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Radiation pattern and radiation balance study over *Brassica campestris* var. yellow sarson in Gangetic West Bengal

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ABSTRACT

Field experiments were conducted in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal (22°57′ N, 88°20′ E) during *Rabi* season of three years (2007-08 to 2009-10). The popular variety of the region B-9 was selected and the biomass, grain yield, leaf area index (LAI), crop height and extinction coefficient were measured for each year. The diurnal variations of net radiation (Rn), global solar radiation (GSR) and incident photosynthetically active radiation (PAR_0) for different crop growth periods were studied. All the three radiation parameters showed a peak at 11.00 to 12.00 hours on an average and diurnal pattern was almost similar. The seasonal variation did not show any definite pattern. In 2009-10, the LE, G and S values were lower due to lesser amount of Rn throughout the season. In all the years no negative value of S was observed indicating that only upward movement of sensible heat flux occurred. The relationship between intercepted photosynthetically active radiation (IPAR) and biomass were also worked out. There is an immense scope of using the radiation pattern and its balance as inputs of crop growth and yield prediction model.

Keywords: Mustard, net radiation, GSR, PAR, Energy balance

Rapeseed and mustard is the second most important oilseed crop in our country. India is fourth in the world in production of rapeseed and mustard, next only to USA, China and Brazil, harvesting about 25 million tonnes of oilseeds against the world production of 250 million tonnes per annum (Chattopadhyay *et al.*, 2005). In West Bengal, it ranks first in terms of production among all oilseeds and is grown in about 421.522 hectares with the production of around 338.581 tonnes and the average yield of the crop is around 803 kg ha^{-1} (Sharma *et al.*, 2009). The yield of rapeseed and mustard in West Bengal is low due to various factors, viz, untimely sowing, inadequate stand establishment, absence of high yielding varieties, lack of agroclimatic zone specific crop production technology, moisture stress and uncertain weather conditions. It is grown mostly under rainfed conditions utilizing profile soil moisture stored during the end of rainy season and scanty winter rainfall.

For better production of the crop, there is a need to study the radiation utilization of the crop and water demand in terms of latent energy. The importance of solar energy in the tropical agriculture was recognised only after World War II (Best, 1962 and Stansel, 1975). The radiation pattern influences temperature pattern mostly. Grain yield is the product of radiation interception, conversion efficiency of intercepted radiation to dry matter and partitioning (Monteith, 1977, Jarwal and Singh, 1990). Radiation use efficiency (RUE), the amount of carbon assimilated per unit intercepted photosynthetic photon flux density, is important in understanding and modelling the relationship between plant growth and physical environment (Campbell *et al.*, 2001). The determination of intensity and spectral distribution of radiation within the crop canopies is very important because of its control on photosynthetic process and on the microclimate of plant community. In turn, the microclimate of plant communities varies with energy balance, turbulent exchange and soil temperature. In India, several works have been done on effect of radiation, temperature and microclimate on crop performance (Kar and Chakravarty, 2000; Singh *et al.*, 2002; Hundal *et al.*, 2004; Singh *et al.*, 2007 and Pandey *et al.*, 2007). Considering the importance of radiation and its balance, the present research work has been carried out to determine the diurnal variation of radiation, radiation balance over crop surface and effect of PAR in case of mustard crop.

MATERIALS AND METHODS

Study area

A field experiment was conducted in the experimental farm of Bidhan Chandra Krishi Viswavidyalaya, Kalyani, Nadia, West Bengal during *Rabi* season of 2007-08, 2008-09 and 2009-10 on *Brassica campestris.*var. *yellow sarson.* The location is near to the Tropic of Cancer (Latitude: 22°57′ N, Longitude: 88°20′ E and Altitude: 9.75 m above mean sea level). The soil of the experimental field was alluvial in nature (Entisol) and silty clay in texture and well drained. Although in *Kharif* season, water requirement of different crops sown in the region is met from the rainfall occurred, farmers have to depend on ground water for irrigation during rest of the year. The main water resources of the study location are ground water. The climate of the zone is sub-tropical with an average annual rainfall of 1467.5 mm ranging from 1195.5 to 1691.9 mm. More than 80% of annual rainfall is received from South-West monsoon during the rainy months of June to September. The area as a whole has humid and warm climate except a short spell of winter.

Field experiment

Field experiment on mustard was conducted in three consecutive years as stated earlier. The most popular mustard variety of the Gangetic West Bengal, namely *Binoy* (B-9) was grown. The experimental design was randomized block design and treatment was dates of sowing (DOS) with four replications for each DOS. The three DOS were 15.10.07, 19.10.08 and 19.10.09. All the recommended cultural practices were followed to grow the crops. The experimental field size was considerably large (48 m X 28 m) and the whole field was divided into four plots. The meteorological observations were taken from the middle of the experimental field and biophysical parameters were taken from each treatment and average values of biophysical parameters were used for further analysis. All the data were taken at 15 days interval covering all the crop growth stages.

Measurement of radiation parameters

Net radiation was measured by Net Radiometer and global solar radiation was measured with the help of Pyranometer. Line quantum sensor was used to measure the photosynthetically active radiation (PAR). The direct incident PAR on the mustard canopy and ground surface (below the mustard canopy) was measured by placing the sensor above canopy and above ground surface respectively. The reflected PAR was also measured from the same places by simply reversing the sensor of the instrument. Line quantum sensor measure PAR in terms of photosynthetic photon flux density (PPFD). All the radiation parameters were measured in Wm^{-2}. Absorbed photosynthetically active radiation (APAR) was calculated using the following equation (Gallo and Daughtry, 1986):

$$APAR = (PAR_0 + RPAR_S) - (TAPR + RPAR_C)$$

Where,

PAR_0 = Portion of the incident PAR above crop surface; TPAR = Transmitted portion of the incident PAR through the canopy; $RPAR_C$ and $RPAR_S$ = Reflected portion from the crop and soil respectively.

Calculation of different fluxes

Different fluxes like sensible heat flux (S), latent heat flux (LE) and ground heat flux (G) can be computed with the help of Bowen Ratio Energy Balance (BREB) technique.

The energy balance equation over the crop surface is

$$R_n = S + LE + G.$$

or

$$LE = (Rn\text{-}G) / (1+\beta)$$

S and LE have been computed using Bowen Ratio Energy Balance (BREB) technique. For daily measurement, 'G' value can be neglected (Watanabe and Nakayama, 2004).

RESULTS AND DISCUSSION

Diurnal variation of Net radiation (Rn), Global solar radiation (GSR) and Incident PAR (PAR_0)

Rn, GSR and PAR_0 were measured at hourly interval at different crop growth stages, namely, flower bud initiation (FBI), 50% flowering (50% FLWR), siliqua emergence (SE), pod formation (PF) and siliqua maturity (SM). It was observed that at 11.00 h to 12.00 h, the Rn reached the maxima and its value reduced drastically after 15.00 h. During the morning hour (8.00 h) the Rn value varied from 104 Wm^{-2} to 220 Wm^{-2} for various growth stages of first year of observation and the magnitude is lesser during second and third years of experimentation (Fig. 1). The pattern of such diurnal variation of Rn follows the solar inclination as well as the variation GSR. For the second and third year, the diurnal variation of Rn for different stages varied more than first year. It may be due to the higher variation of cloud cover vis-à-vis GSR for the particular observation dates.

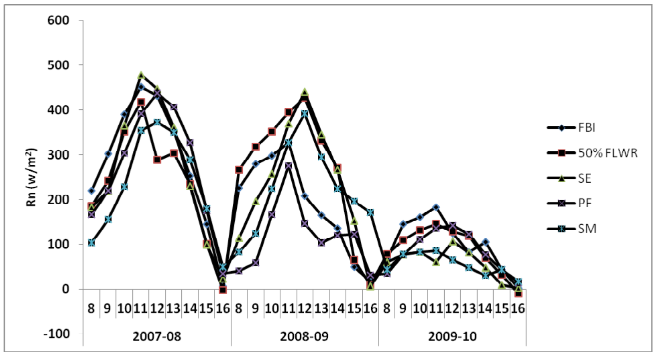

Fig. 1: Diurnal variation of net radiation at different crop growth stages of mustard

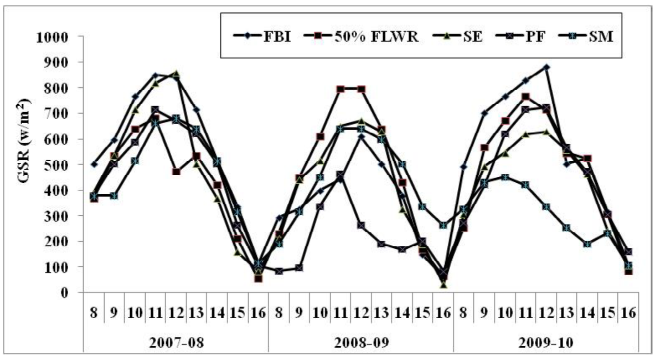

Fig. 2: Diurnal variation of global solar radiation at different crop growth stages of mustard

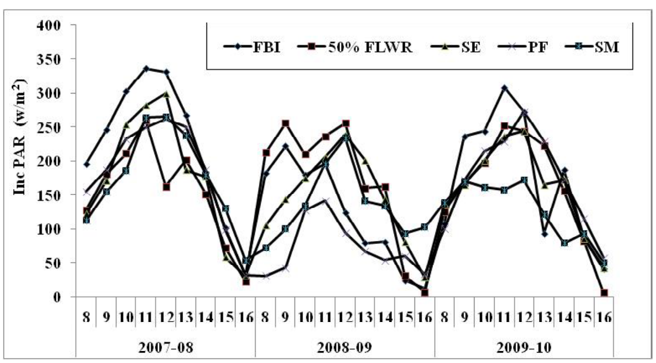

Fig. 3: Diurnal variation of incident PAR at different crop growth stages of mustard

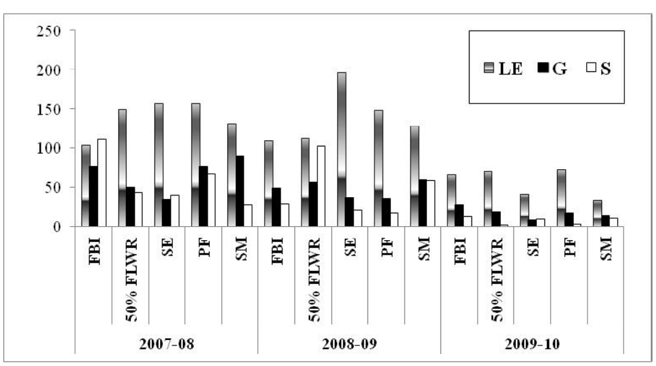

Fig. 4: Seasonal variation of radiation balance components

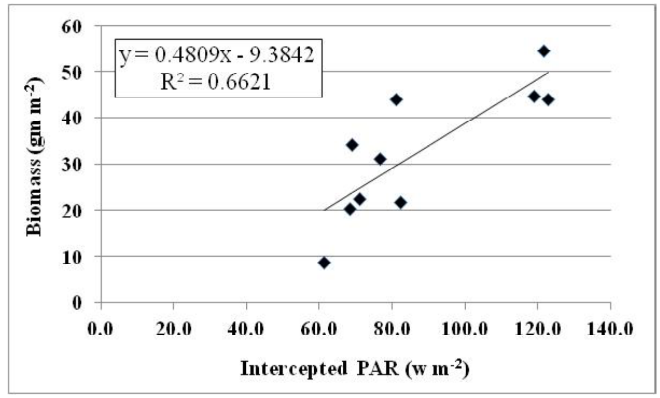

Fig. 5: IPAR-Biomass relationship in mustard

Like Rn, the diurnal variation of Global Solar Radiation (GSR) at different growth stages was measured for consecutive three years. It was observed that magnitude of GSR generally increased slightly from 8.00 hours to 9.00 hours following a jump of its magnitude at 10.00 hours. GSR often reached its maxima at 11.00 hours (in contrary to the fact that maximum GSR is generally observed at midday) which may be due to variation of cloud cover situation in the region (Fig. 2). The maximum GSR varied from 682 Wm^{-2} to 860 Wm^{-2}. The morning GSR is about 60% of the maximum peak value. For example, in the first year (2007-08) at 8.00 hours the GSR varied from 367 Wm^{-2} (at 50% flowering stage) to 504 Wm^{-2} (at flower bud initiation stage). But in the afternoon, the GSR reduced drastically and mostly the magnitude was less than 100 Wm^{-2} during 16.00 hours. Like GSR, Rn also showed a peak during 11.00 hours to 12.00 hours and measured morning Rn is more than afternoon Rn. As GSR does not vary with crop phenological stages, the diurnal variation of GSR follows similar pattern irrespective of crop growth stages and years of observation. Similar type of result was observed by Khem *et al.*, (2012).

The diurnal variation of Incident photosynthetically active radiation (PAR_0) over the crop surface also followed similar diurnal pattern like GSR. The morning PAR_0 was relatively higher than the afternoon PAR_0. PAR followed an increasing trend up to 10.00 hours but from 11.00 hours onwards no definite trend was observed. The general trend of diurnal variation of PAR_0 is gradual, reaching the peak at 11.00 hours to 12.00 hours, then value of PAR_0 gradually decreased. During first year (2007-08) at 8.00 hours, the PAR_0 varied between 113 Wm^{-2} to 196 Wm^{-2} (Fig.3), whereas at 16.00 hours, the PAR_0 was around 50 Wm^{-2} only.

From the above results, it is apparent that all the radiation parameters followed the similar pattern of diurnal variation. In case of Rn, the variation differed widely from year to year due to its dependence on outgoing radiation, which in turn influenced by crop or field condition. Such findings can be supported by Jegede, (1997).

The pattern of radiation balance over the Brassica crop surface

The Net radiation (Rn) is the prime factor in determining different surface energy flux components over any surface. In 2007-08 and 2008-09, it was observed that magnitude of LE was higher than 2009-10 (Fig. 4) which may be due to higher prevailing Rn during first two years (Fig.1). During the siliqua emergence (SE) and pod formation (PF) stages higher value of LE was observed. It may be due to the higher rate of transpiration as in these two stages leaf area index (LAI) are generally maximum and scheduled irrigation was given in flowering and pod formation stages. The soil heat flux was maximum during SM stage, which may be due to lack of soil moisture prevailed during this period. During maturity, the irrigation was withheld and the moisture content at the surface layer was reduced. Hence, at the initial soil layer (0 to 15 cm below from soil surface), the temperature was relatively higher than lower layer causing higher temperature gradient resulting higher soil heat flux during SM stage. The sensible heat flux varied a lot (27.79 Wm^{-2} to 111.75 Wm^{-2}) over crop growth period.

In 2008-09 also higher values of LE were observed at siliqua emergence (SE) and pod formation (PF) stages (Fig. 4) and highest soil heat flux was observed at SM stage. The S values in 2008-09 also showed a wide variation (16.90 Wm^{-2} to 102.48 Wm^{-2}) throughout the crop growth season. Compared to previous two years, in 2009-10, the LE, G and S values were lower due to lesser amount of Rn throughout the season. In all the years no negative value of S was observed indicating that only upward movement of S occurred. Moreover, in all the three years most of the energy was utilised for vapourising the moisture present in the soil plant system due to evapotranspiration.

Relationship between Intercepted photosynthetically active radiation (IPAR) and biomass

To determine the relationship between intercepted photosynthetically active radiation (IPAR) and biomass, the year-wise data were plotted and analysed. Preliminary, it was observed that increasing values of biomass was associated with increasing trend of IPAR. The cumulative values of biomass and IPAR also showed close relationship between biomass and IPAR. Hence, attempt was made to assess the biomass-IPAR relationship (Fig. 5). With the help of following linear equation, the biomass can be predicted from the IPAR data:

$$\text{Biomass (g m}^{-2}) = 0.48\ \text{IPAR (Wm}^{-2}) - 9.38$$

This equation will be valid only for the region under study and for a particular IPAR range (60 to 140 Wm^{-2}).

CONCLUSION

From the study of radiation pattern, it can be concluded that in between 11.00 hours to 12.00 hours the Rn reached the maxima and rate of decrease of its value was more during afternoon than its rate of increase in morning hours. Like the diurnal pattern of Rn, the variation of GSR and PAR_0 throughout a day had shown its peak during 11.00 hours to 12.00 hours. In case of radiation balance studies, only upward movement of sensible heat flux occurred in all the years of study and most of the energy was utilised for vapourising the moisture present in the soil plant system due to evapotranspiration. Net radiation is the governing factor in determining the variation of energy fluxes over mustard crop. The intercepted photosynthetically active radiation influences production of biomass and a close relationship exists between biomass and IPAR. There is an immense scope of using the radiation pattern and its balance as inputs of crop growth and yield prediction model.

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