ORIGINAL RESEARCH ARTICLE OPEN ACCESS

A Web-based Radiation Use Efficiency calculator for Rice Genotypes

Sailaja B*, Voleti SR, Subrahmanyam D, Raghuveer Rao P, Gayathri S and Sudha Madhuri M

Indian Institute of Rice Research, Rajendranagar, Hyderabad-500030
*Corresponding author (Email ID: b.sailaja@icar.gov.in)

Received: 11th March 2020; Accepted: 15th May 2020

Abstract

Radiation Use Efficiency (RUE) is one of the key parameters in measuring the crop biomass and plays a major role in assessing the yield performance of genotypes. RUE can be derived from radiation interception and utilization. Manual process of computing Photosynthetically Active Radiation (PAR) and RUE is tedious and only limited models are available exclusively for computing radiation use efficiency of rice crop. Hence a web-based Radiation Use Efficiency Calculator was developed for Rice genotypes and successfully evaluated with data collected from field trials conducted under All India Coordinated Rice Improvement Programme (AICRIP). Computed RUE values ranged from 0.47-0.87 g/MJ^{-1} at panicle initiation stage and 3.91-5.21 g/MJ^{-1} at maturity stage for the experiment conducted at IIRR, Hyderabad. This software got registered with the copyright no. SW/13541/2020 and presently available to all users in the IIRR website (www.icar-iirr.org) for facilitating computation of RUE at different phenological stages of rice crop.

Key words: Radiation, rice, web based calculator, genotype, software

Introduction

Rice is the most important staple food crop in India feeding more than half of the population. Rice yields need to increase further to meet the substantial increase in demand of the rapidly increasing population. It is well known that accumulated intercepted radiation and radiation use efficiency (RUE) are key indicators for determining crop biomass (Monteith *et al.,* 1977). Many crop growth models use Radiation use efficiency (RUE) parameter to simulate photosynthesis *i.e* converting light energy and CO_2 into biomass. RUE is a key quantifier of crop production in relation to photosynthesis. It combines both the amount of solar radiation captured by the crop and the efficiency of the crop to produce dry matter. It helps in understanding and modelling the relationship between plant growth and the physical environment. Huang *et al*. (2019) indicated that higher RUE rather than accumulated intercepted radiation contributed more to yield improvement. More importantly, the relative contribution of RUE to yield improvement is growth stage dependent because RUE is not consistent during the whole crop growth period (Yonghui Pan *et al.,* 2019). Hence it is necessary to elucidate the crucial growth stage related with rice yield and to understand the relative contribution of RUE to yield improvement. The process of computing daily total radiation, photosynthetically active radiation (PAR) and measuring the fraction of crop intercepted radiation and calculating RUE at different stages of rice crop is cumbersome and time taking. In view of this, efforts were made to develop a web based radiation use efficiency calculator to facilitate easy computation of RUE at different stages of rice crop.

Materials and Methods

Crop growth can be described as the product of the incident Photosynthetically Active Radiation (PAR); the fraction (f) of PAR intercepted by green leaf (*f*); and the 'efficiency' with which the PAR is used as Radiation Use Efficiency (RUE). The PAR intensity depends on the location and time of the year while seasonal *fraction (f)* is affected by the duration and the area of the canopy. Radiation Use Efficiency (RUE) is defined as the ratio of dry matter produced to absorbed photosynthetically active radiation (APAR Mega Joules-MJ/m^2). It is usually measured in grams of total dry matter per megajoule (g TDM MJ^{-1}). The formulae used for computing Radiation Use Efficiency (Bouman *et al*., 2001) at different stages of rice crop are presented in the table 1.

Table 1: Formulae used to compute Radiation Use Effciency(RUE)

Variable	Formula
RUE at Maturity (RUE_{Mat} g/ MJ^{-1})	TDM_{Mat} / ∑APAR from sowing day to maturity TDM: Total Dry Matter
RUE from Panicle Initiation to Maturity ($RUE_{PI\ to\ Mat}$ g/ MJ^{-1})	TDM_{PI-Mat} / ∑APAR from PI to maturity
RUE at Panicle Initiation	TDM_{PI} / ∑APAR from sowing day to maturity
Absorbed Photosynthetically Active Radiation(APAR MJ/m^2)	PAR*40%
Photosynthetically Active Radiation (PAR MJ/m^2)	Shortwave radiation(TMPR1)*fraction of PAR (0.5)
Short wave radiation (TMPR1)	RDD*SINB*(1.0+0.4*SINB)/DSINBE SinB : Actual effective sine of solar inclination
Daily integral of sine of solar angle (DSINB)	2.*3600.*(DAYL*0.5*SINLD-12.*COSLD*ZZCOS/PI)
Daily integral of effective SINB (DSINBE)	2.*3600.*(DAYL*(0.5*SINLD+0.2*SIN-LD**2+0.1*COSLD**2) - & (12.*COSLD*ZZ-COS+9.6*SINLD*COSLD*ZZCOS+ & 2.4*COSLD**2*ZZCOS*ZZSIN)/PI)
Solar Constant (SOLCON)	1370.*(1.+0.033*COS (2.*PI*DOY/365.))
Daily total extraterrestrial radiation (ANGOT- J m^{-2})	SOLCON*DSINB
Declination of Sun (DEC)	-ASIN (SIN (23.45*DEGTRAD)*COS (2.*PI*(DOY+10.)/365.)) Constants: PI=3.1415927, DEGTRAD=0.017453292
Intermediate Variables	SINLD = SIN (DEGTRAD*LAT)*SIN (DEC)
	COSLD = COS (DEGTRAD*LAT)*COS (DEC)
	AOB = SINLD/COSLD
Day Length (DAYL - h)	DAYL = 12.*(1.+2.*ASIN (AOB)/PI)
Intermediate Variable(ZZA)	ZZA = PI*(12+DAYL)/24
Cosine of ZZA(ZZCOS)	ZZCOS = COS (ZZA)
Sine of ZZA(ZZSIN)	ZZSIN = SIN (ZZA)
Daily Total Radiation(RDD kJ m^{-2} d^{-1})	S_0*(a_A+b_A*(sh/day length) Sh: daily sunshine hours S_0 is the theoretical amount of global radiation without an atmosphere (kJ m^{-2} d^{-1}) a_A and b_A are an empirical constants Angstrom A & B parameters

These calculations involve some empirical relationships that calculate the day length and the integral of the sine of the solar angle from the day number and latitude (Goudriaan and van Laar 1994). First, the declination (DEC) is calculated from the day number. Then, the intermediate variables SINLD, COSLD, AOB, ZZA, ZZCOS and ZZSIN are calculated to make the other equations simpler. Appropriate corrections to the daylength (DAYL) and intermediate sine and cosine variables are made by checking the geographic latitude (LAT) within or below the polar circles through AOB. After this, two versions of the integral of the sine of the solar elevation are calculated: the first (DSINB; s d−1) is the straightforward integral of the sine of the solar angle used to calculate daily total extraterrestrial radiation (ANGOT; J m−2 d−1); the second one (DSINBE; s d−1) is a modified integral for radiation at Earth's surface, which takes into account the effect of the daily course in atmospheric transmission. DSINBE is used to calculate the actual radiation at a specific time of the day. The solar constant (SOLCON; W m−2) is calculated as a function of the day number because the distance between Earth and the sun is not constant over the year.

In the present study, daily sunshine hours (sh) were used to compute daily total radiation (RDD kJ m^{-2} d^{-1}). Shortwave radiation was calculated by the product of daily total radiation with the ratio of actual effective sine of solar inclination (SinB) over the integral of effective SINB (DSINBE). Fraction of PAR was calculated from the fraction of diffused radiation which is derived from the atmospheric transmission. This radiation flux at Earth's surface (assuming 100% atmospheric transmission) was calculated from the solar constant, which is the radiation flux perpendicular to the sun rays, multiplied by the sine of the solar inclination (SinB), which changes during the day. APAR (MJ/m^2) and RUE (g/ MJ^{-1}) at different phenological stages of rice crop *i.e* Panicle Initiation (PI), PI to maturity and maturity period were computed using the formulae given in table 1. As there are many intermediate calculations to compute RUE, a software was developed to computer variety-wise and replication-wise RUE at PI, PI to maturity and maturity stages of rice crop.

This software was developed using Microsoft Structured Query Language (MS SQL) as backend and .NET as front end. Three input and one output interfaces were designed. Input interfaces are location and sowing details interface, replication wise grid interface and weather data interface. One output interface was designed to display the variety-wise computed values of RUE and APAR.

Results and Discussion

RUE main interface (**Figure 1**) prompts for location, year and date of sowing, sowing level (Early, Medium and late sowings) and number of replications and number of varieties in each replication of the trial.

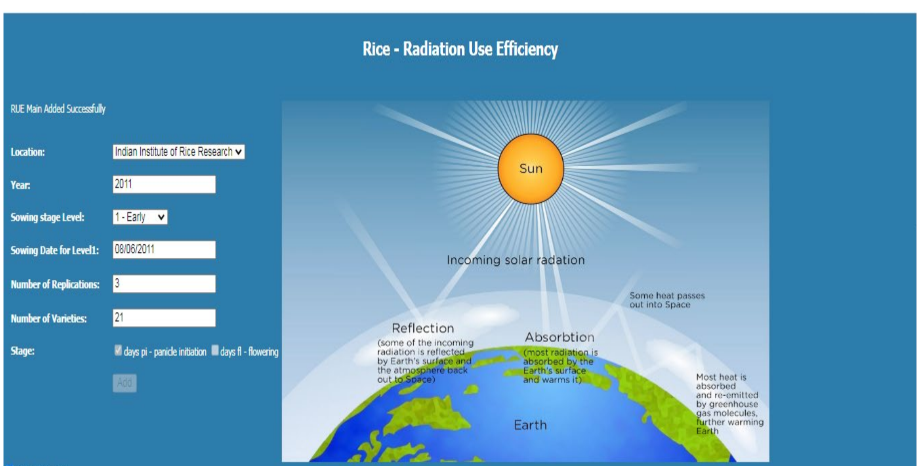


Figure 1: Location and Sowing details interface of Web based RUE

There are two options for stages of crop like panicle initiation and flowering. If user check the boxes then only next screen prompts for the data pertaining to the particular stage, otherwise it will prompt for data at maturity. Immediately after this screen prompts for number of days to maturity stage and total drymatter weight(TDM) to compute Radiation use efficency along with opted details for opted crop stages.

Following this, replication-wise grid interface will be displayed to enter the replication data (**Figure 2**). Another provision is also provided to paste the data using '***copy from excel***' check box. Using the '***Add RUE Details'*** button, the data will be saved in the RUE database.

In sequence with this, weather data interface prompts for day-wise sunshine hours from sowing to maturity (**Figure 3**). Here also '***copy from excel***' provision is available to paste the data from excel. By using ***ADD Weather data***, the data will be inserted in the weather table of RUE database.

Then by using the ***Calculate Result*** command button**,** APAR and RUE at different stages will be computed and displayed in the grid **(Figure 4).**

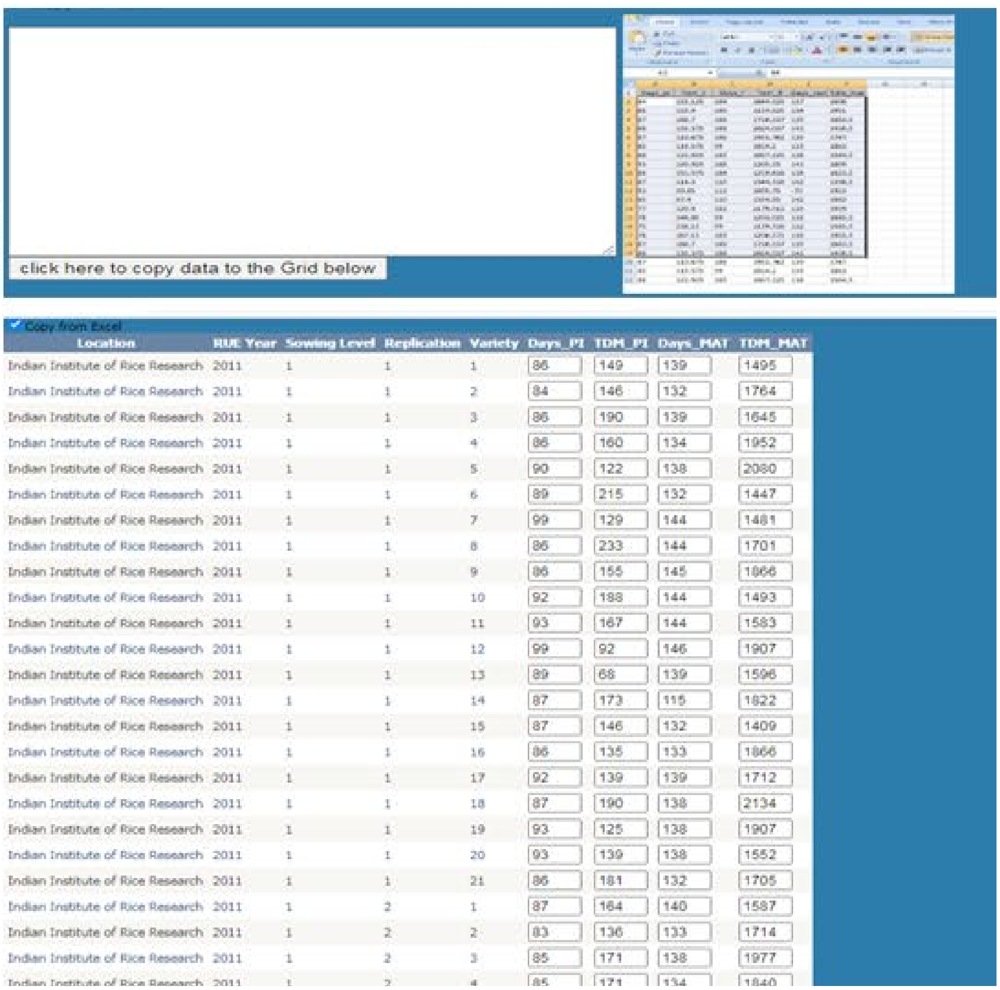


Figure 2: Replication wise grid interface of web based RUE

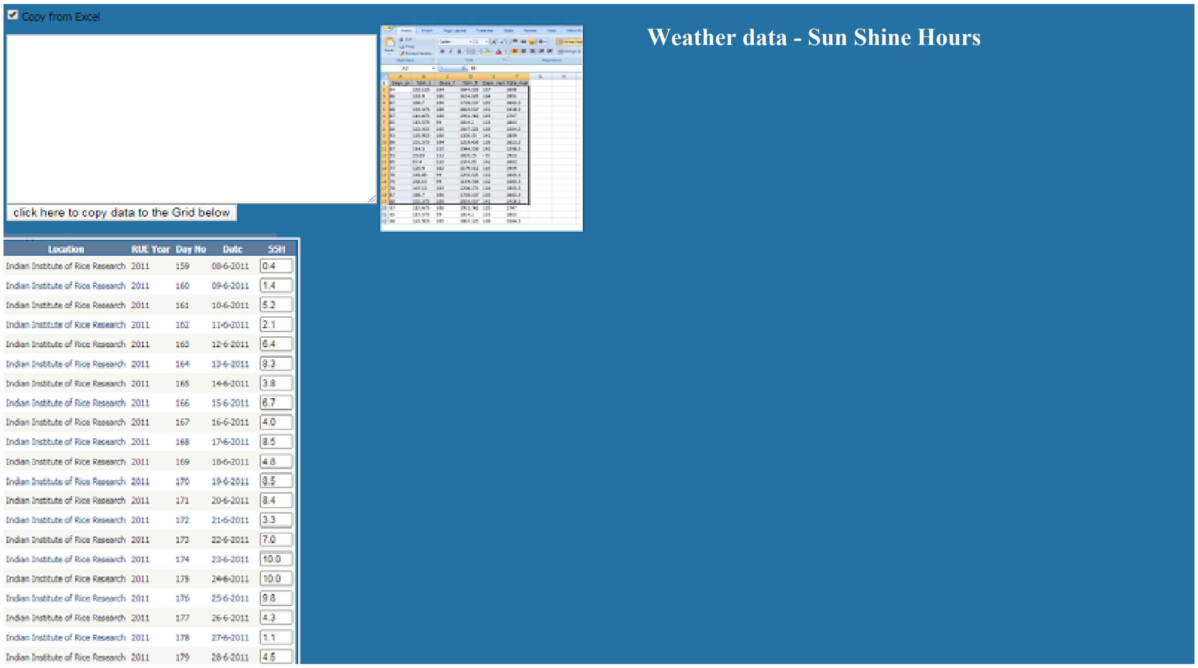
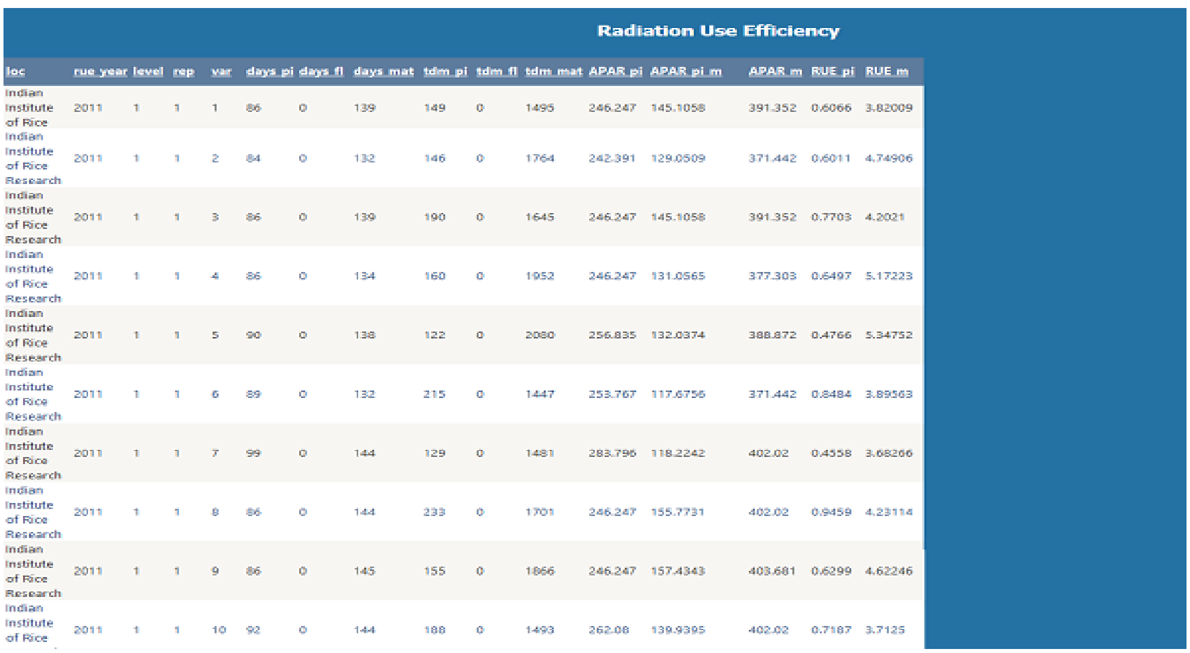


Figure 3: Weather data interface of Web based RUE



Radiation Use Efficiency

loc	rue_year	level	rep	var	days_pi	days_fl	days_mat	tdm_pi	tdm_fl	tdm_mat	APAR_pi	APAR_pi_m	APAR_m	RUE_pi	RUE_m
Indian Institute of Rice	2011	1	1	1	86	0	139	149	0	1495	246.247	145.1058	391.352	0.6066	3.82009
Indian Institute of Rice Research	2011	1	1	2	84	0	132	146	0	1764	242.391	129.0509	371.442	0.6011	4.74906
Indian Institute of Rice Research	2011	1	1	3	86	0	139	190	0	1645	246.247	145.1058	391.352	0.7703	4.2021
Indian Institute of Rice Research	2011	1	1	4	86	0	134	160	0	1952	246.247	131.0565	377.303	0.6497	5.17223
Indian Institute of Rice Research	2011	1	1	5	90	0	138	122	0	2080	256.835	132.0374	388.872	0.4766	5.34752
Indian Institute of Rice Research	2011	1	1	6	89	0	132	215	0	1447	253.767	117.6756	371.442	0.8484	3.89563
Indian Institute of Rice Research	2011	1	1	7	99	0	144	129	0	1481	283.796	118.2242	402.02	0.4558	3.68266
Indian Institute of Rice Research	2011	1	1	8	86	0	144	233	0	1701	246.247	155.7731	402.02	0.9459	4.23114
Indian Institute of Rice Research	2011	1	1	9	86	0	145	155	0	1866	246.247	157.4343	403.681	0.6299	4.62246
Indian Institute of Rice	2011	1	1	10	92	0	144	188	0	1493	262.08	139.9395	402.02	0.7187	3.7125

Figure 4: Interface of Web based RUE to display computed values of RUE and APAR

It was evaluated with six years' data of the Radiation Use Efficiency experiment conducted under All India Coordinated Rice Improvement Programme (AICRIP). The input dataset of RUE experiment under AICRIP during 2011 conducted at IIRR, Hyderabad and computed values of RUE using this software. It was observed that computed RUE values ranged from 0.47-0.87 g/MJ^{-1} at PI stage and 3.91-5.21 g/MJ^{-1} at maturity stage and RUE values were high at PI stage compared to maturity stage (**Table 2**).

The software was specifically designed to compute Rice genotype-wise radiation use efficiency at different phenological stages of rice crop for different locations spread across India.

Table 2: Computed values of RUE using web based RUE calculator

		Input				Output				
S. No	Varieties	Days _pi	Days_m at	TDM_t(g/ m^2)	TDM_mat(g/ m^2)	APAR_pi(MJ/m^2)	APAR_pi _m (MJ/m^2)	APAR_m (MJ/m^2)	RUE_pi (g/MJ^{-1})	RUE_m (g/MJ^{-1})
1	IET 20524	86	140	192.08	1661.50	246.25	146.23	393.21	0.78	4.22
2	IET 20556	83	134	174.34	1788.17	239.53	133.90	374.39	0.73	4.78
3	IET 20924	85	139	213.36	1739.50	244.32	145.56	390.53	0.87	4.46
4	IET 20935	85	136	174.30	1951.17	244.32	134.25	379.21	0.71	5.14
5	IET 21519	90	140	141.00	1957.17	256.83	133.86	389.67	0.55	5.02
6	IET 21528	90	139	180.95	1658.00	256.83	124.22	380.03	0.71	4.36
7	IET 21542	99	142	137.85	1708.17	283.80	117.89	400.85	0.49	4.26
8	IET 22202	85	140	191.38	1779.50	244.32	152.69	397.66	0.78	4.48
9	IET 22218	86	139	181.18	2078.83	244.32	153.24	399.57	0.74	5.21
10	IET 22225	93	145	187.34	1577.50	264.63	139.35	403.13	0.71	3.91
11	IET 22228	93	144	178.87	1597.67	268.00	137.67	402.57	0.67	3.97
12	IET 22237	96	147	127.78	1760.00	256.83	132.11	406.09	0.47	4.34
13	IET 22251	89	144	148.88	1604.83	253.77	141.26	394.08	0.59	4.08
14	KRH-2	86	136	143.68	1719.33	244.32	115.03	361.36	0.58	4.80
15	PA-6129	86	134	178.10	1721.83	246.25	129.02	375.35	0.72	4.58
16	PA-6201	86	136	168.95	1794.50	244.32	131.92	378.25	0.69	4.75
17	PA-6444	93	145	177.33	1791.83	264.63	134.73	398.51	0.67	4.50
18	PHB-71	86	136	162.81	1789.00	246.25	139.95	386.93	0.66	4.62
19	AK.DHAN	93	142	137.19	1835.00	262.08	128.94	393.84	0.52	4.66
20	NDR-359	93	142	136.00	1731.00	264.63	130.06	393.84	0.52	4.39
21	VARADH AN	86	136	155.95	1650.67	248.42	129.96	376.29	0.63	4.39
	Min	**75**	**73**	**127.78**	**1577.50**	**239.53**	**115.03**	**361.36**	**0.47**	**3.91**
	Max	**93**	**143**	**213.36**	**2078.83**	**283.80**	**153.24**	**406.09**	**0.87**	**5.21**

RUE declined as LAI increased, and it decreased significantly after anthesis (Colin et al., 2001). Raghuveer Rao et al (2012) reported that RUE values at PI and maturity stages ranged from 0.24-2.36 g/MJ-1 at IIRR, Hyderabad location. RUE values computed using this model were well in agreement with reported values in the literature (Zhang et al., 2009). However, this model needs to be calibrated and validated to use for other crops like wheat, maize etc. This software got registered with the copyright no. SW/13541/2020.

Rice genotypes can be assessed easily for efficient RUE and yield at different stages of rice crop using this software. The software prompts for minimum input parameters and facilitates the computation of RUE across locations at different stages of rice crop. The data generated by this software can be easily copied to excel and can be used for further statistical analysis with other datasets. This software is easily understandable and user friendly.

References

Bouman BAM, Kropff MJ, Tuong TP, Wopereis MCS, Ten Berge HFM and van Laar HH. 2001. ORYZA 2000: Modeling lowland rice., International Rice Research Institute, Philippines and Wageningen University and Research Center, Wageningen,235p.

Colin S Campbell, James L Heilman, Kevin J McInnes, Lloyd T Wilson, James C Medley, Guowei Wu and Douglas R Cobos. 2001. Seasonal variation in radiation use efficiency of irrigated rice. *Agricultural and Forest Meteorology,* 110 (2001) 45–54

Goudriaan J and van Laar HH. 1994. Simulation of crop growth processes. Dordrecht (Netherlands): Kluwer Academic Publishers. 238 p.

Huang L, Yang D, Li X, Peng S, Wang F. 2019. Coordination of high grain yield and high nitrogen use efficiency through large sink size and high post-heading source capacity in rice. *Field Crops Research,* 233, 49–58.

Monteith JL. 1977. Climate and the efficiency of crop production in Britain. 1977. *Philosophical Transactions of the Royal Society, London,* Series B, 281: 277–294. https://doi.org/10.1098/rstb.1977.0140

Raghuveer Rao P, Sailaja B, Subrahmanyam D, Nageswar Rao D, Voleti SR, Satya Narayana Reddy P and Sudarshana Rao GV. 2012. Variable radiation use efficiency in rice cultures grown at different locations. *Indian Journal of Plant Physiology,* 17(1): 57-60.

Yonghui Pan, Shuai Gao, Kailiu Xie, Zhifeng Lu, Xusheng Meng, Shiyu Wang, Jianwei Lu and Shiwei Guo. 2019. Higher radiation use efficiency produces greater biomass before heading and grain yield in super hybrid rice. *Agronomy*, 10: 209.

Zhang Y, Tang Q, Zou Y, Li D, Qin J, Yang S, Chen L, Xi B. and Peng S. 2009. Yield potential and radiation use efficiency of "super" hybrid rice grown under subtropical conditions. *Field Crops Research,* 114**:** 91–98.