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VARIATION IN ABSORPTION OF PHOTOSYNTHETIC ACTIVE RADIATION (PAR) AND PAR USE EFFICIENCY OF WHEAT AND MUSTARD GROWN UNDER INTERCROPPING SYSTEM

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ABSTRACT

Absorption of PAR (Photosynthetic active radiation) by wheat and mustard crop and PAR use efficiency were estimated from a two year experiment of wheat-mustard intercropping system. The experiment comprised of five treatments (T_1-sole wheat, T_2- sole mustard, T_3 -two wheat: six mustard, T_4: four wheat: four mustard, T_5: six wheat: two mustard) allotted to RBD with 6 replications in a plot of $54m^2$. The sole wheat absorbed nearly 80% of the incident PAR at 11.30h throughout growth phases. Among the intercrop treatments, T_4 recorded very high absorption. In mustard, T_3 absorbed approximately 80% of the incident PAR. Mean RUE (Radiation use efficiency) for dry matter production in wheat ranged from 1.84-2.99 g MJ^{-1} for different treatment combinations and in mustard, it ranged from 2.33-4.34 g MJ^{-1}. The RUE for grain yield ranged from 1.07 to 2.88 g MJ^{-1} and 0.43 to 1.23g MJ^{-1} for wheat and mustard respectively. Sole crop recorded higher RUE than the component crops under intercropping.

INTRODUCTION

Radiation absorption and its ability to produce photosynthates (Radiation use efficiency) serve as one of the key factors in deciding the productive potentiality of a crop stand. RUE may be used to evaluate the crop performance and yield limitation (Sinclair and Muchow, 1999). Both absorption of radiation and its utilisation efficiency of a plant community vary with the radiation distribution within the canopy, which in turn depends upon crop architecture, foliage density, crop geometry and solar elevation angle etc. Apart from this, association of two different crops as in case of intercropping leads to mutual interference in absorption of light for both the component crops. The potential shares of the light that will be absorbed by components of intercrop are determined by the relative heights of their canopy and the efficiency with which they absorb light (Trenbath, 1979). In addition, the amount of light intercepted by the component crops in an intercrop depends on the geometry of crops and foliage architecture (Tsay, 1985; Ofori and Stern, 1987)As a result, a complicated radiation environment is set up with a complexity in leaf illumination and radiation absorption. Furthermore, this alteration in radiation environment might be one of the reasons for the variation in dry matter accumulation and yield under sole and intercropping systems. Radiation absorption and its utilization under intercropping system have not been investigated because of its complexity. We hypothesized to analyse the diurnal pattern of absorption of PAR by wheat and mustard crop under intercropping system with an objective to compare the extent of variation in absorption of PAR and its utilisation efficiency of both the component crops under different treatment combinations.

MATERIALS AND METHODS

The experiment was carried out during *rabi* (November-February) seasons of 2008-09 and 2009-10 at the Instructional Farm, Jaguli, Bidhan Chandra Krishi Viswavidyalaya (Lat. 22º 58' N and long 88º 31' E), West Bengal, India. The study site is located at an altitude of 9.75 m above mean sea level (AMSL). As per USDA modern taxonomical classification, the experimental soil is under the order of Entisol and the great group is under Fluvaquents. The texture of soil was sandy loam with a pH of 6.75.The experimental soil contains 0.54%

organic carbon, 0.053% total N, 15 kg ha^{-1} available P_2O_5 and 153.57 kg ha^{-1} available K_2O. There are five treatment combinations comprising of two sole crop treatments (T_1-sole wheat and T_2-sole mustard) and three intercrop treatments (T_3 - two wheat: six mustard, T_4- four wheat: four mustard, T_5- six wheat: two mustard), where two crops were associated in different row ratios. The experiment was conducted in a RBD with six replications and each plot measured 54m^2 (9m×6m). At the interface of wheat and mustard rows, a furrow of 0.5m width was given to prevent irrigation water flow from wheat and mustard blocks and vice-versa. In case of T_3 treatments, in each block, there were two wheat rows and six mustard rows and in their interface there was a furrow. In this treatment, there were three blocks comprising of six wheat rows and 18 mustard rows. In T_4 treatment, four rows of wheat were associated with four rows of mustard, having a furrow in between them. There were twelve rows of wheat and twelve rows of mustard in this treatment. In T_5 treatment, the scenario of T_3 was mirrored. The wheat (cv. PBW-343) and mustard (cv. *Seeta i.e.* B 85) were sown in the pre-fertilized plots which received the recommended doses of fertilizers [wheat (120 kg N, 60 kg P_2O_5 and 40 kg K_2O per hectare) and mustard (60 kg N, 40 kg P_2O_5 and 40 kg K_2O per hectare)]. The mustard rows received two irrigations of 5cm each at pre-bloom and siliqua development stages whereas; the wheat rows received four irrigations, 5cm each at crown root initiation, late-jointing, flowering and milking stages.

PAR was measured with the help of line quantum sensor (Model MQ301, APOGEE, Logan, UK). It was placed 100cm above the crop across the row to measure the incident PAR, inverted at the same position to get the reflected PAR from the crop canopy; it was lowered down at the 50cm height above ground to get the transmitted and soil reflected PAR. The observations were recorded from 7.30 to 15.30 hours at two hour interval to get a picture of diurnal variation in the receipt of PAR. Absorbed PAR (APAR) by the crop canopy was computed following Gallo and Daughtry (1986).

Radiation use efficiency (RUE) was calculated as ratio of the total crop biomass produced to the total PAR absorbed by the crop (Tsubo *et al.,* 2001; Kindred and Gooding, 2005; Jahansooz *et al.,* 2007; Ruiz and Bertero, 2008). It was expressed as g MJ^{-1}.

RUE for yield = [Total yield (g m^{-2}]/cumulative APAR MJ m^{-2}]

RESULTS AND DISCUSSION

Absorption of PAR by wheat

Results showed a continuous increase in absorption of PAR from 7.30h and reached its peak, when the Sun was at the zenith (11.30h), irrespective of years of observations. As the Sun reaches its zenith at 11 30h, maximum incident PAR over the canopy led to maximum absorption (Gates, 1981; Parya, 2009; Biswas, 2008; Chakraborty,1994).Thereafter absorption of PAR by wheat started to decline. Sole stand of wheat (T_1) absorbed 49 to 87% at 11.30h whereas the wheat under intercropping absorbed less PAR (Fig. 1). When two rows of wheat were replaced by mustard after every six rows (T_5), percent absorption of PAR by wheat slightly declined as compared to sole crop under all the dates of observations. This might be due to the partial shading offered by the adjacent mustard rows. Although mid wheat rows received the full sunlight, but partial shading of wheat rows by the mustard, at the interface resulted in comparatively less absorption of PAR by wheat. In case of T_4, percent absorption of PAR by wheat increased as compared to T_5 treatment. Although, wheat absorbed less PAR as compared to sole stand, but this combination created a more favourable situation for wheat for maximum absorption of PAR among the entire intercrop situation. Increased foliage density of wheat crop might be one of the reasons behind more PAR absorption. Besides, the transmitted and scattered radiation from adjacent mustard rows being captured by the wheat canopy increased the availability of PAR and its simultaneous absorption. Hence, PAR absorbed by wheat under this particular treatment, was proportionately

Table 1: Variation in RUE (g/MJ) of wheat under wheat-mustard intercropping system (2008-09 and 2009-10)

Treatment	RUE for dry matter accumulation										RUE for yield	
	30 DAE		45 DAE		60 DAE		75 DAE		Mean			
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
T_1(Sole W)	0.30	0.43	1.29	1.42	2.38	2.33	4.29	3.19	2.06	1.84	2.74	2.88
T_3(2W:6M)	0.41	1.08	1.58	2.06	3.24	4.06	4.64	4.78	2.47	2.99	1.07	1.65
T_4(4W:4M)	0.31	0.48	1.16	1.42	2.36	2.44	3.68	3.17	1.88	1.88	1.49	1.85
T_5(6W:2M)	0.42	0.92	1.69	2.00	3.03	3.63	5.05	4.76	2.55	2.83	1.96	2.67
SEm(±)	0.008	0.022	0.016	0.030	0.023	0.040	0.028	0.037		0.097	0.099	
CD(0.05)	0.017	0.047	0.034	0.064	0.049	0.085	0.060	0.079		0.200	0.211	

Table 2: Variation in RUE (g/MJ) of mustard under wheat-mustard intercropping system (2008-09 and 2009-10).

Treatment	RUE for dry matter accumulation										RUE for yield	
	30 DAE		45 DAE		60 DAE		75 DAE		Mean			
	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10	2008-09	2009-10
T_2(Sole M)	0.68	0.67	4.32	3.38	6.51	4.41	5.86	4.02	4.34	3.12	1.23	1.04
T_3(2W:6M)	0.75	0.44	3.03	2.35	4.26	3.43	3.71	3.11	2.94	2.33	0.63	0.59
T_4(4W:4M)	1.01	0.85	3.57	2.92	4.55	4.80	4.07	3.78	3.30	3.09	0.56	0.52
T_5(6W:2M)	0.80	0.52	3.64	2.67	5.13	4.07	4.67	3.46	3.56	2.68	0.52	0.43
SEm(±)	0.027	0.019	0.020	0.06	0.025	0.08	0.02	0.026		0.011	0.012	
CD(0.05)	0.058	0.040	0.043	0.128	0.053	0.171	0.043	0.055		0.024	0.025	

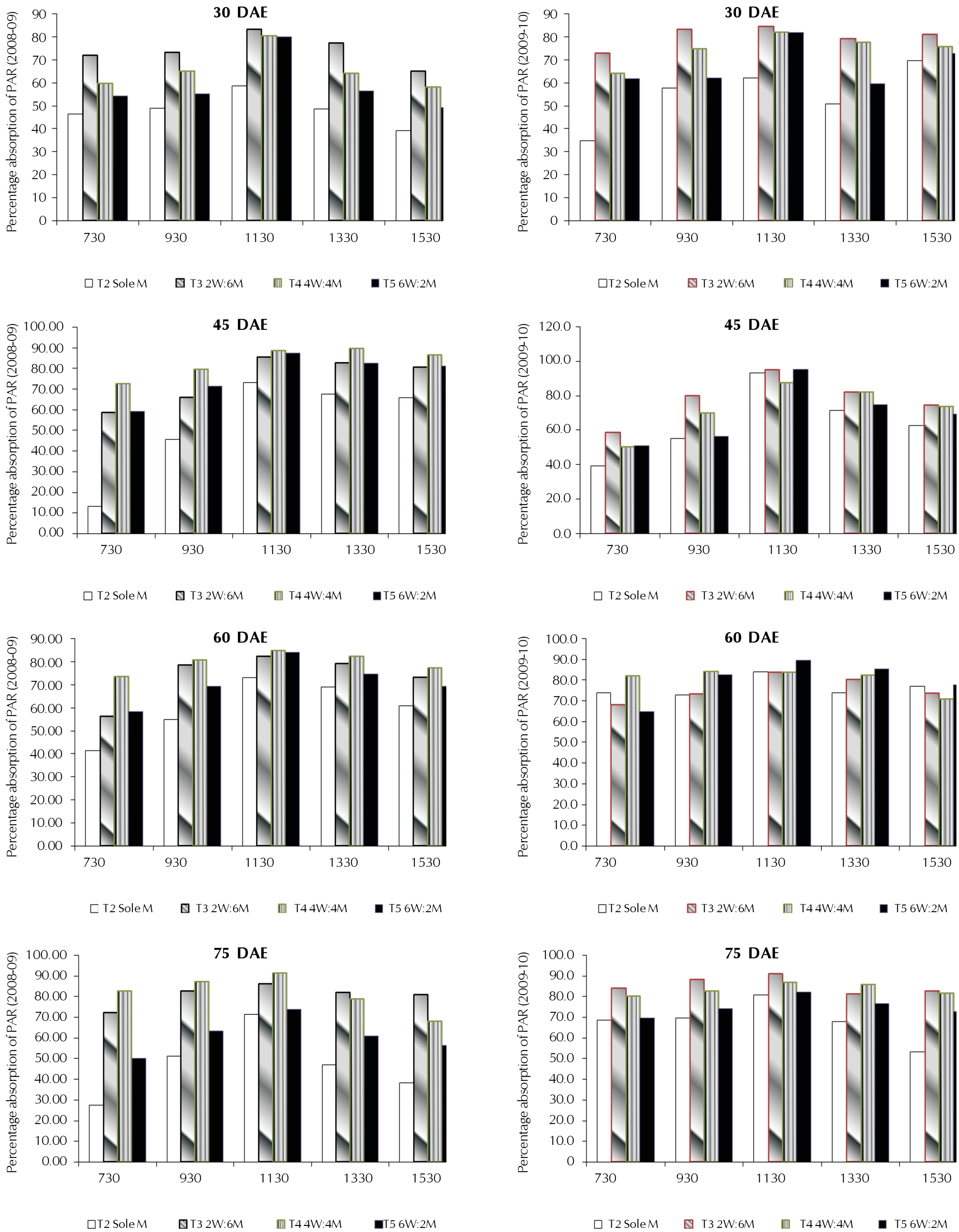

Figure 1: Diurnal variation in percent absorption of PAR of wheat under wheat-mustard intercropping (2008-09 and 2009-10)

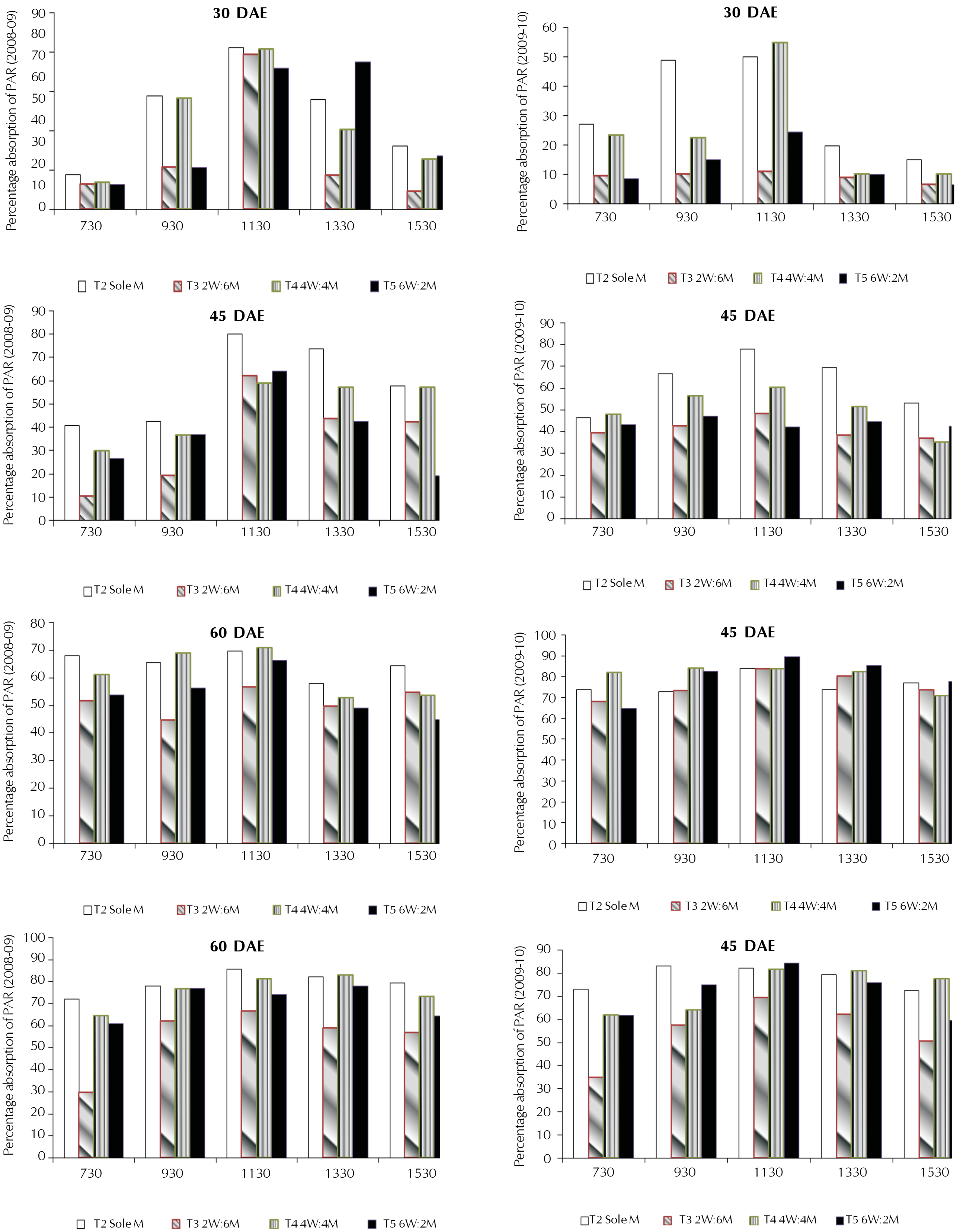

Figure 2: Diurnal variation in percent absorption of PAR of mustard under wheat-mustard intercropping (2008-09 and 2009-10)

more among all intercrop situation on unit area basis (Andrade *et al.,* 2002).Minimum absorption of PAR was recorded, when two rows of wheat crop were associated with six rows of mustard, under all the dates of observation. This might be due to the shadow cast by the associated mustard crop upon the wheat canopy. Generally, taller crop (mustard) created shadow over the shorter crop (wheat) at high densities, caused a reduction in growth and yield (Ofori and Stern,1987). In this particular treatment, both wheat rows were always under the direct influence of adjacent tall mustard crop. Absorption of PAR by wheat increased as the age of the crop increased, which might be attributed to the chlorophyll content of leaves as well as leaf volume (Gates, 1981; Monteith and Unsworth, 2001). PAR absorption varied in different combination because of the shading effect. Li *et al.* (2008) observed the reduction of PAR interception by the wheat crop inside the intercropping system. Nitrogen played a determining role in PAR absorption (Koley and Mitra Sarkar, 2013; Bangemann *et al.,* 2014). PAR absorption by wheat under intercropping was less because of faster N-absorption by accompanying mustard crop.

Absorption of PAR by mustard

Results recorded a gradual increase in absorption of PAR from 7 30h to 11 30h, irrespective of dates and years of observation. Thereafter, it declined, which might be attributed to change in solar elevation angle; the absorption will be more when the Sun approaches the zenith (Gates, 1981). Unlike wheat, minimum absorption of PAR was recorded under sole mustard irrespective of dates and years of observation (Fig. 2). Mutual shading of leaves of similar species might be the reason behind the lowest absorption of PAR under sole crop (Watson, 1952; Wilson, 1977). While considering the intercropped situation, it was observed that, mustard showed increased absorption of PAR as compared to sole mustard under both the years of investigation. When six rows of mustard were associated with two rows of wheat (T_3), highest absorption of PAR by mustard was recorded during earlier dates of observation (30 DAE) in the first year (2008-09). But in the following year, mustard absorbed maximum PAR under T_3 treatment under all the dates of observation. Due to increased height of mustard crop, it surpassed the shading effect of wheat crop excluding the interference at its lower tier. Moreover, the scattered and reflected portion of radiation from the upper surface of wheat canopy, helped to increase the absorption of PAR by mustard under this treatment.

While considering the T_4 treatment, during first year of observation, it was observed that, mustard crop had maximum absorption of PAR, when the crop age reached forty five days. Increased leaf density along with the receipt of scattered and reflected radiation from the short statured crop (wheat) might be the reason for increased absorption of PAR (Jena *et al.,* 2010). However, during the following year of investigation, mustard crop under T_4 treatment recorded comparatively less absorption of PAR than that of T_3 treatment. When radiation environment under T_5 treatment was looked into, it was seen that as two rows of mustard were associated with six wheat rows, they suffered severe interface interaction of wheat at the lower tier resulting in minimum absorption of PAR by mustard under this particular combination.

Radiation use efficiency (RUE) of wheat and mustard under wheat-mustard intercropping system

RUE of wheat

Variation in radiation use efficiency of wheat has been presented in Table 1. Results revealed that all the treatments differed significantly when RUE was taken into consideration. There was a gradual increase in RUE of wheat from 30 DAE to 75 DAE in both the years of investigation. This implied an increased accumulation of photosynthate per unit of PAR absorption with the progress of crop growth. Although maximum absorption of PAR was seen under sole stand of wheat (when compared with other intercrop combination), but the accumulation of dry matter per unit of absorbed PAR (RUE) was lowest, when compared with other intercrop combination irrespective of dates and years of observation. In the first year, maximum RUE (mean) was observed under T_5 treatment (2.55g MJ^{-1}). This was closely followed by T_3 treatment (2.47 g MJ^{-1}). However, in the following year of investigation, mean RUE of wheat was highest under T_3 treatment (2.99 g MJ^{-1}), followed by T_5 treatment (2.83 g MJ^{-1}). Among intercropped treatments, lowest RUE of wheat was recorded under T_4 treatment under both the years of investigation. Although, actual dry matter accumulation was lower under different intercrop combination of wheat, the proportionate dry matter accumulation was more, when considered the basis of unit absorption of PAR. However, the trend was altered, when RUE for grain yield of wheat was looked into. Sole wheat (T_1) recorded significantly highest RUE among all the treatment combinations, irrespective of years of observation. RUEs recorded for this particular treatment were 2.74 and 2.88 g $MJ^{-1}$for both consecutive years respectively. This was followed by RUE under T_5 and T_4 treatment respectively. RUE was minimum under T_3 treatment. Although treatment differences were significant during the first year of observation, no significant difference was found between T_1 and T_5 treatments during the following year of observation. Result showed an increasing trend of RUE, with decreasing number of associated mustard rows. Kiniry *et al.* (1989) observed the RUE for biomass production in wheat as 2.8 g MJ^{-1}. In the present experiment, we obtained the maximum RUE of wheat as 2.99g MJ^{-1} for biomass production.

RUE of mustard

Variation in radiation use efficiency of mustard under sole and intercrop combination has been presented in Table 2. It was observed that significant differences did exist between the treatments for RUE. Unlike wheat, there was a gradual increase in RUE of mustard upto 60 DAE. Thereafter it declined at the later stage of crop growth, irrespective of dates and years of observation. This might be due to shedding of older leaves of mustard at the later stage of crop growth. Depletion of RUE in mustard during later phase was due to low LAI and leaf dry matter accumulation (Tesfaye *et al.,* 2006). Sole mustard recorded significantly higher RUE in terms of dry matter accumulation among all the treatment combinations throughout the crop growth except the early phase (30 DAE). Mean RUE value recorded for sole mustard were 4.34 and 3.12 g MJ^{-1} for two consecutive years respectively. During the first year, mustard in T_5 treatment recorded the maximum RUE among all the intercrop combinations. T_4 treatment closely followed T_5. However, reverse trend was observed in the following year where maximum RUE was recorded in 4W:4M row ratio (T_4) followed by T_5 treatment. The mean RUEs recorded for these two treatments were 3.30 g $MJ^{-1}$and 3.56 g $MJ^{-1}$and 3.09 g $MJ^{-1}$and 2.68 g MJ^{-1} in two consecutive years respectively. However, when RUE for grain yield of mustard was taken into consideration, the trend remained unaltered for sole mustard (T_2). In comparison to intercropping, tall crop under sole stand gives good yield (Mandal *et al.,* 2014), which is due to better light penetration within the canopy. In the present experiment, sole mustard stand recorded significantly higher RUE among all the treatments (Dhaliwal *et al.,* 2007). RUE for grain yield recorded for sole stand were 1.23 and 1.04 g MJ^{-1} for the two consecutive years respectively. Therefore, maximum RUE for grain yield was recorded under sole mustard stand, while among the intercropped situation; the crop exhibited highest RUE under T_3 treatment. This was followed by T_4 treatment and RUE was minimum under T_5 treatment.

Although, lower RUE was recorded under intercropped stand (both for dry matter accumulation and yield), but the value was comparable suggesting intercropping to be a better option for mustard crop. Farmers when consider intercropping of wheat and mustard, the T_4 treatment (4W:4M) may be regarded as a suitable combination, as it recorded an acceptable value of RUE for grain yield in case of both the crops.

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