Journal of Agrometeorology 18 (2) : 190-195 (December 2016)

Radiation utilization efficiency and surface energy exchange of winter maize (*Zea mays* L.) under different irrigation regimes

GOURANGA KAR and ASHWANI KUMAR

Indian Institute of Water Management, Bhubaneswar, Orissa, India
Email: kar_wtcer@yahoo.com

ABSTRACT

Knowledge of resource capture particularly, energy, nutrients and radiation by crop species under different management practices helps in improving productivity of any crop.Growth and yield of any grain crop are largely determined by intercepted photosynthetically active radiation (IPAR), the efficiency of conversion of it into dry matter (RUE) and partitioning of dry matter to grain. In this investigation IPAR, RUE andenergy flux of the winter maize were studied and relationships were established among biomass, yield, RUE and IPAR under different irrigation (120, 180, 240, 300, 360 mm) and nitrogen (30, 60, 90, 120, 150 kg ha^{-1}) levels. Simulation models that rely on RUE for biomass accumulation can use these relationships for predicting biomass and yield of the crop. The RUE of the crop ranged from 1.01 to 2.16 g MJ^{-1}under different irrigation and nitrogen levels whereas, latent heat flux varied with the growth stages and values ranged between 8.64 to 18.77 MJ m^{-2} day^{-1}.

Key words: Light interception, radiation use efficiency, maize, water productivity, surface energy balance

The productivitypotential of winter maize in eastern India is high but abiotic stresses like moisturedeficit owing to meager and erratic winter rainfall and lack of irrigation water limit the crop productivity(Kar *et al.* 2004).Deficit irrigation and sub-optimal nutrient doses create water and nutrient stress and can reduce radiation interception, efficiency of conversion and partitioning of dry matter to grain (Kar *et al.* 2005; Figuerola and Berliner, 2006; Kar *et al.* 2013). As a result, yield components like ear size, number of kernel per year, the kernel weightand productivity of the maize are reduced (Jamma and Ottaman, 1993; Traore *et al.* 2000. Claassen and Shaw (1970) observed that stress before or during silking and pollination (pre-anthesis period) resulted in reduced kernel number, while stress during or after silking reduced kernel weight. An increase in nitrogen concentration at anthesis can result in an increase of LAI by as much as 62% and IPAR by up to 20% (Salvagiotti and Miralles, 2008). Improved biomass andgrain yield would depend on the capacity to improve the amount of photosynthetically active radiation intercepted by the crop or the efficiency with which the canopy converts that radiation into new biomass (RUE) at different stages of the crop (Tesfaye *et al.* 2006;Acreche and Slafer, 2009). In addition to the radiation interception, understanding the surface energy balance and latent heat flux will provide information on crop water requirement and can be used as an effective tool for irrigation scheduling in dry season crop (Figuerola and Berliner, 2006, Kar and Kumar, 2009).

Though some works have been done on radiation interception and RUE of maize in different parts of the world, still there is a paucity of information in regard to the effects of irrigation and nitrogen in combination on light inteception, RUE and growth of the crop. Keeping the importance of those factsin view, research was conducted to study the IPAR and RUE at different growth stages of the crop under different irrigation (120 mm, 180 mm, 240 mm, 300 mm, 360 mm) and nitrogen (30, 60, 90, 120, 150 kg ha^{-1}) levels. Latent heat flux and other components of energy balance were computed to assess the crop water requirements at different stages of the crop under different irrigation levels. Due to limitation in instrumental facilities, the measurements were confined to plots with 120 mm, 240 mm, 300 mm and 360 mm irrigation under 120 kg ha^{-1} nitrogen only.

MATERIALS AND METHODS

The on-farm experiment was conducted during two winter seasons (2007-08 and 2008-09) at Bhuasuni watershed of Dhenkanal district, Orissa, India (Latitude 28^{0}60$^{/}$ North and Longitude of 85^{0}57$^{/}$ East). The soils within the experimental area was found to be relatively homogeneous and soil texture was sandy loam to clay loam in nature where clay content varied from 21.9 % at 0.30-0.45 m soil depth to 34.5 % at 0.90-1.20 m depth. Maize composite (cv. Novjyot) was sown on 23rdNovember, 2007 and 25th November 2008in split plot arrangement with 6 irrigation treatments in main plots and 5 nitrogen treatments in sub-plots. The crop was

Table 1: Irrigation treatment for the field experiments during 2007-08 and 2008-09

Stages	Description	**Irrigation treatments**					
		I_1	I_2	I_3	I_4	I_5	I_6
Stage 0	Period of germination of seed in the soil	X	X	X	X	X	X
Stage 1	Emergence of coleoptile from the soil and seedling growth up to 3 leaves unfolded	X	X	X	60	60	60
Stage 2	Stem elongation (1): Internodes below 5th, 6th, and 7th leaves have begun to elongate	60	60	60	X	X	X
Stage 3	Stem elongation (2): 8 to 11 leaves unfolded, stem elongation rapidly, internodes below 5th and 6th leaves are fully elongated	X	X	X	60	60	60
Stage 4	Stem elongation (3): 12 to 15 or more leaves unfolded, stem still elongates, emergence of tassel from the whorl	60	X	60	60	60	60
Stage 5	Flowering (start of pollen shedding, 50% pollen shedding, 50% silking, end of flowering)	X	60	60	X	60	60
Stage 6	Water ripe stage of caryopsis, start of silk drying	X	60	60	60	60	60
Stage 7	Milk ripe stage (milk to solid conversion of endosperm, but whole kernel content is still milky liquid)	X	X	X	60	X	60
Stage 8	Dry ripe stage (kernel is no longer milky, reached physiological maturity)	X	X	X	X	X	X
Stage 9	Ripeness	X	X	X	X	X	X
Total irrigation during crop growth (mm)		120	180	240	300	300	360

X = No irrigations were applied, values are in mm

sown on 0.60 m spaced ridges keeping plant to plant distance of 0.30 m using a seed rate of 25 kg ha^{-1}.The plot sizes were 4 x 3.5 m^2 and were separated by distance of 1.0 m within the blocks. Dyke height of 0.20 m were built around each plot to retain and prevent runoff/spill over the water applied. The 6 irrigations treatments were phenological based irrigation scheduling (Groot et al. 1986) (I_1 = 120 mm at stage 2, stage 4 ; I_2 = 180 mm at stage 2, stage 5, stage 6, I_3 = 240 mm at stage 2, stage 4, stage 5, stage 6 ; I_4 = 300 mm at stage 1, stage 3, stage 4, stage 6, stage 6 ; I_5 = 300 mm at stage 1, stage 3, stage 4, stage 5, stage 6 ; I_6 = 360 mm at stage 1, stage 3, stage 4, stage 5, stage 6, stage 7) (Table 1). The nitrogen treatments were: N_1= 30 kg N ha^{-1}, N_2= 60 kg N ha^{-1}, N_3 = 90 kg N ha^{-1}; N_4 = 120 kg N ha^{-1}; N_5 = 150 kg N ha^{-1}. In all cases nitrogen was applied in 3 split doses. The dates of important phenological stages, the leaf area index, above ground biomass, yield and yield components were recorded under different treatment. The crop was harvested at physiological maturity. Intercepted photosynthetically active radiation (IPAR) and radiation utilization efficiency (RUE) were measured following earlier methodologies (Kailasanathan and Sinha, 1984;Kar *et al,* 2013).Bowen ratio (b) energy balance method was used to quantify latent heat flux and other energy balance parameters (Kar and Kumar, 2007).The statistical analyses of yield data, which includedanalysis of variance (ANOVA) wasdone usingthe SAS 2.0 statistical software.

RESULTS AND DISCUSSION

Intercepted photosynthetically active radiation (IPAR) and radiation utilization efficiency (RUE)

The peak IPAR, RUE and crop productivity related parameters are presented in Table-1.The IPAR at different phenological stages as influenced by irrigations and nitrogen rates are presented in Fig. 1. Averaged across the years and nitrogen levels, lowest peak intercepted PAR was 66.6% for the I_1which was statistically significant from IPAR of I_2 (77.0%), I_3 (81.0%), I_4 (85.0%), I_5 (88.0%) and I_6 (89.0%) treatments. The I_5 and I_6 recordedpeak IPAR statistically at par.Averaged over irrigation levels, nitrogen rates significantly affected the amount of radiation intercepted.

Table 2: Crop growth and productivity related parameters as influenced by irrigation regimes and nitrogen rates (Pooled data of 2 years)

Factors	Biomass at harvest (kg ha^{-1})	Peak LAI	Grain yield (kg ha^{-1})	H.I.(%)	Grain no.	1000 grain weigh(g)	Peak IPAR(%)	RUE (g MJ^{-1})
I. Irrigation treatments								
I_1	^{E}6393	^{D}3.25	^{E}2129	^{B}33.31	^{E}1049	^{E}203	^{E}66.6	^{E}1.07
I_2	^{D}7161	^{C}4.07	^{D}2490	^{B}34.77	^{D}1142	^{D}218	^{D}77.0	^{D}1.18
I_3	^{C}10430	^{B}4.32	^{C}3553	^{B}34.07	^{C}1487	^{C}239	^{C}81.0	^{C}1.72
I_4	^{B}10980	^{B}5.39	^{B}3785	^{B}34.47	^{C}1545	^{B}245	^{B}85.0	^{B}1.83
I_5	^{A}12300	^{A}5.42	^{A}4534	^{A}37.94	^{B}1821	^{A}249	^{A}88.0	^{A}2.01
I_6	^{A}12700	^{A}5.53	^{A}4675	^{A}37.40	^{A}1870	^{A}250	^{A}89.0	^{A}2.05
Significance	**	**	**	NS	**	**	**	**
II. Nitrogen treatments								
N_1	^{D}6400	^{E}3.45	^{D}2295	^{A}35.86	^{E}977	^{C}235	^{D}67.8	^{D}1.01
N_2	^{C}7768	^{D}4.22	^{C}2714	^{B}34.94	^{D}1150	^{C}236	^{C}78.1	^{C}1.16
N_3	^{B}10040	^{C}4.83	^{B}3319	^{B}33.06	^{C}1406	^{B}236	^{B}83.3	^{B}1.74
N_4	^{A}12700	^{A}5.55	^{A}4385	^{B}34.53	^{B}1812	^{A}242	^{A}89.9	^{A}2.14
N_5	^{A}13100	^{A}5.65	^{A}4525	^{B}34.54	^{A}1870	^{A}242	^{A}91.2	^{A}2.18
Significance	**	**	**	NS	**	**	**	**
Interaction: Sowing dates × Irrigation:	NS	NS	NS	NS	NS	NS	NS	NS

** Significant at 5% probability level, NS = Non significant at 5% probability level. The values in the column followed by same letters are not significant at 5% level of significance based on Duncan's' Multiple Range Test (DMRT).

The minimum peak intercepted PAR (67.8 %) was achieved with N_1 (30 kg N ha^{-1}). The crop with N_5treatment recorded peak IPAR of 91.2 (Table 2). The increase in IPAR with higher level of irrigations and nitrogen rates was due to better crop growth, which gave maximum plant height, LAI and total dry matter.

The relationship between total biomass production and accumulated APAR was established to derive radiation utilization efficiency and showed the linear relationship between total biomass production and accumulated APAR with the R^2 value of 0.86. Maximum RUE (in terms of total biomass) under different irrigation regimes and nitrogen treatments are presented in Table 2. Among irrigation treatments, highest RUE of 2.05 g MJ^{-1}was obtained in case of I_6 but it was statistically at par with I_5 which recorded RUE of 2.01 gMJ^{-1}. Other irrigation treatments were significantly different in respect of RUE (Table 2). Averaged over irrigation treatments, RUE of 1.01, 1.16, 1.74, 2.14 and 2.18 gMJ^{-1}were recorded in N_1, N_2, N_3, $N_4$and N5, respectively, which were statistically significant. Interaction between irrigation and nitrogen treatment was found to be non-significant on IPAR and RUE.

Radiation utilization efficiency of different phenological stages was also computed and is presented in Fig. 2(a) and 2(b). The RUE was found to be higher at dry ripe stage (kernel is no longer milky, reached physiological maturity) and did not reduce during seed filling stages in case of non-stressed irrigation and nitrogen treatments (I_3, I_4, I_5, I_6 and N_3, N_4 and N_5) but the generality of this phenomenon remains to be tested. On the other hand, in case of in irrigation and nitrogen stressed plots (I_1, I_2 and N_1, N_2), RUE was higher in milk ripe stage (milk to solid conversion of endosperm, but whole kernel content is still milky liquid) and reduced during grain filling stage. This might be attributed to the reduced seed weight and grain number in case of water and nitrogen stressed plots ((I_1, I_2 and N_1, N_2), where partitioning of photosynthates towards grain is less and limits the RUE. It appears from our study that, under optimal growth conditions where assimilate supply is likely maintained approximately equal to its demand crop growth

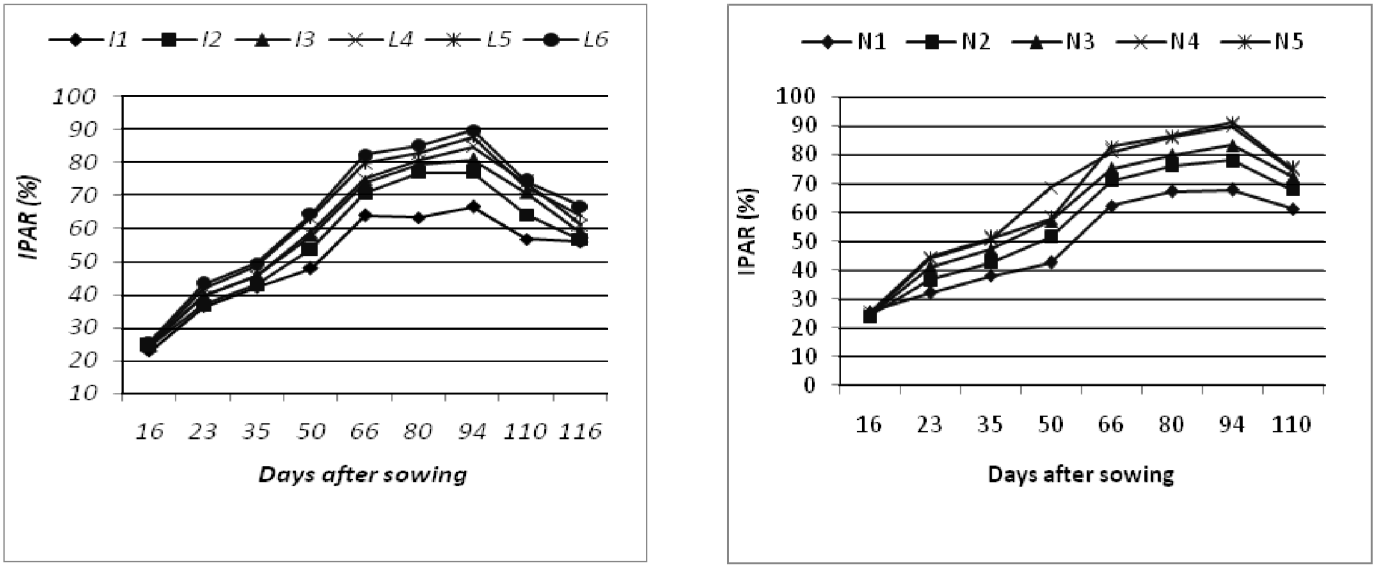

Fig. 1: IPAR (%) at different days after sowing as influenced by (a) irrigation regimes (b) nitrogen application rates

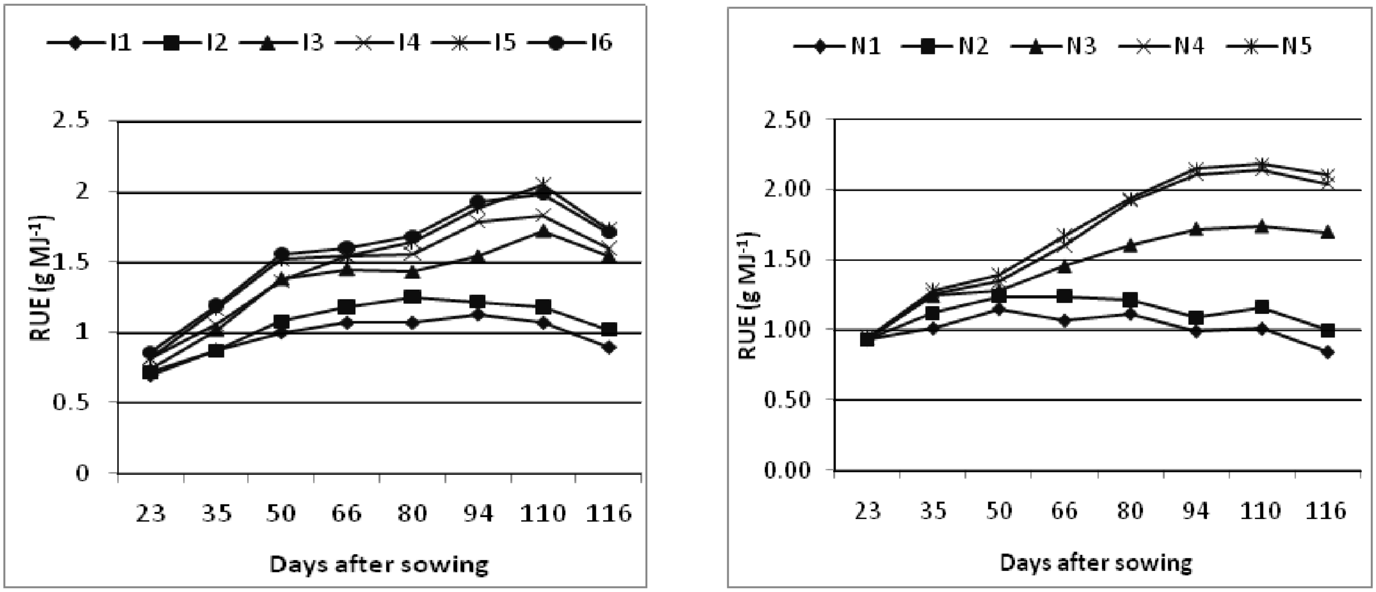

Fig. 2: Radiation utilization efficiency of maize as influenced by (a) irrigation regimes (b) nitrogen application rate

rate was optimized and RUE did not decline. Similar findings were made by Rajcan and Tollenaar(1999).

Surface energy balance

The seasonal variation of surface energy fluxes over maize crop stand during two crop growth seasons (2007-08 and 2008-09) were measured at 7-10 days interval and mid day average value of 10.00-15.00 hour are depicted in Fig. 3 (a,b,c,d) . Due to instrumentation limitation, measurements were restricted to I_2, $I_{3,}$ $I_{5,}$ I_6plots under N_5nitrogen treatments only (120 kg N ha^{-1}) to study the variation of surface energy fluxes under different irrigation regimes. Study revealed that average net radiation (R_n), i.e., amount of energy available for physical or biological processes over the crop varied from 17.09to 21.3 MJ m^{-2} day^{-1} in different irrigation treatments during crop growth period.

The latent heat flux (LE) the most important component of energy balance for irrigation management was largely dependent on development of leaf area index (LAI) and soil moisture content and showed peak when LAI was maximum. The midday average latent heat flux (on clear days) varied from 6.89to 15.30 MJ m^{-2} day^{-1} at different growth stages in I_2. Whereas, in I_3, LE ranged between 7.76 MJ m^{-2} day^{-1} to 16.77 MJ m^{-2} day^{-1}at different growth stages. In I_5 treatment LE varied from 7.98 to 16.58 MJ m^{-2} day^{-1} and in I_6, LE ranged between 8.19 to 17.86 MJ m^{-2} day$^{-1.}$ The LE variation over the crop stand during different growing

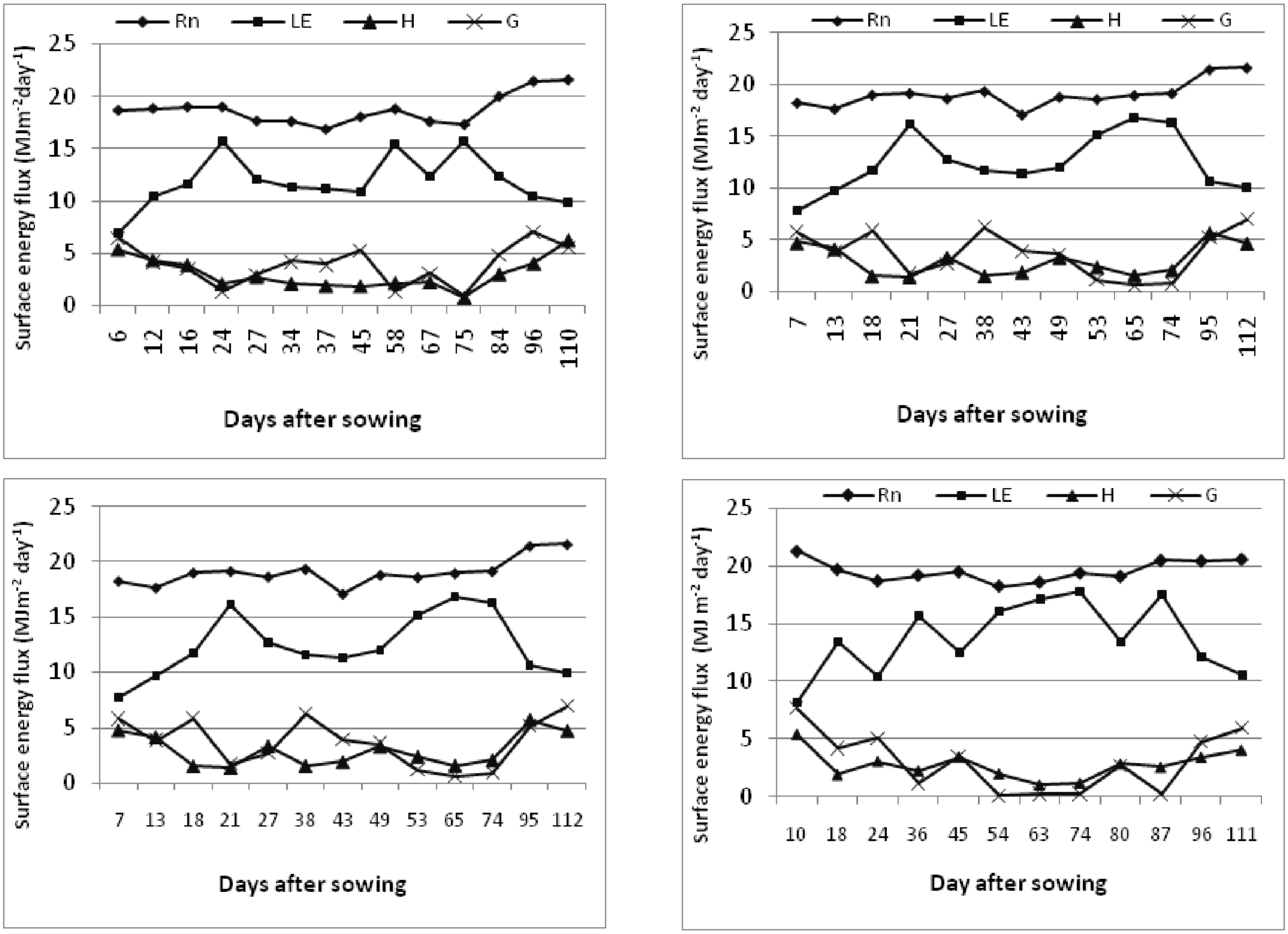

Fig. 3: Surface energy fluxes of maize with (a) three irrigations (I_2) (b) four irrigations (I_3) (c) five irrigations (I_5) (d) six irrigations (I_6)

periods mainly occurred due to variation of solar radiation, temperature, vapour pressure deficit and soil moisture during the crop seasons. The LE by the crop increased immediately after application of irrigation water because of availability of soil moisture to evapo-transpire. Less LE was recorded when the crop was at early stage and it increased with increasing the leaf area index of the crop.

The seasonal course of soil heat flux (G) of crop revealed that variation of 'G' during growth seasons clearly reflected the change of crop growth. The 'G' showed peak value during early vegetative and maturity periods when crop coverage was minimum and soil was dry. Afterwards, the course of 'G' was affected by development of crop canopy or leaf area index. Midday averaged 'G' value of crop stand ranged from 0.75 to 8.1 MJ m^{-2} day^{-1} at different growth stages and seasons and 'G' reduced drastically with the application of irrigation water. The ratio of G/R_n from maximum LAI to senescence stage was found to be 6.8-14.8 % over the crop. Soil heat flux showed declining trend during peak growth stage which coincided with maximum leaf area index (LAI) or maximum intercepted photosynthetically active radiation (IPAR). In general, where water did not limit the transpiration and when soil was wet, latent heat flux consumed most of the energy from net radiation. As the soil dried, water became less available for evapo-transportion and the energy was utilized for heating the soil (soil heat flux) or heating the air (sensible heat flux).

CONCLUSION

Improved biomass depended on the capacity to improve the amount of photosynthetically active radiation intercepted by the crop or the efficiency with which the canopy converts that radiation into biomass (radiation use efficiency) under optimum nitrogen and irrigation regimes.Post-anthesis RUE of the crop in irrigation (I_1, I_2) and nitrogen stressed plots(N_1, N_2) was decreased by reducing the sink size which recorded lower number of grains per m^2. Therefore, increase in grains per unit area and grain size could permit to improve yield via increases in post-anthesis RUE in non-stressed plots when assimilate supply is likely maintained approximately equal to its demands.It is concluded that attainment of high LAI that intercepts and converts radiation into dry matter efficiently, and partitioning of the dry matter to the seed is the major requirement to attain higher yield. Regarding surface energy balance, when water did not limit the transpiration and the soil was wet, latent heat flux consumed most of the energy from net radiation. As the soil dried or in water stressed plots less water became available for evapotranspiration and net radiation was mostly utilized for heating the soil (soil heat flux) or heating the air (sensible heat flux).

REFERENCES

Acreche, M.M. andSlafer, G.A.(2009). Grain weight, radiation interception and use efficiency as affected by sink-strength in Mediterranean wheat released from 1940 to 2005. *Field Crops Res.,* 110 (2): 98-110.

Claassen, M.M. and Shaw, R.H.(1970). Water deficit effects on corn. II. Grain components.*Agron. J.,*62: 652–655.

Figuerola, P.I. andBerlinger, P.R. (2006).Characterization of the surface layer above a row crop in the presence of local advection.*Atmosfera,* 19: 75-108.

Groot, J.J.R., Kropff, M.J.,Vossen, F.J.H., Spitters, C.J.T. andRabbinge, R.(1986).A decimal code for the developmental stages of maize and its relation to accumulated heat units.*Netherlands J. Agric. Sci.,* 34: 67-73.

Jama, A.O. andOttman, M.J.(1993). Timing of the first irrigation in corn and water stress conditioning. *Agron. J.,*85: 1159–1164.

Kailashnathan, K. and Sinha, S.K. (1984). Radiation, productivity potential and actual biology yield at Delhi.*Proc. Indian Nat. Sci Acad. B-46,* 5: 688-693.

Kar, G., Singh, R. andVerma, H.N.(2004). Alternative cropping strategies for assured and efficient crop production in upland rainfed rice areas of eastern India based on rainfall analysis. *Agric. Water Manag.* , 67(1): 47-62.

Kar, G., Verma, H.N. and Singh, R.(2005). Effects of winter crop and supplemental irrigation on crop yield, water use efficiency and profitability in rainfed rice based cropping system of eastern India. *Agric. Water Manag.*, 79(3): 280-292.

Kar, G. andKumar, A. (2007). Surface energy fluxes and crop water stress index in groundnut under irrigated ecosystems. *Agric. Forest Meteorol.*, 146 (1-2): 94-106.

Kar, G. andKumar, A. (2009). Surface energy fluxes and crop water stress index in groundnut under irrigated ecosystems. *Agric. Forest Meteorol.,* 146 (1-2), 94-106.

Kar, G., Kumar, A., Sahoo, N. and Mohapatra, S. (2013). Radiation utilization efficiency, latent heat flux, and crop growth simulation in irrigated rice during post-flood period in east coast of India. *Paddy Water Environ.*, 12 (2): 285-297.

Rajcan, I. andTollenaar, M.(1999). Source: sink ratio and leaf senescence in maize: I. Dry matter accumulation and partioning during grain filling. *Field Crop Res.*, 60: 245-253.

Salvagiotti, F. and Miralles, D.J.(2008). Radiation interception, biomass production and grain yield as affected by the interaction of nitrogen and sulfur fertilization in wheat. *European J. Agron.,* 25: 282-290.

Tesfaye, K., Walker, S. andTsubo, M.(2006).Radiation interception and radiation use efficiency of three grain legumes under water deficit conditions in a semi-arid environment.*European J. Agron.,* 25 (1): 60-70.

Traore, S.B., Carlson, R.E., Pilcher, C.D. and Rice, M.E.(2000).Bt and Non-Bt maize growth and development as affected by temperature and drought stress. *Agron. J.,* 92: 1027–1035.

Received : March 2014 ; Accepted : October 2016