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Rice yield estimation using spectral and meteorological parameters

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ABSTRACT

With an aim to develop yield models in terms of spectral and meteorological parameters for rice crop, field experiments were conducted in the wet seasons of 1984 and 1985 at the Main Rice Research Station, Nawagam, Gujarat. Fertiliser, varietal and dates of planting treatments were included so as to induce variability in yield and to arrive at a model that can be used to predict yield under a wide range of growing conditions. Spectral data like radiance values in different wavelength bands namely, visible and near infrared (NIR) and biometric data like leaf area index, wet biomass and dry biomass were collected at weekly intervals over these plots. Regression analysis was done to study the relations existing between spectral and biometric parameters. A linear relation between leaf area index and NIR/red radiance ratio was observed. Linear relations were also found to exist between spectral parameters measured and grain yield. A linear regression relationship incorporating the radiance ratio and a multilinear regression relationship incorporating integrated radiance ratio and accumulated temperature degree days were tried to estimate yield. The relationships developed for 1984 were tested for the year 1985. The relationship incorporating both the spectral and meteorological variables fared better.

Any crop production forecasting system has two vital components, namely crop acreage and yield. Crop acreage estimation using remotely sensed data has been well demonstrated in the country and elsewhere (MacDonald and Hall 1980, Dadhwal and Parihar 1985, Kalubarme and Mahey 1987). However, use of remotely sensed data for yield prediction, in advance of harvest has been rather limited. Field experiments conducted on rice so far have shown that the ratio of radiance of the crop in the near infrared (NIR) to that in the red region is a good indicator of vegetative growth and final yield (Tucker 1979, Singh *et al.* 1983, Hatfield *et al.* 1985, Patel *et al.* 1985a, 1985b, Sharma *et al.* 1985). It has also been shown that leaf area index can be estimated using spectral data (Kanemasu 1974, Wiegand *et al.* 1979, Richardson *et al.* 1982). However, spectral data alone cannot account for all the variability in yield. Effect of weather at critical growth stages may not result in changes in spectral data of the crop but may influence the final yield. Hence, a hybrid approach for the development of yield models in terms of spectral and meteorological data is necessary. In order to build up a database for this, field experiments on rice undergoing various treatments such as different levels of nitrogen application and different dates of planting were conducted during the wet seasons of 1984 and 1985. Temporal variation of radiance ratio and leaf area index was also studied. Attempts made to derive yield relationships based on the analysis of two years data are presented in this paper.

MATERIALS AND METHODS

Grain yield of a crop is determined by many factors like soil type, variety used, cultural practices adopted, and meteorological variables. These variables were introduced in the field experiment by imposing different treatments like dates of planting, levels of fertiliser and varieties. The experiments were conducted at the Main Rice Research Station of Gujarat Agricultural University, Nawagam, about 32 km away from Ahmedabad. The research station is situated at 22°48'N and 72°35'E and at an altitude of 32.4 m above mean sea level. The annual average rainfall for ten years (1975-1984) is 987.9 mm. The soil type is sandy loam. The total annual rainfall fort he year 1984 was 789.8 mm while it was only 484.6 mm for 1985.

Nitrogen was applied at 0, 50, 100, 150 and 200 kg N per hectare. The experiment was laid out in randomised complete block design (RCBD) with three replications. The plot size was 4.95 × 4.4 m. Two seedlings per hill were transplanted on 27th August 1985 with a spacing of 20 × 15 cm. A dwarf, medium duration and non-shattering variety (CR 138-928) was used. Nitrogen was applied in four splits, at the time of puddling (basal dose), tillering, panicle initiation and at boot-leaf stage. Observations were made at regular intervals throughout the crop growth period.

Generally, planting is done during the first fortnight of July in Nawagam and surrounding areas. The date-of-planting treatments were imposed in such a way that it includes early (Jun 15 and Jul 1), normal (Jul 17 and Aug 1) as well as late (Aug 16 and Sep 1) plantings. The experiment was laid out in simple RCBD with six dates of planting and two varieties. GR 11, a dwarf medium duration variety and P 203, a tall maturing variety were used. However, for data analysis only GR 11 was considered as the other variety was susceptible to lodging and was severely damaged by blast.

Meteorological variables such as total rainfall, maximum and minimum temperature, relative humidity and sunshine hours were obtained for the crop season from the meteorological observatory located at the Main Rice Research Station, Nawagam. The rainfall received during the year 1985 (484.6 mm) was erratic and below normal as compared to the year 1984 (789.8 mm).

Biometric observations included leaf area index (LAI), total wet biomass (TWB), total dry biomass (TDB) and crop phenological stages. They were recorded at regular intervals during crop growth period by sampling five hills per plot at a time. The plants were kept in polyethylene bags immediately after harvest to maintain the turgidity of leaves. Fresh weight of the entire biomass obtained from the sample plants was recorded before taking the measurement of leaf area. Leaf area was determined with a leaf area meter, Li Cor, model LI-3000.

Radiometric observations viz., radiance and irradiance measurements were made prior to biometric observations. These measurements were always recorded between 10.00 hours to 11.30 hours using an indigenously developed seven-band ground truth radiometer. The seven bands comprise of four in visible region of electromagnetic spectrum namely B_1 (445-515 nm), B_2 (495-565 nm), B_3 (570-650 nm), B_4 (625-695 nm), and three in near infrared region (NIR), namely B_5 (692-758 nm), B_6 (805-885 nm) and B_7 (1004-1076 nm). Prior to radiometric observations on the crop, irradiance values in each of the seven bands were recorded using a barium sulphate coated white reflectance panel. Three measurements of radiance in each plot were made by holding the radiometer vertically above the crop canopy at a height of 1-1.5 m. The average of these readings was used for further analysis.

Upon maturity, the crop was harvested plot-wise, sun-dried and threshed using a paddle thresher. The weight of the grain was recorded and converted into yield per hectare.

In spectral data analysis, band 6 was used as NIR band and band 3 as red band. Using the radiance values obtained in the near infrared (NIR) and red bands, simple radiance ratio of NIR/red as well as normalised difference (NIR-red/NIR+red) were calculated. Linear regression analysis was done to derive relationships between final yield and radiance ratio measured at different growth stages. Integration of radiance ratio over certain growth stages was done and related to the final yield. The impact of weather variables in conjunction with spectral parameters on yield was arrived at by a multilinear regression relationship.

RESULTS AND DISCUSSION

Fertiliser experiment

It can be seen from Figure 1 (top left) that radiance ratio (NIR/red) for plots of different fertiliser treatments increased with the development of crop, reached a peak when the canopy cover was maximum (boot leaf to flowering stage) and thereafter decreased. The plot with less nitrogenous fertiliser showed lower radiance ratio while it was maximum for the highest level. With the increased supply of nitrogen, the crop developed green, healthy leaves. This was the reason for increased LAI with higher levels of fertiliser application (Fig. 1, top right).

Since, the spectral response of crop observed from space is dominated by leaves, there have been several studies relating leaf area index to spectral reflectance measurements from field, aircraft as well as satellite altitudes. Investigation on several crops, for instance, corn (Walburg *et al.* 1982), rice (Singh *et al.* 1983, Patel *et al.* 1985a, 1985b) and wheat (Pollock and Kanemasu 1979) have revealed the usefulness of spectral indices in the estimation of LAI, a key parameter for studying biomass and productivity.

The spectral and growth characteristics recorded at several critical stages of rice crop were subjected to linear regression analysis The results showing the relationship of radiance ratio with LAI and biomass is presented in Table 1. It was found that LAI, wet biomass and dry biomass were well correlated with radiance ratio at booting stage (45-49 days after transplanting). Leaf area index usually increases during the growth and development of a stand, until most plants reach reproductive stage (boot leaf to flowering stage). Kanemasu (1974) reported that the ratio of reflectance at 540 and 660 nm closely followed crop growth and development. Wiegand *et al.* (1974) concluded that the ratio of a visible band to a near-infrared band is a good indicator of vegetative cover and density. In the two years of experimentation, 1984 was a normal year while 1985 was a drought year. As a result, the values of linear relationships obtained at various growth stages for different biometric parameters differed in the combined analysis carried out for two-year data. However, the trend remained the same. It was observed that radiance ratio was well correlated with LAI at booting stage ($r^2=0.87$). Fairly good relation was found to exist at flowering stage for 1984 data though it was relatively poor for pooled data of two years because of the drought conditions in the second year (1985). Relationship between LAI and radiance ratio for pooled data at flowering is shown in Figure 1 (bottom left). Good correlation was found to exist between radiance ratio and total wet biomass at booting stage. Better correlation ($r^2=0.89$) was also found between radiance ratio and dry biomass during this stage (Table 1).

Spectral data vis-a-vis yield

Correlation coefficient was high at flowering stage for both the spectral indices. The results of similar analysis for two-year data are given in Table 2. Here also, the yield was well related to radiance ratio at the booting

Table 1. *Correlation coefficient, slope and intercept values of the linear regression analysis between radiance ratio and crop growth variables for pooled data of 1984 and 1985*

Growth stage	Days after transplantation	LAI			TWB			TDB		
		B_0	B_1	r	B_0	B_1	r	B_0	B_1	r
Tillering (TL)	32	1·67	0·62	0·63	1·46	2·19	0·71	1·47	10·24	0·69
Booting (BT)	45–49	0·95	1.45	0·93	0·73	2·92	0·82	0·87	12·47	0·95
Flowering (FL)	59-62	1·93	1·01	0·78	2·48	0·95	0·62	3·09	4·41	0·57
Soft dough (SD)	78-84	2·49	0·50	0·82	1·86	0·67	0·89	1·93	1·92	0·85
Hard dough (HD)	90-95	1·99	0·40	0·62	1·67	0·32	0·62	1·63	0·81	0·58
TL + BT	—	1·31	1·05	0·78	1·56	1·69	0·67	1·22	5·46	0·85
BT + FL	—	1·35	1·16	0·78	2·07	1·16	0·61	2·13	6·88	0·65
FL + SD	—	2·35	0·79	0·83	2·49	0·67	0·53	3·75	0·11	0·03
SD + HD	—	2·07	0·65	0·85	1·36	0·73	0·74	1·72	1·44	0·48
Total (All stages)	—	1·71	0·95	0·81	1·99	0·74	0·53	2·76	0·59	0·15

TWB, Total wet biomass; TDB, Total dry biomass.

LAI $= B_0 + B_1 R$, where R= Radiance ratio, B_0 and B_1 are coefficients.

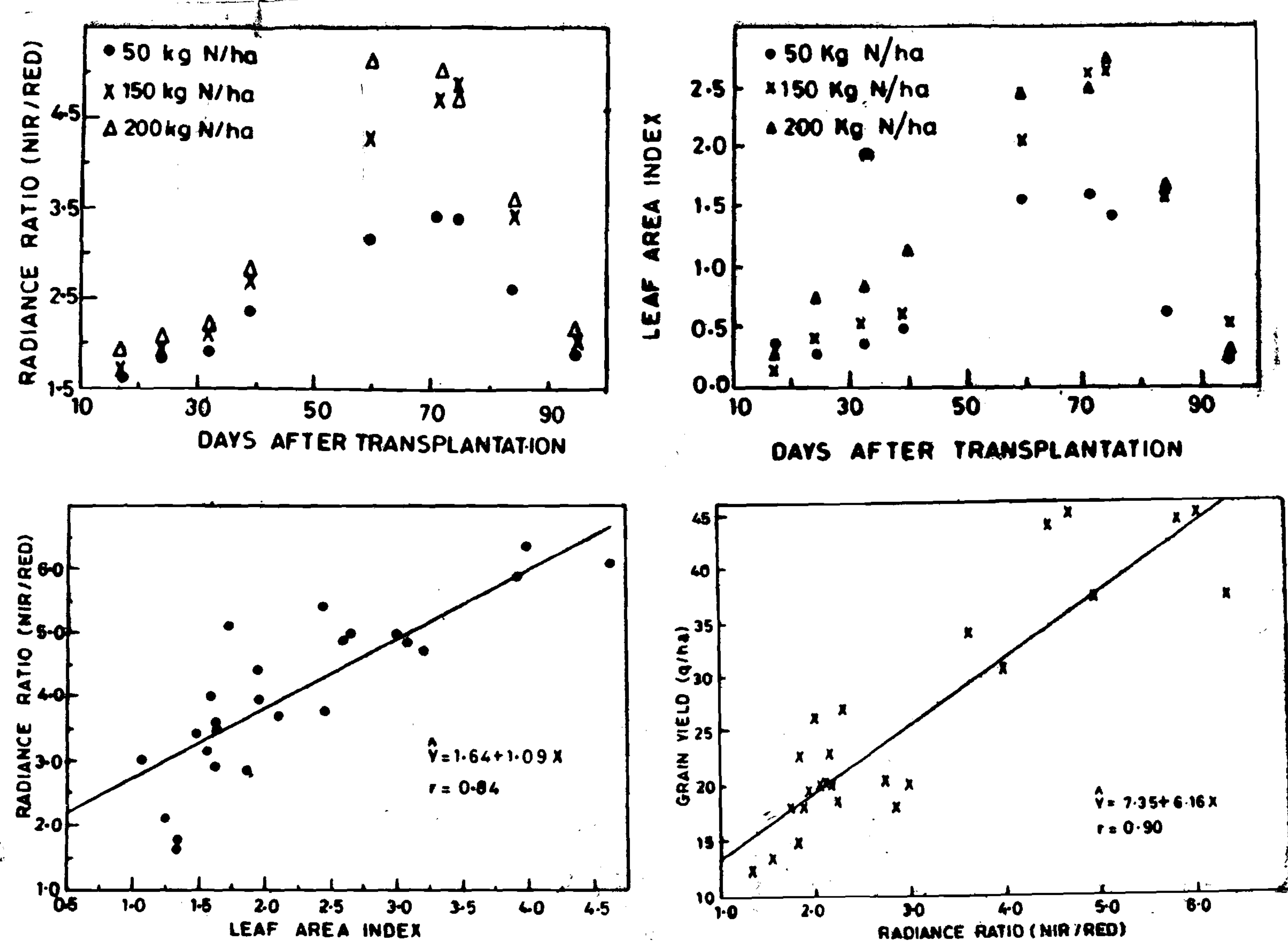


Fig. 1. (Top, left) ; *Temporal variation of radiance ratio,* (Top, right) : *Temporal variation of leaf area index,* (Bottom, left) : *Relation between radiance ratio and leaf area index over two years at flowering stage, and* (Bottom, right) : *Relation between grain yield and radiance ratio at booting stage for fertiliser experiment over two years*

stage ($r^2 = 0.81$). The next higher correlation between yield and radiance ratio was found at the flowering stage ($r^2 = 0.60$).

The relationship obtained for 1984 experiment (normal year) at flowering stage was as follows.

$$Y = -6.38 + 8.60 X$$

where, Y = grain yield (q/ha) and X = radiance ratio.

Figure 1 (bottom right) reveals the relationship between grain yield and radiance ratio at the booting stage. In the opinion of Aase *et al.* (1986), the relationship with pre-flowering growth phase radiometric data was strong, compared to that with post-flowering phase as seen here. Radiance ratio was also shown by them to be closely related to canopy biomass for rice during the middle of growth cycle (booting to heading). During the final development stage (dough to maturity) when the senescence sets in, the use of radiance ratio is meaningless. This is also evident from the low correlation coefficients obtained for later stages (Table 2).

Dates of transplanting

Temporal variation of spectral data. There were six different dates-of-planting treatments imposed to study how the spectral ratio was influenced by them and finally to see how these spectral parameters can be related to yield. Figure 2 (top left) shows the temporal variation of radiance ratio for first three dates for the variety GR 11. Radiance ratio was highest for the normal date of planting (D_3 : Jul 17) while for the two earlier dates, peak reached earlier but at a lower level than D_3. It was noted that with further postponement of planting (beyond July), the vegetative growth period of crop decreased. In fact, reduced biomass and decreased interception of solar energy with late dates of planting might have been responsible for gradual decline in yield with the delay in planting.

The growth stages for different dates of planting were different at a single point of time. Hence, it was decided to take into account the time factor by integrating the values of radiance ratio as well as temperature

Table 2. *Correlation coefficient, slope and intercept values obtained from regressing the radiance ratio and the normalised difference against grain yield for pooled data of 1984 and 1985*

Growth stage	Days after transplantation	Ratio			ND		
		B_0	B_1	r	B_0	B_1	r
Tillering	32	5·16	9·56	0·53	10·70	43·51	0·48
Booting	45-49	7·37	6·16	0·90	1·75	54·76	0·90
Flowering	59-62	—0·36	6·39	0 77	—6·40	55·79	0·68
Milking	70	7·10	4·69	0·38	—8·63	58·75	0·45
Soft dough	83-84	—1·79	9·07	0·48	—10·96	74·14	0·51
Hard dough	90-95	—28·46	24·97	0·65	—23·02	133·52	0·64

$Y = B_0 + B_1 X$,

where Y = Grain yield (q/ha),

X = Radiance ratio.

to study their impact on grain yield. The concept of integration of radiance ratio is analogous to that of leaf area duration which expresses in quantitative terms, how long a plant maintains its active assimilating surface.

Relationship of grain yield with spectral and weather data

Temperature affects many plant processes including nutrient uptake, water absorption, photosynthesis, respiration and translocation of photosynthates. Hence, it is considered an important environmental factor governing plant development (Coelho and Dale 1980). Moomaw and Vergara (1964) indicated that mean temperature, temperature sum, range, distribution pattern and diurnal change or a combination of these may be highly correlated to yield. A high correlation was found between grain yield and accumulated temperature for 1985 data ($r^2 = 0.64$).

To see that the relationship takes into account the crop's response to environmental changes such as temperature, a multilinear regression analysis relating integrated radiance ratio, accumulated mean temperature and grain yield was carried out for wet season 1985. Accumulated temperature was obtained by the summation of mean temperature over a period. The relationship of yield in terms of integrated radiance ratio and accumulated temperature degree day ($r^2 = 0.67$) is given below.

$$Y = 1.55 + 0.17\, X_1 + 0.04\, X_2$$

where Y = grain yield (q/ha), X_1 = integrated radiance ratio, and X_2 = accumulated temperature degree day (°C day).

A pooled data analysis for 1984 and 1985 showed a poor correlation as the climatic conditions varied much during 1985 (drought) as compared to 1984 (normal year). Because of the abnormal weather conditions during 1985, the multilinear regression relationship developed from combined data of 1984 and 1985 did not provide a realistic estimate of grain yield. The estimated values of grain yield and its deviation from the actual values are presented in Table 3. It can

Table 3. *Estimated grain yield of rice for wet season 1985 using the linear regression relation derived from two year data (1984 and 1985)*

Plot No.	Observed yield (Y) (q/ha)	Estimated yield (Yest) (q/ha)	Yest– Y
Fertiliser			
1	20·11	18·17	−1·94
2	14·93	16·82	1·89
3	20·37	25·77	5·40
4	19·58	23·67	4·09
5	18·10	20·13	2·21
6	22·79	19·15	−3·64
7	20·51	23·71	3·20
8	20·25	21·20	0·95
9	18 68	26·27	7·59
10	12·36	15·76	3·40
11	26·25	22·68	−3·57
12	27·01	23·51	−3 50
13	13.50	17 96	4·46
14	23·12	22 00	−1·12
15	18·05	24·21	6·16
Date of planting (Var. GR 11)			
1	57·70	25·27	−32·43
2	59·80	28·06	−31·74
3	64·00	35·24	−28·76
4	33·40	45·15	11·75
5	54·80	48·99	− 5·81
6	40·20	40·30	0·10

Linear regression relationship used ; $Y = 13{\cdot}26 + 0{\cdot}42\, X$, where X = Radiance ratio at boot leaf to flowering stage.

be seen that for fertiliser experiment, estimated yields were reasonably good. But for dates-of-planting treatment, the estimated yields were far below the actual though the magnitude of difference narrowed down with the later plantings. The greater difference in the first three dates was due to high degree of stress during the initial stages of growth. The late-planted treatments viz., the later three plots were not subjected to as much stress as the first three plots. With delayed planting, the duration of crop also reduced compared to longer stand period of the early planted ones. As a result, the estimated yields for later plantings (plot 4, 5 and 6) were better.

In addition to pooled data analysis, the empirical relation developed for 1984 crop season was applied to estimate the yields of 1985. Relationship including only radiance ratio as well as multilinear regression type were tried. The estimated yield values for both the relationships are shown in Table 4.

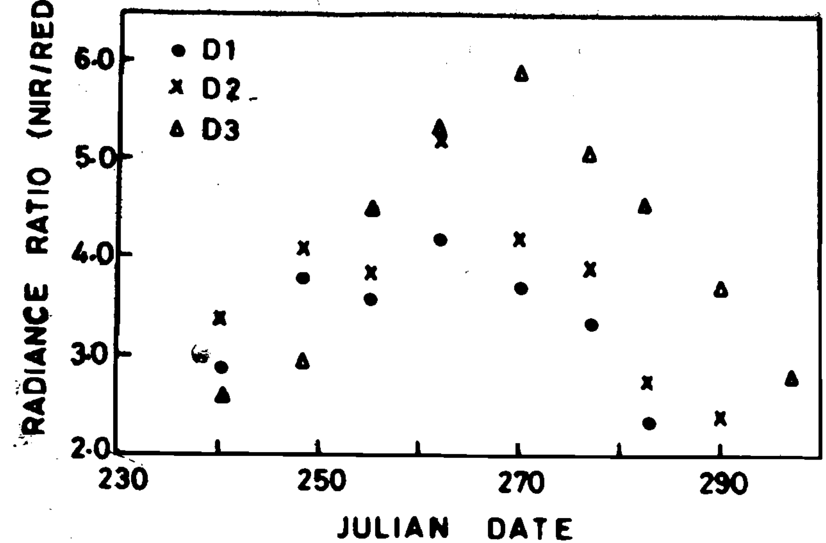
Figure 2 (top left) shows the correlation between observed and estimated values for

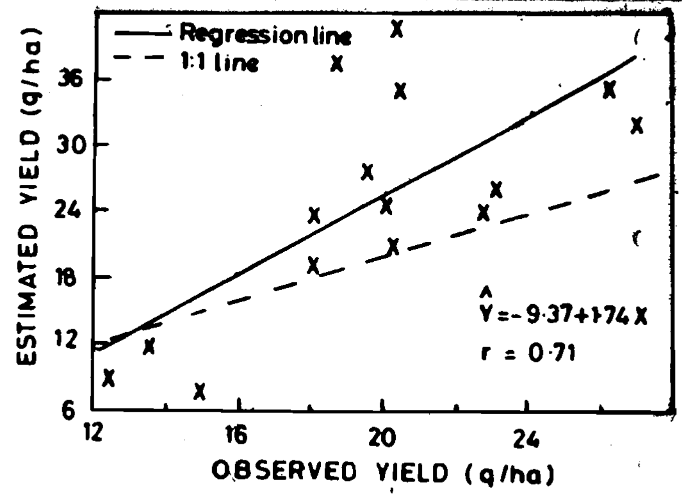
Table 4. *Observed and estimated values of grain yield for fertiliser experiment of wet season 1985 using linear regression relationships derived from wet season 1984 experiments*

Plot No	Observed grain yield (q/ha)	Estimated yield from linear model Yest (q/ha)	Yest—Y	Estimated yield from multi—linear model (Y'est)	Y'est—Y
1	20·11	24·23	4·12	21·87	1·76
2	14·93	7·52	—7·41	10·69	— 4·24
3	20·37	40·62	20·25	26·19	5·82
4	19·58	27 65	8·07	22·15	2·57
5	18·10	23·50	5·40	17·43	— 0·67
6	22·79	23·82	1·03	18·07	— 4·72
7	20·51	6·05	14·46	25·12	4·61
8	20·25	20·74	0·49	16·45	3·80
9	18·68	37·62	18·94	24·60	5·92
10	12·36	8·67	—3·69	8·80	— 3·56
11	26·25	35·15	8·90	23·93	—11·22
12	27·01	31·79	4·38	17·70	— 9·31
13	13·50	11·59	—1·91	10·03	— 3·47
14	23·12	26·08	2·96	18·65	— 4·47
15	18·05	18·84	0·79	15·16	— 2·89

Linear Yield relationship :
$Yest = -6{\cdot}38 + 8.60\ X$
where X = Radiance ratio.

Multilinear yield relationship :
$Y'est = -31{\cdot}21 + 0{\cdot}24\ X_1 + 0.026\ X_2$
where X_1 = Integrated radiance ratio, from booting to dough stage.





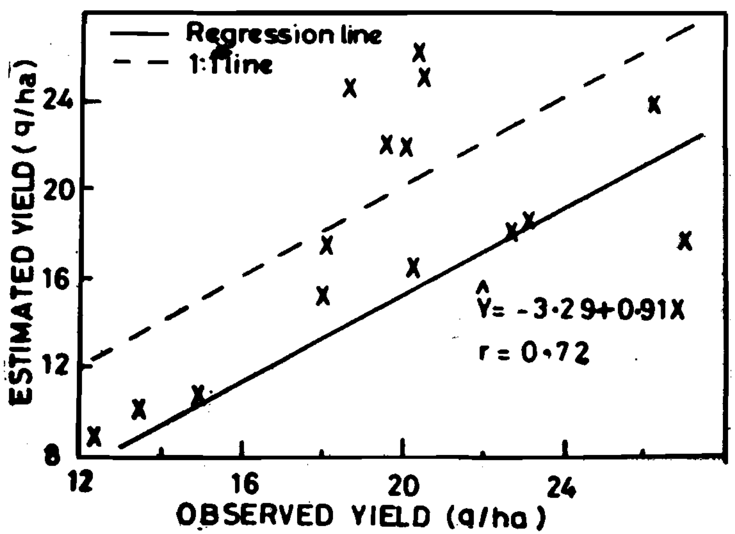


Fig. 2. (Top, right) : *Temporal variation of radiance ratio for date of planting experiment of 1985*, (Top, left) : *Observed yield versus estimated yield for the year 1985 using linear regression relationship derived from fertiliser experiment of 1984* and (Bottom, left) : *Observed yield versus estimated yield for the year 1985 using multilinear regression relationship derived from date of planting experiment*

linear regression relationship using only radiance ratio at booting to flowering stage while Figure 2 (bottom left) indicates for that of multilinear relationship. It is quite obvious from these figures that when a meteorological parameters like temperature was included, the estimate of grain yield was better. Thus, agromet-cum-spectral approach seems to be a better estimator of yield as it takes into consideration many of the crop-weather parameters than either agromet or spectral approach independently.

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