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Radiation Use Efficiency in Different Row Orientation of Maize (*Zea mays* L.)

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Abstract: An experiment was conducted at the Field Laboratory of Department of Environmental Science, Bangladesh Agricultural University, Mymensingh, Bangladesh to evaluate the radiation use efficiency (RUE) in different row orientation of maize, to determine parameters affecting RUE and to make a comparison of results of the study with previous results observed at different location of the world. The dry weight was taken at 7 days interval by destruction of five plants and kept them oven drier at 80^{o}C for 48 hours and it was expressed as gm^{2}. Dry matter accumulation values at different dates of sampling were regressed with the corresponding cumulative intercepted PAR values and the slope of the regression line was then taken as RUE. The efficiency of radiation utilization varies throughout the crop life cycle. Radiation use efficiency (RUE) was positively correlated to leaf area index (LAI), leaf chlorophyll content, extinction coefficient (k), incident radiation and total solar period of crops and negatively correlated to water stress and light reflection. RUE was highest in vegetative stage, where RUE was higher (0.89 gMJ^{-1} PAR) in N-S row orientation than E-W row orientation (0.75 gMJ^{-1} PAR), after that RUE decreased gradually in tasseling stage. Again RUE was slightly increased during maturity. RUE of maize was almost similar with the findings of other researchers and it ranged from 0.85 to 1.5 gMJ^{-1}, it was due to similar plant architecture and stand duration.

Key words: Maize, Radiation, Use efficiency

Introduction

Maize (*Zea mays* L.) is the only member of the genus Zea under the family Graminae. It is one of the most efficient crops which can give high biological yield as well as grain yield in relatively short period of time due to its unique photosynthetic mechanism (Hatch and Stack, 1996). The performance of maize crop depends on many factors like genetic potential, environmental condition, micrometeorological and agronomy practices. Solar radiation and soil temperature are two vital environmental factors regulation as well as reproductive growth of maize. The yield of maize may be increased by regulating the soil temperature and interception of solar radiation through the suitable row orientation.

Solar radiation interception, penetration and albedo were affected by row orientations (Baten and Kon, 1997). Lower albedo was found at smaller solar zenith (noon hours) or higher sun elevation because of the trapping of reflected radiation beneath the canopy (Millar, 1959; Graham and King, 1961).

At low solar elevation angles on 35^{o}46″ N latitude, penetration of solar radiation is larger at the soil surface between N-S rows that of E-W rows (Baten and Kon, 1997).

The arrangement, shape and number of leaves in plant canopy affect the penetration, interception, distribution, and reflection of light (Blad and Leumer, 1979). Larger interception of light on crop canopy with smaller mutual shading produces high harvest index (Donald and Hamblin, 1976; Monteith, 1977).

The concept of radiation use efficiency (RUE) has been widely used in crop growth analysis-Warren Wilson (1967) introduced the relationship between crop growth rate and the amount of intercepted solar radiation is defined as RUE.

Radiation use efficiency (RUE), a concept employed initially in crops research, is the amount of biomass produce (gm^{-2}) per unit of intercepted solar radiation (MJ^{-1}m^{-2}) (Monteith, 1977).

RUE varies within a species on the light saturated rate of leaf photosynthesis (Sinclair and Horie, 1989). RUE of most crop species under well-watered conditions is constant throughout most of the growth and unaffected by aerial environment (Muchow *et al.*, 1993).

RUE is now central component of current empirical models of crop growth analysis. Over the last 25 years, considerable attention has been focused on addressing the issue of RUE in most agricultural crops and forest stands, as a tool for biomass production (Sinclair *et al.*, 1992). Proper manipulation of microclimate through suitable row orientation could improve the growth and yield of crops (Kler *et al.*, 1992).

The studies concerning radiation use efficiency by any plant had been conducted so far in Bangladesh were on single direction, i.e. North-South or East-West. But this study is the first approach to measure radiation use efficiency in different direction i.e. North-South and East-West.

Considering the above facts, the present study was under taken with a view to evaluate the following objective.

1. To compare the radiation use efficiency in different row orientation of maize.

Materials and Methods

Investigation of radiation use efficiency in different row orientation over maize was carried out at the field laboratory of the Department of Environmental Science, Bangladesh Agricultural University, Mymensingh. In this chapter, the details of different materials used and methodologies followed during the experimental period are described under the following heads.

Plant material used

Maize var. Barnali was used as test crop in experiment. Barnali is a high yielding variety developed by the Bangladesh Agricultural Research Institute (BARI) in 1986.

Experimental Details

Maize was grown as sole crop in E-W and N-S row orientation and the plot size was 10 m × 1 m.

Instruments Settings and Measurement of Micrometeorological Parameters

Pyranometer

Three Pyranometers (K91025 Japan) were placed in soil surface between two rows of E-W and N-S to measure averaged penetration of solar radiation below the maize canopy, following Baten *et al.* (1996). To measure, global solar radiation ($Rs\downarrow$) over the canopy, long iron bar was placed at the center of tower and Pyranometer (K91026, Japan) were set on the bars at 180 cm height above the soil surface. Pyranometer (K92016, Japan) were set inversely on the bars at 180 cm height above the soil surface to measure the reflected solar radiation over maize field.

PAR Sensor

To measure global, penetrated and reflected light intensity three PAR sensors were used. PAR (EKOS91023.120) was placed at soil surface, PARQ23553 LICOR was placed, above the canopy and PARS91023.117 was set inversely at 180 cm above the soil surface to obtain penetrated, global and reflected light intensity respectively. These locations were carefully selected to measure averaged data and data were recorded at 15 minutes intervals by computer controlled Data logger, CR10X, USA.

In addition, intercepted PAR (PAR) was determined at about weekly interval by the following equation:

IPPA = PRA [1-exp (-k × LAI)] .... (1)

Where, IPAR = Intercepted Photosynthetically Active Radiation

PAR = Incident Photosynthetically Active Radiation

K = Extinction Coefficient

LAI = Leaf Area Index

Fractional intercepted and reflected photosynthetically active radiations were determined by using the following equation:

$$fIPAR = IPAR/PAR_0 \quad \text{....................} \quad (2)$$

$$fPAR_R = PAR_R/PAR_0 \quad \text{..................} \quad (3)$$

Calculation of different PAR and calculation of Radiation Use Efficiency (RUE)

Different fractions PAR

For each set of measurement, the different fractions in relation to incident radiation were calculated as:

Fraction PAR transmitted $\left(fT_{PAR}\right) = \frac{T_{PAR}}{\varphi}$

Fraction PAR reflected $\left(f\ R_{PAR}\right) = \frac{R_{PAR}}{\varphi}$

Fraction PAR intercepted ($f\ I_{PAR}$) = 1 - $f\ T_{PAR}$

Fraction PAR absorbed ($f\ A_{PAR}$) = $f\ I_{PAR} - f\ R_{PAR}$

Radiation Use Efficiency (RUE)

The radiation use efficiency was calculated by the following formula (Monteith, 1977):

$$e_i = \frac{DM}{\int_{t1}^{t2} \alpha f 1(\beta Rs)dt}$$

Where,

e_i is the radiation use efficiency (RUE; the subscript i denotes `the experimental treatments), the variable t, including the integration limits (t_l and t_2) represented times of the growing season.

f_I is a function of canopy development and stand duration including the fraction of radiation intercepted by the stand canopy, i.e. intercepted solar radiation (Wm^{-2})

α, the canopy absorptivity for PAR, i.e. absorbed PAR (Wm^2)

$$\beta = \frac{PAR}{Rs} = 0.45$$

= 0.45 × Rs, here Rs (Wm^{-2}) denotes daily averaged global solar radiation.

Finally, crop Radiation Use efficiency (RUE) was obtained as the slope of the linear regression between cumulative biomass and cumulative intercepted radiation in gMJ^{-1}.

Morphological and Physiological attributes

Plant height and canopy width were measured with measuring scale in cm.

Total Dry Matter (TDM)

For the determination of dry weight five random plants were selected and its leaves, stems and roots were separated then kept it on oven drier at 80^oC for 48 hours. Then dry weight was taken and expressed as gm^{-2}. Each determination was done at interval of 6 to 10 days.

Leaf Area Index (LAI)

Leaf area was measured with a digital automatic leaf area meter (LI-COR Squarecentimeters, L13 100 area meter, USA) and the leaf area index (LAI) was calculated as the sum of the leaf area divided by ground area expressed as (m^2m^{-2}). LAI was measured at every week interval.

Results and Discussion

Observations of micrometeorological parameters such as air temperature, relative humidity, soil temperature, light intensity, solar radiation and radiation use efficiency (RUE) that observed over maize field have been presented and discussed in this chapter.

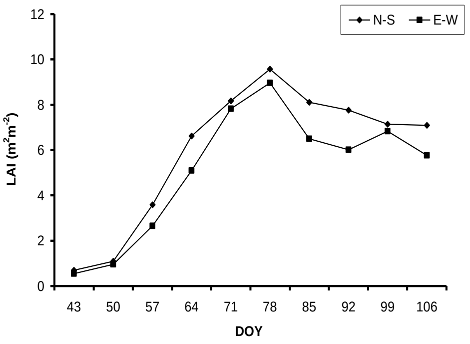

Fig. 1. Leaf area index as a function of plant growth

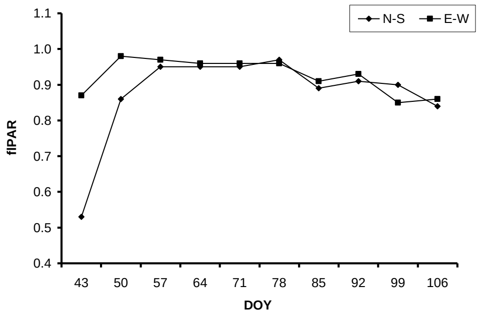

Fig. 2. Fractional intercepted PAR as a function of plant growth

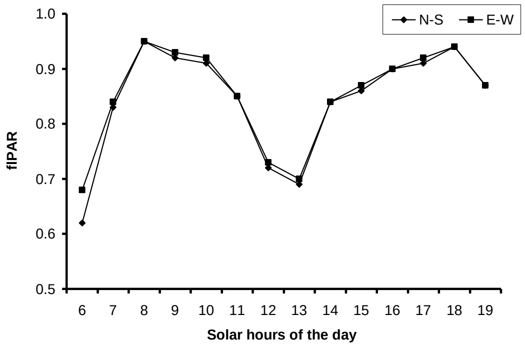

Fig. 3. Diurnal time-course of the fraction of PAR intercepted by maize canopy

Leaf Area Index (LAI)

Fig. 1 clearly indicates that LAI at seedling stage was very low (<1.0) due to smaller size of plants and with the advancement of plant growth. LAI gradually increased and attained maximum value at 72 DOY when maize became full vegetative stage. After than LAI gradually decreased up to maturity due to very poor development of new leaves, leaf rolling and leaf senescence. The average value of LAI was 6.04 and 5.13 in N-S and E-W rows, respectively because of the high solar radiation in N-S rows. The microclimatic parameters varied according to both changes in LAI and stomata resistance (Anda, 1998).

Fractional intercepted photo synthetically active radiation

Intercepted PAR is important for plant because plant actually utilize this light. Fig. 2 clearly indicates that PAR interception was gradually increased and contributes the higher amount of interception from vegetative to pre-flowering stages. In this time PAR was intercepted from 60-80%. After flowering PAR interception became reduced from 85-80%. Diurnal time course of PAR exhibited a very interesting pattern (fig 3).The ***f***

IPAR increased a little soon after sunrise until about 07.00-08.00 h. Then, ***f*** IPAR gradually decreased to form a low point at 12.00 h by a gradually reincrease untill 16.00-17.00 h. After that, the ***f*** IPAR again decreased upto sunset.

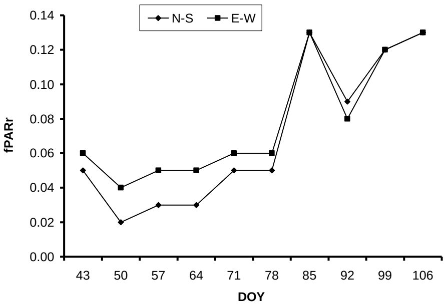

Fig. 4. Fractional reflected PAR as a function of plant growth

Fractional reflected PAR

Fig 7 indicated that at early growth stage reflected PAR of maize was low (10%) after then it increased up to flowering stage. After flowering stage (78 DOY) fractional PAR reflection was sharply increased (20%) up to maturity. On an average 10 to 20% of incident light was reflected back by the maize canopy throughout the growing period. After flowering stage plant canopy became narrower and leaves yellowing take placed it probably increased light reflection. Most of the agricultural crops reflect on an average 18 to 25% of incident radiation (Rogenberg, 1983).

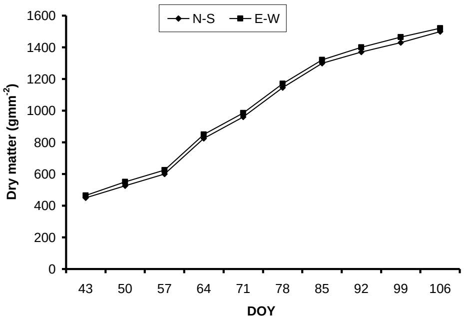

Fig. 5. Dry matter in different row orientation of maize

Total Dry Matter (TDM) in N-S and E-W row orientation

The total dry matter was recorded from 43 DOY till at harvest, at an interval of 7 days and calculated as the sum of dry weight of leaves to root. Dry matter production steadily increased up to 106 DOY in both of the row orientation of the maize plant (Fig. 10). Total Dry Matter production in plant of N-S row orientation was high than the plant of E-W row orientation because of the average solar radiation of N-S row orientation was also high. Mutsaers (1980) documented that at latitude 35^{o}N the N-S orientation absorb 18% more radiation than that of E-W orientation.

Radiation Use Efficiency

Measurements components of RUE on daily basis have been presented in Table 1.

Table 1. Measurement components of radiation use efficiency

DOY	Incident	R_{PAR} W/m^{-2}		T_{PAR} W/m^{-2}		fT_{PAR} W/m^{-2}		fR_{PAR} W/m^{-2}		fI_{PAR} W/m^{-2}		fA_{PAR} W/m^{-2}		IRS W/m^{-2}	GRs W/m^{-2}		TDM W/m^{-2}	
		N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W	N-S	E-W		N-S	E-W	N-S	E-W
43	114.02	5.48	6.91	53.81	14.76	0.47	0.13	0.05	0.06	0.53	0.87	0.48	0.81	70.53	35.15	31.89	465	450
50	160.87	2.67	6.48	23.19	2.67	0.14	0.016	0.02	0.04	0.86	0.98	0.84	0.94	58.14	34.93	31.68	550	525
57	115.64	4.14	6.12	5.78	4.14	0.05	0.03	0.03	0.05	0.95	0.97	0.91	0.92	72.73	44.49	38.63	625	600
64	135.09	4.89	6.6	6.57	4.89	0.05	0.04	0.03	0.05	0.95	0.96	0.92	0.91	51.38	48.61	45.55	850	825
71	150.97	7.67	8.67	7.5	5.9	0.05	0.04	0.05	0.06	0.95	0.96	0.90	0.90	106.76	73.99	70.74	985	960
78	158.65	8.4	9.56	4.0	5.8	0.03	0.04	0.05	0.06	0.97	0.96	0.92	0.90	111.97	79.21	75.95	1170	1145
85	63.03	8.28	8.09	6.69	5.67	0.11	0.09	0.13	0.13	0.89	0.91	0.76	0.78	107.85	75.08	71.83	1320	1300
92	74.33	6.84	6.55	6.42	4.9	0.09	0.07	0.09	0.08	0.91	0.93	0.82	0.85	94.18	61.48	58.16	1400	1370
99	45.46.	5.36	5.47	4.42	6.88	0.10	0.15	0.12	0.12	0.90	0.85	0.78	0.73	77.47	44.91	41.67	1465	1430
106	53.54	7.08	6.9	8.39	7.43	0.16	0.19	0.13	0.13	0.84	0.86	0.71	0.73	101.78	69.0	65.35	1520	1500

So, the RUE of 43 DOY was, according to Monteith's (1977) integral equation:

$$e_{43} \text{ in N} - \text{S rows} = \frac{450}{\int_{7}^{18} 0.48 \times 35.15 \times 0.45 \times 70.53 dt} \text{gm}^{-2}/\text{Wm}^{-2}$$

= 0.076 g/W
= 0.076 × 11.57 gMJ^{-1} day
= 0.89 gMJ^{-1} day

$$e_{43} \text{ in E} - W \text{ rows} = \frac{465}{\left[\int_{7}^{18} 0.81 \times 31.89 \times 0.45 \times 70.53 dt\right]} \text{gm}^{-2}/\text{Wm}^{-2}$$

= 0.065 g/W
= 0.065 × 11.57 gMJ^{-1} day
= 0.75 gMJ^{-1} day

Similarly, the average RUE of corresponding day,

N-S	**E-W**
e_{50} = 0.78 gMJ^{-1} day	e_{50} = 0.74 gMJ^{-1} day
e_{57} = 0.58 gMJ^{-1} day	e_{57} = 0.52 gMJ^{-1} day
e_{64} = 0.56 gMJ^{-1} day	e_{64} = 0.47 gMJ^{-1} day
e_{71} = 0.34 gMJ^{-1} day	e_{71} = 0.35 gMJ^{-1} day
e_{78} = 0.33 gMJ^{-1} day	e_{78} = 0.33 gMJ^{-1} day
e_{85} = 0.50 gMJ^{-1} day	e_{85} = 0.49 gMJ^{-1} day
e_{92} = 0.68 gMJ^{-1} day	e_{92} = 0.68 gMJ^{-1} day
e_{99} = 0.72 gMJ^{-1} day	e_{99} = 0.69 gMJ^{-1} day
e_{106} = 0.78 gMJ^{-1} day	e_{106} = 0.71 gMJ^{-1} day

Radiation Use Efficiency

In this study, the maximum RUE was 0.89 gMJ^{-1} in N-S rows and 0.60 gMJ^{-1} PAR day in E-W row orientation at 43 DOY and the lowest RUE was 0.33 gMJ^{-1} in both row orientation. Similarly Reddy and Willey (1981) and Marshall and Willey (1983) reported that the maximum values appeared in the first 60 days growth period, followed by a dramatic decline and than a slight increase during maturity. Table 2 clearly indicates that RUE was increase in vegetative stage (at 43 DOY) and than RUE was dramatic decline up to 78 DOY and after 78 DOY, RUE was slightly increase during maturity.

Under optimum condition the maximum efficiency of radiation utilization as high as 4% has been recorded during the middle season of corn (Lemon, 1963). RUE decreased significantly due to decreased leaf chlorophyll content.

A wide range of radiation use efficiency was documented for peanuts (0.95-2.24 gMJ^{-1} PAR) depending on air temperature genotype, growth stage, population of density, altitude and latitude of the growing stands (Reddy and Willey, 1981; Marshall and Willey, 1983; Harries *et al.*, 1987; Bell *et al.*, 1994b).

Conclusion

To evaluate the radiation use efficiency (RUE) in different row orientation for better productivity of maize through the maximum utilization of solar radiation, determined parameters affecting RUE and made a comparison of our results with previous results in different environments.

Row orientation significantly influenced on radiation penetration, interception and utilization of crop canopy. PAR penetration was higher in N-S rows than E-W rows. After than PAR penetration was increase in both rows because of very poor development of new leaves leaf rolling and leaf senescence.

LAI was higher in N-S row than E-W row orientation because of the high solar radiation in N-S rows.

Total try matter production in plant was high in N-S row orientation than the plant of E-W row because of the average solar radiation was also high in N-S row orientation.

Radiation use efficiency was measured by following Monteith's resource capture concept and the RUE was higher (0.89 gMJ^{-1} PAR) in N-S row orientation than E-W row orientation

(0.75 gMJ^{-1} PAR). The yield was high in N-S orientation (11.04 ton/ha.) than E-W (10.27 ton/ha.) row orientation.

In this study it was observed that North-South row direction showed the better performance for larger economic yield and higher harvest index than East-West rows.

With respect to these views, the studies of radiation use efficiency in different row orientations, suggest that N-S row orientation is better for the production of maize in the latitude of Bangladesh.

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