factors and canopy NDVIs. Therefore, ~~rice~~ leaf NDVIs can be estimated by canopy NDVIs and multisource environmental data that may be used for rice growth management.

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[CJR stopped editing at this point.]

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