Journal of Agrometeorology 9(2) : 138 - 148 (Dec. 2007)

CERES-Rice model: Calibration, evaluation and application for solar radiation stress assessment on rice production

DILLIP KUMAR SWAIN*, SRIKANTHA HERATH[1], SANJOY SAHA and RABINDRA NATH DASH

Central Rice Research Institute, Cuttack-753006, India

[1]Environment and Sustainable Development, United Nations University, Tokyo, JAPAN

ABSTRACT

CERES–Rice model (DSSAT v. 4.0) was calibrated and evaluated for cultivar IR 36 at Cuttack, Orissa using experimental data of wet seasons (June-December) 2001 and 2002. The model accurately predicted phenological events i.e. flowering and maturity date. The simulated grain yield at different N levels was in close agreement with experimental grain yield. Application of the model for solar radiation stress assessment due to Atmospheric Brown Clouds on the same site during dry season (January-May) on historical weather data (1983-2002) revealed a reduction in rice grain yield by 4% with reduction of incident solar radiation by 30% under non-fertilized condition. Compared to non-fertilized condition, grain yield reduction was higher up to 12% with similar solar radiation stress under high rates of N application (120 kg N ha^{-1}). The reduction in grain yield is associated with lower grain formation.

Key words: CERES-rice model, calibration, evaluation, solar radiation stress, rice grain yield

A recent international study under the Indian Ocean Experiment (INDOEX) has revealed that a brown haze, a pollutant as a result of biomass burning and industrial emission pervaded particularly during December to April (dry season) over south Asian region and the tropical Indian Ocean, Arabian Sea and Bay of Bengal. This brown haze is named as Atmospheric Brown Cloud. The most direct effect of Atmospheric Brown Cloud is a significant reduction in the solar radiation reaching the surface, which results in reduction of agricultural productivity, reduction in the precipitation efficiency by inhibiting the formation of larger raindrop size particles, and adverse health effect (UNEP, 2002). The reduction in photo synthetically active solar radiation is a major concern to Asia, the largest agricultural continent with 60 – 90% of the world's agricultural population (Fu *et. al.*, 1998) and producer of 80 to 90% of world's rice. Data on radiation measurements over several stations in India

* Present address : IIT, Kharagpur, Email : swain@agfe.iitkgp.ernet.in

showed more than 5% reduction in global radiation during December to May (Shende & Chivate, 2000). In South Asian region, rice is mainly grown in wet season (June – December) as rainfed or irrigated and in dry season (January – May) under irrigated condition. A reduction in solar radiation during dry season due to Atmospheric Brown Cloud can affect the rice yield adversely. So, it has become imperative to assess the impact of varying solar radiation on yield of rice during dry season.

Crop simulation model is a tool for this kind of scientific endeavor. Jintrawet (1995) used the CERES-Rice model to develop a decision-support system for the fast assessment of rice-cropping alternatives in lowland areas of Thailand. The system that was evolved caters for the decision making at the farm and policy levels. In view of its potential, present investigation was attempted to calibrate and evaluate CERES-Rice model with optimization of genotype coefficients for medium duration (120 days maturity) cultivar IR 36 and to assess the impact of solar radiation stress on rice grain yield.

MATERIALS AND METHODS

CERES-rice, a dynamic crop model is based on vegetative and reproductive development, growth, water flow relationships, and soil, floodwater, and plant N dynamics (Singh, 1993; Godwin & Jones, 1991). The model simulates growth and development of a rice crop and water balance under fully flooded conditions, rainfed conditions with fluctuating water regime, and fully upland conditions where the soil is never flooded. The model operates on a daily time step. The output generated by the model could be readily analyzed using graphics and applications programs (Hoogenboom *et. al.*, 1995) available in the DSSAT. CERES-Rice of DDSAT v. 4.0 was used for this study. The minimum data requirement for the CERES-Rice model is presented in Table 1. Simulation work was done at UN University, Tokyo, Japan with field experimental data of CRRI, Cuttack.

Field experiments were conducted at the Central Rice Research Institute, Cuttack (20^0 40' N and 85^0 38' E, 300 m elevation), under rainfed lowland ecosystem during wet seasons (June – December) in 2001 and 2002 to study the effect of varying N levels (0, 40, 80 and 120 kg N ha^{-1}) on crop performance of twelve popular rice varieties of medium duration (120-130 days maturity) and late duration (140-150 days maturity) group. The most popular varieties IR 36 of 120 days maturity were chosen for the present study and the N levels selected were 40 and 80 kg N ha^{-1}, as the farmers generally use fertilizer in this range. Nitrogen was applied as urea in 4 equal splits at basal, active tiller initiation, panicle initiation and at flowering stages. The experiment was laid out in a split plot design, replicated thrice with variety in the main plot and N levels in sub plots. Phosphorus and potassium were applied uniformly at the rate of 60 kg P_2O_5 and 60 kg K_2O ha^{-1} to the puddle soil at planting. Planting was done with 30 days old seedlings at 20 cm X 15 cm spacing. Plots remained flooded up to

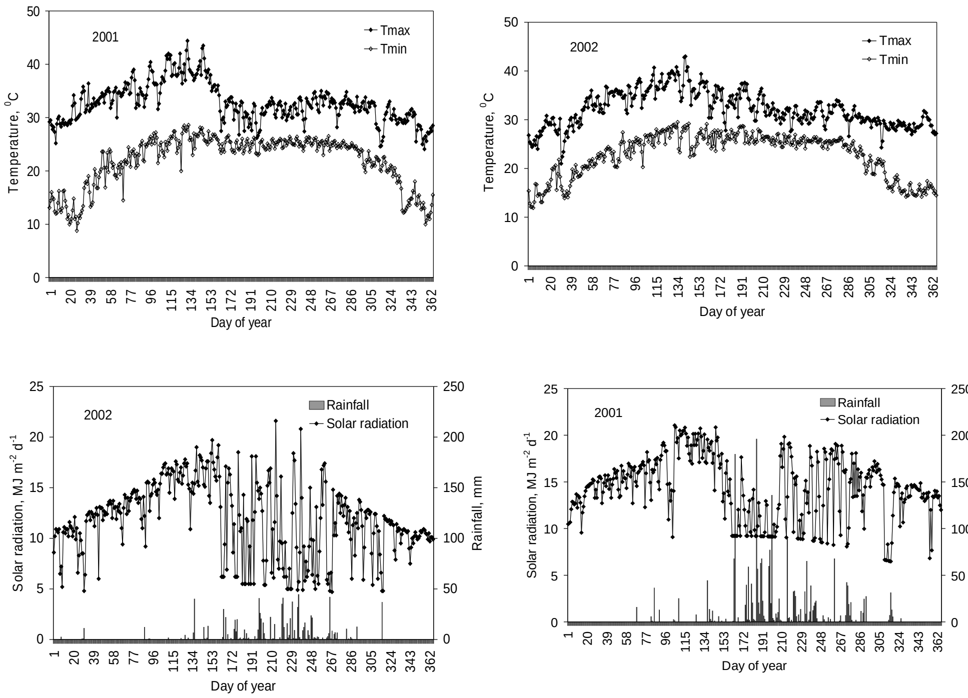

Fig. 1 : Daily rainfall, solar radiation, maximum and minimum temperature of the experimental site in India for the year 2001 and 2002

25 cm with rainwater throughout the experiment during the year 2001. Plant samples were collected at active tillering, panicle initiation, flowering and maturity stages of the variety following Thyagarajan *et al*. (1995) in order to reduce error in sampling. After collection, the plant samples were cleaned to remove surface contamination, then separated into stems (leaf sheath + stem), leaves and panicles. The samples were oven dried to stop enzymatic reactions and to remove moisture. The dry weight of the samples was recorded till constancy. The total dry matter production at all stages of crop growth was determined. The data recorded from this experiment was used for calibration of genotype coefficients.

The average rainfall of the region is 1421 mm with standard deviation of 262 mm (Directorate of Agriculture and Food Production, 2003). About 81% of the total rainfall is received during monsoon months (June to September). During the wet season 2001, the rice crop was grown without any water stress. The weather for both the years are shown in Fig. 1. Rainfall during the year 2001 was 2250 mm and during 2002, it was only 950 mm. The soil was sandy clay loam

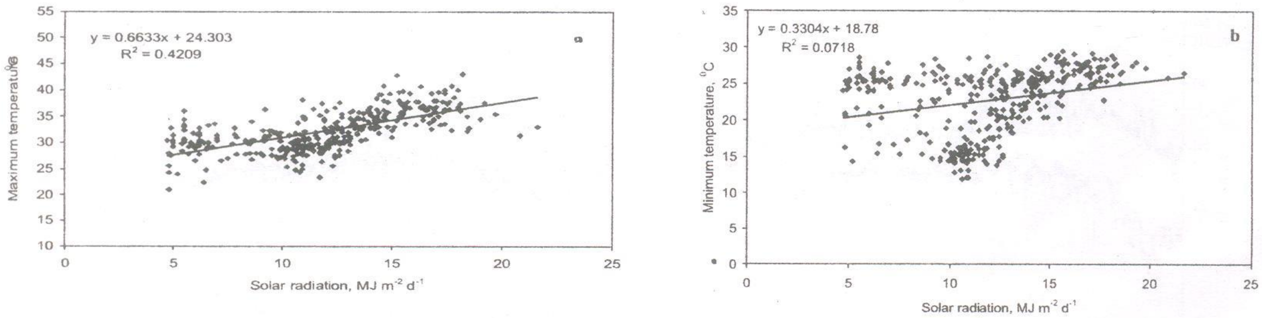

Fig. 2: Relationship between incident solar radiation and maximum temperature (a) and minimum temperature (b) averaged over 20 years (1983-2002) for the experimental site in India

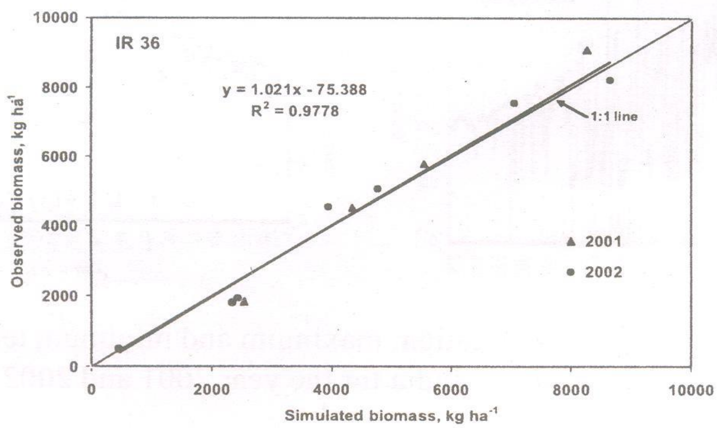

Fig. 3: Comparison of observed and simulated biomass of rice cultivar IR 36

in texture having organic carbon content 0.57 % and pH 6.2. The total N content of the soil was 0.07 %.

A graphics package (Wingraf) was enclosed in CERES model to simplify the comparison of model outputs throughout a growing season with recorded data. This package is useful for calibration of cultivar traits. The experimental data sets from an optimum N application level (80 kg N ha^{-1} recommended by Central Rice Research Institute, Cuttack, India) of the year 2001 was used for calibration of genotype coefficient of the cultivar IR 36 by 'fitting' coefficient procedure (Hunt and Boote, 1998). The calibrated genotype coefficients and their meaning are given in Table 2.

For model evaluation, a graphics package, GBuild, is available for easy comparison of model output and real data for a trait of concern. The goodness-of-fit of model output and recorded data are for comparisons that involve predictions of the time of occurrence of discrete events during the life cycle (e.g., flowering date, maturity date), or of yield or biomass at maturity. Regression analysis (Huda, 1988) was applied to a set of simulated and observed data for evaluation purpose. With such an approach, good predictability is indicated if the regression slope is near 1.0, if the intercept is close to 0, and if the R^2 value is high. The experimental data pertaining to phenological events, biomass and grain yield of the year 2001 at 40 kg N level and of the year 2002 at both N levels (40 N and 80 N) were used for model evaluation.

The model was used to simulate the effect of varying incident solar radiation levels on crop behavior of cultivar IR 36 at N application levels 0, 40, 80 and 120 kg N ha^{-1} during dry season (January-May) at Cuttack, India. Rice yield was estimated with corresponding variation in temperature. The maximum/minimum temperature and solar radiation are normally distributed and the correlation of each variable may be described by a first-order linear autoregressive model (Richardson, 1982). The relation between incident solar radiation and temperature was obtained by plotting curves (Fig. 2) for mean weather data of past 20 years (1983-2002). The relation of incident solar radiation was stronger with maximum temperature than with minimum temperature. With reduction of incident radiation by 10 %, not much variation in maximum temperature was noted. Whereas increased reduction of incident radiation by 20% and 30% decreased the maximum temperature considerably. Hence the impact of reduction in incident solar radiation was used to simulate rice grain yield. The crop was planted on 1st February 2002 using 25 days old seedling with 20 cm row spacing and planting density was 99 plants m^{-2}. The crop was irrigated as and when required.

RESULTS AND DISCUSSION

Model calibration and evaluation

The calibrated genotype coefficients for the rice cultivar IR 36 are given in Table 2. The genotype coefficients at different phases indicated that the temperature required for vegetative stage is higher than for the reproductive stage. The model was evaluated with reference to phenological occurrence of anthesis and physiological maturity days after transplantation, biomass and grain yield.

A comparison between observed and simulated phenological events (Table 3) shows that the model predicted both anthesis and maturity days almost accurately. The weather of 2002 is highly contrasted from that of 2001, with respect to quantum of rainfall received. A good match between observed and simulated phenological events in varied weather condition reflects the consistency in model performance. These predictions are important because flowering is the most critical stage of rice crop and stresses for moisture or nutrients at this stage cause massive reduction in grain yield (Saseendran *et. al.*, 1998).

Table 1: Data inputs for CERES-Rice model

Particulars	Descriptions
Weather	Daily values of maximum and minimum temperature, rainfall, and solar radiation.
Site characterization	Latitude, longitude, altitude, bare soil albedo, drainage (percolation) rate, runoff curve number
Soil characterization	Data for up to 15 layers: layer depth, organic C, volumetric moisture content at various moisture levels (the lower limit, the drained upper limit, and field saturation), bulk density, cation-exchange capacity, and rooting preference factor.
Soil fertility and soil water	Soil fertility and soil water variables for each layer in the soil profile: pH, extractable NH_4-N, NO_3-N, volumetric soil water content before the commencement of the experiment.
Crop variables	transplanting date, number of plants per hill, number hills per square meter, age of seedling, and average ambient temperature in the seed nursery.
Cultivar-specific coefficients	Thermal time (base 9°C) for the duration of basic vegetative phase (juvenile phase) and for the grain- filling duration (ripening phase), photoperiod sensitivity and critical photo period, potential spikelet number per unit of stem weight at anthesis, single grain weight under nonstressed condition, potential tillering habit, and tolerance—sensitivity to high or low temperatures.
Fertilizer management	Fertilizer data: dates, amounts, sources, method of incorporation and placement of all fertilizer applications, depth of placement where appropriate.

The time series simulated and observed top biomasses is presented in Fig. 3. The simulated biomasses were very close to observed biomasses in both the years for the cultivar IR 36. This is confirmed from the regression coefficient (b = 1.02) and R^2 value (0.98) between the observed and simulated biomass of the cultivar. Good predictability of the model is indicated as the regression slope is near to 1.0 and the R^2 value is quite high (Hunt and Boote, 1998).

A comparison of experimental and simulated grain yield at 40 and 80 kg N ha^{-1} application levels during wets seasons 2001 and 2002 is given in Table 4. The grain yield simulation by the model was within an error of 5 %. The high accuracy in grain yield predication in different weather

Table 2: Calibrated genetic coefficients for the rice cultivar IR 36 used for model evaluation and application

Genetic coefficients (abbreviations)	Value
Juvenile phase (P1), GDD	474
Critical photo period (P2O), h	11.7
Photoperiod sensitivity (P2R), GDD h^{-1}	90
Ripening phase (P5), GDD	385
Potential spikelet number (G1)	69
Single grain weight (G2), g	0.023
Potential tillering habit	1.0
Temperature tolerance	1.0

GDD, growing degree days (^{0}C)

Table 3: Comparison of observed and simulated days to anthesis and maturity after transplantation of rice cultivar IR 36 at different N application levels during wets seasons 2001 and 2002

N levels	Anthesis		Maturity	
	Observed	Simulated	Observed	Simulated
	Wet season 2001			
N_{40}	57	57	84	84
N_{80} (Calibration)	57	57	84	84
	Wet season 2002			
N_{40}	53	55	83	82
N_{80}	53	55	83	82

N_{40} and N_{80} indicate the N application levels at 40 and 80 kg per hectare

Table 4: Comparison of experimental and simulated grain yield (t ha^{-1}) of rice cultivar IR 36 at different N application levels during wets seasons 2001 and 2002

N levels	Experimental	Simulation
Wet season 2001		
N_{40}	4.36	4.41
N_{80} (Calibration)	5.43	5.66
Wet season 2002		
N_{40}	3.40	3.38
N_{80}	3.75	3.90

N_{40} and N_{80} indicate the N application levels at 40 and 80 kg per hectare

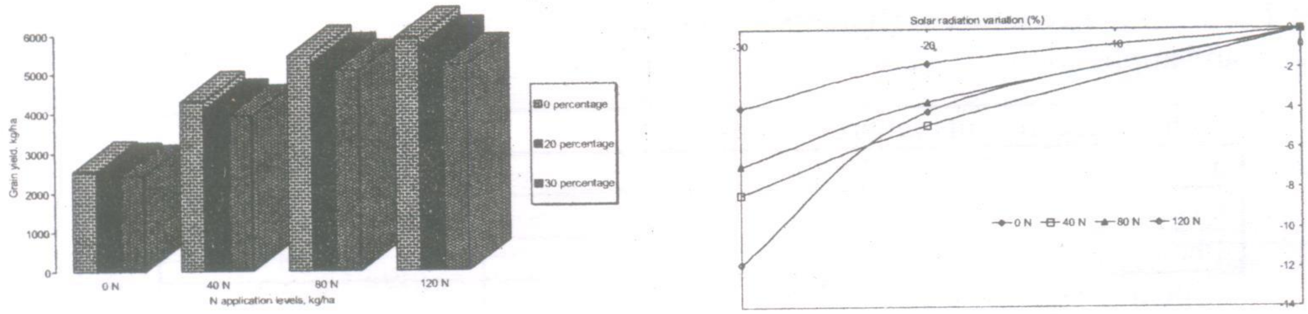

Fig. 4: Impact of reduction in incident solar radiation (0, 20 and 30 percentage) on grain yield (a) and percentage variation in grain yield (b) of rice at different N application levels (0, 40, 80 and 120 kg N ha^{-1})

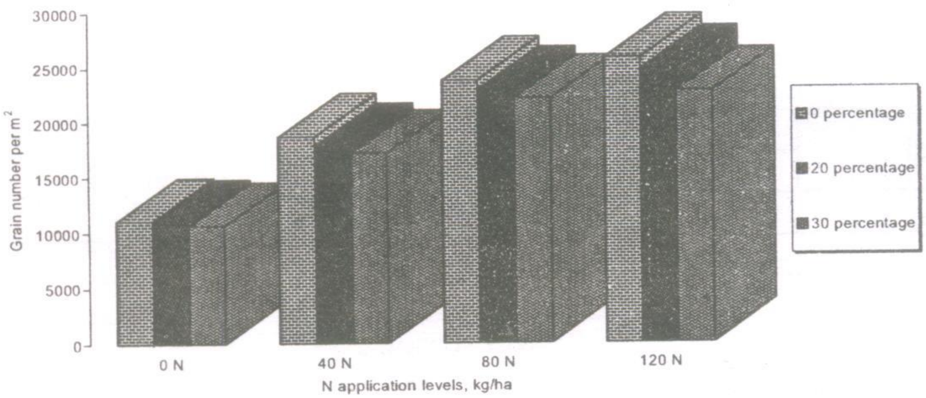

Fig. 5: Impact of reduction in incident solar radiation (0, 20 and 30 percentage) on grain number of rice at different N application levels (0, 40, 80 and 120 kg N ha^{-1})

condition emphasizes applicability of the model for climatic change scenario.

Model application

Application of model to varying incident solar radiation revealed a decrease in grain yield with increasing reduction of solar radiation by 20% to 30% as compared to that in normal radiation (Fig. 4 a and b). The intensity of effect was 2-4% under non-fertilized condition and 7-12% under fertilized condition (40-120 kg N ha^{-1}). Rice yield reduction due to incident solar radiation stress was higher with high N treated crop. This is because the canopy CO_2 assimilation is based on the light response of individual rice leaf. This response follows a saturation type of function. The light saturated rate of leaf CO_2 assimilation (A_m) varies considerably as a function of leaf age and environmental condition. A good approximation has been made to relate A_m to N concentration expressed per leaf area unit because that determined the amount of chlorophyll per unit area (Penning de Vries *et al.,* 1990). A_m varies between 10-50 kg CO_2 ha^{-1} leaf h^{-1} for rice depending on leaf N concentration and photo synthetically active radiation (PAR). For lower leaf N concentration (1.5% N), A_m reaches 10 kg CO_2 ha^{-1} leaf h^{-1} at a level of lower radiation (PAR, 250 J m^{-2} s^{-1}). However, A_m reaches 50 kg CO_2 ha^{-1} leaf h^{-1} only at a higher radiation level (PAR, 400 J m^{-2} s^{-1}). Further, intensity of reduction in A_m due to limitations in PAR is more evident at high N concentration (Ehleringer, and Pearcy, 1983). The most probable effect of limited PAR will be a substantial reduction in grain yield at high leaf N concentration as compared to lower leaf N concentration. We observed reduction in yield to the extent of 12 % at high N application rates with PAR limitations, which was due to interaction of high leaf N concentration and limited PAR. Panicle differentiation begins a 42-day critical sunlight-requiring period (Ronald and Ralph, 2002) and any variation in radiation level beyond this causes significant reduction in grain yield. The present simulation study also reflects lower grain number under incident solar radiation depletion (Fig. 5) in both fertilized and non-fertilized condition.

CONCLUSION

The CERES-Rice (DSSAT v. 4.0) was able to simulate phenological events and grain yield with high accuracy under varied weather condition. The model provides insights about the response mechanism to different N management and various weather conditions. As the CERES-Rice model is found to be capable of predicting the crop yield fairly well, it can serve as a tool in assessing yield potential of alternate technologies and management practices to avoid the yield loss due to reduced solar radiation incidence. The adaptation strategies for climatic change scenarios can be evaluated through the model.

ACKNOWLEDGEMENT

The World Bank funded National Agricultural Technology Project (Project No. NATP-RRPS 25) and Japan Society for the Promotion of Science are gratefully acknowledged for financial assistance in execution of this research work.

REFERENCES

Directorate of Agriculture and Food Production. 2003. Orissa Agricultural Statistics, 2000-2001, Directorate of Agriculture and Food Production, Orissa, Bhubaneswar, India. 3 pp.

Ehleringer, J, and Pearcy, R.W. 1983. Variation in quantum yield for CO_2 uptake among C_3 and C_4 plants. *Plant Physiol.*, 73, 555-559

Fu, C.B., Kim, J.W., and Zhao, Z.C. 1998. Preliminary assessment of impacts of global change on Asia. Asian Change in the Context of Global Climatic Change, Galloway, J. N. & Melillo, Jerry M. (Eds.), Cambridge University

Press.

Godwin, D.C., and Jones, C.A. 1991. Nitrogen dynamics in soil-plant systems. P. 287-321. In Hanks J. and Ritchie JT (ed.) Modeling plant and soil systems. Agron Mongr. 31. ASA, CSSA, and SSSA, Madison, WI.

Godwin, D., Singh, U., Ritche, J.T., and Alocilja, E.C. 1993. A User's Guide to CERES-Rice. International Fertilizer Development Centre, Muscle Shoals, AL.

Hoogenboom, G., Tsuji, G.Y., Jones, J.W., Singh, U., Godwin, D.C., Pickering, N.B., and Curry, R.B. 1995. In C. Rosenzweig et al., (ed.) Climate change and Agriculture: Analysis of potential international Impacts. ASA Spec. Publ. 59. ASA, Madison, WI, pp 51-75.

Huda, A.K.S. 1988. Simulating growth and ytield responses of sorghum to changes in plant density. *Agron. J.* 80: 541-547.

Hunt, L.A., and Boote, K.J. 1998. Data for model operation, calibration, and evaluation.. In G. y. Tsuji et al. (ed.) Understanding Options for Agricultural Production. Kluwer Academic Publishers in cooperation with International Consortium for Agricultural Systems Applications. The Netherlands. P. 9-40

Jintrawet, A. 1995. A decision support system for rapid assessment of lowland rice-based cropping alterna tives in Thailand. *Agric. Systems,* 47: 245—258.

Penning de Vries, F. W. T., Van Keulen, H, and Alagos, J.C.1990. Nitrogen redistribution and potential production in rice. In: Proceedings of the International Congress of Plant Physiology, 15-20 February1988, New Delhi, India. Eds S.K.sinha, P.V.Sane, S.C.Bhargava and P.K.Aggarwal, (Volume 1): pp 513-520

Richardson, C.W. 1982. Dependence structure of daily temperature and solar radiation. *Trans. ASAE.,* 25 (3) : 735-739

Ronald, L. Sass, and Cicerone, Ralph J. 2002. Photosynthate allocation in rice plants: Food production or atmospheric methane? *Proc. Nat Acad Sci, USA.* 99 (19):11993-11995.

Saseendran, S.A, Singh, K.K., Rathore, L.S., Rao, G.S.L.H.V.P., Mendiratta Nisha, Lakshmi Narayan K., Singh, S.V. 1998. Evaluation of the CERES version 3.0 model for the climate conditions of the state of Kerala, India. *Meteorol. Appl.* 5: 385-392

Shende, R.R., and Chivate, V.R. 2000. Global and diffuse solar radiant exposures at Pune. *Mausam,* 51:349-358.

Singh, U. 1993. Nitrogen management strategies for lowland rice cropping system. P. 110-130. In Proc. Ini. Conf.

on Fertilizer Usage in the Tropics, Kuala Lumpur, Malaysia, 24-27 Aug. 1992. Malaysian Society of Soil Science, Kuala Lumpur, Malaysia.

Stansel, J.W. 1975. In Six Decades of Rice Research in Texas (Texas Agricultural Experiment Station, College Station)

Thiyagarajan, T.M., Sivasamy, R., and Budhar, M.N. 1995. Procedure for collecting plant samples at different growth stages of transplanted rice crop. In SARP Research Proceedings: Nitrogen management studies in irrigated rice by Thiyagarajan *et al.* (ed). International Rice Research Institute, Los Banos, Philippines, 18 April – 6 May, 1994, pp 99-102.

Uehara, G. and Tsuji, G.Y. 1993. The IBSNAT project. In Penning de Vries *et al.*, (ed.) Systems approaches for agricultural development. Kluwer Academic Publ., Dordrecht, the Netherlands. p. 505-513

UNEP. 2002. Report commissioned by United Nations Environment Programme, Nairobi, Kenya, pp 1.