

Generation of district level rice crop inventory, growth profile and yield estimation in Orissa using spot-vegetation data

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सार – उड़ीसा के धान की फसलों की किस्म तथा उनकी स्थितियों के मूल्यांकन का अध्ययन करने के लिए एन. डी. वी. आई. मिश्रित 10 दिवसीय स्पॉट वेजिटेशन आँकड़ों के विश्लेषण किए गए। वर्ष 1998 (एस 1) और वर्ष 2001 (एस 2) के मानसून (खरीफ) ऋतु में जो क्रमशः सूखा और सामान्य वर्ष था, जुलाई से दिसम्बर तक की अवधि के कुल 17 बिम्बावलियों के विश्लेषण किए गए। नियम आधारित एक श्रेणीबद्ध निर्णय द्वारा क्रमानुसार वनस्पति रहित भूमि, जंगल, परती और अन्य फसलों वाले क्षेत्रों का आंकड़ों को धान की फसल तालिका से हटा दिया गया। धान की एन. डी. वी. आई. स्थानिक प्रोफाइल्स द्वारा धान की किस्मों की ग्रीष्म और शीत ऋतु की धान की किस्म के रूप में पहचान की गई। दूर संवेदी के माध्यम से राज्य में मानसून ऋतु में धान की खेती का क्षेत्र वर्ष 1998 में 4.5 मिलीयन हेक्टेयर तथा वर्ष 2001 में 4.05 मिलीयन हेक्टेयर होने का पता लगाया गया जो आर्थिक सर्वेक्षण निदेशालय (डी. ई. एस.) द्वारा राज्य स्तर पर धान की खेती के आकलित क्षेत्र क्रमशः 4.26 एवं 4.22 मिलीयन हेक्टेयर, से 7 प्रतिशत कम है। इसके लिए नई प्रोफाइल फिट अर्थात् छः प्राचलों की संघोधित गौसियन पद्धति अपनाई गई। स्पेक्ट्रमी प्रोफाइल से पता चला कि निचली भूमि में वर्ष 2001–2002 में शीत ऋतु के धान की फसल (जून–जुलाई में लगाई गई) वर्ष 1998–1999 की तुलना में चरम वृद्धि प्रोफाइल में उच्च औसत का एन. डी. वी. आई. दर्शाता है। इस प्रकार वर्ष 2001–2002 में धान की फसल सामान्य देखी गई जबकि 1998–1999 का वर्ष सूखा प्रभावित रहा है। धान की फसल के जिलावार एन. डी. वी. आई. प्रोफाइल्स तैयार किए गए और चरम एन. डी. वी. आई. तथा चरम प्रोफाइल की तिथि जिला एवं कृषि जलवायवीय क्षेत्र स्तर पर धान की पैदावार के सहसंबंधित पाए गए। पैदावार मॉडल ग्रुप में स्पेक्ट्रमी प्रोफाइल प्राचलों में वर्षा आँकड़ों के उपयोग से जिलों अथवा क्षेत्रीय स्तर के पैदावार नियतांक के निर्धारण में सुधार हुआ है। इस अध्ययन से मानसून ऋतु के दौरान धान की फसल का मूल्यांकन करने के लिए 1 कि.मी. के क्षेत्र और 10 दिवसीय एन. डी. वी. आई. मिश्रित आँकड़ों की उपयोगिता का पता चला है।

ABSTRACT. Spot-vegetation 10 day NDVI composites over Orissa state were analysed to study rice crop inventory and condition assessment. A total of 17 images from July to December during the monsoon (kharif) season of 1998 (S1) and 2001 (S2) a drought and normal year, respectively were analysed. A hierarchical decision rule-based approach that successively eliminated data loss, non vegetated land, forest cover, fallow and other crops was adopted for rice inventory. NDVI temporal profiles of rice could distinguish autumn and winter rice. The total monsoon rice area identified by RS in the state was 4.5 M ha in 1998 and 4.05 M ha in 2001 and was within 7 percent of the state level rice estimate given by Directorate of Economic Survey (DES) *i.e.*, 4.26 and 4.22 M ha, respectively. A new profile fit *i.e.*, a six parameter modified Gaussian approach was adopted. The spectral profile indicated higher mean NDVI at peak growth profile of lowland winter rice (sown in June-July) in 2001-02 compared to 1998-1999. Thus, 2001-2002 rice was seen to be normal while in 1998-1999 a drought affected year. District-wise NDVI profiles of rice were generated and peak NDVI and date at peak profile were found to be correlated with rice yield at district and agro-climatic zone level. Use of rainfall with spectral profile parameters in yield model group of districts or zonal level improved coefficient of determination. This study demonstrates the utility of 1 km and 10 day NDVI composite data for rice crop assessment during monsoon season.

Key words – Spectral profile, Rice, Yield, Acreage, NDVI, Spot-vegetation, Crop assessment.

1. Introduction

Rice is the most extensively grown food grain crop in the kharif (monsoon) season in Indian sub-continent

(Bangladesh, India, Nepal and Pakistan), occupying nearly 50 million ha, of which 44.3 M ha in 2000-01 were planted in India (DES, 2002). The geographical area of Orissa state is 15.54 million hectare of which 41.6 percent

area is under cultivation. Rice is the dominant crop grown during kharif season. Irrigation facilities are available to 32 percent and 16 percent of the cultivated area during monsoon and winter seasons, respectively. The state comprise of 30 revenue districts and 314 development blocks. Average rainfall of the state is 1497 mm of which about 88 percent is received during monsoon (June to September) season. Prediction of crop production before harvest is a challenging task. Remote sensing (RS) technique with the capability of multi-temporal, multi-spectral and synoptic coverage have demonstrated a good potential in providing broad status of crop condition and production potential at regional level. Crop discrimination is the primary step needed for crop area estimation and subsequently used with Vegetation Indices (VI) for production forecasts. Much progress has been made through intensive studies on inventory and production forecasting for major crops, such as wheat, rice, maize, etc. (Tennakoon *et al.*, 1992; Fang *et al.*, 1998; Reynolds *et al.*, 2000). A review of Indian work on crop acreage estimation and production forecasting using optical RS data is done by Dadhwal *et al.* (2002) and Dadhwal *et al.* (2003), respectively. A number of approaches have been investigated for use of RS data for crop yield estimation/forecasting. They are namely: (a) Assessment of crop growing condition (rainfall, temperature or soil moisture or vegetation vigour), (b) Development of empirical-statistical relations between spectral response and crop yields, (c) Use of RS data in physical models or as input to crop simulation models. VI generally computed as linear combination of red and near-infrared bands, indicate crop vigour and inter-year comparison of VI thus indicates crop growth and likely yield. State level production forecasting for rice crop have been attempted using agro-meteorological parameters along with RS data based on water requirement of the crop (Patel *et al.* 2004). Gomarsca *et al.* (1991) conducted crop inventory using Landsat multi-spectral data and suggested requirement of multi-temporal data at least for three phenological stages. Dutta *et al.*, (2001) have demonstrated the separation of different crops grown with rice during rabi (post winter) season of 2000-2001 in Orissa state using multi-temporal WiFS data.

Due to high frequency of clouds in kharif season, data of high repetitive coverage but coarse spatial resolution such as NOAA-AVHRR (2-3 day), IRS-AWiFS (3-5 day) and spot-vegetation (daily) has been used. However, in coarse resolution data, most of the pixels are mixed pixels. Information from multi-date data has been used to compensate for coarse resolution. Use of multi-temporal data has been found to improve classification accuracy (Brisco *et al.* 1995, Brisco and Brown 1992). The multi-date database has special

significance for yield modeling through crop profile-based techniques. The parameters obtained from spectral profile of rice crop show high correlation with its yield. The spectral growth profile of the crop can establish the timeliness of its phenological transitions, which in turn manifests its yield attributes. This method has been exploited for comparing its relative yield deviations in a drought affected year with respect to a normal year.

Present study was conducted in Orissa state using multi-date IRS SPOT-VEGETATION data for assessment of monsoon rice crop classification and its relation to rice yield. Analysis was done for drought affected year in 1998 and bumper production year with good monsoon in 2001 with the use of 10 day vegetation composites. Extension of previous work in Orissa with NOAA-AVHRR was carried out, specifically to

- (i) Distinguish autumn and winter rice.
- (ii) Quantitatively model NDVI profile with modified Gaussian model.
- (iii) Develop agro-climatic zone wise yield model and
- (iv) Combining RS and weather for yield forecasting.

2. Materials and method

2.1. Study area

Orissa is situated in the sub-tropical belt in the eastern region of India between 17° 52' N and 22° 45' N Latitude and 81° 45' E and 87° 50' E Longitude. The State is grouped according to its physiography into four zones (Sahu, 1979) *i.e.*, Coastal Delta Zone (CDZ) comprising 11 districts, Central Tableland Zone (CTZ) comprising 9 districts, Northern Plateau Zone (NPZ) comprising 3 districts and Eastern Ghat Zone (EGZ) comprising 7 districts. Rice is the major crop of the state covering approximately 48 percent of the cropped area during kharif season. Other major cereal crops are ragi and maize, which account for 2.9 and 1.5 percent of the gross cropped area, respectively.

2.2. Data used

SPOT-VEGETATION 10 day composite NDVI data of Orissa state extracted from South East Asia data product generated from SPOT-4 satellite from June 1998 to December 1998 and June 2001 to December 2001 were used in this study. SPOT-VEGETATION data were NDVI composite product generated from near infrared band

(0.78-0.89 μm) and red band (0.61-0.68 μm) at resolution of 1 km. The NDVI data was scaled as (provided in the dataset):

$$\text{Scaled NDVI (VI}_s) = 250 * \text{NDVI} + 25$$

Henceforth the NDVI mentioned in this paper is referred to as scaled vegetation index (VI_s). The multi-date images were overlaid in LCC projection according to projection and co-ordinate system designed by Rajak *et al.* (2002) for RS data analysis over India.

2.3. Signature generation

Data coinciding with maximum vegetative growth stage of upland (September) and lowland rice (October) in the monsoon season was selected for identification of pure crop pixels. Training areas of 2×2 and 4×4 pixels were marked based on ground truth information and temporal curves drawn to characterize each crop.

2.4. Data analysis for crop discrimination

Crop discriminations was essentially based on the distinction between the multi-temporal VI_s profile of different land-cover features. The data was provided in geographic projection. In this approach, a multi category classification was obtained by connecting a set of suitable binary classifiers into decision tree (Fig. 1). The analysis procedure for multi-date classification is a binary form of decision tree (Lee and Richards, 1985). The classification was carried in two stages. In first stage, major land-cover classes like forest, water, sand, settlements, etc. were identified and mask of only agricultural pixels were created. In second step, segregation of rice pixels from other vegetation pixels were segregated based on their phenological differences manifested in the spectral profiles. The logic applied for segregating different land cover pixels among the data set was decided interactively. The flow diagram for segregating crop pixels is shown in Fig. 1. Similarly, other classes like settlement, sand, mangrove, upland rice, etc. were identified. The acreage of rice crops obtained by this method was compared with the acreage obtained from directorate of economics and statistics (DES) by conventional procedure.

Rice crop grown in monsoon season included autumn and winter rice. The profile based vegetation index (VI_s) was also calculated separately for autumn and winter rice. The monsoon rice yield was correlated with the area weighted VI_s of autumn and winter rice crop pixels. Analysis of DES acreage for autumn and winter rice showed that winter rice occupied majority of total monsoon rice grown in the state. The autumn to winter rice area ratio in 1998-1999 and 2001-2002 were 0.24 and

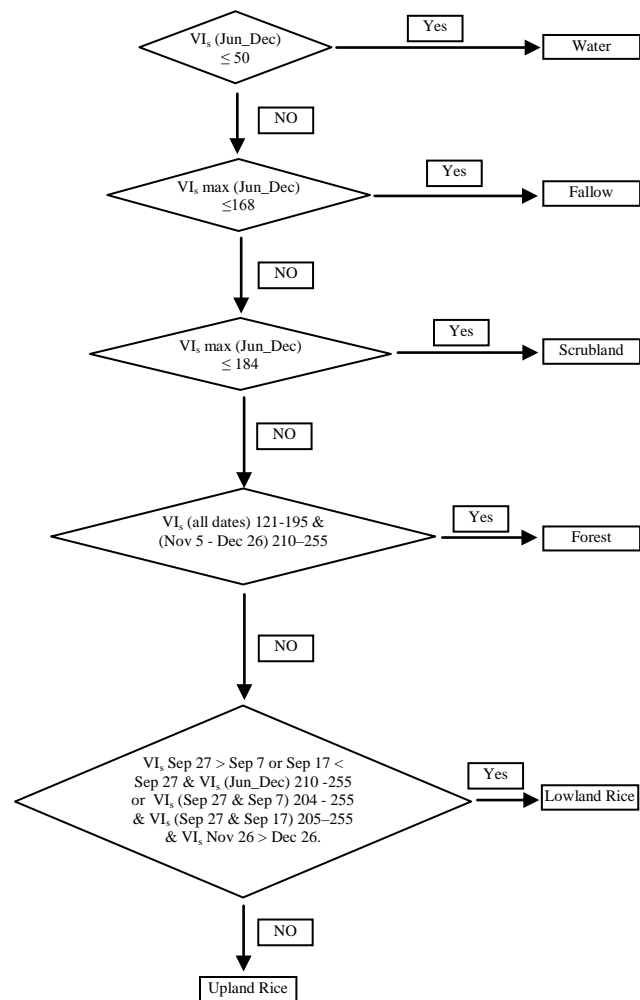


Fig. 1. Flow diagram of hierarchical decision tree based classification rule

0.25 respectively. Thus winter rice profile parameters were related to winter yield.

2.5. Description for generation of rice growth profile

Spot vegetation composite data of 17 dates at 10 day interval from July 19 to December 26 were used for two rice growing monsoon seasons *viz.*, 1998 and 2001. District boundary map of Orissa state was digitized and overlaid on the geo-referenced vegetation composite image. Even the 10 day composite image had many intermittent cloud pixels due to the persistent cloud cover during the season. To reduce the intermittent cloud pixels a median filter was applied across the temporal domain using a window size of 3×3 . This filter replaced the maximum NDVI value of a cloud free pixel in a

TABLE 1

Year	Comparison of rice acreage of Orissa state in M ha					
	RS estimate		DES estimate		Ratio of Area (RS/DES)	
	State	24 dist.	State	24 dist.	State	24 dist.*
1998	4.50	3.35	4.26	3.45	1.06	0.97
2001	4.05	3.28	4.22	3.50	0.95	0.93

*excluding six districts.

subsequent 3 date composite image. Further, to ensure pure rice pixels within a district, the vegetation data was filtered again to take 99 percent or 3σ of the data which removed the outlier pixels.

The VI_s of rice pixels (winter rice and autumn rice) for each district were used to generate a temporal growth profile. A six parameter modified Gaussian model was used to represent the temporal growth profile of rice in each of the 30 districts. The spectral profile represented the growth pattern of the crop from transplanting to maturity stage.

$$G = a_0 \exp\left(-\frac{z^2}{2}\right) + a_3 + a_4 * T + a_5 *(T)^2 \quad (1)$$

$$\text{Where, } Z = \frac{T - a_1}{a_2}$$

where, G is the average district VI_s of rice at time T and $a_0, a_1, a_2, a_3, a_4, a_5$ are the parameters of the growth profile. The profile reaches its peak at time T_p given by

$$T_p = \left[-a_4 - (a_0/a_2)Z \exp\left(\frac{z^2}{2}\right) / 2a_5 \right] \quad (2)$$

The peak VI_s value (G_m) in the profile is obtained by replacing T_p value for T in above equation of G (Eqn. 1).

$$G_m = a_0 \exp\left(-\frac{z^2}{2}\right) + a_3 + a_4 \left[-a_4 - (a_0/a_2)z \exp\left(\frac{z^2}{2}\right) / 2a_5 \right] + \left[(-a_4 - a_0/a_2)z \exp\left(\frac{z^2}{2}\right) / 2a_5 \right]^2 \quad (3)$$

2.6. Spectral-yield relationship

The peak VI_s (G_m) and date of peak spectral profile (T_p) from the spectral profile was correlated with district level winter rice yield.

TABLE 2

Zone	No. of district	Comparison of zonal level rice growth profile attributes					
		Peak NDVI (G_m)		Date of Peak NDVI (T_p)		Ratio (RS/DES)	
		1998	2001	1998	2001	1998	2001
CTZ	6	194.02	196.28	12 Oct	30 Sep	0.998	1.00
CDZ	11	202.30	211.04	9 Oct	1 Oct	0.97	0.91
NPZ	3	190.63	192.62	30 Sep	30 Sep	0.96	1.1
EGZ	4	207.04	210.84	4 Oct	24 Sep	0.94	0.61

3. Results and discussion

During the monsoon season in Orissa, rice is the dominant crop throughout the state. According the DES estimate in 1998 season, out of 30 districts in the state, rice area in 5 districts only occupied more than 50 percent of the district's geographic area. In 14 districts rice was found to occupy between 25 to 50 percent of geographic area, 8 districts occupied rice area between 11 to 25 percent and 3 districts showed rice area at or less than 10 percent of its geographic area. The rice pixels identified by the hierarchical procedure, due to coarse spatial resolution (1 km) include minor non-rice crops and some mixed pixels of rice – natural vegetation areas. Thus, SPOT-VEGETATION rice area is expected to have some deviation with respect to the field based estimates of DES. The mean ratio of the RS estimated area by the SPOT-VEGETATION data to DES was 0.85 for first category districts, but increased to 1.01, 1.10 in category 2nd and 3rd respectively, while in 4th category of districts the mean ratio obtained was 0.93. Similarly in 2001 monsoon season, rice area in only 2 districts occupied more than 50 percent of the district's geographic area, 17 districts were found to occupy between 25 to 50 percent, 8 districts rice occupied area between 11 to 25 percent and 3 districts showed rice area at or less than 10 percent of its geographic area. Their mean ratio of RS to DES estimate was 0.87, 0.93, 1.17 and 0.68 respectively. It showed that in less dominant areas the rice pixels were underestimated due to omission of more mixed pixels. The comparison of area estimation of Orissa state in both the years is given in Table 1. RS estimate of rice area in 1998 was higher compared to 2001. In 1998 the dry spell led to low VI of crop which mixed with that of other grasses leading to over estimation of rice crop.

The weighted average was taken of autumn and winter rice area as well as their peak VI_s as area weighted VI_s . This weighted peak VI_s of the autumn and winter rice pixels in a district was compared with that of their weighted mean yield obtained from DES. Six districts

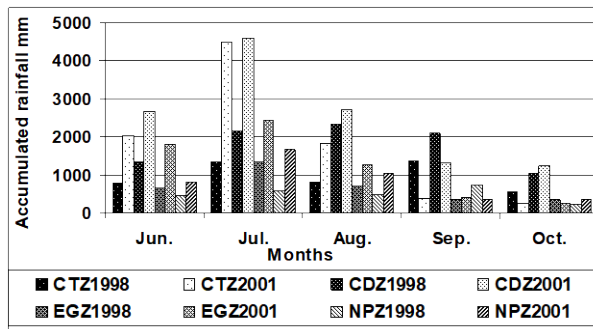


Fig. 2. Comparison of accumulated monthly rainfall for 1998 and 2001 at zonal level

Dhenkanal, Bolangir, Sambalpur, Koraput, Malkangiri and Nawarangpur having ratios of DES to RS area higher than 1.4 and lower than 0.4 were not included for developing yield relationship. As these districts are poor rice producing districts have scattered rice fields and low proportion of rice area, due to low spatial resolution of RS data these districts showed higher commission and omission error in classification. Hence, yield relationship has been developed for 24 out of 30 districts only. The estimated rice acreage of the 24 districts as well as of the state is shown in Table 1.

The variability in rice growth pattern was found to be similar within the zone but varied in inter-zonal growth profile attributes. The comparison of inter-zonal rice growth profile attributes is given in Table 2. The 1998-99 monsoon season was drought affected whereas 2001-02 received normal rainfall conducive for high crop yield. The contrasting years were studied to understand the effect of growing conditions on its spectral profiles. In Table 2 the mean value of VI_s of the peak of profile (G_m) showed increase in all the zones from 1998 to 2001. The mean values of VI_s were obtained by averaging the VI_s values of districts falling in one zone. For individual districts the difference of peak value (G_m) varied from 0 to 11 VI_s range.

The mean peak date of the profile (T_p) appeared earlier in 2001 by 10 days or more in almost all districts compared to 1998 for the zones CTZ, CDZ and EGZ. In individual districts the range of difference in attaining the peak growth occurred between 10 to 20 days between 1998 and 2001 except in NPZ. This could be attributed to late onset of monsoon in 1998 compared to 2001 except NPZ. The 1998 rainfall data (Fig. 2) also showed the same trend except in plateau region *i.e.*, NPZ. Fig. 2 shows the accumulated monthly rainfall data in the rice growing monsoon season of the state. The volume of rainfall increased from first fortnight of July in both the years. Therefore, the spectral profiles of this zone shows almost similar date of peak growth (T_p) (Table 2).

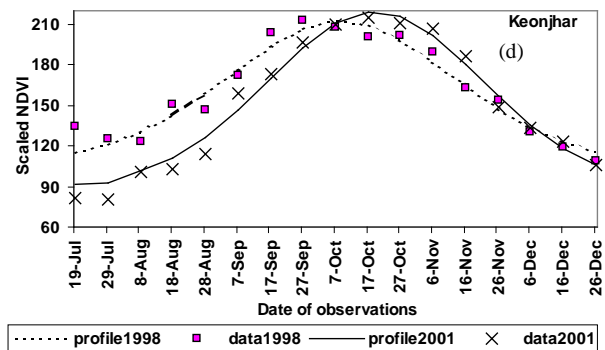
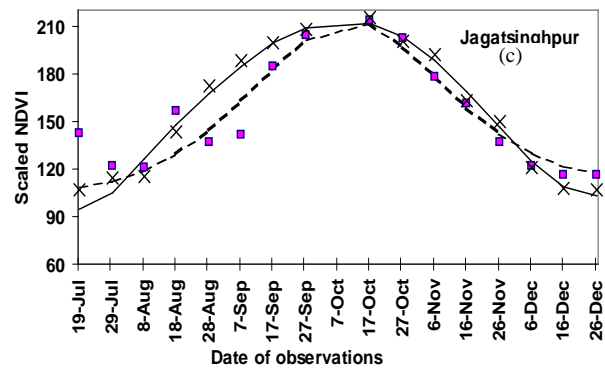
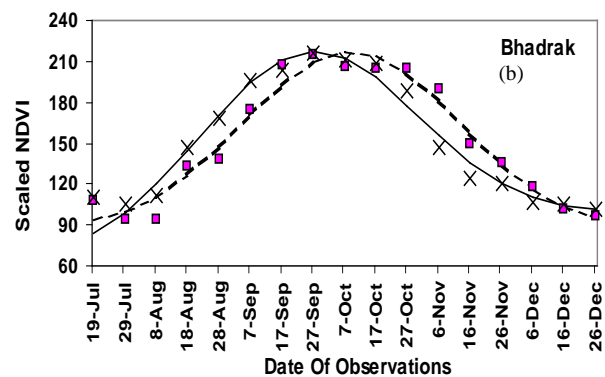
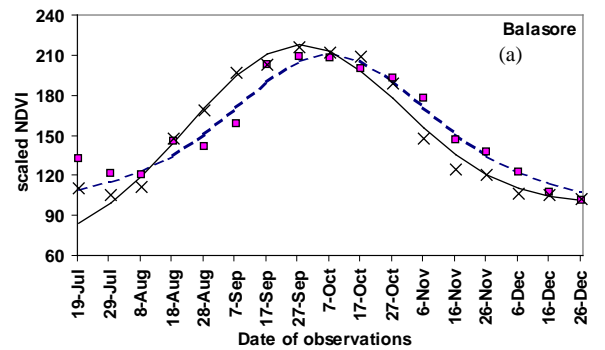


Fig. 3(a-d). Mean scaled NDVI and profile fit using modified Gaussian distribution model for rice pixels of 1998 and 2001 season

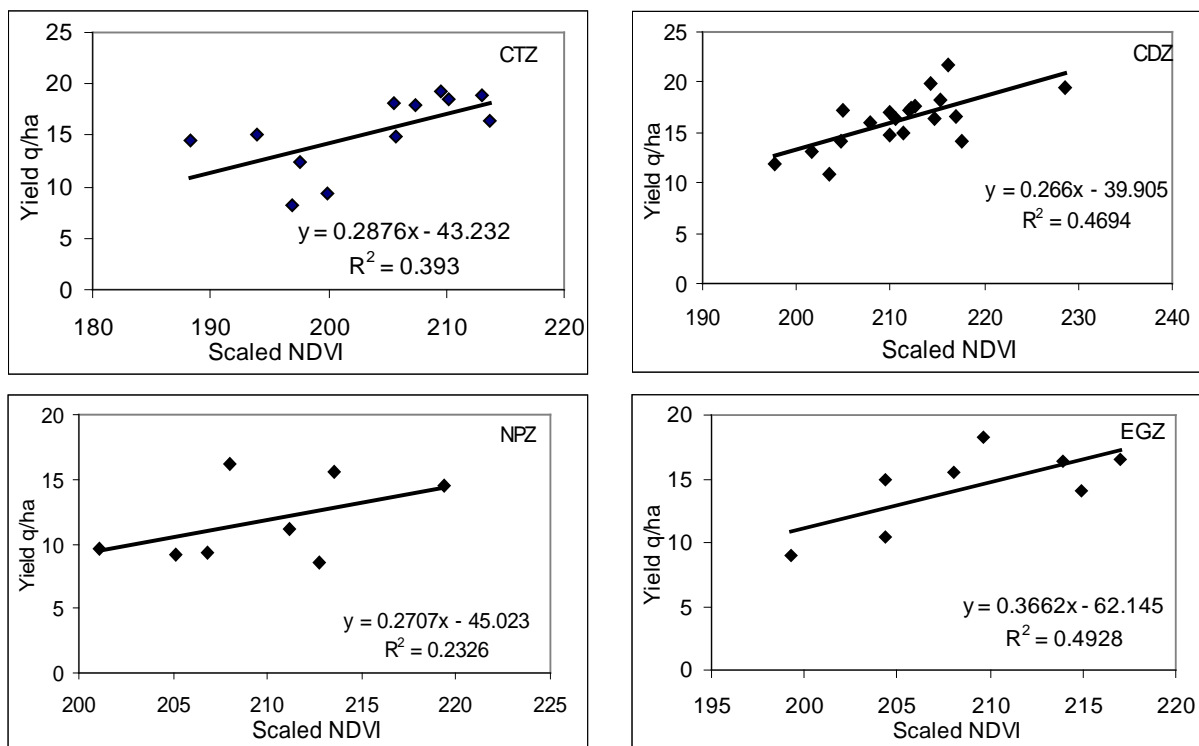


Fig. 4. Spectral relationship with rice yield for the zones of CTZ, CDZ, NPZ and EGZ

The spectral profiles of all rice pixels in some of the typical rice growing districts are shown in Figs. 3(a-d). In Figs. 3(a&b) the spectral profiles of mainly coastal districts (CDZ zone) are shown with a perfect gaussian fit. Whereas in Figs. 3(c&d) spectral profiles of hilly districts are shown where rice fields are sparse, scattered and small in dimension. In these areas, the rice profile has a mixture of other vegetation while being dominated by rice. The district wise peak weighted VI_s of 1998-99 and 2001-2002 were compared to find its correlation with their kharif (Autumn + winter) yield in quintals/hectare (q/ha). Remote sensing based spectral yield relation was developed for these zones as shown in Fig. 4. The analysis of districts at zonal level explained upto 50 percent of their variability with their peak weighted VI_s values (Table 3) as shown in Fig. 4. The difference in yield between two years showed good correlation with the difference in attaining peak spectral profile (T_p) as shown in Table 4. The shift in the rice profile in 1998 and 2001 manifest the onset of drought condition and poor yield in 1998 and good production in 2001 [Figs. 5(a&b) and Table 4].

3.1. Modelling with date of peak spectral growth (T_p)

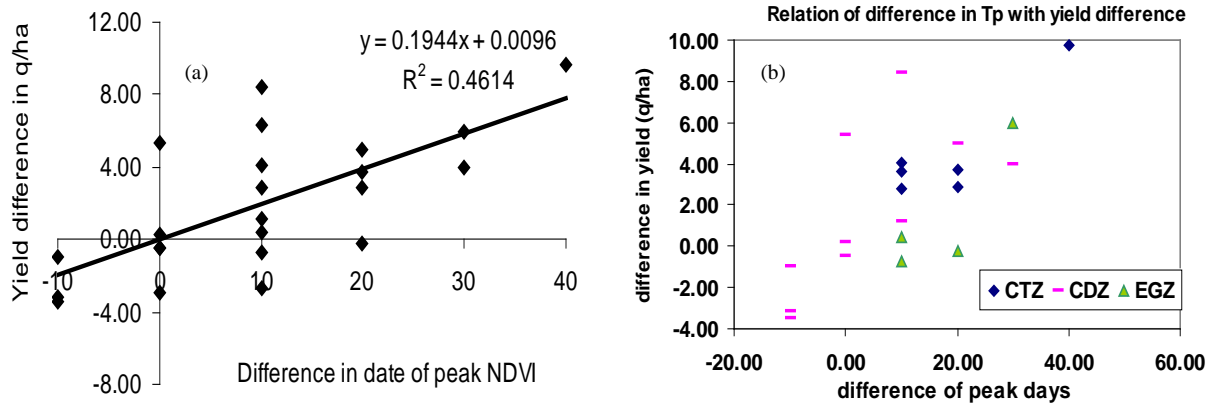
The analysis of two contrasting years' data showed that rice matured early in 2001 compared to 1998 in

TABLE 3

Relationship of district-level rice yield with peak NDVI values for four zones in Orissa

Zone	No. of obs.(N)	Yield equation	R^2	RMSE
CTZ	12	$Y = 0.2713 * VI_s - 39.193$	0.39	3.02
CDZ	22	$Y = 0.266 * VI_s - 39.905$	0.47	1.97
NPZ	6	$Y = 0.2707 * VI_s - 45.023$	0.23	3.02
EGZ	8	$Y = 0.3662 * VI_s - 62.145$	0.49	2.45

districts falling in zones CTZ, CDZ and EGZ (Table 2). This could be related to early onset of monsoon in 2001 whereas in 1998 the onset was delayed (Fig. 2). In districts of zone NPZ rice matured at the same time in both the years but their peak values (G_m) decreased in drought years (Table 2). The date of peak spectral profile (T_p) was also correlated with yield. In poor yield zones like NPZ and EGZ, the T_p occurred earlier than in good yield condition in this two year comparison. The analysis of district wise difference in date of attaining peak spectral growth (T_p) between 1998 and 2001 showed good correlation with their respective yield difference of rice as shown in scatter plot Figs. 5(a&b) and Table 4.



Figs. 5(a&b). Relation of district wise difference in date of peak VIs between 1998 and 2001 with their respective rice yield difference (a) for 24 districts in the state and (b) for respective zones CTZ, CDZ, EGZ

TABLE 4

Zonal level relationship of difference in peak spectral profile (T_p) in days with the yield difference in q/ha

Zones	N	Relation with peak (T_p) difference	R^2	RMSE	F value	F signific.
CTZ	6	$Y = 0.1599 * X + 0.8924$	0.77	1.40	13.26	0.022
CDZ	11	$Y = 0.1987 * X + 0.8038$	0.46	1.47	6.94	0.029
EGZ	4	$Y = 2.768 * X + 3.4818$	0.73	6.08	5.43	0.145
NPZ	3	$Y = 1.712 * X - 3.807$	0.97	2.63	29.30	0.116
All zones	24	$Y = 0.1944 * X + 0.0096$	0.47	2.72	16.096	0.0008

Where Y = difference in rice yield (q/ha) between 1998 and 2001,
 X = difference in date of attaining peak (T_p) spectral profile.

TABLE 5

Zonal level rice yield model developed with peak VI_s and monthly rainfall

Zones	N	Relation with rice yield	R^2 (Adj. R^2)	SEOE
CTZ	12	$-33.188 + 0.017 * RF_{aug} - 0.018 * RF_{oct} + 0.222 * VI_s$	0.71 (0.60)	2.21
CDZ	22	$-4.289 + 0.009 * RF_{aug} - 0.008 * RF_{sep} + 0.005 * RF_{oct} + 0.087 * VI_s$	0.52 (0.40)	2.04
NPZ	6	$-80.53 + 0.022 * RF_{aug} + 0.44 * VI_s$	0.88 (0.81)	1.45
EGZ	8	$-89.7 - 0.019 * RF_{sep} + 0.499 * VI_s$	0.70 (0.58)	2.21

RF_{aug} = rainfall of August month, RF_{sep} = rainfall of September month, RF_{oct} = Rainfall of October month.
 VI_s = scaled NDVI

3.2. Modelling of spectral parameters with rainfall data

Analysis of district level spectral parameters (G_m and T_p) and district level monthly rainfall pattern showed good correlation with their yield. Within each zone the peak scaled NDVI (G_m) was correlated with

monthly rainfall. The low yield of crop correspond to lower values of G_m and *vice versa* in both the years' spectral data Table 2). The combined model showed improved correlation with yield compared to single parameter G_m shown earlier above. Table 5 shows the model developed including the effect of rainfall and spectral parameter. Since the model included two

contrasting years *i.e.*, deficit rainfall in 1998 and good rainfall in 2001, this model should perform equally good if not better in normal years of monsoon.

4. Conclusion

(i) District-wise vegetation profile of rice were developed for two contrasting seasons in Orissa state. The derived profile parameters were found to be well correlated with district wise rice yield.

(ii) Rice yield models were developed based on profile derived parameters T_p , G_m and rainfall. The low crop yield corresponds to lower values of G_m and *vice versa* in both the years' spectral data. Similarly, in poor yield zones, the T_p occurred earlier than in higher yield zones.

(iii) A combined yield model was developed by including rainfall and spectral profile derived parameters at zonal level. Since the model included two contrasting years, a drought affected year with low reported yield by DES and a good monsoon year with high reported yield, this would increase the robustness of the yield model developed.

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