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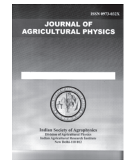

Research Article

Radiation Interception, Radiation Use Efficiency and Seed Yield in Three Different Cultivars of Mustard Grown in North-West India

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ABSTRACT

Indian mustard (*Brassica juncea*) is an important oilseed crop in India, grown mainly in the N-W plains during *rabi* season (October to April). A study was undertaken to compare the radiation interception, radiation use efficiency and seed yield of three mustard cultivars i.e. Pusa Vijay, Pusa Mustard-21 and Pusa Bold. The highest seed yield was obtained from Pusa Bold followed by Pusa Mustard-21 and Pusa Vijay which can be attributed to varietal differences. The observed seed yield values were 2.224 t ha^{-1}, 2.248 t ha^{-1} and 2.375 t ha^{-1} for Pusa Vijay, Pusa Mustard-21 and Pusa Bold, respectively. The fIPAR observations for the three cultivars were insignificant. TIPAR was found to be highest for Pusa Vijay followed by Pusa Bold and Pusa Mustard-21 and also the RUE was highest for Pusa Bold followed by Pusa Mustard-21 and Pusa Vijay.

Key words: Indian mustard, Radiation Use Efficiency, Radiation Interception, Biomass, Seed Yield

Introduction

Indian mustard is grown in *rabi* season (October to April) in northern plains of India. Due to sensitivity of this crop to temperature and photoperiod, diverse pattern of growth and development was found under different environmental conditions (Neog and Chakravarty, 2005). Current climate prediction models indicate a gradual increase in ambient temperature and an enhancement in the frequency and amplitude of heat stress in near future (Ahuja *et al*., 2010; Mittler and Blumwald, 2010; Mittler *et al*., 2012). Partitioning of incoming solar radiation within the crop canopy is indicated by radiation balance over the crop canopy. Solar radiation absorption, transmission and reflection within the crop canopy determine the crop growth rate and productivity (Sharma, 2000; Lindquist *et al*., 2005; Parya, 2009). Interception of light is fundamental need for plant growth and development and the relationship between light interception and crop growth is an important concept applicable for almost all the crops (Monteith, 1977). Despite of the well-known importance of radiation interception, measurements of these parameters are often neglected as it is difficult to estimate accurately within crop canopy (Purcell, 2000). Radiation received at the top of the atmosphere and crop canopy consist of both direct and diffused component (Smolander and Pauline, 2001). Row spacing and row orientation can be altered for efficient utilization of solar energy (Kingra *et al*., 2017). Diffused radiation has significant impact on growth of wheat and mustard at reduced level of solar radiation in winter season and crop grown within the shade

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net (Yadav, 2016). Radiation use efficiency in the canopy is directly limited to the rate of photosynthesis of well watered leaves (de Wit, 1965). Variation in dry matter accumulation could arises from the differences in the amount of cumulative intercepted radiation by the canopy in response to different management practice leading to reduced leaf area production. Radiation use efficiency indicates the crop mass accumulation relative to light levels. Determination of RUE is an important approach for understanding crop growth and yield production (Sinclair and Muchow, 1999; Katsura *et al*., 2007; Katsura *et al*., 2008). Study showed that the production of dry matter was largely determined by the penetration and absorption of photosynthetically active radiation (PAR) within the crop canopy which further determines the performance of the crops (Nanda *et al*., 1996; Yadav *et al*., 2000). The above ground biomass (AGB) production of crop is directly related to the amount of intercepted photosynthetically active radiation (IPAR) by the crop canopy during its life cycle (Monteith, 1977; Abbate *et al*. 1997; Sandana *et al*. 2009; Pradhan *et al*. 2014). Keeping these in view, a study was undertaken to compare the radiation interception, radiation use efficiency and seed yield of three mustard cultivars i.e. Pusa Vijay, Pusa Mustard-21 and Pusa Bold.

Materials and Methods

Study area

This research was carried out in the experimental farm (Main Block-4C) of Division of Agricultural Physics of ICAR-Indian Agricultural Research Institute, New Delhi situated at 28°37′ N latitude, 77°10′ E longitude (28°36′50″ N 77°10′32″ E) and an altitude of about 228.16 m from mean sea level with naturally leveled topography. The climate of the district is characterized by dry air with intense hot summer and cold winter. The cold season is from middle of November to middle of March. The hot season continues to about June. The summer monsoon arrives at the end of June and South west monsoon prevails from July to September. The daily weather parameters were collected from the Agromet Observatory of IARI, located about 0.1 km from the experimental plots. The soil is sandy loam (Typic Haplustept) with medium to angular blocky structure, non-calcareous and slightly alkaline in reaction (pH 7.7).

Weather and climate

Daily weather data were collected from the agrometeorological observatory, Division of Agricultural Physics ICAR-IARI, New Delhi. The observatory is located near the experimental field (MB-4C). The daily data collected were used to compute weekly means on the basis of standard meteorological weeks (SMW) during the crop growing season. The weekly mean maximum temperature during the *rabi* season 2018-19 followed a decreasing trend from 31.2°C (43rd SMW, October) to 18.7°C (4th SMW, January) at the starting of *rabi* crop growing season (Fig. 1). After that it followed the increasing trend upto 33°C (13th SMW, March) at the end of the growing season. The weekly mean minimum temperature was 11.1°C in 43rd SMW at the time of sowing (25-October), then went up to 13.3°C in 44th SMW and after that it decreased to minimum i.e. 1.9°C during 52nd SMW. The *rabi* season of 2018-19 was wet and cool in general as it received a cumulative rainfall of 137.0 mm over the seven weeks. The rainfall received in seven different standard meteorological weeks was as follows: 4.2 mm (46th SMW), 4.9 mm (1st SMW), 46.9 mm (4th SMW), 55.3 mm (6th SMW), 7.0 mm (7th SMW), 3.5 mm (8th SMW) and 14.7 mm (9th SMW) (Fig.1). The highest rainfall was received in 6th SMW. Frequent rain (around 1/3rd of crop growing season) was received during this crop growing season that led to high biomass and seed yield by mustard cultivars. Weekly pan evaporation was higher at the beginning of the growing season i.e. 3.7 mm day^{-1} and then followed a decreasing trend towards the mid of season i.e. 1.5 mm day^{-1} (in 1st SMW) due to decreased bright sunshine hours (BSS) and increased cloudiness. After that it followed an increasing trend towards the end of the growing season and reached to its maximum (4.7 mm day^{-1}). Fig. 1 also shows the weekly rainfall and evaporation pattern during *rabi* season 2018-19.

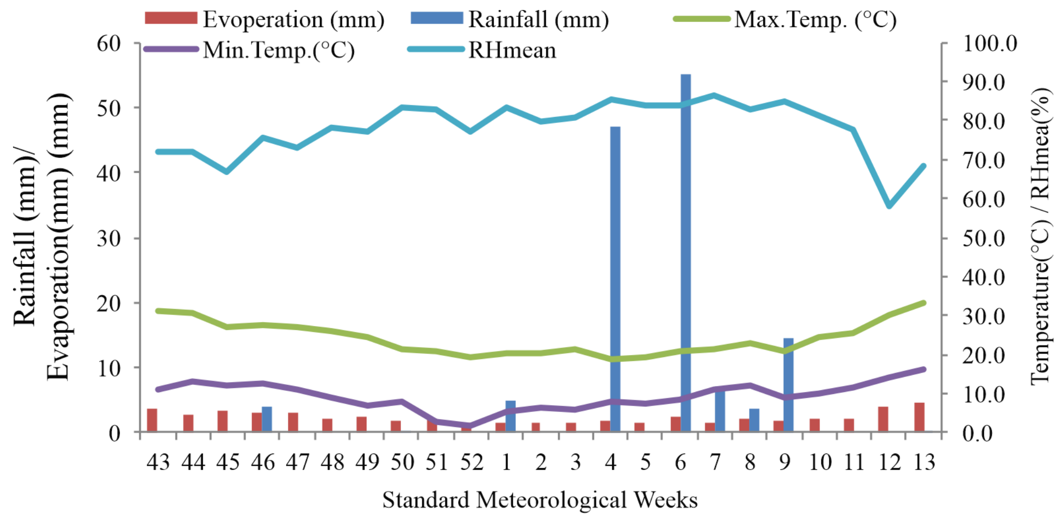

Fig. 1. Weekly means of the maximum, minimum temperature, cumulative rainfall, mean pan evaporation and RH at IARI farm during rabi season 2018-19

Weekly means of mean relative humidity (RH) showed fluctuating patterns during the *rabi* season of 2018-19. The weekly mean RH varied between 57.8% to 86.5%, but most of the time it remained around 75-80% (Fig. 1).

Experimental design

The experiment was carried out in randomized block design (RBD) with 9 replications of three cultivars as V-1 (Pusa Vijay), V-2 (Pusa Mustard-21) and V-3 (Pusa Bold) in 5m × 4m plots. The mustard cultivars were sown at a seed rate of 5 kg/ha with row spacing of 40 cm and plant spacing of 10 cm using a manual seed drill. Fertilizers were applied as per recommended dose i.e., 90 kg N, 45 kg P_2O_5 and 45 kg K_2O per hectare. Full dose of P_2O_5 and K_2O plus half dose of N were applied through manual broadcasting at the time of sowing and remaining half dose of N was applied just before first irrigation. The plots were kept weed free. The crop was allowed to grow naturally by allowing the incidence of pest and diseases without any control measures.

Radiation Interception and Radiation use efficiency

Line quantum sensor (LICOR-3000, U.S.A.) was used to measure both incoming and outgoing photosynthetically active radiation (PAR) values at the top and bottom and at mid of the mustard canopy throughout the season. The observations were taken on regular basis once in a ten days intervals at around 12:21 PM IST (local noon in Delhi) on a cloud free day such that when disturbances due to leaf shading and leaf curling and solar zenith angle were minimum. To take the observations, the sensor of the instrument should be facing sky above the canopy to get the radiation received at the top of the canopy by crop (I_0) and then turn the sensor towards the ground surface to record the reflected radiation from top of the canopy (R_0). The intercepted photosynthetically active radiation (IPAR) (equation 1) for a particular day was calculated as the difference between photosynthetically active radiation (PAR) at the top and bottom of canopy. The ratio between intercepted PAR and total incident PAR on a particular day gives the fraction intercepted photosynthetically active radiation (fIPAR) (equation 2) (Jha *et al*., 2012). Values for fIPAR for each day after sowing were interpolated between actual measurements by linear interpolation throughout the crop season. Daily incoming solar radiation was calculated by the procedure described in Allen *et al*. (1998) using daily bright sunshine hours' observation. The daily incoming solar radiation was multiplied by a factor 0.48 (Monteith, 1972) to get incoming incident PAR. Then the daily incident PAR values were multiplied by corresponding daily fIPAR values to compute daily intercepted PAR (IPAR). The daily IPAR was accumulated for the whole crop season to get total IPAR (TIPAR) (Goyal *et al.*, 2018). After these, readings were taken below the canopy by repeating the above steps, as sensor facing upward (just above the soil) to record the transmitted light to soil through canopy (T_C) and facing downward (just above the soil) to get proper reflected radiation from soil (Rs). The above observations were taken on regular basis once in a ten days intervals at around 12:21 PM IST (local noon in Delhi) on a cloud free day. The observations were further used to compute and analyze different secondary parameters which are related as follows:

$$IPAR = I_0 - T_C \quad \ldots(1)$$

$$fIPAR = \frac{IPAR}{PAR} = \frac{Io - Tc}{Io} \quad \ldots(2)$$

Where,

IPAR= Intercepted Photosynthetically Active Radiation

fIPAR=Fractional Intercepted Photosynthetically Active Radiation

I_0 = Radiation received at the top of the canopy

T_C = Transmitted radiation to soil through canopy

R_0 = Reflected radiation from top of the canopy

R_C = Reflected radiation from soil later re-absorbed by the canopy

Biomass and seed yield

One sample of mature mustard crop was harvested from 1x1 m^2 area in each plot and they were allowed to air dry. The total weight of grain plus straw was recorded in each plot using spring balance. Sample as well as per plot yield were recorded after plot wise thrashing and winnowing by mechanical thrasher.

Results and Discussion

Radiation Interception and Radiation use efficiency

In all the cases, fIPAR showed an increasing trend during vegetative growth then reaching a plateau at flowering stage and later decreased with the progress of season in reproductive stage. No significant differences in fIPAR were observed among the three cultivars (Table 1). Maximum LAI reached around 87-90 days after sowing, but fIPAR reached its plateau around 60-70 days after sowing. It indicates that maximum interception of light reached at a lower LAI of around 4.0 than its maximum value. Actually the canopy covers around 90% of the ground at LAI value between 3.0 and 4.0. After that time the upper leaves and middle leaves only intercept PAR and lower leaves near ground are shaded by upper leaves and are devoid of direct solar radiation. The TIPAR values were found to be 666.74, 660.63 and 656.72 which was highest for Pusa Vijay followed by Pusa Bold and Pusa Mustard-21 respectively.

Table 1. Light interception by mustard cultivars at different phenological stages at IARI farm during *rabi* season, 2018-19

Cultivars	Fractional intercepted photosynthetically active radiation				
	Early vegetative (35DAS)	Rossette (45 DAS)	Flowering (63 DAS)	Pod development (74 DAS)	Seed filling (91 DAS)
V-1	0.31^A	0.83^A	0.95^A	0.97^A	0.97^A
V-2	0.25^A	0.79^A	0.95^A	0.96^A	0.97^A
V-3	0.29^A	0.80^A	0.94^A	0.97^A	0.97^A
Mean	0.28	0.81	0.95	0.97	0.97
CD5%	0.079	0.077	0.018	0.010	0.004
LSD5%	NS	NS	NS	NS	NS

NS- Non-significant, V-1 = Pusa Vijay, V-2 = Pusa Mustard-21 and V-3 = Pusa Bold

Table 2. TIPAR, RUE_B and RUE_Y of the three mustard cultivars at IARI farm during *rabi* season, 2018-19

Cultivars	TIPAR (MJ)	BM (t ha^{-1})	Seed Yield (t ha^{-1})	RUE_B (kg MJ^{-1})	RUE_Y (kg MJ^{-1})
V-1	666.74	12.74	2.224	19.11	3.33
V-2	656.72	12.00	2.248	18.27	3.42
V-3	660.63	11.85	2.375	17.93	3.59

The RUE based on biomass of the three mustard cultivars Pusa Vijay, Pusa Mustard-21 and Pusa Bold are 19.10, 18.27, and 17.93 Kg/MJ respectively (Table 2). Due to unavailability of the radiation interception reading for the initial 30–40 days after sowing, linear interpolation of TIPAR from sowing to the first reading was done in the present study which might have led to overestimation of the RUE. RUE is smaller if a greater proportion of biomass is partitioned to the roots (Siddique *et al*., 1989). Stressful environments have higher root-shoot ratios (Hamblin *et al*., 1990), which give rise to lower RUE (Jamieson *et al*., 1995). The RUE based on yield for the three mustard cultivars Pusa Vijay, Pusa Mustard-21 and Pusa Bold were 3.33, 3.42 and 3.59 kg/MJ respectively.

Seed yield

The average seed yield obtained after harvesting and threshing of the three different cultivars of mustard are presented in the Table 2. The observed seed yield values were 2.224 t ha^{-1}, 2.248t ha^{-1} and 2.375 t ha^{-1} for Pusa Vijay, Pusa Mustard-21 and Pusa Bold, respectively. Among the cultivars there was no significant difference in seed yield for the same management practices. The highest seed yield of 2.37 t ha^{-1} was obtained from Pusa Bold followed by Pusa Mustard-21 and Pusa Vijay. Although Pusa Bold is the very old variety released in 1980's, still it is the highest yielder under no biotic and abiotic stress. Among the cultivars, there was little difference in final biomass accumulation. Pusa Vijay (12.74 t ha^{-1}) had higher final biomass accumulation as compared to Pusa Mustard-21 (12.0 t ha^{-1}) and Pusa Bold (11.85 t ha^{-1}) but these were significantly different only at flowering, seed filling stage and only Pusa Vijay was significantly different from other two cultivars at oil accumulation stage.

Conclusion

The study undertaken to compare the radiation interception, radiation use efficiency and seed yield of three mustard cultivars i.e. Pusa Vijay, Pusa Mustard-21 and Pusa Bold showed varied results. The study showed a contradictory result as the highest seed yield was obtained from Pusa Bold followed by Pusa Mustard-21 and Pusa Vijay. This may be attributed to the difference in varietal characteristics. The fIPAR observations for the three cultivars were insignificant. The RUE based on biomass was highest for Pusa Vijay followed by Pusa Mustard-21 and Pusa Bold. The results showed that the maximum light interception was observed at lower value of LAI (=4.0) instead of its maximum value. Also the three mustard cultivars showed non-significant difference in seed yields for the same management practices. The highest seed yield was obtained from Pusa Bold followed by Pusa Mustard-21 and Pusa Vijay. The RUE based on yield for the three mustard cultivars Pusa Vijay, Pusa Mustard-21 and Pusa Bold were 3.33, 3.42 and 3.59 Kg/MJ respectively.

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