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Estimation of Water Use Efficiency of Mustard Crop Under Variable Weather Conditions

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Abstract: *A field experiment was conducted at IARI during Rabi 2011-12 for understanding crop water needs required for irrigation in mustard. Three varieties of mustard were sown at three different dates for creating different weather condition for different crop stages. The actual crop evapotranspiration were calculated using single crop coefficient, dual crop coefficient and water balance equation. The crop biomass, LAI, radiation interception, soil moisture at regular interval and seed yield were measured. Results showed higher value of biomass, seed yield, water use efficiency and radiation use efficiency in Pusa Jaikisan followed by Pusa Bold and Gold. The value of biomass, seed yield and radiation use efficiency was found to be more in first sowing followed by second and third sowing. The value of water use efficiency calculated using dual crop coefficient were more near to the value of water use efficiency calculated by soil water balance as compared to the value calculated by single crop coefficient. From the above studies it can be concluded that water need requirement in mustard crop can be estimated more accurately by dual crop coefficient approach as compared to single crop coefficient and soil water balance because water use calculated by dual crop coefficient consider both soil evaporation coefficient and basal crop coefficient.*

Keywords: *Water use efficiency, biomass, seed yield, Radiation use efficiency.*

INTRODUCTION

Long spell of drought and competing water demands in most parts have put enormous pressure on water resources. One of the ways by which we can reduce the total water used for irrigation is to employ practices that improve crop yield per unit volume of water used *i.e.*, water use efficiency. Increased water use efficiency of crops was possible through proper irrigation scheduling by providing only the water that matches the crop evapotranspiration and providing irrigation at critical growth stages (Eck, 1984; Wang, 1987; Turner, 1987; Wang *et al.*, 2001; Hunsaker *et al.*, 1996; Kipkorir *et al.*, 2002; Norwood and Dumler, 2002; Kar *et al.*, 2005). For most agricultural crops a relation can be established between evapo-transpiration and climate by the introduction of the crop coefficient (K_c), which is the ratio of crop evapotranspiration (ET_c) to reference evapotranspiration (ET_0) (Door- enbos and Kassam, 1979). In the present paper crop growth parameters, radiation use efficiency and the water use efficiency were calculated under different weather conditions of semi arid region.

MATERIAL AND METHODS

Field experiments were conducted during *Rabi* 2011-12 at IARI, New Delhi Research farm. Three varieties of mustard were sown at three different dates for creating different weather condition for different stages. The crop parameters and soil moisture at different intervals and final seed yield were measured. The water use efficiency was calculated using the following formula:

$$\text{Water use efficiency (WUE)} : \frac{\text{Biomass or yield produced (g m}^{-2}\text{)}}{\text{Amount of water used (cm)}}$$

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The samples collected for estimating leaf area index were utilized for assessing the biomass production. Plants samples were oven dried at 65°C for 48 hours or more until constant weight is achieved in order to estimate the accumulation of dry matter in different plant parts. The Both incoming and outgoing Photosynthetically Active Radiation (PAR) values were measured at three heights viz. top, middle (50 percent canopy height) and bottom of mustard crop throughout the season using line quantum sensor (LICOR-3000). To get reflected radiation from top, middle and bottom ground, the sensor was held in inverse position. The above measurements were taken at weekly intervals on clear days between 11:30 and 12:00 hours IST when disturbances due to leaf shading and leaf curling and solar angle were minimum. These data were further used to derive radiation use efficiency.

$$\text{Radiation Use Efficiency} = \frac{\text{Amount of dry matter produced (g m}^{-2})}{\text{Amount of Cumulative light absorbed } (MJ\ \text{m}^{-2})}$$

Daily data of maximum and minimum temperatures, for growing season were obtained from the records of the meteorological observatory of the Division of Agricultural Physics, located adjacent to the experimental site. These data were used to calculate *GDD*.

$$GDD = \sum(T_{\max} + T_{\min})/2 - T_b°D$$

Where, $T_{\max}$ and $T_{\min}$ represent the daily maximum and minimum temperatures and T_b is considered as 5°C.

Percentage oil content of the seeds for each plot was measured using low resolution pulsed H1 NMR (model no. PC20 Bruker made, frequency- 20MHz) in the Nuclear Research Laboratory, IARI. For this purpose, 10g of dry and clean seeds from each plot were kept for drying at 105°C in the oven and then kept for desiccating till measurement was taken. About 2 to 3g desiccated seeds were inserted into the NMR and the signal was recorded. Finally, oil content (per cent) was determined using calibration curves. Since sensitivity of the NMR instrument depends on any change in Instrumental components, air temperature and relative humidity, it is recommended to calibrate the instrument before taking reading in each time. Equation of calibration curves with oil content is given as follows:

$$\text{Oil content (per cent)} = \{(\text{Signal} + \text{intercept})/(\text{Weight of seeds} \times \text{slope})\} \times 100$$

$$Y = 1.3156 \times X - 0.0727\ (R^2 = 0.99)$$

STATISTICAL ANALYSIS

The data were analysed using the software SPSS 16.0 and MS office excel. Computation of correlation coefficients, critical difference and student t test was carried out using Excel and SPSS packages

RESULTS

Biomass Production

Biomass production of the plant is the process of organic substance formation from carbohydrates, the products of photosynthesis and from small quantity of inorganic substance absorbed by roots from the soil. The timely accumulation of dry matter by the crop is important as it is followed by adequate translocation of assimilates to the sink resulting in higher yield. The higher biomass in the first sowing dates may be due to favourable weather during crop growth period. The maximum above ground biomass in the first sowing was observed in first sowing Pusa Jaikisan (1890g/m^2) followed by Pusa Bold (1734 g/m^2) and Pusa Gold (892g/m^2).

Similarly, in case of second sowing, the corresponding behaviour of biomass production was observed under Pusa Jaikisan (1260 g/m2) followed by Pusa Bold (1252 g/m^2) and Pusa Gold (713 g/m^2). In third sown crop the corresponding value of biomass production were 677 g/ m^2 for Pusa Jaikisan, 642g/ m^2 for Pusa Bold and 417g/m^2 for Pusa Gold (Figure 1). The reduction in the magnitude of maximum biomass production in second sown crop as compared to first sown crop was 20 %, 33% and 28% in Pusa Gold, Pusa Jaikisan and Pusa Bold while the reduction in biomass production was further reduced in third sown crop to 53 %, 64% and 63% in Pusa Gold , Pusa Jaikisan and Pusa Bold as compared to first sown crop. Thus, it may be inferred that biomass production in all three varieties was higher in first sown crops as compared to late sown crops, which might be due to more favourable weather condition for first sown crop as compared to other two dates during crop growing period.

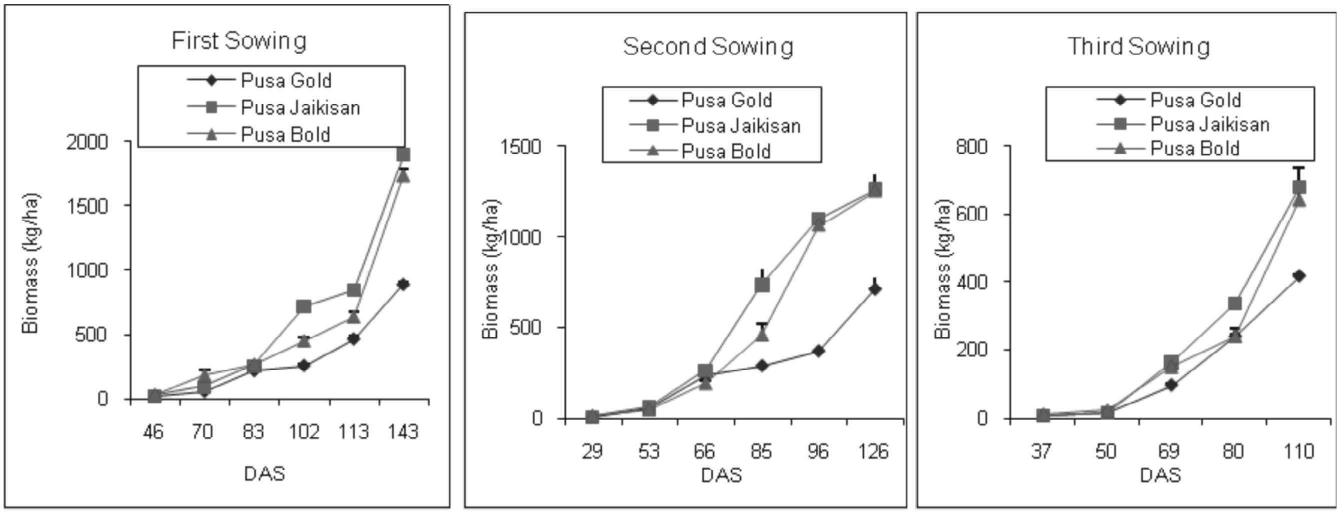

Figure 1: Biomass in different varieties of mustard under different weather conditions

Among the three varieties, it can be concluded that Pusa Jaikisan produced higher biomass as compared to Pusa Bold and Pusa Gold irrespective of sowing dates which might be due to higher leaf area index, leaf area duration and more proliferating nature. The biomass production was higher in Pusa Jaikisan by 8%, 0.7% and 5% as compared to Pusa Bold and 53 %, 43% and 62% as compared to Pusa Gold in first, second and third sown crop.

Thermal Response and Biomass Production

As the ambient daily temperatures are highly variable, the response of the plants to the thermal environment for their growth and development can be better expressed through the accumulated heat units instead of temperatures. Growing Degree Days (GDD) are the most common and simple ways of quantifying the thermal environment. Degree-day based approach is based on the premise that plants need a certain definite amount of accumulated heat to fulfil their requirement for phenological development. Differentiation in phenological events does not take place until this requirement is met. The basic concept of heat unit assumes a linear or logarithmic relationship between growth and temperature, which is predicted by Vant Hoff's Law. Heat unit is a measure of departure of mean daily temperature from a base temperature below which the internal biochemical activity ceases.

The response of plant growth parameters (LAI, biomass and seed yield) to the prevailing thermal environment (represented by thermal units GDD) can be depicted by curves, termed as "thermal response curves". Thermal response curves may serve as ready reference for expressing the relationship of growing degree-days with LAI and biomass production and these curves can be used for predicting biological or economical yield of a crop well in advance, besides in crop simulation studies.

LAI and biomass was significantly correlated with GDD. It was observed third order polynomial equations in biomass that 97 to 100 per cent variation in production could in Pusa Gold and Pusa Jaikisan and 98 to 99 in Pusa Bold (Figure 2) be explained through the accumulated heat unit (GDD), when crop was sown in variable weather conditions.

Seed Yield

During the crop season the seed yields of Pusa Gold, Pusa Jaikisan and Pusa Bold were 1225, 2522 and 2475 Kg/ha in first sown crop (14^{th} October). In second sown crop (31^{st} October) the seed yield were 1080, 2512 and 2258 Kg/ha, while the yield were lowest in third sown crop (16^{th} November) and the value were 434, 1587 and 1583 Kg/ha in Pusa Gold, Pusa Jaikisan and Pusa Bold respectively. Delay in 15 days sowing from 14^{th} October decreased seed yield to the 14 % in Pusa Gold, 0.4 % in Pusa Jaikisan and 9 % in Pusa Bold respectively.

Further delay in sowing by 15 days reduced the yield to 65% in Pusa Gold, 37 % in Pusa Jaikisan and 36 % in Pusa Bold. Early sown crop yielded higher seed yield than late sown crop in all varieties.

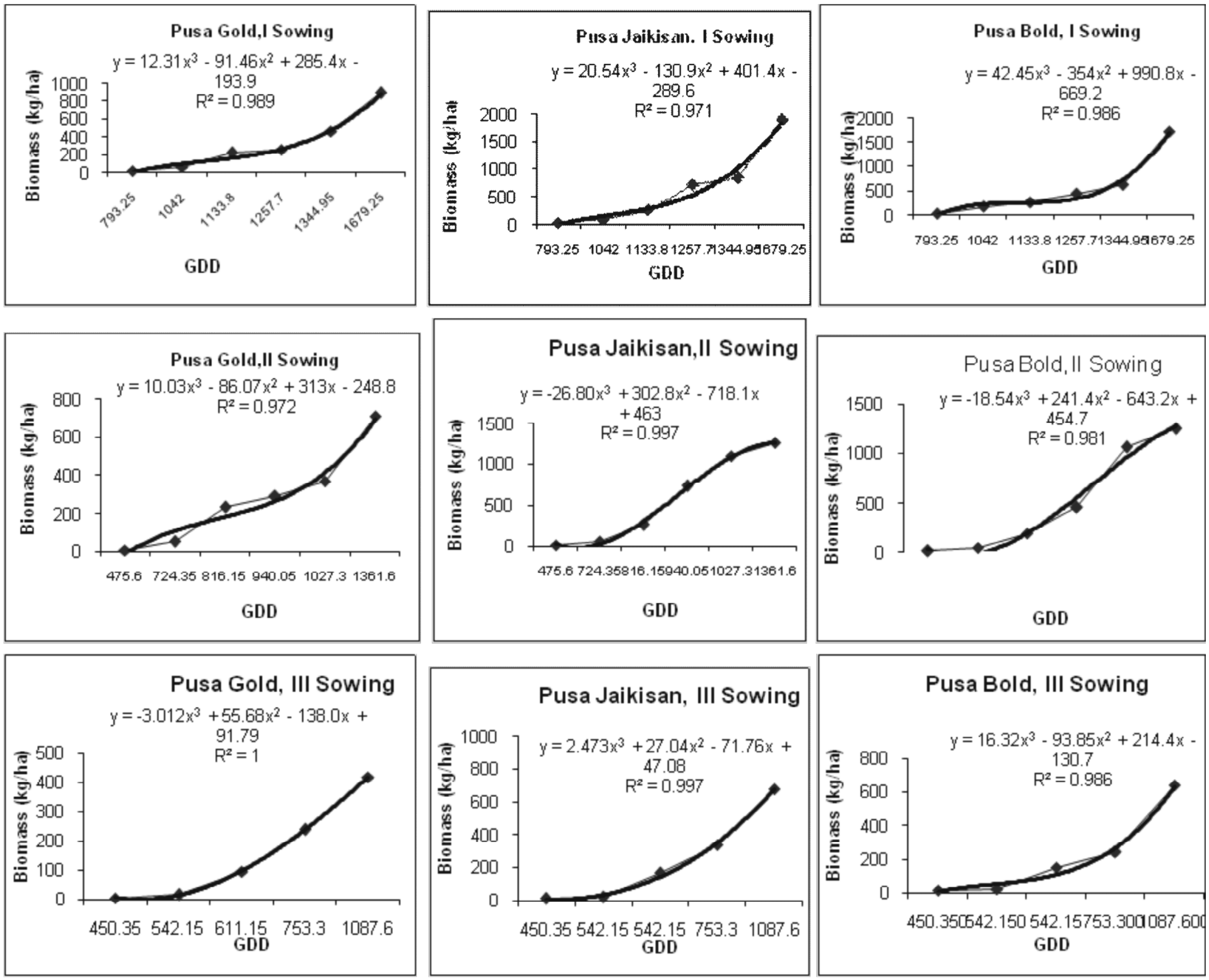

Figure 2: Thermal response curve of Biomass of different varieties of mustard under different weather conditions

The seed yield was found to be higher in Pusa Jaikisan followed by Pusa Bold and Pusa Gold in all three date of sowing. Pusa Jaikisan have 51%, 57% and 72% higher yield than Pusa Gold in first, second and third sown crop respectively and 2%, 10% and 0.3% higher yield than Pusa Bold in first, second and third sown crop respectively (Table 1).

Table 1
Seed Yield (Kg/ha) in different varieties of mustard grown at variable weather conditions

Varieties	*14th October, 2011*	*31th October, 2011*	*16th November, 2012*
Pusa Gold	1225.0 ±106.1	1080.0± 125.7	434.2 ± 85.7
Pusa Jaikisan	2522.5 ± 157.6	2512.5 ± 149.4	1587.5 ± 169.9
Pusa Bold	2475.0 ± 274.1	2258.3 ± 40.8	1583.3 ± 102.7

Percentage Oil Content

The percentage oil content was 32.14, 31.33 and 30.05 in Pusa Gold, 35.85, 35.09, 33.89 in Pusa Jaikisan and 34.05, 33.99 and 32.09 in Pusa Bold respectively grown in variable weather conditions (Table 2). The percentage oil content was found to be slightly more in the first sown crop followed by second and third sown crop. The percentage reduction in oil content for second sowing was 2.5%, 2.1% and 0.2 % in Pusa Gold, Pusa Jaikisan and Pusa Bold as compared to first sowing. However further delay in sowing by 15 days for third sowing reduced the oil content by 6.5 %, 5.5 % and 5.8 % in Pusa Gold, Pusa Jaikisan and Pusa Bold as compared to first sowing. The percentage oil content in Pusa Jaikisan was higher than the Pusa Gold and Pusa Bold in all the three dates of sowing. The percentage oil content was higher in Pusa Jaikisan by 10.3, 10.7, 11.3% and 5, 3.1, 5.3% as compared to Pusa Gold and Pusa Bold respectively under different weather conditions.

Table 2
Percentage oil content in mustard grown at variable weather conditions

Varieties	*First sowing*	*Second sowing*	*Third sowing*
Pusa Gold	32.14 ±0.28	31.33 ± 0.25	30.05 ±0.27
Pusa Jaikisan	35.85 ± 0.29	35.09 ± 0.44	33.89 ± 0.36
Pusa Bold	34.05 ± 0.42	33.99 ± 0.45	32.09 ±0.44

Water Use Efficiency (WUE)

The values of Water use efficiency (WUE) calculated based on the single crop coefficient were found to be 4.82, 3.80, 2.04 Kg/ha/mm for Pusa Gold, 8.79, 8.74 and 4.65 Kg/ha/mm for Pusa Jaikisan and 8.61, 7.97 and 4.61 Kg/ha/mm for Pusa bold under different weather conditions (Figure 3a). The value of Water use efficiency (WUE) calculated based on the dual crop coefficient were found to be 4.25, 3.50, 1.83 Kg/ha/mm for Pusa Gold, 7.51, 8.05 and 4.31 Kg/ha/mm for Pusa Jaikisan and 7.39, 7.28 and 4.27 Kg/ha/mm for Pusa bold under different weather conditions (Figure 3b).

The value of Water use efficiency (WUE) calculated based on the water balance equation were found to be 4.0, 3.80, 1.59 kg/ha/mm for Pusa Gold, 7.52, 7.66 and 5.29 kg/ ha/mm for Pusa Jaikisan and 7.22, 7.28 and 5.40 kg/ha/mm for Pusa bold under different weather conditions (Figure 3c). The water use efficiency calculated by all three approaches was found to be more in Pusa Jaikisan followed by Pusa bold and Pusa Gold. The value of water use efficiency calculated using dual crop coefficient were more near to the value of water use efficiency calculated by soil water balance as compared to the value calculated by single crop coefficient. In case of Pusa Gold and Pusa Bold the water use efficiency was more in first sown crop followed by second and third sown crop.

However in case of Pusa Jaikisan the value of water use efficiency was found to be more in second sown crop followed by first and third sown crop when calculated by soil water balance equation and dual crop coefficient approach. Pusa Jaikisan had 45 to 57% and 1 to 8.8% more value of water use efficiency as compared to Pusa Gold and Pusa Bold respectively in different weather conditions, when calculated by single crop coefficient approach. Water use efficiency when calculated by dual crop coefficient had 43 to 57% and 0.8 to 9.5 % more value of water use efficiency in Pusa Jaikisan as compared to Pusa Gold and Pusa Bold respectively in different weather conditions. Pusa Jaikisan had 47 to 70% and 0 to 5% more value of water use efficiency as compared to Pusa Gold and Pusa Bold respectively in different weather conditions when calculated by water balance equation.

Radiation Use Efficiency (RUE)

During the crop growing period the peak value of RUE (g/MJ) was 4.59, 5.73, 5.65 g/MJ and 4.01, 5.50, 5.33 for Pusa Gold, Pusa Jaikisan, Pusa Bold in first

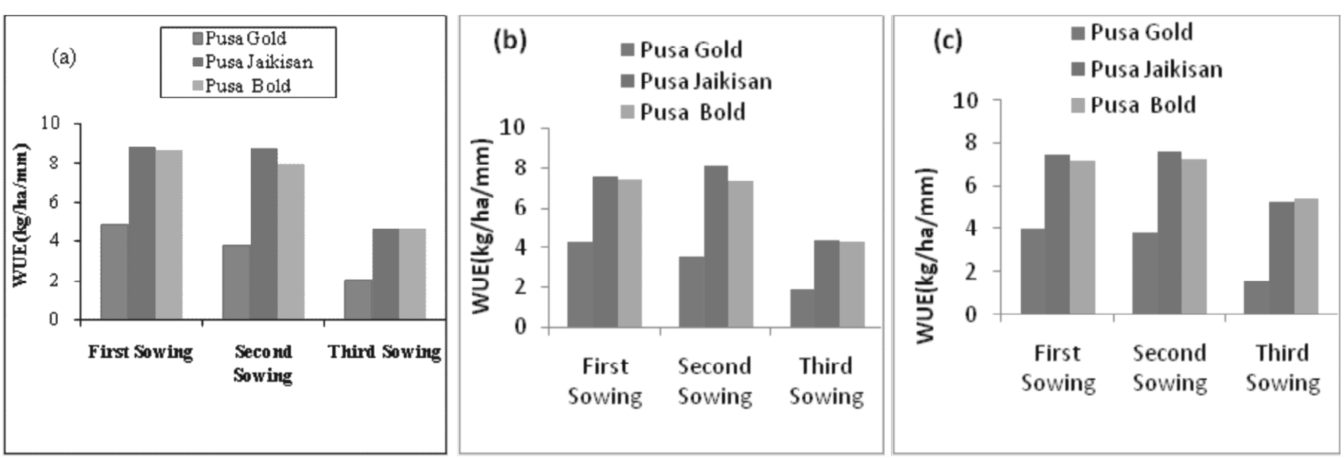

Figure 3: Water use efficiency calculated using (a) Single crop coefficient method, (b) Dual crop coefficient method and (c) soil water balance equation under different weather conditions

Table 3
Radiation Use efficiency (RUE) of different varieties of mustard grown under different weather conditions.

	First Sowing			*Second sowing*			*Third sowing*		
DAS	*Pusa Gold*	*Pusa Jaikisan*	*Pusa Bold*	*Pusa Gold*	*Pusa Jaikisan*	*Pusa Bold*	*Pusa Gold*	*Pusa Jaikisan*	*Pusa Bold*
40	3.99	4.15	4.09	3.40	4.05	4.02	3.23	3.56	3.85
70	3.89	4.99	4.37	3.77	4.19	4.04	3.38	4.02	3.70
100	4.59	5.73	5.65	4.01	5.50	5.33	2.19	3.52	2.94
130	2.19	2.78	2.68	1.48	1.65	1.63	1.02	1.24	1.32

and second sown crop at 100 days after sowing while the peak value of RUE for third sown crop was 3.38, 4.02 and 3.70 at 70 days after sowing (Table 3).

The first sown crop had higher value of RUE as compared to second sown and third sown crop. The percentage reduction of peak value of radiation use efficiency was 13, 4, 6% and 26, 29 and 35% for Pusa Gold, Pusa Jaikisan and Pusa Bold respectively in second and third sown crop as compared to first sown crop. Pusa Jaikisan has higher value of RUE followed by Pusa Bold and Pusa Gold. Pusa Jaikisan had 20, 27 and 38% higher value of RUE as compared to Pusa Gold and 1, 3 and 16% as compared to Pusa Bold in different weather conditions.

DISCUSSION

Biomass production in all three varieties was higher in first sown crops as compared to late sown crops, which might be due to more favourable weather condition for first sown crop as compared to other two dates during crop growing period. The biomass production levels obtained in the present study and the reduction of biomass production due to late sowing are in conformity with the earlier findings of Bhargava (1991) and Kar and Chakravarty (2001). Leaf area index (LAI) and biomass production in *Brassica* species were reported to be positively correlated with GDD accumulation during the crop growth period (Chakravarty and Sastry, 1983 and Patel and Mehta, 1987). The response of plant growth parameters (LAI, biomass and seed yield) to the prevailing thermal environment (represented by thermal units GDD) can be depicted by curves, termed as "thermal response curves". Thermal response curves may serve as ready reference for expressing the relationship of growing degree-days with LAI and biomass production and these curves can be used for predicting biological or economical yield of a crop well in advance, besides in crop simulation studies.

During the crop season the RUE (g/MJ) for the first sown crop had higher value as compared to second sown and third sown crop. The results are in conformity with the earlier findings of researchers (Kar and Chakravarty, 1999, Dhaliwal and Hundal, 2004) who reported RUE in the range of 1.0 to 5.0 g/MJ in different mustard varieties grown under varied thermal regimes. Early sown crop yielded higher seed yield than late sown crop in all varieties. Cold spell during initial period for third sown crop might have restricted growth. Incidentally, relatively higher temperatures at the later stage of the crop growth resulted early maturity. There was reduction in seed yield due to delay of sowing. The yield attributes and yield of mustard significantly decreased in delayed sowing even under protected conditions (Patel *et al.*, 2004). The results are in conformity with the earlier findings of researchers (Mendham *et al.*, 1990) who reported a reduction in seed yield due to delay of week/fortnight from the normal sowing. In the first sowing, the percentage oil content was higher than late sowing. Reduction in oil content in delayed sowing was reported by Bhattacharya *et al.*,(2000), Saha *et al.*, (2000) and Neog *et al.*, (2005). Our findings are in close conformity with their observations.

Gimenez *et al.* (1994) and Gardner *et al.* (1994) concluded that, for any given canopy size (LAI), canopy structure (leaf angle and orientation) determine the fraction of intercepted radiation, interception of PAR and its utilization efficiency with which, PAR drives photosynthetic gain in terms of productivity.

Increasing the efficiency of water use by crops continues to escalate as a topic of concern because of the increasing demand for water use and improved environmental quality by human populations. Efficiency is a term that creates a mental picture of a system in which we can twist dials, tweak the components, and ultimately influence the efficiency of the system (Hatfield *et al.*,2001). Earlier summaries developed by Unger and Stewart (1983) provided a strong foundation for understanding role of soil management on WUE.

Much of the research that forms the foundation for understanding the relationships among precipitation, soil water, plant water use, and crop response has been conducted in semiarid regions and it was suggested that semiarid region may have the most potential for improvement in WUE (Hatfield *et al.*,2001).

CONCLUSION

The Biomass and seed yield were relatively higher in the first sown crop because of more congenial weather conditions during the entire crop growth period. The RUE was found to be higher in first sown crop as compared to late sown crop. Delay in sowing time reduces the yield significantly. The water use efficiency calculated by all three approaches, single crop coefficient, dual crop coefficient and soil water balance equation were found to be more in Pusa Jaikisan followed by Pusa bold and Pusa Gold.

The value of water use efficiency calculated using dual crop coefficient were more near to the value of water use efficiency calculated by soil water balance as compared to the value calculated by single crop coefficient. From the above studies it can be concluded that water need requirement in mustard crop can be estimated more accurately by dual crop coefficient approach as compared to single crop coefficient because water use calculated by dual crop coefficient consider both soil evaporation coefficient and basal crop coefficient.

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