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Spectral Properties Analysis and Crop Growth Simulation Modelling in Rice

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WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
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PREFACE

Rice is the main staple food of tropical countries. In India, the rice crop occupies 42 million hectares which is about 23 percent of the total cropped area or 31.4 percent of the area under food grains. The crop is mostly grown as rainfed (28 million hectares) and as a result cultivation is mainly confined to rainy season (June–September). Sometimes due to lack of proper distribution of rainfall, the crop growth and development suffer. The stress in the crop may also occur due to nutrient deficiency or pest and disease infection. It is necessary to assess crop conditions during the growth cycle in order to estimate the production of the harvest in advance. Agronomic parameters such as leaf area index, above ground dry biomass production, chlorophyll content etc. have been found to be related to crop yield. But measurement of LAI and other agronomic parameters of the crop by conventional method is time consuming, and tedious especially when the measurement are required throughout the growth cycle of the crop. Remote sensing techniques which are based on the measurement of spectra reflected by crop canopies at different wavelengths may become useful tools in the assessment of stress effects on crop growth and yield performance.

In recent times simulation modelling has become one of the most powerful tools for analyzing the interactions in the soil plant atmosphere system. With the advent of computer use in agriculture, utility of meteorological, soil and plant physiological parameters has been increased to predict crop yield or dry matter.

Keeping the importance of above aspects in view in this study, variations in remotely sensed reflectance spectra on rice were monitored and analysed. These indices were correlated with plant growth and physiological parameters to predict dry matter or yield. The crop growth parameters and yield were simulated using two important rice simulation models viz., CERES-Rice and ORYZA1.

We take this opportunity to extend our deep sense of gratitude and indebtedness to the Director General, Deputy Director General (Natural Resources Management) and Assistant Director General (IWM), ICAR for their encouragement and guidance to carry out the study. The authors are extremely helpful to Space Application Centre (ISRO), Ahmedabad for providing fund to execute on-farm research work required for the study. We are grateful to different programme leaders of WTCER, Bhubaneswar for providing laboratory facilities for soil and plant analysis. Author's sincere thanks are due to villagers of Jatni, Khurda, Orissa for their active participation during study. Thanks are due to project associates, scientists, senior research fellows and staff members of WTCER, for their moral support and help rendered during the study.

(AUTHORS)

CONTENTS

1. INTRODUCTION

Rice is the main staple food of tropical countries. In India, the rice crop occupies 42 million hectares which is about 23 percent of the total cropped area or 31.4 percent of the area under food grains. The crop is mostly grown as rainfed (28 mha) and as a result cultivation is mainly confined to rainy season (June–September). Sometimes due to lack of proper distribution of rainfall, the crop growth and development suffer. The stress in the crop may also occur due to nutrient deficiency or pest and disease infection. It is necessary to assess crop conditions during the growth cycle in order to estimate the production of the harvest in advance. Agronomic parameters such as leaf area index (LAI), above ground dry biomass production, chlorophyll content etc. have been found to be related to crop yield. But measurement of LAI and other agronomic parameters of the crop by conventional method is time consuming, and tedious especially when the measurement are required throughout the growth cycle of the crop, and in large spatial scale.

Remote sensing techniques with multispectral repetitive coverage have been found effective in estimating the agronomic parameters and monitoring the changes in these parameters during the growth cycle of the crop. Remote sensing techniques which are based on the measurement of spectra reflected by crop canopies at different wavelengths, may become useful tools in the assessment of stress effects on crop growth and yield performance.

Spectral reflectance indices which are formulated based on simple operations between the reflectance at given wavelengths, are mainly used in the assessment of plant characteristics related to the total photosynthetic area of the canopy. To utilize the full potential of remote sensing for the assessment of crop condition and yield prediction, it is essential to quantify the relationships between agronomic parameters and the spectral properties of the crop.

In recent times simulation modelling has become also one of the most powerful tools for analyzing the interactions in the soil plant atmosphere system. With the advent of computer use in agriculture, utility of meteorological, soil and plant physiological parameters has been increased to predict crop yield or dry matter. Models in the field of agriculture are mathematical equations that represent the reactions that occur within the plant and the interactions between the plant and its environment. Owing to the complexity of the system, inevitably, different models are built by many researchers for different subsystems.

The most prominent types of crop models are :

(i) *Empirical model* (direct description of observed data and are generally expressed as regression equations)

(ii) *Mechanistic model* (describes the behaviour of the system in terms of lower level attributes) *(iii) Static models* (does not contain time as a variable even if the end-products of cropping systems are accumulated over time, e.g., the empirical models).

(iv) Dynamic models It explicitly incorporates time as a variable and most dynamic models are first expressed as differential equations:

$dy/dt = f(X)$, where

y = an attribute of the system (crop yield)

t = time variable

f = some function, possibly of y, t and other parameters.

The integration of the above equation will give the actual behaviour of the system over time.

(v) Deterministic model (It makes definite predictions for quantities, eg. crop yield or rainfall with any associated probability distribution, variance, or random event).

(vi) Stochastic models (When variation and uncertainty reaches a high level, it becomes advisable to develop a stochastic model that gives an expected mean value as well as associated variance).

(vii) Simulation and optimizing models

Simulation models form a group of models that is designed for the purpose of imitating the behaviour of a system. They are mechanistic and in the majority of cases they are deterministic. Since they are designed to mimic the system at short time intervals (daily time-step), the aspect of variability related to daily change in weather and soil conditions is integrated. Optimising models on the other hand have the specific objective of devising the best option in terms of management inputs for practical operations of the system.

Keeping the importance of above aspects in view in this study, variations in reflectance spectra on rice were monitored and analysed. Vegetation indices like Infrared/Red, Normalized Difference Vegetation Index (NDVI), Perpendicular Vegetation Index (PVI) etc. were derived from ground based remotely sensed spectral measurements of the rice canopy during two *kharif* seasons (2004 and 2005). These indices were correlated with plant growth and physiological parameters to predict dry matter or yield.

The genetic coefficients of 5 popular varieties of rice in the region were also calculated and crop growth parameters (leaf area index, specific leaf weight, crop growth rate, relative growth rate, net assimilation rate, leaf area ratio, agronomic efficiency etc.) and yield were simulated using two important rice simulation models *viz.*, CERES-Rice and ORYZA1. The simulated results were validated with the observed values.

2. REVIEW OF LITERATURE

2.1 Review of rice models

In different phases, rice researchers have developed crop growth simulation model on rice where climatic, edaphic, hydrology, biotic, agronomic and socio–economic factors were taken into consideration to simulate crop growth and yield. An attempt was made to develop rice models, IRRI MOD, by CSIRO Australia and IRRI (Whisler *et al.*, 1986) where processes like growth, phasic development, soil nitrogen, transpiration and evaporation have been taken careof. In another attempt Van Keulen, of Wageningen agricultural University, Wageningen developed rice model GRORYZA where processes like gross assimilation and respiration were treated (Whisler *et al.*, 1986). In another instance Mc Menmy and O'toole of International Rice Research Institute developed a model RICE MOD for rice where processes like photosynthesis, respiration and growth were treated (Whisler *et al.*, 1986). But more comprehensive mechanistic and detailed process oriented ORYZA group of models were developed by collaborative project–Simulation and Systems Analysis for Rice Production (SARP). Recent efforts in the International Benchmark Sites Network for Agrotechnology Transfer (IBSNAT) project have focussed on developing a series of models and CERES-Rice is one of the mechanistic models simulating processes of plant growth and development. The model was designed to access yield as constrained by crop variety, soil, water and nitrogen. Some of the important rice models are given in Table-1.

Table-1: Available simulation models on rice

	Research group	Institutions	Model Name	Processes treated
1.	Mc. Mennamy and O' Toole (1983).	IRRI (Philippines)	RICEMOD	Photosynthesis, Respiration, growth.
2.	Horie (1987)	Kyoto University, Japan.	SIMRIW	Crop development, growth, harvest index.
3.	Godwin *et al.* (1990); Alocilja and Ritchie (1988).	University of Hasvaii, USA.	CERES Rice	Crop growth, development and yield components of different varieties in different agro-climatic conditions.
4.	Van Diepen *et al.* (1988)	Centre for Agro- Biological Research, Wageningen Agril. University, Netherlands.	WOFOST	Photosynthesis, respiration, assimilation, light interception, leaf area development, biomass partioning, water balance, nitrogen supply, N uptake, phenological development, partioning, phasic development, growth.
5	Penning de vries *et al.* (1989)	Wageningen Agril. University, Netherlands	MACROS-LID	Process of crop growth, photosynthesis, water movement.
6	Spitters *et al.* (1989); van Laar *et al.* (1997)	Wageningen Agril. University, Netherlands.	SUCROSE	A model for crop growth for potential and water limited production situations for wheat and maize.

7	Graf *et al.* (1990 and 1991)		RICESYS	A simulation model for the dynamics of rice growth and development.
8	Bastiaans (1991)	Wageningen Agril. University, Netherlands.	LIDFDE	The standard model for foliar diseases.
9	Ten Berge *et al.* (1992)	Wageningen Agril. University, Netherlands.	SAWAH	Soil water balance module
10	Kropff and van Laar (1993)	Wallingford, U. K.	INTERCOM	An ecophysiological model for crop-weed interactions.
11	Bouman (1993)	Wageningen Agril.University, Netherlands	LOWBALL	Water balance for puddled low land soil under rice production
12	Bouman (1993); Wopereis *et al.* (1996)	Wageningen Agril. University, Netherlands	ORYZA-W	Growth and development of rice in irrigated and rainfed lowland and rainfed upland condition.
13	Kropff *et al.* (1994)	Wageningen Agril. University, Netherlands	ORYZA-1	Growth of crop and organs, development,photosynthesis, respiration.
14	Ten Berge *et al.* (1994)	Wageningen Agril. University, Netherlands	ORYZA-0	Formulations of phenological development, leaf area development, light interception, respiration, assimilation, partitioning, remobilization, sink size are reduced to simple coefficients.
15	Drenth & Berge (1994)	IRRI, Philippines.	ORYZA-N	Growth of crop and organs, development,photosynthesis, respiration, N uptake and N alocation to crop organs
16	Elings and Rubia (1994)	Wageningen Agril. University, Netherlands.	BLIGHT	Model for blight disease of rice
17	Riethoven *et al.* (1995); ten Berge *et al.* (1996).	Wageningen Agril. University, Netherlands	MANAGE-N	Formulations of phenological development, leaf area development, light interception, respiration, assimilation, partitioning, remobilization, sink size are reduced to simple co-efficients.
18	Aggarwal *et al.* (1996)	IARI, New Delhi.	ORYZA-1N	A model to determine the reletive importance of plant traits.
19	Bouman *et al.* (2001)	IRRI (Philippines) and Wageningen Agril. University and Research centre, Netherlands.	ORYZA- 2000	Growth of crop and organs, development, photosynthesis,respiration, N uptake and N content, evapotranspiration, nitrogen dynamics, soil-water balance.
20	Barney (2002)	IRRI, Philippines	DS RICE 1	Simulating seed reserve mobilization and seedling growth of rice.
21	Aggarwal *et al.* (2006 a,b)	IARI, New Delhi.	INFOCROP	A generic and dynamic crop model based on several earlier models that included the effect of pest and diseases for several crops.

2.2 Review of spectral properties

Satellite or aircraft remote sensing can provide a timely spatial distribution information on crop performance and be incorporated into farm management scheme. Applications such as precision farming activities, growth and production estimation and land surface characteristics evaluation are made possible with remote sensing technique (Mass, 1988). Before these practical applications, vegetation spectral properties from remote sensing must be in connection with some physical characters of plant canopy so that plant performance can reasonably be assessed (Wiegand *et al.*, 1992).

Vegetation indices are mathematical transformations intended to estimate the spectral contribution of crop vegetation to multi spectral observations. The formula of vegetation indices are derived mostly from discrete green, red and near-infrared bands, especially the two ends of so called chlorophyll red-edge (Jackson etal., 1983; Tucker, 1979). By correlating vegetation indices with physical characters of plant canopy, changes of vegetation feature can be potentially assessed and predicted from values of vegetation indices during the growing season (Maas, 1998; Tucker *et al.*, 1979; Yang and Ko, 1997; Curran, 1983; Sinclair *et al.*, 1971).

Canopy reflectance expressed as the Normalized Difference or greenness is very closely related to leaf area index. (Asrar *et al.*, 1984, 1985 c; Daughtry *et al.*, 1983, Wiegand and Richardson, 1984), which in turn, is of interest of researchers because it is related to whole plant biomass, light interception and loss of water through evapo-transpiration.

Various studies have been carried out to calculate the canopy variables of different crops with in-situ measured radiance/reflectance data (Tucker, 1979; Holben *et al.*, 1980; Tucker *et al.*, 1980; Aase and Siddoway, 1981; Miller *et al*, 1983). Patel *et al.*, (1985) studied spectral response of rice crop and its interrelationship with yield and yield attributes . Good estimates of actual biomass, ground cover and LAI were derived from spectral measurements (Bouman *et al.*, 1992; Leblon *et al.*, 1991; Clevers, 1989). But studies of various biophysical plant feature by remotely sensed data is complex, because the reflectance of vegetative canopy is determined not only by plant morphology and phenology but also by soil characteristics (Huete and Jakson, 1985).

3. MATERIALS AND METHODS

3.1 Weather of the study area

The study area was undertaken in Jatni Block, Khurda districts, Orissa (Latitude 20^0 $10'$ to 20^0 $15'$ and longitude 85^0 $40'$ to 85^0 $45'$) during *Kharif* crop seasons of 2004 and 2005 (Fig-1). The normal weather conditions of the study area given in Table–2 which reveals that the mean monthly maximum temperature ranges from 41.6^{O}C in May to 26.9 ^{O}C in January. On the other hand, mean minimum temperature varies between

27.7 °C in May to 17.7 °C in December. The mean total annual rainfall is 1439 mm and 69.2 % of which occurs during southwest monsoon period (June- September). On an average, premonsoon and southwest monsoon showers contribute 6.1 % and 69.2 % of the total annual rainfall. Based on seasonal distribution of rainfall, farmers are advised to perform summer tillage with pre-monsoon shower, so that they can sow the direct seeded crops in rainfed area just with the onset of southwest monsoon. Besides, summer tillage in light textured soils improves water retention capacity and reduces weed, pest and disease infestation. During post or retreating monsoon period (October-November), 22 % of total annual rainfall occurs, which will be helpful for lowland, long duration rice because this crop are at reproductive stage during that period.

The mean date of onset of effective monsoon (OEM) was found to be 14th June and southwest monsoon generally ended on 28th September. The earliest and latest probable dates of OEM were found to be 5th and 20th June, respectively. Whereas, earliest and latest probable dates of monsoon withdrawal were worked out to be 13th September and 02nd October, respectively.

Table -2: Weather normal of Khurda district

Month	Max. temp. (°C)	Min. temp. (°C)	RH1 (%)	RH2 (%)	Rain (mm)	Wind speed (k/hr)	Av. Vapour pressure (mb)	Av. Atm. Pressure (mb)
January	26.9	17.9	73	68	9	11.9	18	1014.75
February	28.3	20.8	73	72	19	15.9	22	1012.3
March	30.0	24.6	76	79	13	20.5	28	1009.65
April	35.7	26.6	80	85	12	24.0	32	1002.45
May	41.6	27.7	82	86	62	26.2	35	998.8
June	36.7	27.4	82	85	186	23.2	34	998.75
July	34.6	26.7	83	85	296	23.3	33	1000.15
August	31.0	26.8	82	83	256	19.7	33	1003.2
September	31.4	26.6	80	81	257	15.9	32	108.7
October	31.2	25.0	77	75	242	12.3	28	1012.55
November	29.3	20.8	71	64	75	10.2	21	1012.55
December	27.2	17.7	70	62	7	10.5	17	1014.65

The weekly water balance of the study region was computed using Thorthwaite and Mather's book keeping procedure. Total annual potential evapotranspiration (PET) and actual evapotranspiration (AET) were computed as 1531 mm and 795 mm, respectively. The moisture availability index (AET/PET) exceeded 0.5 for 22

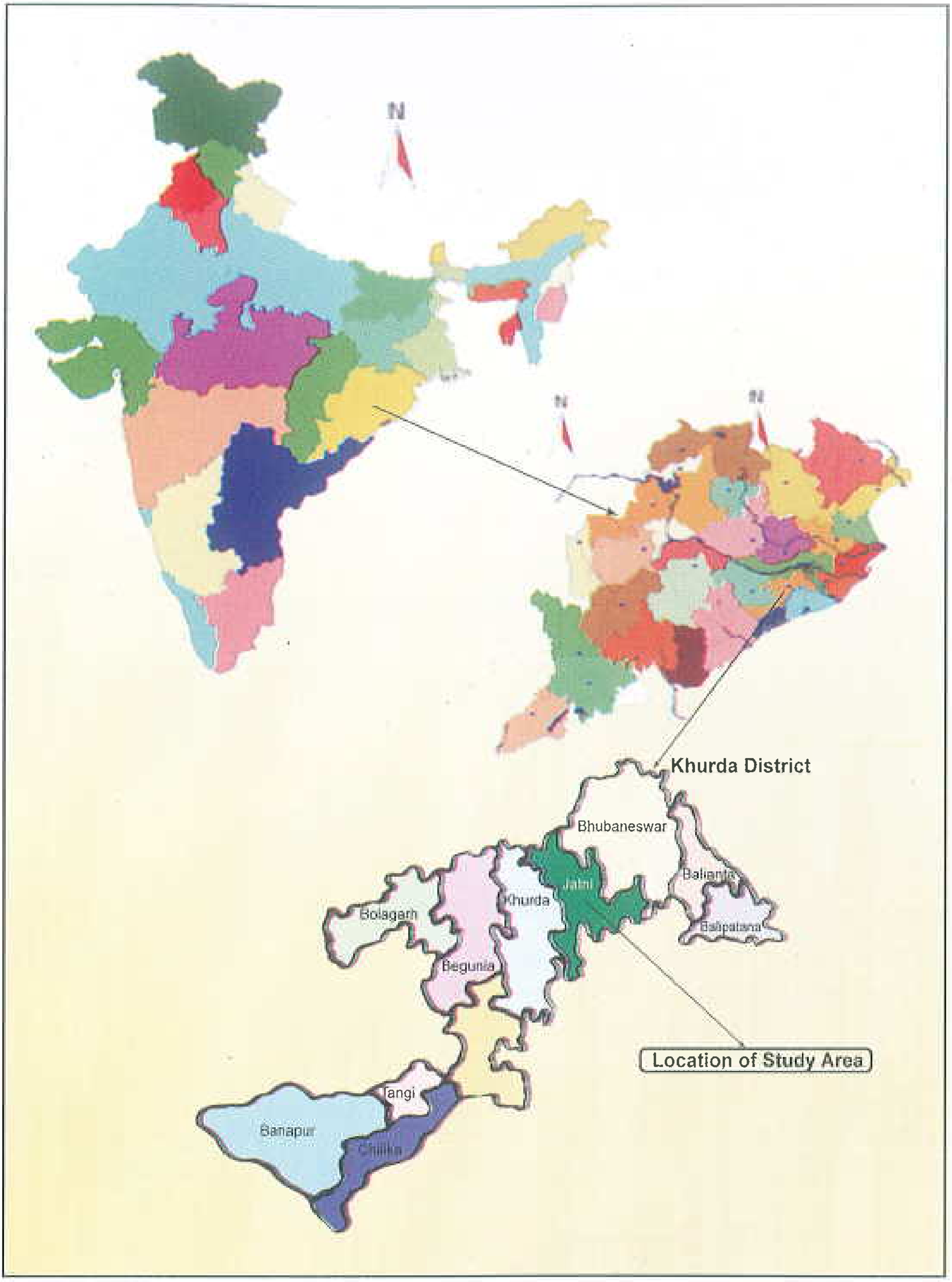


Fig-1 : Spatial location of the study watershed weeks in the region, which can be considered as length of the growing periods (LGP).

3.2 Soils of the study area

The soils of the study area were sandy loam to sandy clay loam in texture (Table-3). The soil pH was slightly acidic to normal. The soil moisture content at field capacity ranged from 0.252 $m^3 m^{-3}$ to 0.281 $m^3 m^{-3}$

Table-3: Basic soil properties of the study area

Field IDs	Depth (cm)	Texture	FC ($m^3 m^{-3}$)	PWP ($m^3 m^{-3}$)	O.C. (%)	pH	Avalible P(ppm)	Avalible K(ppm)
F1	0-15	sl	0.252	0.095	0.48	5.7	2.5	65
	15-30	scl	0.287	0.119	0.42	6.7	<1.0	56
F 2	0-15	sl	0.268	0.010	0.62	5.1	<1.0	56
	15-30	scl	0.281	0.108	0.44	6.3	3.1	65
F3	0-15	sl	0.258	0.109	0.68	6.7	2.1	55
	15-30	scl	0.281	0.123	0.60	7.0	2.3	67
F4	0-15	sl	0.260	0.107	0.39	6.3	3.1	67
	15-30	scl	0.281	0.109	0.32	6.5	1.9	70
F5	0-15	sl	0.275	0.109	0.69	5.3	<1.0	55
	15-30	scl	0.269	0.115	0.57	6.2	2.1	80
F6	0-15	sl	0.268	0.119	0.81	5.8	1.9	45
	15-30	scl	0.271	0.117	0.60	5.4	1.0	87

F1, F2, F3, F4, F5 and F6 are the different farmers' field.
FC - Field capacity, PWP - Permanent Wilting point, O.C. - Organic carbon
sl - Sandy loam, scl - sandy clay loam

3.3 Crop management and experimental procedure

For simulating crop growth and y..ld of rice, the experiments were conducted at Jatani Block of Khurda districts of Orissa with five rice varieties viz., 'Lalat', 'Ranjit', 'Gayatri', 'Savitri' and 'Swarna' during 2004 and 2005 *Kharif* seasons. In each year, rice was transplanted on last weak of July. The plant to plant and row to row distances were kept as 15 and 20 cm, respectively. The fertilizer doses (N:P:K) were applied in the ratio of 80 : 50 : 50. Full dose of P and K and 1/3rd of nitrogen were applied as basal. The remaining N fertilizer was applied at tillering and panicle initiation stages in two equal doses. Other crop management practices like weeding, intercultural operations were followed using standard agronomic package and practices.

3.4 Measurement of plant growth and physiological parameters

The plant growth parameters like total crop biomass, leaf area and phenological observations of 5 rice varieties were undertaken at weekly interval. The following crop growth parameters were derived based on observed leaf area and total biomass.

LAI: Leaf area index

$= \text{Leaf area of five hills } (cm^2) / \text{Land area covered by five hills } (cm^2)$

SLW: Specific leaf weight $= \text{Leaf weight (mg)} / \text{Leaf area } (dm^2)$

CGR: Crop growth rate $= (W_2 - W_1) / (T_2 - T_1)$, $g/m^2/day$

RGR: Relative growth rate $= (\ln W_2 - \ln W_1) / (T_2 - T_1)$, mg/g/day

NAR: Net assimilation rate

$=\{(W_2 - W_1) \times (\ln LA_2 - \ln LA_1)\} / \{(LA_2 - LA_1) \times (T_2 - T_1)\}$, $mg/dm^2/day$

LAR: Leaf area ratio

$= \{(LA_2 - LA_1) \times (\ln W_2 - \ln W_1)\} / \{(\ln LA_2 - \ln LA_1) \times (W_2 - W_1) \times (T_2 - T_1)\}$, cm^2/g

Where, W_1 = Total biomass of crop at time T_1

W_2 = Total biomass of crop at time T_2

LA_1 = Leaf area of crop at time T_1

LA_2 = Leaf area of crop at time T_2

T_1 = Time in days after transplanting as first sampling

T_2 = Time in days after transplanting as second sampling

Agronomic efficiency = (Yt – Yc) / Nt

Where,

Yt – Grain yield in N treated plot, kg/ha

Yc – Grain yield in control plot, kg/ha

Nt – Nitrogen applied in treated plot, kg/ha

3.5 Measurement of photosynthetically active radiation (IPAR) and net radiation

Intercepted photosynthetically active radiation (IPAR) was measured by the Light Transmission Meter (EMS 7) using the following relationships:

IPAR = Incident radiation on the canopy - reflected radiation by the canopy - transmitted radiation through the canopy + reflected radiation from the ground

$$\text{IPAR (\%)} = \frac{\text{IPAR}}{\text{PAR incident above the canopy}} \times 100$$

The net radiation was measured using BABUC M net radiometer at 0.5 m distance from the crop canopy.

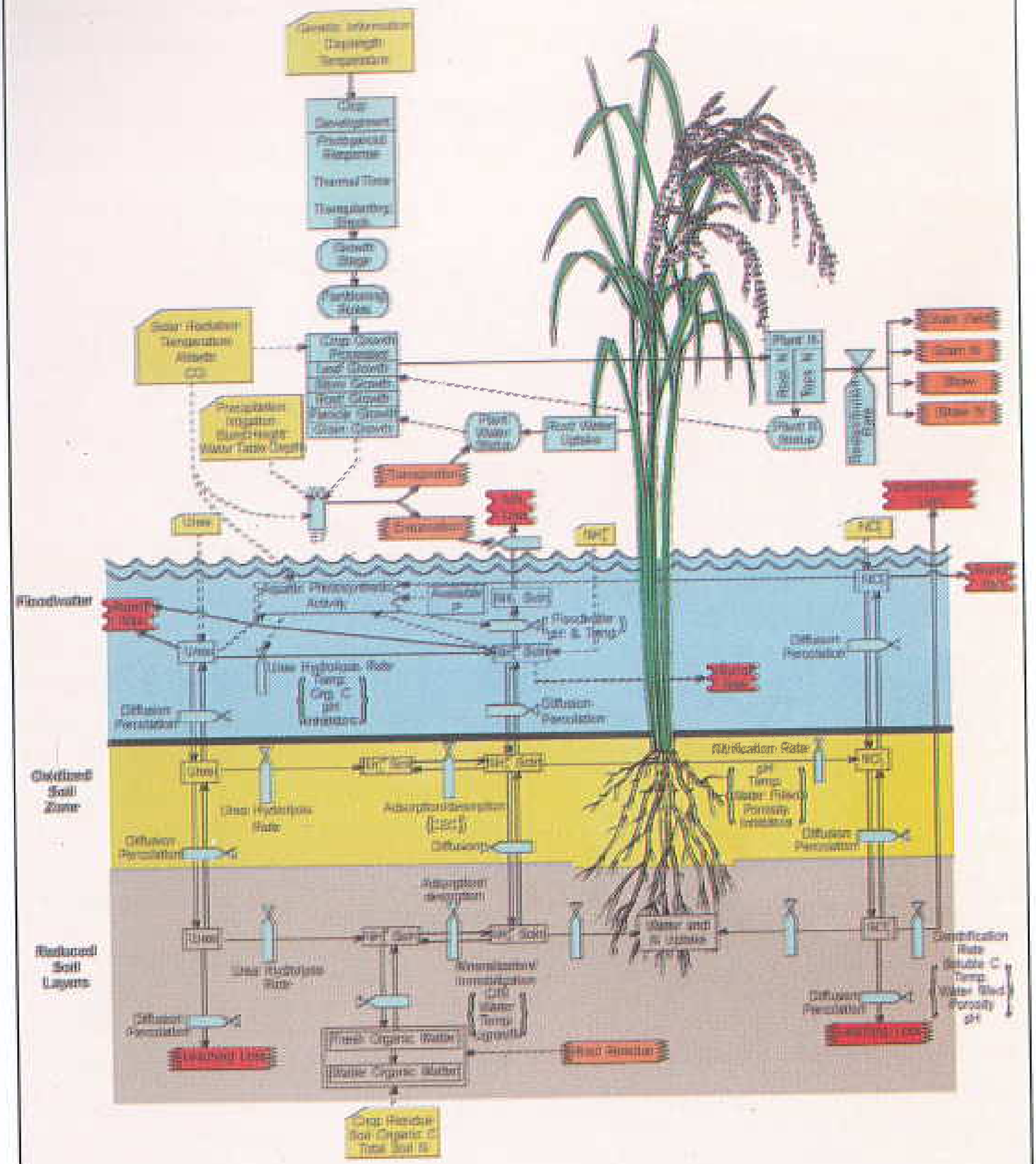


Fig-2 : Schematic diagram of different processes of the CERES-Rice model.

3.6 Measurement of spectral indices

Spectral reflectance of the crop was measured with the help of UNISPEC spectroradiometer with the same four spectral brands as those of LANDSAT MSS. The measurements were made once a week from 13[th] day after transplanting between 10.00 to 11.00 hours IST (Indian standard time).

The following vegetation indices were derived based on spectral reflectance data and correlated with plant parameters and yield.

(i) Infrared/Red ratio (IR/R) = $\frac{\rho_{ir}}{\rho_r}$

Where, ρ_r is the red reflectance and ρ_{ir} is the very near infrared reflectance.

(ii) Normalised Difference Vegetation Index or NDVI.

$$NDVI = \frac{\rho_{ir} - \rho_r}{\rho_{ir} + \rho_r}$$

Both IR/R and NDVI are based on the marked contrast between low reflectance of healthy green vegetation in the visible red and high reflectance in very near infrared red (VNIR) regions, which is not in the case of spectral behaviours of soils.

(iii) Perpendicular Vegetation Index (PVI) : To correct further for soil interferences, PVI, Perpendicular Vegetation Index has been introduced which requires bare soil data for computation.

$$PVI = \sqrt{(\rho_{ir} - \rho_{ir,s})^2 + (\rho_{ir} - \rho_{r,s})^2}$$

Where, $\rho_{r,s}$ is the red reflectance of a bare soil, $\rho_{ir,s}$ the VNIR reflectance of a bare soil. PVI calculates the deviation of the reflective signal of vigorous vegetation that is less sensitive to the underlying soil type.

(iv) Sum Vegetation Index (SVI) = Near Infrared (NIR) +Red (R)

(v) Difference Vegetation Index (DVI) = NIR-R

(vi) Green-red ratio vegetation index (SAVI) = [(NIR-R)x1.5]/[(NIR - R)+0.5]

NIR = Near Infrared, R = Red

3.7 Crop growth and yield simulations with CERES-RICE and ORYZA models

3.7.1 Simulating crop growth and yield with CERES-RICE

CERES-RICE is the DSSAT (Decision Support System for Agrotechnology Transfer) group of model which works on daily timestep basis and requires weather, soils and management related data. It computes crop phasic and morphological development using temperature, day length and cultivar characteristics.

Data base component in the model includes crop management, soil and weather information to characterize how, where and when the crop was grown and to characterize measured crop and soil performance. The various utility programs available for database management are:

XCREATE	:	This is to create an experiment description file i.e. to create FILEX.
WEATHERMAN	:	This program is to reformat weather data files to make them compatible with DSSAT models, file in missing data, compute statistics and graph weather data. WGEN computes statistics for daily weather generation
WINGRAPH	:	It gives graphs for simulated and observed data as time series graphs or as observed vs simulated yield or other variables for validation purposes
GENCLAC	:	This is to calculate cultivar coefficients for different crops. This program runs the crop models for existing experiments a number of times, modifying cultivar coefficients each time until simulated and observed crop traits are equal or within a defined tolerance
LIST/EDIT	:	This program is to obtain lists of different input files and editing.
SOIL PROFILE CREATE	:	This is to create new soil profiles for their experimental analysis. Inputs for this program are specific information for soil characterization (e.g. number of layers, % of sand, silt and clay, bulk density etc.). Soil water storage and other variables, are compared by a programme to provide a full set of soil profile data required by the crop models.

Model structure of CERES-Rice along with other modules of DSSAT are presented in Fig-2.

Table 4: Data required for operation and evaluation of CERES Rice (Hunt and Boote, 1994)

OPERATION:	
Site	Latitude, longitude, elevation, slope, aspect, water table depth
Weather	Daily maximum and minimum temperatures, global solar radiation, rainfall, wind, dew point temperatures or relative humidity
Soil	Classification using the local system and (to family level) the USDA-NRCS taxonomic system), root growth factor, drainage coefficient
Soil physical properties	Depths of layers; percentages of sand, silt, and clay, and bulk density at various depths; moisture content at wilting point (15 bar) and field capacity (1/3 bar) and at saturation for various depths. If these are not available, could be estimated from percentages of sand, silt, and clay and bulk density).
Soil chemical properties	pH; organic C; total N; CEC
Initial conditions	C:N ratio and weight of root and shoot residues of previous crop incorporated or retained in field; date and depth of residue (material type, amount, and N concentration), incorporation; soil water, and KCl extractable ammonium and nitrate N by soil layer); in-crop season (ammonium and nitrate N); between phases (Organic C and total N); tillage practice.
MANAGEMENT :	
Establishment	Dates of planting/transplanting; age of transplanted; seedling, environmental, temperature; plant population (number of plants for direct sowing; number of seedlings per hill for transplanting).
Water	Bunding ; flood water depth (date, and depth); depth of furrows and of flood water (for beds); irrigation amount and dates; date of water removal; percolation rate (beds- from bed surface and furrows); perched water table depth (beds- from bed surface and furrows)

3.7.2 Simulating crop growth and yield with ORYZA1.

Site, weather, biomass partitioning, initial conditions, physical properties, crop establishment etc. are the main input parameters of the model. (Table-5). The general structure of the Oryza1 model is presented in the Fig-3 under favourable growth conditions. The model follows the daily calculation scheme for the rates of dry matter production of the plant organs, and the rate of phenological development.

Input parameters

Table 5: Minimum data required for operation and evaluation of ORYZA1

OPERATION	
Site	Latitude, longitude
Weather	Daily radiation, maximum and minimum temperatures
Chemical properties	Nitrogen fraction in leaves
Initial conditions	Initial development stage, weight of leaves, weight of stems, weight of storage organ and weight of roots.
MANAGEMENT	
Establishment	Dates of planting/transplanting; age of transplants; seedling (seedbed) environment temperature; plant population (number of plants for hill, number of hills)

4.0 RESULTS AND DISCUSSION

4.1 Temporal variation of spectral vegetation index and its relationship with crop growth

The reflectance values of 4 rice varieties viz., 'Lalat', 'Ranjit', 'Gayatri', 'Savitri' were used to compute ratio vegetation index (Infrared/Red) and normalised difference vegetation index (NDVI). Study revealed that reflectance in the near infrared (NIR) region was increased whereas reflectance in the red region was decreased with the increase of vegetative cover. The ratio vegetation index was increased very fast with the vegetative growth and reached its maximum around the active tillering to panicle initiation stage and then started declining (Fig-4). The temporal variation of NDVI was also computed and is presented in Fig-5 which revealed that at tillering to panicle initiation stage it increased fast 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. The similar pattern was observed by all the 4 varieties.

4.2 Observed phenological development and crop growth analysis.

The duration of important phenological stages of five rice varieties viz., 'Gayatri', 'Lalat', 'Samrat', 'Ranjit', 'Swarna' were recorded and are presented in Table-6. All the 5 varieties were transplanted at 30 days after sowing. Study revealed that active tillering started at 48-59 days after sowing for all the varieties selected for the study. The total duration ranged from 124 days in 'Lalat' to 149 days in 'Savitri'. The flowering stage of the crop varied between in 95 days in 'Lalat' to 149 days in 'Savitri'.

The important crop growth parameters like dry weight of leaves, stem, tiller number, above ground biomass, leat area index were recorded at different growth stages and are presented in Fig 8-19. Study revealed that dry weight of the leaves at active tillering stage ranged between 0.64 t/ha in 'Swarna' to 1.64 t ha^{-1} in 'Lalat'. At panicle initiation stage, dry weight of the leaves was the highest (1.24 to 1.55 t ha^{-1} in different varieties). On the other hand, at maturity the dry weight of the leaves ranged between 0.49 to 0.78 t ha^{-1} in different varieties studied. At tillering stage, dry stem weight of the crop ranged between 0.77 t ha^{-1} in 'Swarna' to 1.43 t ha^{-1} in 'Lalat'. At maturity it varied from 2.31 to

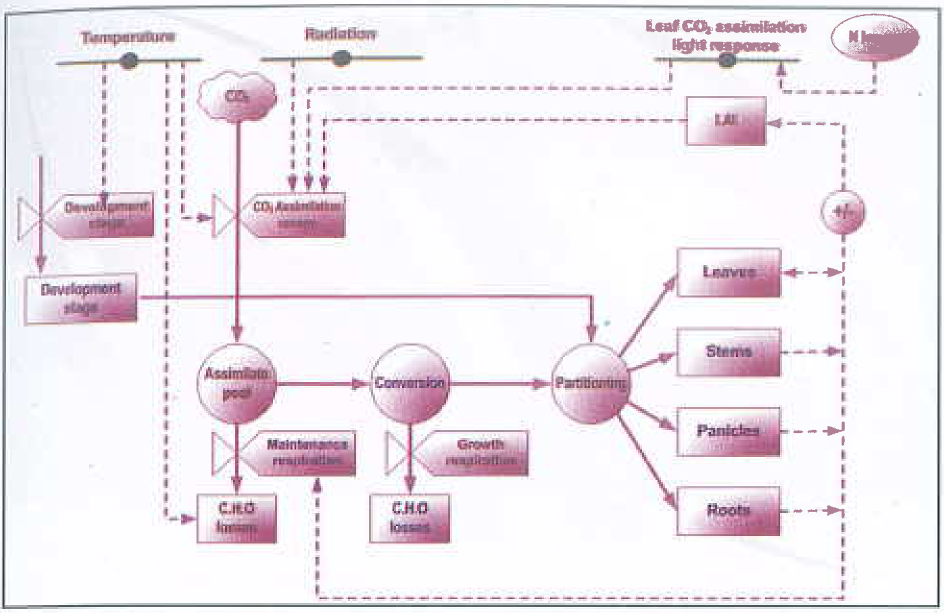


Fig- 3: A schematic representation of the model ORYZA1. Boxes are state variables, valves are rate variables and circles are intermediate variables. Solid lines are flows of material, dotted lines are flows of information

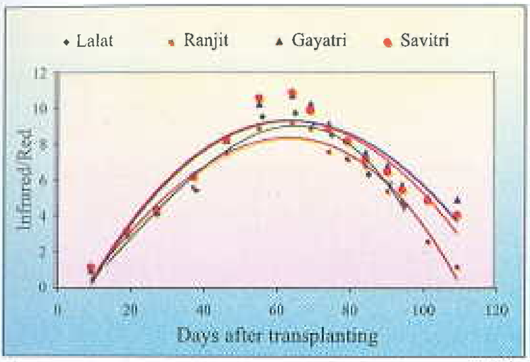


Fig-4: Temporal variation of IR/R of 4 rice varieties throughout the growing season.

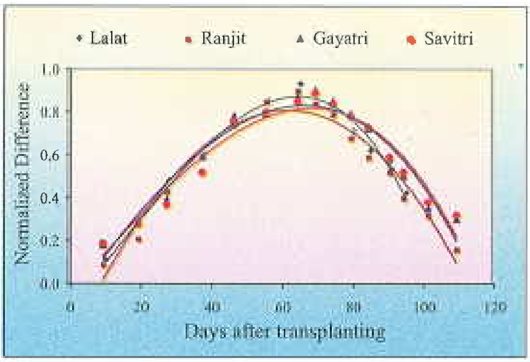


Fig-5: Temporal variation of NDVI of 4 rice varieties throughout the growing season.

Table-6: Observed duration of different phenological stages (pooled data of 2004 and 2005)

Varieties	Phenological developments (days after sowing)				
	TP	AT	PI	FL	MAT
Gayatri	30	58	84	116	147
Lalat	30	48	75	95	124
Ranjit	30	54	83	114	145
Savitri	30	59	85	118	149
Swarna	30	55	81	112	142

TP- Transplanting , AT- Active tillering , P I – Panicle initiation, FL. – Flowering, MAT. – Physiological maturity

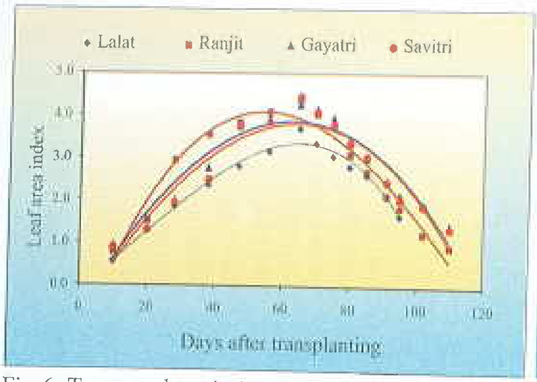


Fig-6: Temporal variation of LAI of 4 rice varieties throughout the growing season.

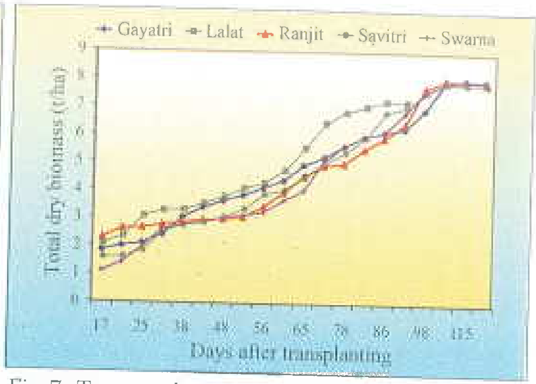
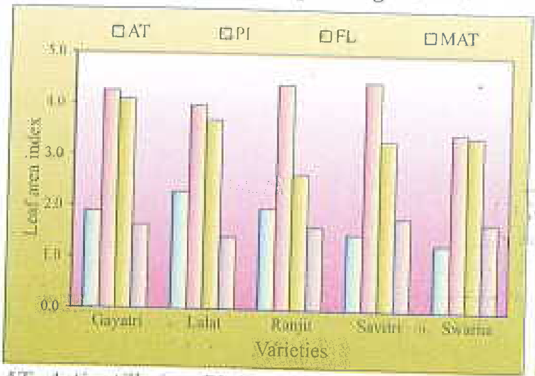
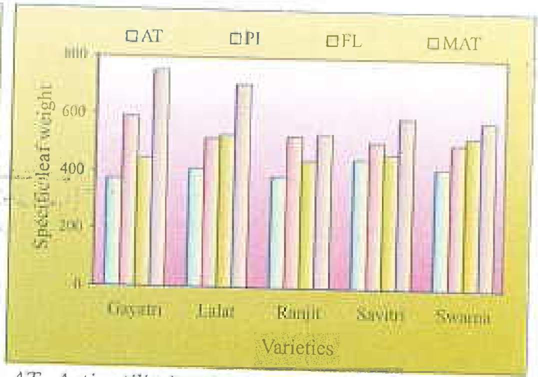


Fig-7: Temporal variation of above ground biomass of 5 rice varieties.



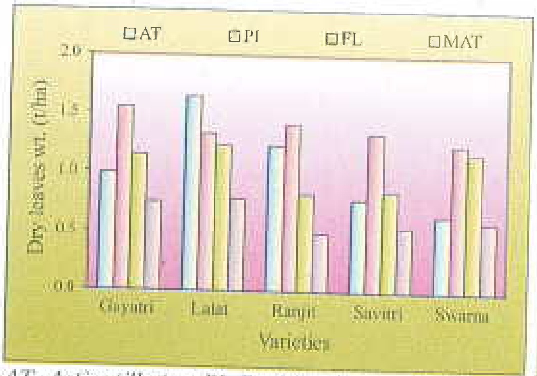
AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig-8: Observed leaf area index of selected varieties of rice.



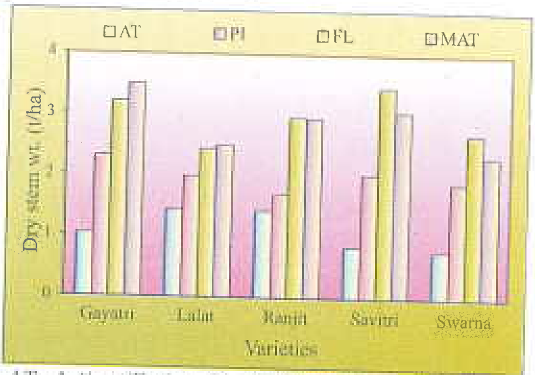
AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig-9: Observed specific leaf weight of selected varieties of rice.



AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig-10: Observed dry weight of leaves of selected varieties of rice.

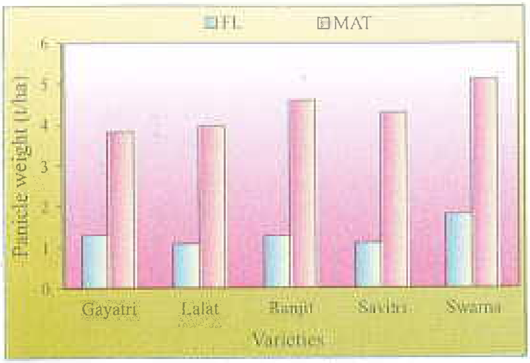


AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig- 11: Observed dry stem weight of selected varieties of rice.

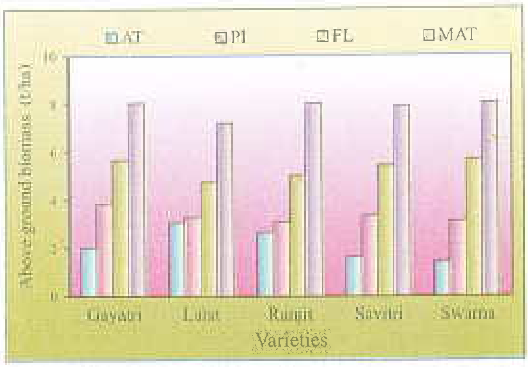
3.49 t ha^{-1} in different rice varieties. The highest above ground dry biomass was recorded at physiological maturity in 'Gayatri' variety with the value being 8.05 t ha^{-1}. The panicle weight at maturity ranged between 3.81 t ha^{-1} in 'Gayatri' to 5.12 t ha^{-1} in 'Swarna'.

At active tillering stage, the tillers/m^2 were 492 in 'Savitri' to 632 in 'Lalat'. On the other hand at maturity the tillers/m^2 varied from 323 in 'Savitri, to 477 in 'Lalat'. The highest leaf area index was computed as 3.46 in 'Swarna' to 4.46 in 'Savitri'. These observed growth parameters were compared with that of simulated results using two rice crop growth models viz., CERES-Rice and ORYZA1. The comparative analysis of different crop growth parameters are presented in Table 12 to 18.



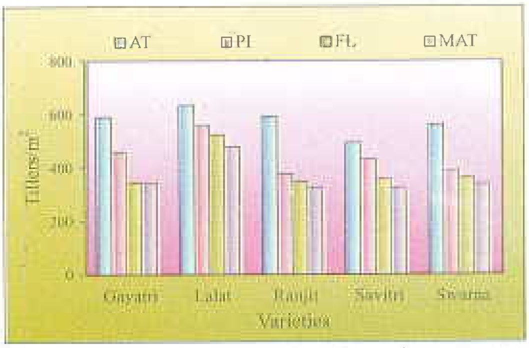
FL- Flowering and MAT- Maturity stages.

Fig-12: Observed panicle weight of selected varieties of rice.



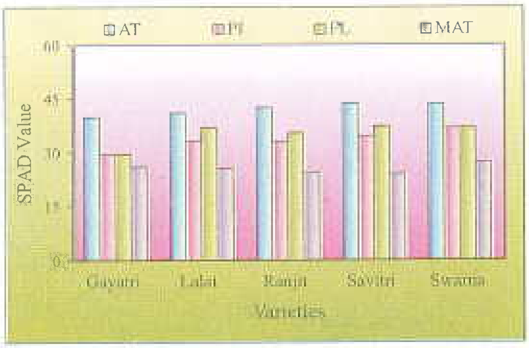
AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig-I3: Observed above ground biomass of selected varieties of rice.



AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig-I4: Observed tillers/m^2 of selected varieties of rice.



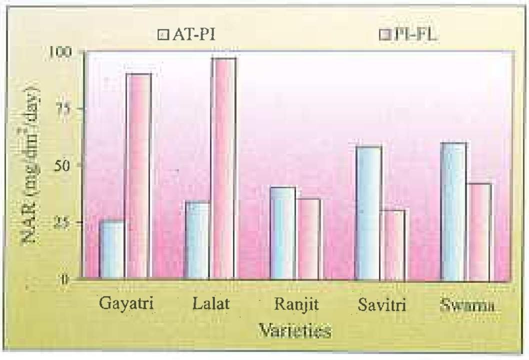
AT- Active tillering, PI- Panicle initation, FL- Flowering and MAT- Maturity.

Fig-15: Observed SPAD values of selected varieties of rice.

4.3 Correlation coefficients among crop growth characteristics and vegetation indices in rice.

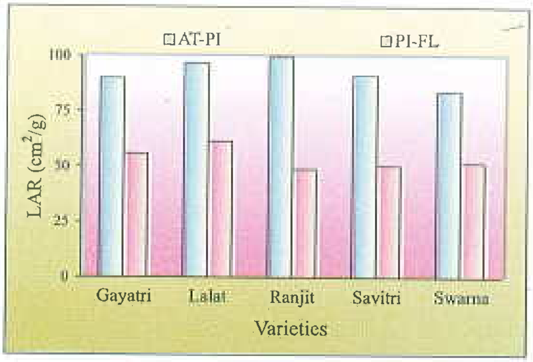
The different plant growth parameters like leaf area index, leaf number, leaf dry weight, above ground dry biomass and plant height were measured and correlated with six vegetation indices viz., (i) sum vegetation index (SVI), (ii) difference vegetation index (DVI), (iii) ratio vegetation index (IR/R), (iv) green-red ratio vegetation index, (v) Normalized Difference Vegetation Index (NDVI), (vi) soil adjusted vegetation index (SAVI).

Study revealed that spectral properties were highly influenced by leaf biometric parameters and had significant (at 5% level) correlation with leaf number, leaf dry weight and leaf area index. However, spectral indices were not significantly correlated with above ground dry matter and plant height (Table-7).



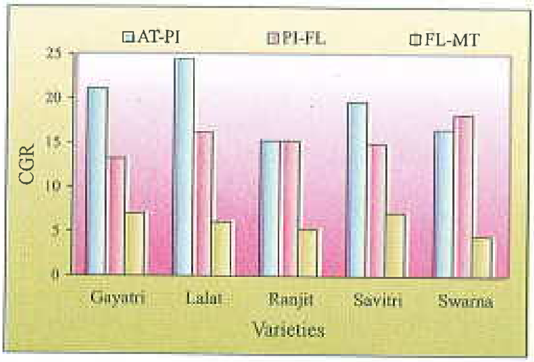
Active tillering to Panicle initation (AT-PI) and Panicle initation to Flowering (PI-FL)

Fig-16: Observed NAR of selected varieties of rice.



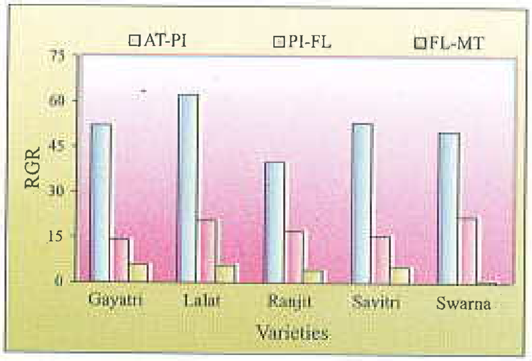
Active tillering to Panicle initation (AT-PI) and Panicle initation to Flowering (PI-FL)

Fig-17: Observed LAR of selected varieties of rice.



Active tillering to Panicle initation (AT-PI), Panicle initation to Flowering (PI-FL) and Flowering to Maturity (FL-MAT).

Fig-18: Observed CGR of selected varieties of rice.



Active tillering to Panicle initation (AT-PI), Panicle initation to Flowering (PI-FL) and Flowering to Maturity (FL-MAT).

Fig-19: Observed RGR of selected varieties of rice.

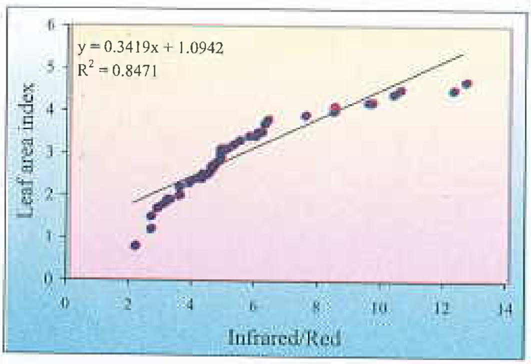


Fig-20: Relationship between IR/R and LAI.

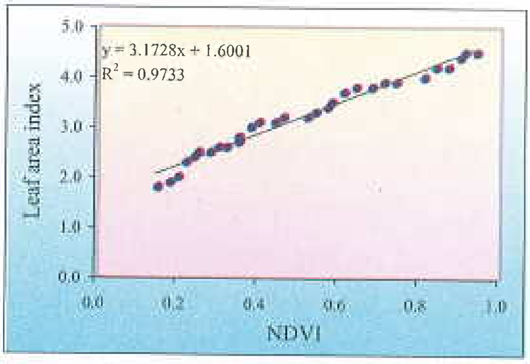


Fig-21: Relationship between NDVI and LAI.

Table 7: Correlation coefficients of crop growth characteristics and vegetation indices in rice.

Vegetation Index	Leaf Number		Leaf dry weight		LAI		AGDM		Plant Height	
	2004	2005	2004	2005	2004	2005	2004	2005	2004	2005
NDVI	0.795	0.735	0.756	0.712	0.77	0.725	0.245	0.235	0.341	0.351
SAVI	0.805	0.763	0.745	0.705	0.81	0.812	0.178	0.189	0.213	0.225
RVI	0.735	0.712	0.709	0.719	0.79	0.778	0.178	0.189	0.345	0.355
DVI	0.593	0.603	0.678	0.648	0.79	0.763	0.234	0.212	0.234	0.254
SVI	0.635	0.612	0.598	0.578	0.57	0.589	0.494	0.485	0.539	0.549
GRVI	0.703	0.698	0.601	0.612	0.49	0.487	0.451	0.467	0.212	0.292

LAI - Leaf area index; AGDM - Above ground dry matter, NDVI -Normalized Difference Vegetation Index, SAVI - Soil Adjusted Vegetation Index, RVI - Ratio Vegetation Index, DVI - Difference Vegetation Index, SVI - Sum Vegetation Index, GRVI - Green Red Ratio Vegetation Index.

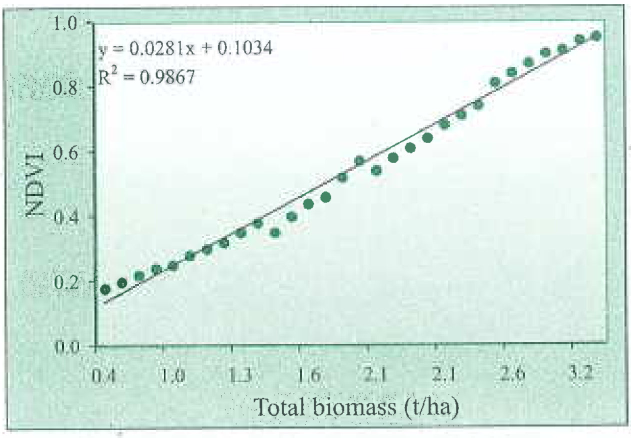


Fig-22: Relationship between NDVI and total biomass.

The temporal variation of IR/R and NDVI with leaf area index and total above ground total dry biomass (from pooled data of 2004 and 2005) are presented in Fig 20-22.

The PVI was derived as per the procedure described in the methodology and established relationship with ground cover (%) (Fig-23). For PVI computations, (red reflectance of a bare soil) and (the near infrared reflectance of a bare soil) values were assigned the values of the non-cropped plots. Regression analysis between ground cover and the PVI revealed that R^2 was 0.708.

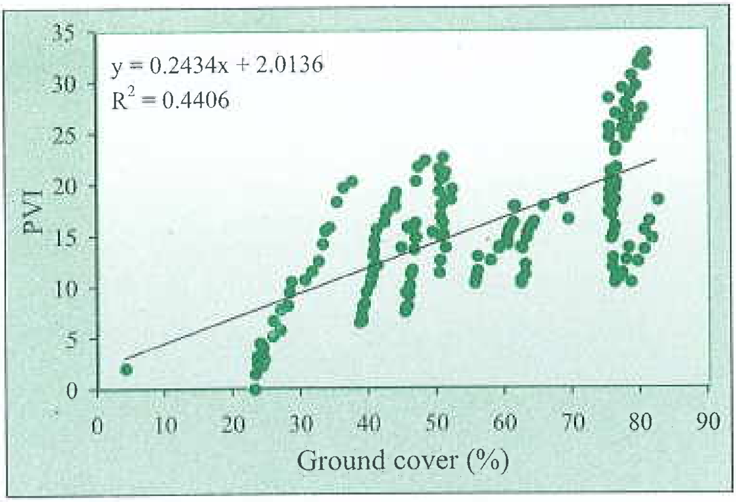


Fig-23 : Relationship between PVI and % ground cover

4.4 Spectral reflectance with different fertilizer treatments

Experimental trails with different doses of fertilizer were conducted in 8 m x 5 m plot size with the most popular long duration variety in the region i.e., "Gayatri". The variety was transplanted on 23rd July, 2004 and 25th July, 2005 in two seasons, respectively. The plant to plant distance was 15 cm and row to row distance of 20 cm was maintained. A full dose of P and K fertilizers and 1/3rd dose of N-fertilisers were applied as basal. The remaining dose of nitrogen fertilizers was applied at tillering and panicle initiation stages and applied in two equal doses. To determine grain, straw and total yield, plant samples from an area of 3.0 m x 2.0 m in the centre of each plot was harvested after maturity. The temporal variations of ratio vegetation index were studied with 3 different N doses (40, 80, 120 kg/ha) and uniform doses of P and K fertilizers (50 kg/ha). Study revealed that the higher ratio vegetation index was observed in the plots with high nitrogen dose (Fig-24). But the difference of ratio vegetation index was not statistically significant among the plots with uniform N dose and varying doses of P and K fertilizers (Fig-26).

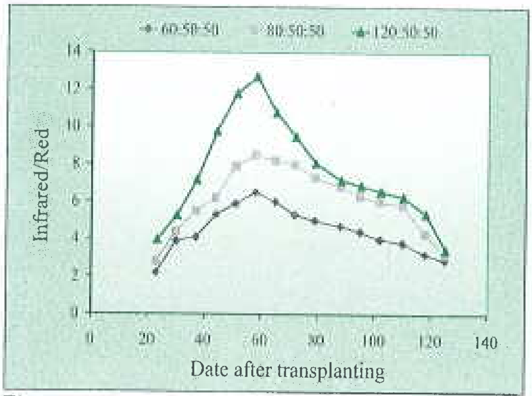


Fig-24: Temporal variation of IR/R with variable N and uniform P and K in 'Gayatri'

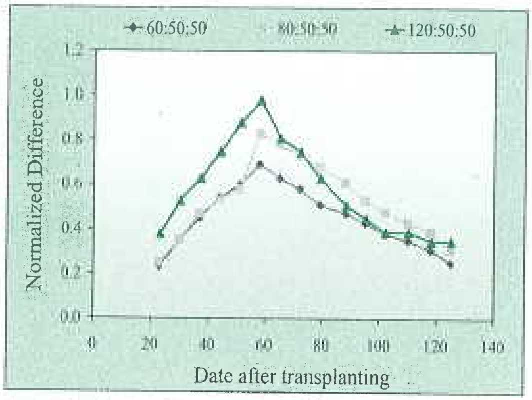


Fig-25: Temporal variation of NDVI with variable N and uniform P and K in 'Gayatri' rice.

From the study, it can be concluded that differentiation of rice varieties would be difficult using remotely sensed spectral reflectance data because all the five varieties exhibited similar temporal spectral response. It was also found that spectral reflectance values were significantly correlated with leaf growth parameters like LAI, above ground dry biomass. In regard to variation of ratio vegetation index with different types and doses of fertilizer, it was revealed that N fertilizer has a significant effect on spectral response, but spectral index was not significantly different with varying dose of P and K on soils. Similar observations were also found by Patel *et al.*, 1985.

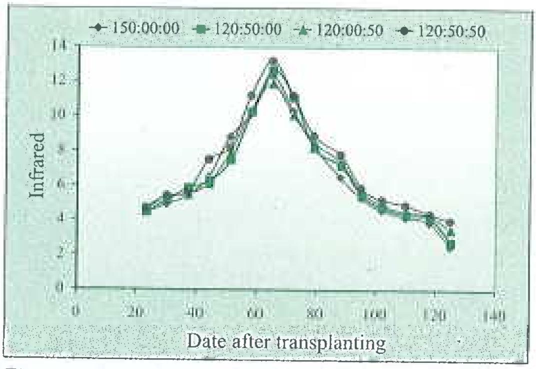


Fig-26: Temporal variation of IR/R with uniform N and variable P and K in 'Gayatri' rice.

4.5 Development of genetic coefficients of 5 rice varieties

The genetic coefficients of 5 varieties of rice were calculated for ORYZA1 model. These are DVRJ- Crop development rate during the juvenile phase $(^0Cd)^{-1}$, DVRI – Crop development rate during photoperiod-sensitive phase $(^0Cd)^{-1}$, DVRR – Crop development rate during the grain filling phase $(^0Cd)^{-1}$ and DVRP – Crop development rate during panicle development phase $(^0Cd)^{-1}$. The variations among these genetic coefficients were noted (Table-8) to calibrate and simulate the model.

Table-8: Developed genotype coefficients of different rice varieties for ORYZA1 model

Varieties	DVRJ	DVRI	DVRP	DVRR
Gayatri	0.00042	0.00076	0.00057	0.00194
Lalat	0.00055	0.00076	0.00084	0.00189
Ranjit	0.0006	0.00076	0.0009	0.00176
Savitri	0.0004	0.00076	0.00051	0.00195
Swarna	0.00042	0.00076	0.00063	0.00206

DVRJ - Crop development rate during the juvenile phase
DVRI – Crop development rate during photoperiod-sensitive phase
DVRR – Crop development rate during the grain filling phase
DVRP – Crop development rate during panicle development phase.

Table-9: Calculated fractions for biomass partitioning in ORYZA1 model.

Varieties	DVS	FLV	FST	FSO
Gayatri	0.20	0.6000	0.4000	0.0000
	0.47	0.5000	0.5000	0.0000
	0.60	0.2739	0.7261	0.0000
	0.83	0.0000	0.1486	0.8514
	1.51	0.0000	0.0000	1.0000
Lalat	0.11	0.5714	0.4286	0.0000
	0.27	0.5795	0.4205	0.0000
	0.49	0.2800	0.7200	0.0000
	0.85	0.0000	0.0351	0.9649
	1.54	0.0000	0.0000	1.0000
Ranjit	0.20	0.5556	0.4444	0.0000
	0.47	0.4793	0.5207	0.0000
	0.60	0.2107	0.7893	0.0000
	0.84	0.0000	0.1657	0.8343
	1.51	0.0000	0.0000	1.0000

Savitri	0.21	0.6000	0.4000	0.0000
	0.49	0.4868	0.5132	0.0000
	0.66	0.2232	0.7768	0.0000
	0.84	0.0064	0.2866	0.7070
	1.51	0.0000	0.0000	1.0000
Swarna	0.10	0.6667	0.3333	0.0000
	0.23	0.4538	0.5462	0.0000
	0.40	0.2869	0.7131	0.0000
	0.77	0.0000	0.4944	0.5056
	1.51	0.0000	0.0000	1.0000

DVS - Developmental stage , FLV - Fraction of leave, FST - Fraction of stem, FSO - Fraction of storage organ

Table-10 : Genotype coefficient for different rice varieties computed through CERES-Rice model.

Genetic parameter	Description	Gayatri	Lalat	Ranjit	Savitri	Swarna
P1	Time period (GDD)of basic vegetative phase	500	720	450	560	380
P2R	Extent phasic development (GDD)	50	120	149	20	150
P5	Time period (GDD) of grain filling phase	490	580	350	390	300
P2O	Critital photo period (hour)	12.5	10.5	11.7	13.5	12.8
G1	Potential spikelet number	62	65	68	60	38
G2	Single grain weight	0.026	0.028	0.023	0.025	0.021
G3	Tillering coefficient	1	1	1	1	1
G4	Temperature tolerance coefficient	1	1	1	1	1

4.6 Observed yield and its interrelationship with vegetation index

With the 80 kg. N/ha, the grain yield of 5 rice varieties were recorded and presented in Table-11 . Study revealed that medium duration variety 'Lalat' produced the yield of 4.89 t/ha, whereas, long duration variety 'Savitri' recorded the highest yield (6.24 tha^{-1}). The other three long duration varieties 'Gayatri', 'Ranjit' and 'Swarna' produced the grain yield of 5.52, 5.42 and 5.12 tha^{-1}, respectively.

The grain yield was correlated with peak IR/R and NDVI values to predict it in advance based on spectral reflectance values (pooled data of 2 years and 5 varieties). The relationships between IR/R vs grain yield and NDVI vs grain yield are presented in Fig-27 and Fig-28, respectively. Study revealed that peak NDVI values were better index to predict grain yield at least 30-40 days in advance. Agricultural efficiency of these 5 rice varieties were computed as 14.2, 11.4, 18.9, 21.7 and 27.8 for 'Gayatri', 'Lalat', 'Ranjit', 'Savitri' and 'Swarna', respectively.

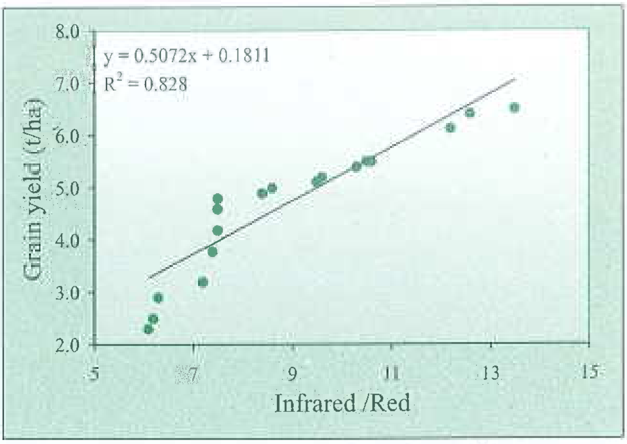


Fig-27: Relationship between peak (IR/R) and grain yield.

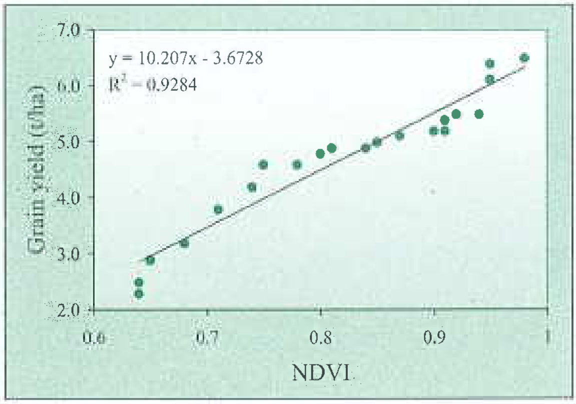


Fig-28: Relationship between peak NDVI and grain yield.

Table-11: Observed yield and yield attributes of five rice varieties (pooled data of 2004 and 2005)

Varieties	Crop Duration (days)	Plant Ht. (cm)	Panicle /m^2 (Maturity)	1000 grain weight (Maturity)	No. of grain/ panicle	Straw yield (t ha^{-1})	Agril. efficiency (Kg. Grain/ Kg. N applied
Gayatri	146	135	340	23.5	99	10.08	14.2
Lalat	119	113	422	25.6	53	7.72	11.4
Ranjit	140	123	308	19.4	107	8.47	22.6
Savitri	150	115	323	22.1	95	9.59	21.7
Swarna	134	102	337	20.7	88	6.94	27.8

Table 12: Comparison between observed and simulated dry weight of leaves at different crop growth stages

Varieties	Dry Wt. of Leaves (t/ha)											
	AT			PI			FL			MAT		
	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY
Gayatri	0.99	0.96	0.99	2.40	2.30	2.32	2.25	2.21	2.23	1.15	1.22	1.13
Lalat	1.18	1.26	1.15	2.55	2.68	2.69	2.45	2.67	2.42	1.25	1.20	1.36
Ranjit	0.95	1.01	1.01	3.10	3.26	3.04	1.92	2.09	1.90	0.81	0.78	0.81
Savitri	0.77	0.83	0.83	2.83	2.70	2.75	1.97	1.95	1.94	1.00	0.96	0.96
Swarna	0.68	0.65	0.67	2.44	2.44	2.36	2.25	2.24	2.40	0.89	0.87	0.85

OBS - Observed, CER - Simulated result of CERES-Rice, ORY - Simulated result of ORYZA1
AT - Active tillering, PI - Panicle Initiation, FL - Flowering. MAT - Maturity

Table 13: Comparison between observed and simulated stem dry weights at different crop growth stages

Varieties	Stem dry weight (t/ha)											
	AT			PI			FL			MAT		
	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY
Gayatri	0.91	0.89	0.83	4.10	3.62	3.96	7.50	6.09	7.14	5.45	5.31	5.43
Lalat	1.03	0.87	0.98	3.81	3.77	3.33	4.83	4.56	4.28	3.99	3.22	3.44
Ranjit	1.10	0.97	1.04	3.44	3.30	2.78	6.94	6.66	6.43	4.81	4.53	3.88
Savitri	0.83	0.81	0.71	4.29	4.22	4.27	7.96	7.61	7.22	5.63	5.40	4.93
Swarna	0.82	0.81	0.72	3.69	2.98	3.08	5.17	5.07	4.20	3.46	3.07	3.30

AT- Active tillering, PI - Panicle Initiation, FL - Flowering. MAT - Maturity
OBS - Observed, CER - Simulated result of CERES Rice, ORYZA1 - Simulated result of ORYZA1

Table 14: Comparison between observed and simulated panicle weight at different crop growth stages

Varieties	Panicle weight (t/ha)					
	FL			MAT		
	OBS	CER	ORY	OBS	CER	ORY
Gayatri	1.29	1.36	1.61	3.81	4.19	3.72
Lalat	1.08	1.47	1.35	3.95	3.57	3.99
Samrat	1.27	1.79	1.88	4.59	5.53	4.74
Savitri	1.10	1.45	1.60	4.30	4.11	5.00
Swarna	1.80	1.81	2.19	5.12	4.99	4.83

AT -Active tillering, PI - Panicle Initiation, FL - Flowering. MAT - Maturity
OBS - Observed, CER - Simulated result of CERES Rice, ORY - Simulated result of ORYZA1

Table 15: Comparison between observed and simulated above ground biomass of leaves at different crop growth stages

Varieties	Above ground biomass (t/ha)											
	AT			PI			FL			MAT		
	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY
Gayatri	1.90	1.86	1.82	6.50	5.92	6.28	11.04	9.57	10.75	13.66	13.43	13.38
Lalat	2.21	2.13	2.13	6.36	6.46	6.02	9.40	9.25	8.80	11.54	10.71	11.50
Ranjit	2.05	1.98	2.05	6.54	6.56	5.82	11.83	11.96	11.17	12.90	13.12	12.68
Savitri	1.60	1.64	1.54	7.12	6.91	7.02	12.45	11.97	11.86	14.58	13.96	14.46
Swarna	1.50	1.45	1.39	6.13	5.42	5.43	9.22	9.28	8.49	12.03	11.56	11.61

AT - Active tillering, PI - Panicle Initiation, FL - Flowering. MAT - Maturity

Table 16: Comparison between observed and simulated leaf area index at different crop growth stages

Varieties	Leaf Area Index											
	AT			PI			FL			MAT		
	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY
Gayatri	1.90	1.21	1.29	4.25	2.92	2.53	4.09	2.14	2.08	1.63	1.16	1.15
Lalat	2.28	1.48	1.35	3.97	2.71	2.98	3.69	2.16	2.57	1.41	1.57	1.31
Ranjit	1.97	1.13	1.32	4.39	2.39	2.84	2.65	2.43	2.23	1.62	1.32	1.24
Savitri	1.48	1.79	1.61	4.46	3.78	3.42	3.31	2.81	2.78	1.81	1.67	1.39
Swarna	1.30	1.46	1.38	3.46	2.98	3.01	3.40	2.20	2.52	1.73	1.20	1.39

AT - Active tillering, PI - Panicle Initiation, FL - Flowering. MAT - Maturity

Table 17: Comparison between observed and simulated specific leaf weight at different crop growth stages

Varieties	SLW (mg / dm^2)											
	AT			PI			FL			MAT		
	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY	OBS	CER	ORY
Gayatri	372	356	358	588	628	632	444	466	485	752	822	822
Lalat	410	395	401	515	499	510	529	573	573	704	700	766
Ranjit	386	381	413	524	570	563	442	424	423	532	517	584
Savitri	448	441	435	508	496	489	467	460	452	592	571	581
Swarna	418	403	411	503	503	500	526	559	514	581	570	560

AT - Active tillering, PI - Panicle Initiation, FL - Flowering. MAT - Maturity

Table 18: Comparison between observed and simulated grain yield of different rice varieties (Kharif 2004, Jatni, Khurda)

	Grain yield (t/ha)				
Data source	Gayatri	Lalat	Ranjit	Savitri	Swarna
Observed	5.04	4.98	6.27	6.24	5.12
CERES-Rice	4.88	5.23	6.48	6.40	5.29
ORYZA1	4.91	4.80	6.35	6.09	5.16

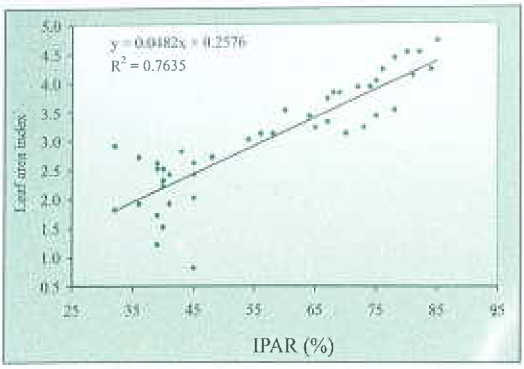


Fig-29: Relationship between IPAR and LAI

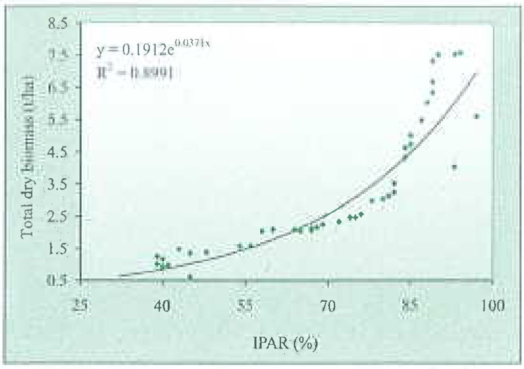


Fig-30: Relationship between IPAR and above ground biomass

4.7 Validation of observed values with simulated results

The simulated results of crop growth parameters and yields of five rice varieties with observed values are presented in tables 12-18. A detailed statistical analysis carried out with chi-square test (for observed and simulated data) with test for significance at 5% level. Different crop growth stages were taken in columns and varieties in rows for statistical analysis (Table 19 & 20). The probabilities of estimates (simulation results) were also tabulated. It was observed that dry weight of leaves (t/ha), stem weight (t/ha), panicle weight (t/ha), above ground biomass (t/ha), LAI and grain yield (t/ha) were not significant (5% level) for both CERES-Rice and ORYZA1 results with observed values. The probabilities for CERES-Rice and ORYZA1 were in the range of 0.72-1.0 and 0.82-1.0, respectively. Only Specific leaf weight (mg/dm^2) was seen to be significant for CERES-Rice and ORYZA1 with probabilities 0.02 and 0.0005 respectively. From this analysis, it is revealed that both the models can be adopted for simulation purpose with equal importance (for common model attributes) to predict crop growth parameters and yield.

Table-19 : Chi-square text between observed and simulated results through CERES-Rice

SN	Chi-square test for observed & CERES-Rice	Rows	Columns	Degrees of free dom	Chi-square values		Prob- (chi-X, df)	Signi-ficancy
					Actual	Tab- (5%,df)		
1	Wt. of Leaves (t/ha)	5-var	AT-PI-FL-MT	12	0.08238	21.02607	1.00000	Not-Sig.
2	Stem weight (t/ha)	5-var	AT-PI-FL-MT	12	0.92500	21.02607	0.99999	Not-Sig.
3	Panicle weight (t/ha)	5-var	FL-MT	4	0.10155	9.48773	0.99875	Not-Sig.
4	Above ground bio-mass (t/ha)	5-var	AT-PI-FL-MT	12	0.53474	21.02607	1.00000	Not-Sig.
5	Leaf Area Index	5-var	AT-PI-FL-MT	12	8.73124	21.02607	0.72570	Not-Sig.
6	Specific leaf weight (mg/dm^2)	5-var	AT-PI-FL-MT	12	23.72703	21.02607	0.02215	Sig.
7	Panicle weight & Grain Yield (t/h)	5-var	FL-MT-HR	8	0.13502	15.50731	1.00000	Not-Sig.

AT - Active tillering, PI- Panicle initiation, FL - Flowering, MT - Physiological maturity, HR-Harvesting

Table-20 : Chi-square text between observed and simulated results through ORYZA1.

S N	Chi-square test for observed & CERES-Rice	Rows	Columns	Deg-rees of freedom	Chi-square values		Prob-(chi-X, df)	Signifi-cancy
					Actual	Tab-(5%,df)		
1	Wt. of Leaves (t/ha)	5-var	AT-PI-FL-MT	12	0.04850	21.02607	1.00000	Not-Sig.
2	Stem weight, (t/ha)	5-var	AT-PI-FL-MT	12	1.24685	21.02607	0.99995	Not-Sig.
3	Panicle weight(t/ha)	5-var	FL-MT	4	0.17807	9.48773	0.99626	Not-Sig.
4	Above ground bio-mass (t/ha)	5-var	AT-PI-FL-MT	12	0.43106	21.02607	1.00000	Not-Sig.
5	Leaf Area Index	5-var	AT-PI-FL-MT	12	7.44443	21.02607	0.82690	Not-Sig.
6	Specific leaf weight (mg/dm^2)	5-var	AT-PI-FL-MT	12	34.67380	21.02607	0.00053	Sig.
7	Panicle weight & Grain Yield (t/h)	5-var	FL-MT-HR	8	0.19327	15.50731	1.00000	Not-Sig.

AT - Active tillering, PI- Panicle initiation, FL - Flowering, MT - Physiological maturity, HR-Harvesting

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