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Forecasting rainfed rice yield with biomass of early phenophases, peak intercepted PAR and ground based remotely sensed vegetation indices

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ABSTRACT

Rice is the main staple food of the country but crop productivity in some years declines due to erratic monsoon and non-uniformity in spatial and temporal distribution of rainfall. Hence, assessing productivity of the rice crop in advance using meteorological and plant physiological attributes will be helpful for planners to take decision on contingency measures. In this investigation, dry biomass of early phenophases (active tillering, panicle initiation, boot leaf stages, flowering),peak intercepted photosynthetically active radiation (IPAR), peak spectral reflectance based vegetation indices of 3 rice varieties under 3 nitrogen levels (50, 100 and 130 kg ha^{-1}) were made correlated with grain yield.Based on interrelationship it was found that biomass of flowering period was better correlated with grain yield with the R^2 value of 0.75.Inter-relationship between peak IPAR(%), remotely sensed peak simple ratio index (IR/R) and normalized difference vegetation index (NDVI)with the rice yield were also established. Multiple regression modelwas developed by interrelating yield as dependant variable with dry biomass of flowering stage, peak IPAR(%) and peak IR/R and NDVI as independent variables which may be used as an effective tool for early prediction of rice yield, at least 30-40 days in advance. The grain yield was also estimated through developed algorithm using MODIS satellite derived NDVI and compared with that of actual yield.

Key words : Radiation interception, rice, vegetation index, yield forecasting, biomass

Rice is an essential food for more than two billion people of the globe particularly in Asia, Africa and Latin America. In India, rice is the main staple food and the challenge in rice system here is to achieve regional food security and increase farm income using site-specific crop management techniques. In Odisha, maximum rice (78% of total rice area in the region) is grown during wet/rainy season (July to October), when rainfall occurs due to southwest monsoon. Though the region receives 1480 mm average annual rainfall but in some years the rainfall is erratic and dry spells occur during crop period. As a result the crop productivity is affected in those years but any negative fluctuation in rice production in the region will have direct impact on food security of the country. Accurate and real-time estimation of rice yield at different scales is thus becoming increasingly important in the region. In particular, crop yield estimation may play a fundamental role in supporting policy formulation and decision-making in agriculture, even affecting a country's security and stability (Zhang *et al.,* 2012). Hence, optimization of natural resources and soil fertility parameters and assessing crop growth and productivity in advance using meteorological and plant physiological attributes will be helpful for planners to take decision on contingency measures (Graf et al., 1990;Ritchie *et al.*, 1989;Bouman *et al.,* 2007; Swain *et al.,* 2007). The amount of solar radiation intercepted and its utilization efficiency by a crop are major determining factor for the total dry matter and grain yield production. (Biscoe and Gallaghar 1978). Thus, a detailed study of radiation interception and its utilization efficiency forms an important supplementary component to improve the productivity of rice of a crop (Shibles and Weber 1966; Monteith 1972; Biscoe and Gallagher 1978; Ong and Monteith 1985; Kinry *et al.* 1989; Williams *et al.* 1990; Kar 2009). Along with the radiation interception, understanding the surface reflectance pattern of the crop and its relationship with crop health will providein-sight for assessing crop growth and productivity in diverse ecological locations. During the past several years, estimates of biomass, leaf area index and productivity using spectral reflectance based vegetation indices have shown promising results in different parts of the world. (Asrar *et al.,* 1984; Daughtry *et al.,* 1983; Huete, 1988; Myneni& Williams, 1994; Bouman *et al.,* 1992).In eastern India, still there is a paucity of such type of information where rice is grown under rainfed situations during rainy season when the sky remains cloudy. Keeping the importance of above points in view, in this study, radiation interception, spectral reflectance based vegetation indices in relation to crop growth and productivity of 3 rainfed rice varieties under 3 nitrogen levels (50, 100 and 130 kg ha^{-1}) were studied during rainy season under tropical monsoon climate. Multiple regression model was developed by interrelating yield with biomass of flowering stage, IPAR and spectral reflectance based vegetation indices (IR/R and NDVI) for predicting crop yield in advance. These relationships can be used to predict crop yield in advance at least 30-40 days before harvesting of the crop. To validate the MODIS satellite based NDVI derived yield, the actual grain yield of the field was compared with that of MODIS-NDVI derived yield.

MATERIALS AND METHODS

Experiment (wet seasons 2004 and 2005) was carried out at Jatni Block, Khurda district, Orissa, India (Lat. 20^0 $10^/$ to 20^0 $15^/$ N, Longitude 85^0 $40^/$ to 85^0 $45^/$ E and elevation 30 m above sea level. The climate is typically tropical monsoon type with long-term mean annual rainfall of 1408 mm and 70-80 % of rainfall occurs during southwest monsoon period (June-September).

The on-farm trial was conducted in split plot design with 3 replications. The treatments were 3 varieties of rice (V_1= 'Lalat', V_2 = 'Gayatri', V_3 = 'Savitri') in main plots and three levels of nitrogen (N_1 = 50 kg N ha^{-1}, farmers' practice; N_2 = 100 kg N ha^{-1}; N_3 = 130 kg N ha^{-1}) in subplots. In each year, rice was transplanted on last week of July with plant to plant and row to row distance of 0.15 m and 0.20 m, respectively. Phosphorus and Potassium were used at the rate of 50 kg ha^{-1} in all plots. Full dose of P and K and 1/3rd of N were applied as basal. The remaining N fertilizer was applied at tillering and panicle initiation stages in two equal splits. Other crop management practices like weeding, intercultural operations were performed using standard agronomic package of practices.Plant samples were collected from five plants at active tillering, panicle primordia initiation, booting, heading/flowering/panicle initiation/anthesis, milky, dough, yellow ripe, maturity stages of the crop for measuring leaf area index and above ground dry biomass.

Intercepted photosynthetically active radiation (IPAR)

Photosynthesis in green leaves uses solar energy in wavelengths from 0.4 to 0.7 ìm, often referred to as photosynthetically active radiation (PAR) or simply light. The intercepted PAR (IPAR) was measured using light transmission meter (EMS-7) as per the following relationship.

$I_i = I_o - I_{rc} - I_t + I_{rg}$

I_i (%) by the canopy= (I_i / I_0) x 100

Ii = Intercepted Photosynthetically ActiveRadiation (PAR) by the canopy; Io = Incident PARon the canopy, I_{rc} = Reflected PAR by the canopy; I_t =Transmitted PAR through the canopy, I_{rg} = Reflected PAR from the ground.

Measurements of radiation at ground level were taken by placing the linear sensor diagonally across the inter-row space with the ends of the sensor coinciding with the centre-line of the rows. All measurements were performed at 1100 h to 1300 h local time in a clear day at important phenological stages like active tillering, panicle initiation, booting, flowering/ anthesis/ heading, milky, dough and maturity stages and peak values of it were correlated with grain yield.

The reflectance pattern of the crop canopy indicates crop growth stage, crop health and are useful to detect any biotic or abiotic stress on crops. (Rouse *et al.,*1974;Clevers*et al.,* 1991; Bouman, 1995). Various vegetation indices are derived as a carefully chosen combination of reflection coefficients in various wavebands. The first index to be used was the IR/R ratio (Rouse *et al.,* 1974) for assessing crop growth and productivity. The same authors used a normalized difference vegetation index (NDVI) for estimating crop characteristics.

The vegetation indices were derived based on spectral reflectance data at different phenological stages using a hand held Spectroradiometer (UNISPEC, USA) and peak values of IR/R and NDVI were correlated with grain yield of rice.

During the course of the experiment, weather conditions (rainfall, solar radiation, temperature) were collected from the Deras farm, Mendhsal, Khurda, Orissa, India, which is located near to the experimental field.

Statistical analysis

Experimental plots were laid-out in split Plot design with three blocks. The ANOVA, multiple comparisons of parameters were made using PROC GLM of SAS software.

Four independent variables viz., biomass at

Table 1: Above ground dry biomass of different phenophases of rice as influenced by variety and nitrogen levels

Factors	Biomass at active tillering stage (kg ha^{-1})	Biomass at panicle initiation stage(kg ha^{-1})	Biomass at boot leaf stage (kg ha^{-1})	Biomass at flowering (kg ha^{-1})	Biomass at maturity (kg ha^{-1})	Grain yield (t ha^{-1})
I. Year						
2004	^{A}3576	^{B}4724	^{B}6862	^{B}8162	^{B}13500	^{B}4.81
2005	^{A}3606	^{A}4894	^{A}7048	^{A}8234	^{A}14910	^{A}5.20
Significance	NS	NS	***	**	**	
II. Varieties						
Lalat	^{A}3481	^{B}4720	^{B}6716	^{B}7812	^{B}12310	^{B}4.32
Gayatri	^{A}3585	^{A}4954	^{A}7068	^{A}8390	^{A}15410	^{A}5.30
Savitri	^{A}3558	^{A}4905	^{A}7095	^{A}8392	^{A}14910	^{A}5.35
Significance	NS	*	****	**	**	
III. Nitrogen levels						
50 kg N ha^{-1}	^{C}3265	^{C}4441	^{C}6741	^{C}7867	^{C}11100	^{C}4.20
100 kg Nha^{-1}	^{B}3548	^{B}4798	^{B}6920	^{B}8272	^{B}13550	^{B}5.05
130 kg Nha^{-1}	^{A}3811	^{A}5188	^{A}7204	^{A}8455	^{A}15400	^{A}5.72
Significance	**	**	****	**	**	

Interaction:
Year × Varieties: NS NSNSNS** **
Varieties × **Nitrogen:** NS NSNSNS ** **
Year × Varieties × Nitrogen: NS NSNSNS ** **

*Significant at 1% probability level, ** Significant at 5% probability level, NS = Non significant
The values in the column followed by same letters are not significant at 5% level of significance based on Duncan's' Multiple Range Test (DMRT).

flowering, maximum IPAR, IR/R, NDVI were used to develop multiple regression model for predicting crop yield. Using SGSCATTER procedure of SAS, scatter plots of above independent variables and yield were generated to examine the relationship between seed yield and biomass at flowering, maximum IPAR, IR/R, NDVI. Using PROC CORR of SAS software, correlation matrix of biomass at flowering, maximum IPAR, IR/R, NDVI and yield were developed.

RESULTS AND DISCUSSION

Interrelation between grain yield and dry biomass at different phenophases

Above ground dry biomass (AGDM) of active tillering, panicle initiation, boot leaf, flowering and maturity stages were measured and are presented in Table-1. The TDM production increased steadily after crop establishment until maturity in all the treatments.

Year effect on total above ground dry biomass (AGDM) accumulation was found to be significant. The crop accumulated more AGDM during 2005 (14.91 t ha^{-1}) as compared to 2004 (13.5 t ha^{-1}), which might be attributed to uniform distribution of rainfall in 2005. In regard to varieties, the AGDM production was found to be non-significant between 'Gayatri' and 'Savitri' throughout the season, while 'Lalat' accumulated statistically lesser AGDM (12.3 t ha^{-1}) as compared to other two varieties, which was statistically non-significant. Total AGDM production responded positively to nitrogen application. Maximum AGDMat harvest (15.4 t ha^{-1})in the N_3 treatment

Table 2: IPAR, vegetation indices and biomass of flowering stage of rice as influenced by variety and nitrogen levels

Factors	**$IPAR_{max}$ (%)**	IR/R_{max}	$NDVI_{max}$
I. Year			
2004	^{B}84.30	^{B}7.81	^{B}0.70
2005	^{A}87.10	^{A}8.21	^{A}0.74
Significance	**	**	**
II. Varieties			
Lalat	^{B}82.00	^{B}7.60	^{B}0.69
Gayatri	^{A}88.83	^{A}8.16	^{A}0.75
Savitri	^{A}87.33	^{A}8.19	^{A}0.76
Significance	**	**	**
III. Nitrogen levels			
50 kg N ha^{-1}	^{C}81.83	^{C}6.88	^{C}0.66
100 kg Nha^{-1}	^{B}86.50	^{B}8.13	^{B}0.74
130 kg Nha^{-1}	^{A}91.83	^{A}9.14	^{A}0.82
Significance	**	**	**

Interaction:
Year × Varieties:NS NSNS
Varieties × Nitrogen:NS NSNS
Year × Varieties × Nitrogen::NS NSNS
*Significant at 1% probability level, ** Significant at 5% probability level, NS = Non significant
The values in the column followed by same letters are not significant at 5% level of significance based on Duncan's' Multiple Range Test (DMRT).

(130 kg N ha^{-1}) followed by N_2 (13.55 t ha^{-1}). Minimum AGDM (11.1 t ha^{-1}) was achieved with 50 kg N ha^{-1}.

To explore the possibility of grain yield with biomass of early phenophases and predicting yield in advance, dry biomass of the crop was measured at active tillering, panicle initiation, boot leaf and flowering stages of the crop and the biomass of each stage was correlated with grain yield. Study revealed that among biomass of all the stages, flowering stage biomass was better correlated with grain yield with the R^2 value of 0.75. Hence, if yield is to predicted in terms of biomass of early phenophases, flowering stage biomass can be used for yield prediction which was achieved 30-35 in advance before harvesting of the crop.

Y (Yield) = a + b * X (Biomass at respective stage)

Yield (t ha^{-1})= 1.141 +0.001 *BM_{AT}(R^2 = 0.21)

Yield (t ha^{-1})= 1.380 +0.0018 *BM_{PI}(R^2 = 0.24)

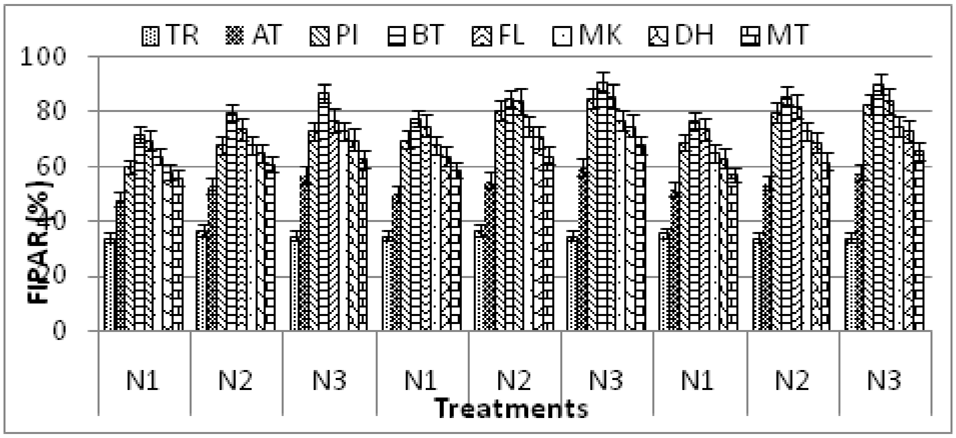
Yield (t ha^{-1})= -6.55 +0.002*BM_{BT} (R^2 = 0.43)

Yield (t ha^{-1})= -7.044 +0.0015*BM_{FL} (R^2 = 0.75)

Where, BM_{AT}= Above ground dry biomass at active tillering stage (kg ha^{-1}), BM_{PI} = Above ground dry biomass at panicle initiation stage(kg ha^{-1}), BM_{BT} = Above ground dry biomass at boot leaf stage (kg ha^{-1}), BM_{FL} = Above ground dry biomass at flowering stage (kg ha^{-1}).

Intercepted photosynthetically active radiation (IPAR)

The IPAR was measured at different phenological stages and are depicted in Fig.1. Study revealed that IPAR (%) was higher in boot leaf stage (coincided with maximum leaf area index) followed by flowering stage. Generally IPAR values steadily increased and reached maximum value during booting stage (at 75-80 DAS in 'Lalat' and around 90 DAS in other two varieties) ; thereafter it slightly declined in all the treatments and reached its minimum values at about 45-60% towards the maturity period. The effect of treatments on the amount of maximum



TR=Transplanting stage, AT = Active tillering, PI = Panicle initiation stage, BT = Boot leaf stage, FL = Flowering stage, MK = Milky stage, DH = Dough stage, MT = Maturity stage

Fig. 1: IPAR (%) as influenced by different nitrogen levels in 3 rice varieties (mean value of 2 years)

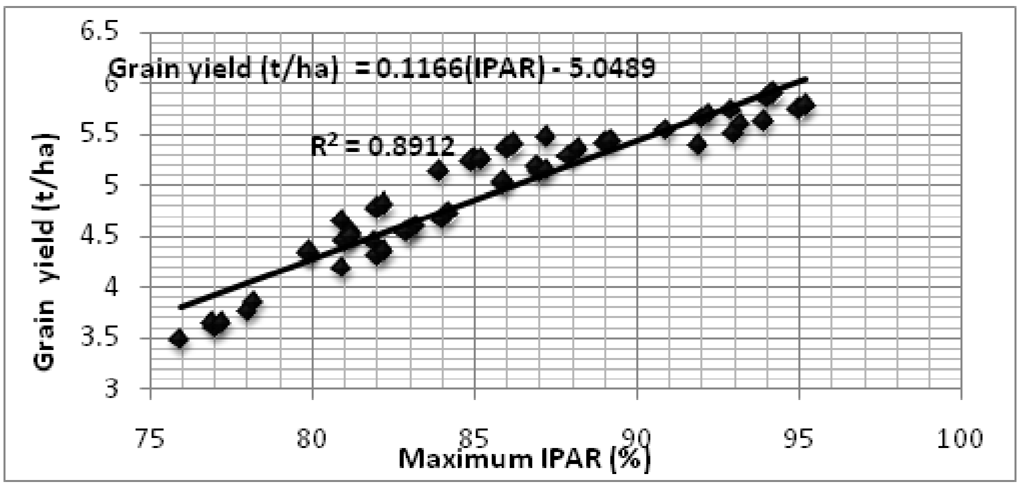


Fig. 2: Interrelationship between grain yield and maximum intercepted photosynthetically active radiation

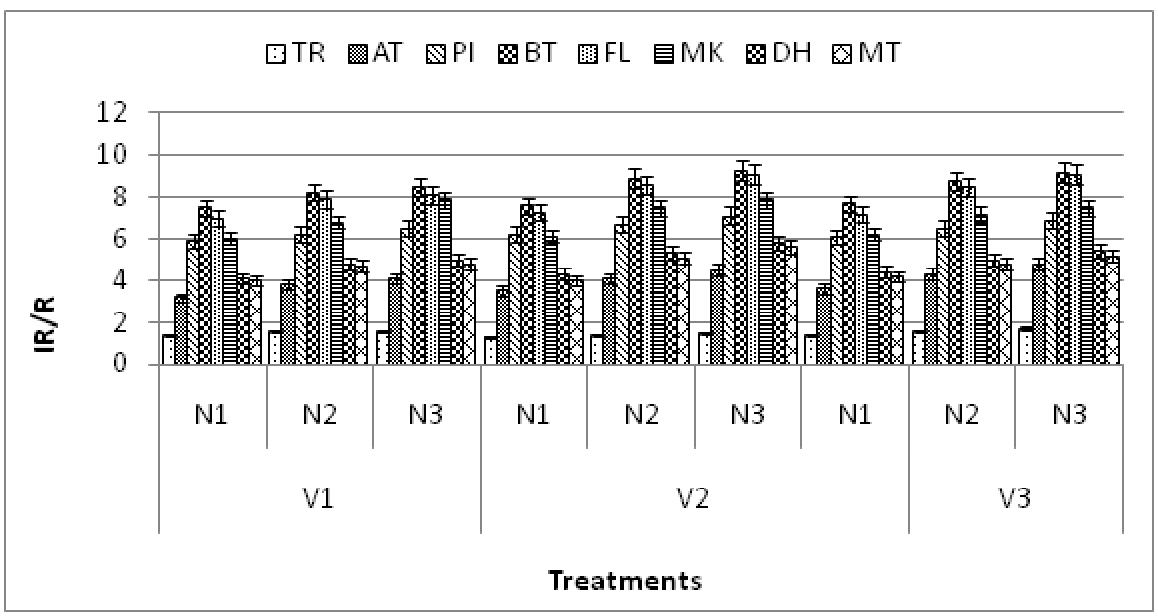


Fig. 3: Peak IR/R as influenced by different nitrogen levels in 3 rice varieties (mean value of 2 years)

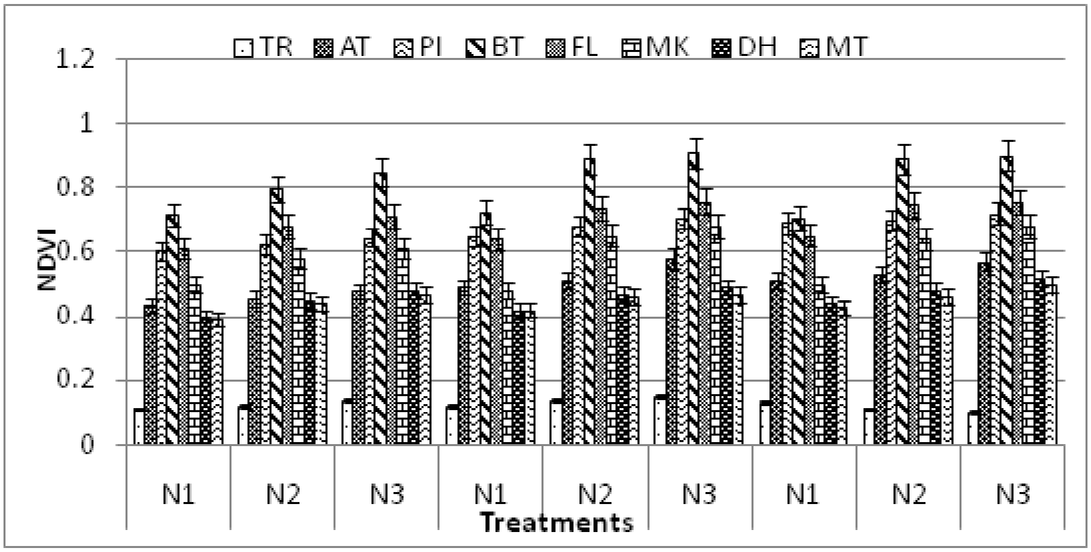


Fig. 4: Peak NDVI as influenced by different nitrogen levels in 3 rice varieties (mean value of 2 years)

Table 3: Validation of MODIS NDVI derived yield with actual field yield

Land parcel	Longitude	Latitude	$NDVI_{max}$ of MODIS (Date:15.10.2006)	Estimating yield ($t\ ha^{-1}$)	Actual yield ($t\ ha^{-1}$)	Error (%)
Parcel1	85.691	20.205	0.69	4.75	4.55	4.39
Parcel2	85.697	20.178	0.59	3.88	3.78	2.64
Parcel3	85.683	20.204	0.70	4.84	4.65	4.08
Parcel4	85.727	20.155	0.71	4.66	4.15	5.42
Parcel5	85.721	20.193	0.69	4.75	4.50	5.55

intercepted photosynthetically active radiation (IPAR) is given in Table-2. The peak IPAR was higher (87.1%) in second year than in first year (84.3%) and the difference was statistically significant. Higher values of IPAR in 2005 might be attributed to higher biomass, LAI and crop height in second year than in the first year. In regard to cultivars, peak intercepted PAR was 82.0% for cultivar 'Lalat' which was significantly different from other two varieties. But the differences were found to be non-significant between cultivar 'Gayatri' (88.8%) and 'Savitri' (87.3%).

Nitrogen levels significantly affected the amount of peak radiation intercepted. Averaged over years and varieties, mean IPAR was 91.8% when plots were fertilized with 130 kg N ha^{-1} (N_3). The IPAR of 81.8% and 86.5% was recorded with 50 and 100 kg N ha^{-1}, respectively. The increase in IPAR (%) with higher level of nitrogen was due to better crop growth, which produced maximum plant height, LAI and total dry matter. The relationship between peak IPAR (%)and grain yield was also established and are presented in Fig. 2. Study revealed that peak IPAR was linearly related with the grain yield with the R^2 value of 0.89. The distribution of IPAR and its median values as influenced by nitrogen level and varieties are also presented in Fig.3.

Temporal variation of spectral vegetation index and its relationship with crop yield

Two remotely sensed spectral reflectance based vegetative indices viz; IR/R and NDVI were computed at different phenophases using spectral reflectance data and peak values are presented in Fig. 3 and 4, respectively. The IR/R was increased very fast with the vegetative growth and reached its maximum around to panicle initiation to boot leaf stage and then started declining. The temporal variation of NDVI was also computed which revealed that at boot leaf stage it reached peak

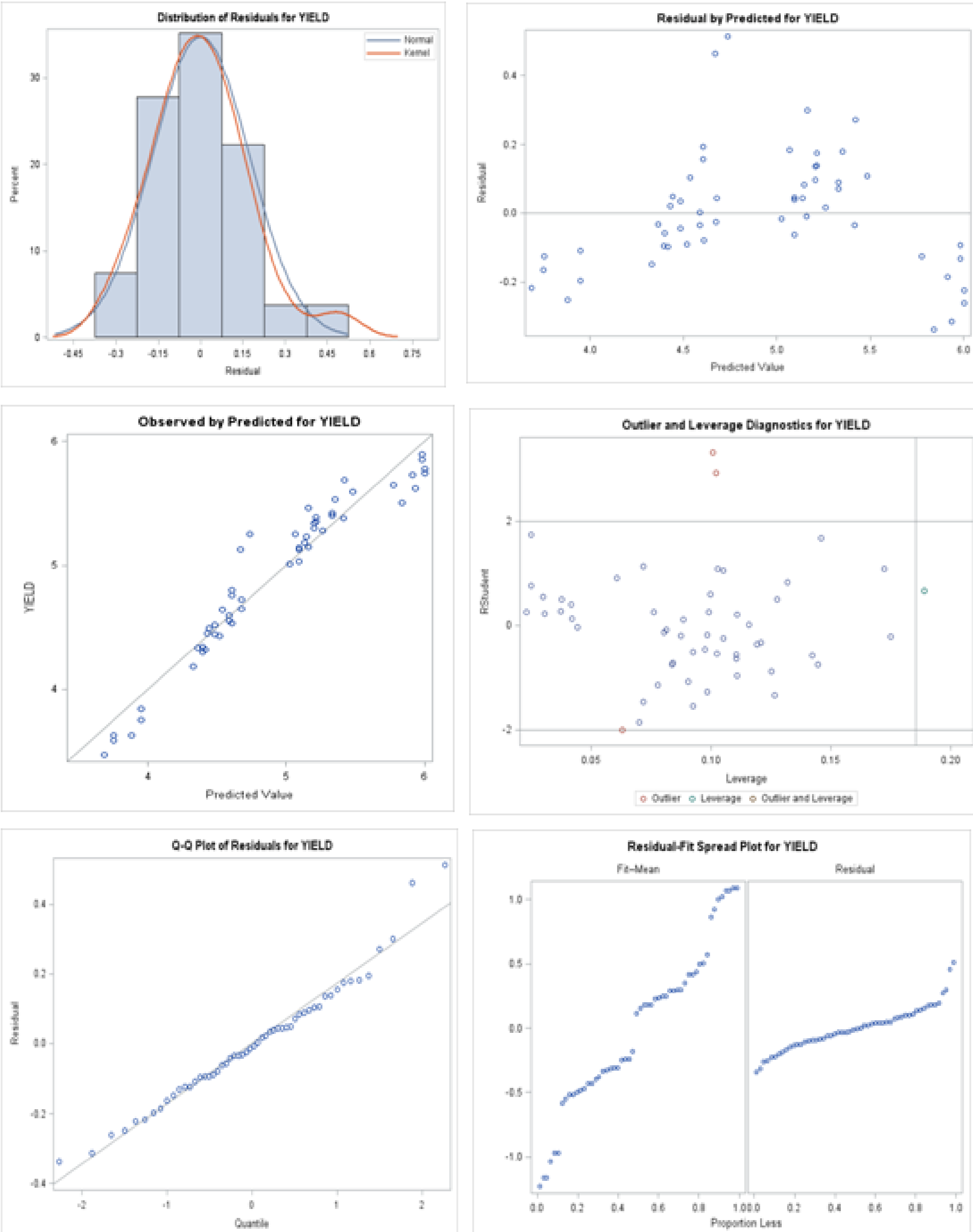


Fig. 5: Scatter plot of seed yield with IPAR, NDVI, IR/R and biomass of flowering stage

values and then declined from flowering stage of the crop. Due to decreased trend of leaf area index, the IR/R and NDVI showed downward trend after flowering stage.

Algorithms were developed to predict grain yield using peak IR/R and NDVI values and linear relationship between grain yield with peak IR/R and NDVI are developed.

The yield predicting equations using IR/R and NDVI are as follows:

Yield = - 0.0836+ 0.625 (IR/R), R^2= 0.81

Yield = - 1.26 + 8.715 (NDVI), R^2 = 0.83

Based on the above equations, yield can be predicted using peak IR/R and NDVI which occurred at boot leaf stage, at least 40-45 days before harvesting of crop.

The peak values of IR/R and NDVI were affected by years, varieties and nitrogen as presented in Table 2. The IR/R value (8.2) was higher in 2005 than that of 2004 (7.81) which was also statistically significant. The IR/R was also affected by nitrogen level, averaged over years and varieties; IR/R of 9.14 was achieved when the plot was fertilized with 130 kg N ha^{-1}. The IR/R values of 6.88 and 8.13 were recorded with 50 kg and 100 kg N ha^{-1}, respectively which were statistically significant. Similar trend was also found in case of NDVI. The NDVI (0.70) was higher in 2005 than that of 2004 (0.74) which was also statistically significant. Averaged over years and varieties, NDVI of 0.82 was achieved when the plot was fertilized with 130 kg N ha^{-1}. The NDVI values of 0.66 and 0.74 were recorded with 50 kg and 100 kg N ha^{-1}, respectively which were statistically significant.

Development of model for predicting yield using biomass, IPAR, IR/R, NDVI

The multiple regression model was developed to predict yield with 4 predictors related to dry biomass of flowering stage, intercepted photosynthetically active radiation(IPAR) and reflectance based indices (IR/R, NDVI). The significance of each of the independent variables have been evaluated. Using SGSCATTER procedure of SAS, panel of scatter plot was generated to examine the relationship between seed yield and biomass at flowering stage, IPAR (%), IR/R, NDVI. All the four predictor's variables appeared to have positive relationship with yield. The P-value of the model for NDVI is less than 0.0001. Because this is smaller than any reasonable alpha level, null hypothesis is rejected and this predictor variable explains a significant amount of variability in the response variable (grain yield). The regression table indicates that adjusted R-square is 0.956 and therefore, the model is better fit than the mean model for predicting yield.

Looking at the parameter estimates, the estimated multiple regression equation is:

Yield (kg/ha^{-1}) = -4.869-0.0167(IR/R) + 3.7056(NDVI) + 0.00025(Biomassf)+0.0609(IPAR)

Adjusted R^2 = 0.956

The assumption of normality of linear regression was also verified by examining the histogram and normal quantile plot of the residuals (Fig. 5). The histogram of residuals is shown with a normal density curve and a kernel density curve is overlaid. The normal density, represented by the smooth line, is constructed assuming that the data is from a normal distribution; the kernel density, represented by the dotted line, makes minimal assumptions about functional form of the data and allows the data to determine the shape of the curve (Fig. 5). The histogram of residuals shows a fairly normal distribution of the residuals of independent variables.

The normal Quantile plot shows that the residuals closely follow the reference line (Fig. 5). The figures for Cook's D for seed yield, residual fit spread and Q-Q plot of residuals for seed yield are also presented in Fig.5 which shows that this multiple regression has good potential to estimate grain yield.

Validation of actual rice yield with MODIS-NDVI derived yield

To test the equation, yield = - 1.26 + 8.715 (NDVI) and to compare actual and satellite derived yield, MODIS-NDVI data with a 250 m resolution was used to estimate the rice yield from homogeneous rice area in Khurda, district, Odisha where medium duration variety "Lalat" was grown under farmers' management practices. Since the ground based observations revealed that peak NDVI was achieved during boot leaf stage, the NDVI of 15th October, 2006, coincided with boot leaf stage was used to get the peak NDVI. The derived linear regression relationship between yield and peak NDVI was applied to estimate yield based on MODIS satellite derived peak NDVI. Finally, the results were validated by comparing ground yieldwith the MODIS-NDVI derived grain yield and the percentage of errors were computed (Table 3). The results showed that the relative errors of the predicted yield using MODIS-NDVI were between 2.64% and 5.55%. A good predicted yield data of rice could be got about 40 days ahead of harvest time, i.e. at the booting-heading stage of the crop for forecasting rice yield.

CONCLUSION

Nitrogen significantly influenced the performance of crop growth parameters like biomass at different phenophases and affected IPAR, IR/R and NDVI significantly. Greater biomass could be attributed to significant increases in leaf expansion i.e. length and breadth and more growth due to high N levels. Among the dry biomass of early phenophases, biomass at flowering stage was found to be better correlated with grain yield with the R^2 value of 0.75. Hence, total biomass of the flowering stage may be used for yield prediction, atleast 30-35 days in advance before harvesting of the crop. The yield can also be predicted in terms of peak IPAR, IR/R and NDVI 40-45 days in advance. Multiple regression model was developed by interrelating grain yield with peak IPAR, IR/R, NDVI and biomass of flowering stage, among this, peak NDVI was found to be the most significant. The MODIS satellite based NDVI has potential to estimate grain yield with the error (%) of 2.64 to 5.55%.

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