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District-Level Rice-Yield Estimation for Orissa Using Satellite Data

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ABSTRACT

Remotely-sensed data transformed into a vegetation index (radiance ratio of near infrared to red) has been related to district rice yields for Orissa using IRS-1A LISS-I data of kharif seasons 1988-89 and 1989-90. Using the empirical relation of the first year, estimation of rice yield has been done for the 1989-90 kharif season. Deviations in the districts of coastal tract and central tableland ranged from 1.9 to 11.1 percent whereas deviations were larger in Eastern Ghat and Northern plateau of Orissa.

Introduction

Yield forecasting of a crop is based on the proposition that crop yield is determined by the degree of vegetative development and this can be estimated using remotely sensed (RS) data. Procedures for yield estimation based on RS data have certain advantages over those based solely on biometric or meteorological parameters in that RS-based approach considers the integrated effects of biometric, meteorological and soil factors and is applicable for large areas. Spectral indices that are derived from multispectral data provide useful information about the crop. It has been clearly observed that spectral indices developed from RS data in red and near infrared (NIR) wavelength regions have a strong correlation with the crop-growth parameters like leaf area index, biomass and grain yield (Patel *et al.*, 1986; Dubey *et al.*, 1990; Sharma *et al.*, 1992).

In an earlier study (Patel *et al.*, 1991) a yield-spectral index relationship was derived for rice in the Cuttack and Puri districts of Orissa by using three years' (1984-86) LANDSAT MSS data and block-level rice-yield data. This relation was used to estimated rice yields in the coastal tract, an agroclimatic zone comprising Cuttack, Puri, Baleshwar and Ganjam districts with IRS-1A LISS-I data for kharif 1988. The objective of the present study was to develop yield-spectral relation at district-level and test its applicability to predict district-wise rice yield in Orissa.

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Methodology

The study was carried out in Orissa where rice is the major crop in the kharif season. The thirteen districts of the state with a total geographical area of 1,55,400 km² have been categorised into four agro-climatic zones (Sahu, 1979) namely (i) Coastal tract comprising Baleshwar, Cuttack, Ganjam and Puri, (ii) Central tableland comprising Bolangir, Dhenkanal and Sambalpur, (iii) Eastern Ghat with Kalahandi, Koraput and Phulbani, and (iv) Northern plateau covering Keonjhar, Mayurbhanj and Sundargarh districts.

Satellite data of two kharif seasons (Table 1) were used to arrive at yield-radiance ratio relationship averaged at district-level. Digital analysis of spaceborne data was done using Microvax computer with DIPIX image processor at Space Applications Centre, Ahmedabad. Randomly selected sample segments within each district were used to compute Area-Weighted Average Radiance Ratio (AWAR). Details of the steps involved are briefly stated below.

Selection of Sample Segments

The sampling approach successfully

Table 1. Satellite Data Used in Digital Analysis

Sensor	Path	Row	Date of acquisition	
			1988-89	1989-90
	19	53	12-10-88	
	19	54	12-10-88	
	20	52	13-10-88	
	20	53	13-10-88	(1) 30-09-89
				(2) 22-10-89
	20	54	13-10-88	30-09-89
	21	52	14-10-88	
IRS-1A	21	53	14-10-88	23-10-89
LISS-I	21	54	14-10-88	(1) 01-10-89
				(2) 23-10-89
	22	53	15-10-88	
	22	54	15-10-88	02-10-89
	22	55	15-10-88	24-10-89
	23	54	16-10-88	
	139	45		01-10-89
LANDSAT MSS	139	46		01-10-89
	141	45		15-10-89

demonstrated by Parihar *et al.* (1990) for rice-yield estimation has been adopted to select sample segments in the present study. A grid of 7.5 x 7.5 km was prepared at the scale of 1:250,000 for each district. This was superimposed on the false colour composite (FCC) prints of the same scale and each grid cell was visually interpreted so as to substratify the segments under each agro-physical stratum. Segments having an agriculture area of approximately more than 50 percent, between 25-50 percent and less than 25 percent were defined as A, B and C type of segments, respectively. Ten percent segments of each type in a district were selected using random number table and location of selected segments were marked on the maps. After displaying the image, the location of the upper left hand corner of the selected segments in terms of scanlines and pixels were noted by comparing with permanent identifiable features on the map. These starting co-ordinates were used in further analysis of sample segments.

Signature of Rice Crop

FCC image was generated using green, red and near-infrared bands data and displayed on the monitor. Rice-crop sites were identified on the image with the help of a topographical map and ground information. Spectral values of near-infrared and red bands were obtained for all the sites of rice crop within a scene. Based on the upper and lower limits of the NIR/red ratio, rice-crop pixels were identified. It may be noted that the upper and lower limits of radiance ratio used varied from scene to scene, the lowest and the highest limits being 1.4 and 2.8, respectively.

Average Radiance Ratio

Digital counts were converted into radiance using constants provided for IRS-1A LISS-I sensor (Anon., 1988). Average radiance ratio of band 4 (NIR) and band 3 (red) was calculated for rice pixels in every segment. A few segments were selected from LANDSAT MSS data for want of cloud-free conditions in IRS-1A data during 1989-90 crop season. Radiance values of such segments in MSS data were converted in terms of radiance values of LISS-I using the procedure described earlier (Patel *et al.*, 1991).

Normalisation of Data of Different Acquisition Dates

Experiments conducted on rice crop have conclusively shown that radiance ratio of NIR to red at maximum canopy cover stage is a good indicator of final yield (Patel *et al.*, 1985; Ravi *et al.*, 1988) and the difference in vegetation index from flowering to grainfilling stage to be good indicators of grain yield (Nageswara Rao *et al.*, 1985). Since all acquisition dates of satellite data do not correspond to peak growth period of rice crop, date normalisation was done using a growth profile obtained by quadratic fitting of the field spectral data for rice in Cuttack (Patel *et al.*, 1991). The peak value of ratio for rice was observed around October 20. The equation used for the profile generation is:

$$Y = -2.34 + 0.19X - 0.0012X^2$$

where Y is the radiance ratio (NIR/red) and X is the number of days after transplantation of crop.

Normalisation factor is calculated as the ratio of Y_p/Y_o where Y_p is the ratio at peak growth stage of the crop while Y_o is the ratio on the day of observation by the satellite.

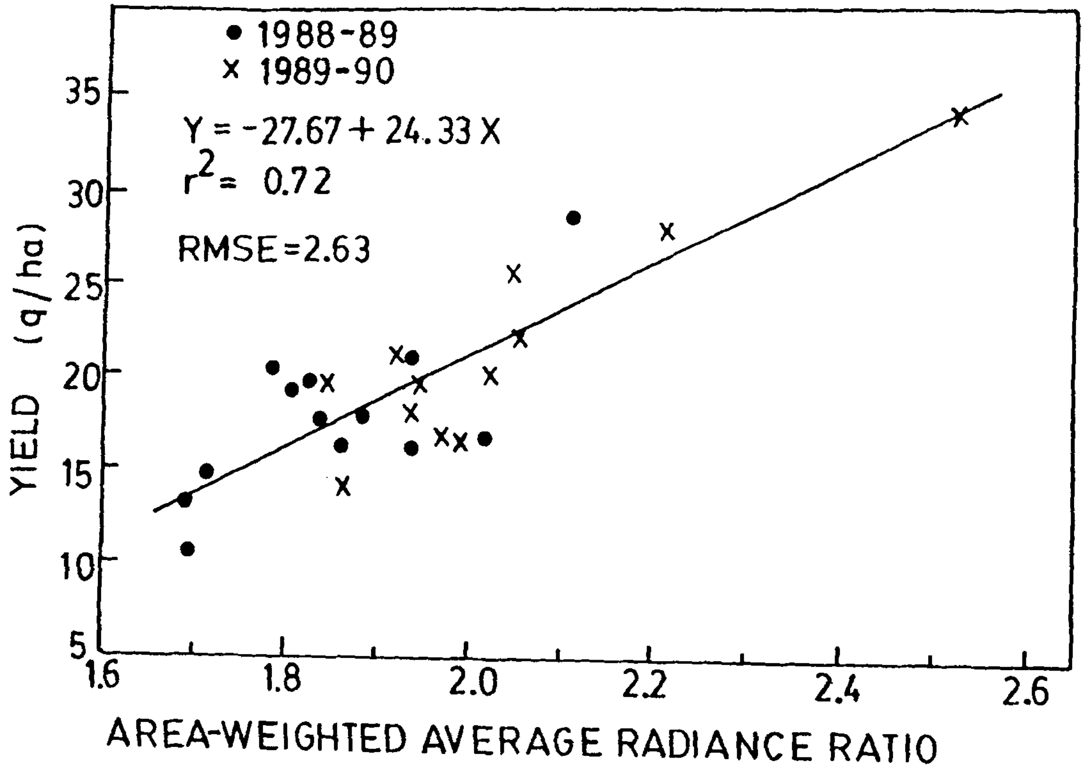

Fig. 1. Relationship between district-level rice yield and radiance ratio for pooled data of 1988-89 and 1989-90 for Orissa

Regression Analysis

Regression analysis was done between AWAR and mean district yield. AWAR for a district was computed from radiance ratio and number of rice pixels in each of the segments falling within a district. As both autumn (early) and winter (late) rice is grown with varying proportions in different districts, area-weighted average of autumn and winter rice yields was used. Linear regression analysis was done for 13 districts during 1988-89 and for 12 districts during 1989-90, both for individual years as well as for pooled data.

Results and Discussion

Regression analysis between AWAR measured around the peak growth and district rice yield for two years' combined data (Fig. 1) showed a high correlation (r^2 = 0.72). Thus, AWAR, a key spectral index was found to account for 72 percent variability in the rice yield. Coefficients of individual year regression analysis as well as for pooled data of 1988-89 and 1989-90 (Table 2) indicate that the slopes are not very much different for the two years. A standard test to check the equality of regression equations (Rao, 1973) was performed. Coefficients of regression equations for two individual years were not significantly different thereby justifying the pooled-data analysis. Coefficient of determination (r^2) is higher for the year 1989-90, accounting for 81 percent variability in yield compared to 52 percent for 1988-89 data.

Using the empirical relationship derived for 1988-89 data, yield estimation for 1989-90 kharif season was carried out in 12 districts of Orissa. A comparison of estimated yields by remotely sensed (RS) data and Bureau of Economics and Statistics (BES) (Table 3) reveals that RS estimates are comparable to BES in nine districts wherein the relative yield difference go upto 11 percent. The deviation is more in Kalahandi district of Eastern Ghat (25.6%), and in Keonjhar (23%) and Mayurbhanj (28%) of Northern plateau. This may be attributed to uneven terrain, diversified environmental conditions such as differences in the onset of monsoon and rainfall distribution.

In the present study, yield-spectral relationship derived taking rice yield and radiance ratio averaged at district-level for the coastal tract. A higher correlation (r^2 = 0.91) was observed (Fig. 2) having the following relationship:

$$Y = -18.30 + 20.87X \quad ...(1)$$

where Y is yield (q/ha) and X is Area-weighted average radiance ratio. This is an improvement over an earlier study (Patel *et al.*, 1991) wherein yield-spectral relation was derived using block-level data as given below:

$$Y = -21.01 + 22.32X \; (r^2 = 0.52) \quad ...(2)$$

It can be seen that coefficients of equation (1) are not significantly different from equation (2) indicating the stability of the empirical relationship for the coastal

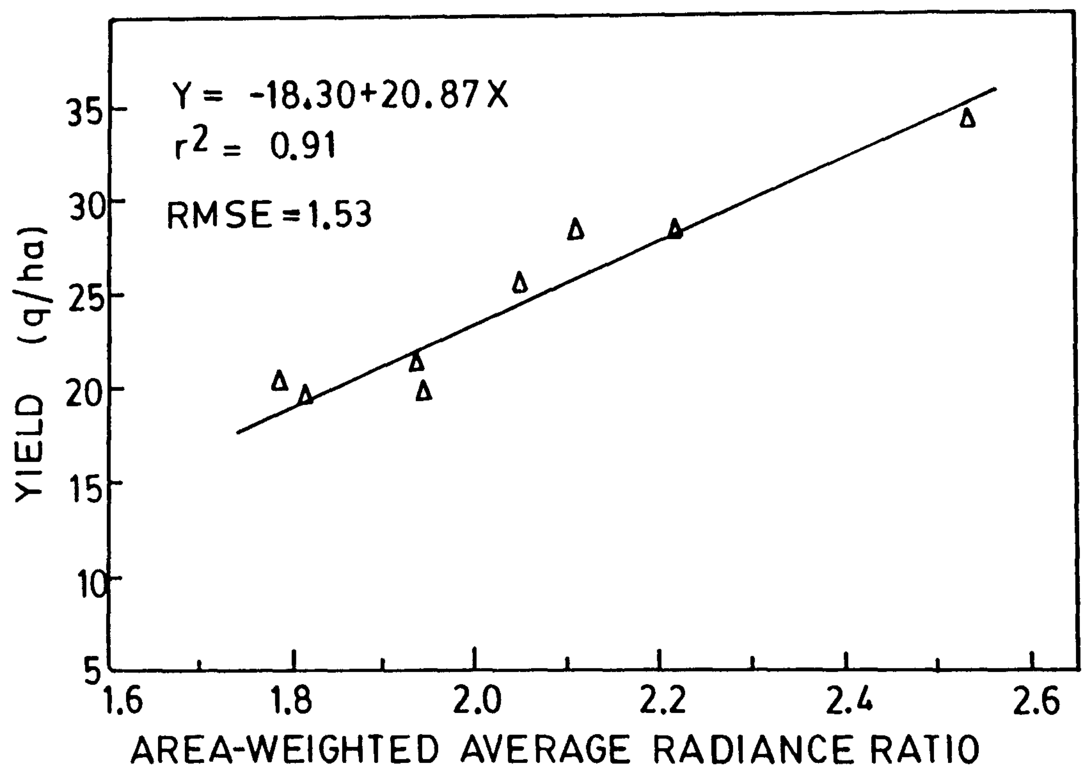

Fig. 2. Relationship between district-level rice yield and radiance ratio for pooled data of 1988-89 and 1989-90 for the four coastal districts of Orissa

Table 2. Coefficients obtained by regressing AWAR with grain yield for combined as well as individual data of kharif 1988 and 1989.

Season	Slope (B_o)	Intercept (B_1)	r^2
Pooled	-27.67	24.33	0.72
1988-89	-27.41	24.39	0.52
1989-90	-32.45	26.49	0.81

Table 3. Comparison of RS and BES rice yield estimates (with husk) for kharif 1989-90

Agroclimatic zone	District	Estimated yield (q/ha)		Relative difference	
		RS	BES	q/ha	%
Coastal tract	Baleshwar	20.01	19.45	0.56	2.8
	Cuttack	22.55	25.38	2.83	-11.1
	Ganjam	34.35	33.80	0.55	1.6
	Puri	26.60	28.28	-1.68	-3.5
Central tableland	Bolangir	22.53	22.10	0.43	1.9
	Dhenkanal	21.94	20.09	1.85	9.2
	Sambalpur	17.45	19.48	-2.03	-10.4
Eastern ghat	Kalahandi	17.99	14.32	3.67	25.6
	Koraput	19.82	18.15	1.67	9.8
	Phulbani	19.53	20.95	-1.42	-6.8
Northern Plateau	Keonjhar	20.55	16.72	3.52	22.9
	Mayurbhanj	20.92	16.33	4.59	28.1

tract agroclimatic zone over the period. The linear relationship between rice yield and radiance ratio at the peak growth stage suggests the feasibility of preharvest crop yield prediction. It was seen that agroclimatic zone-wise relationship improved the results. Hence, it is worth trying to derive yield-spectral relations based on agroclimatic stratification with a larger database over years and validate such relations, if possible, with the inclusion of meteorological parameters.

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