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THERMAL TIME ACCUMULATION AND HEAT USE EFFICIENCY OF DIRECT SEEDED FINE AROMATIC RICE

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ABSTRACT

Weeds pose serious threat to success of direct seeded rice (DSR). Cultural practices can alter dynamics of weed-crop competition through alteration of growth and accumulation of thermal time for phenological development. Thermal time accumulation by the DSR crop under different tillage systems, sowing times and durations of weed competition was studied through field experiments during the summer of 2010 and 2011. A commonly grown fine aromatic rice cultivar, Super Basmati was sown on the 15th June and 7th July under zero and conventional tillage, and subjected to different durations of weed competition (10, 20, 30, 40, 50 days after sowing and season long competition A randomized complete block design with the split-split arrangement employing three replications was used. Tillage systems were kept in main plots, while the sowing times and the durations of weed competition were assigned to sub- and sub-sub plots, respectively. The net plot size was 7 m × 2.2 m. Weed free plots were maintained under each tillage system and sowing time for comparison. Thermal time accumulated by DSR between different phenological stages was significantly affected by tillage systems, sowing times, duration of weed competitions, and their interaction. Time taken from sowing to emergence was longer in case of conventional tillage than zero tillage. Crop sown on 7thJuly reached heading stage with comparatively less accumulation of thermal time than 15th June-sown crop. The DSR plots subjected to increasing duration of weed competition needed more heat units to reach heading while thermal time from heading to maturity was decreased. Increasing duration of weed competition reduced heat use efficiency by DSR. In conclusion, late sown DSR crop exposed to weed competition was less efficient in converting accumulated heat units into economic yield. Hence, a DSR crop should preferably be sown by mid-June and weeds must be controlled before 20 DAS to avoid delay in heading and reduction in accumulation of heat units from heading to maturity so that the crop gets an appropriate grain filling period.

Key words: crop phenology, growing degree days, rice direct seeding, thermal time, tillage systems, weeds.

INTRODUCTION

Rice is a core cash crop and staple food in many Asian countries (Rao *et al*., 2007; Kumar and Ladha, 2011). Traditionally, rice is established through transplanting 30-35 days old seedlings into a puddled seed bed. This method is cumbersome, costly and labor intensive. In a water deficit country like Pakistan, continuous flooding is a huge burden on already scarce fresh water resources. Flooding is also responsible for lower water productivity due to non-judicious use of water (Tuong *et al*., 2005). Looming water crises, rising wage rates and stagnant productivity of rice-wheat cropping systems have compelled researchers and farmers to seek alternative methods of rice establishment (Kumar and Ladha, 2011). Direct seeded rice (DSR) seems potential alternative in quest of higher water productivity and to eliminate time and edaphic conflicts in the rice-wheat cropping system (Khaliq *et al.*, 2011, 2012). Nonetheless, sustainability of DSR cultures is threatened by heavy weed infestation and dry-DSR is particularly vulnerable to weed competition (Rao *et al*., 2007; Kumar and Ladha, 2011, Chauhan, 2012). More than 50 weed species have been reported to cause yield losses in DSR (Rao *et al*., 2007) that range between 30 to 98% (Oerke and Dehne, 2004; Gowda *et al*., 2009; Khaliq *et al*., 2012). The enormous yield loss caused by weeds in DSR warrants the need to look for yield improvement through effective manipulation of cultural practices.

A DSR crop can be planted into a prepared seed bed following dry tillage practices or under zero tillage into an undisturbed seed bed with loose or anchored wheat straw (Chauhan, 2012). Studies are available that document rice production under no tillage and direct seeding (Cho *et al*., 2001; Bhushan *et al*., 2007). Nevertheless, these studies evaluated overall productivity of cropping system with little emphasis on rice crop especially its phenological development. Land preparation affects both crops and weeds directly by altering soil environment and indirectly by affecting weed-crop association. The influence of tillage on weed suppression in DSR has been noticed for some species (Pittelkow *et al*., 2012). Literature also reports the influence of tillage on rice yield and yield components

(Saharawat *et al*., 2010). However, studies on the impact of tillage on phenological development of DSR crop under different durations of weed competition are lacking.

Sowing date is one of the important agronomic factors influencing weed dynamics, weed-rice interference (Kobayashi and Oyanagi, 2006) and crop productivity (Ahmad *et al.*, 2010). Selection of an appropriate sowing time might reduce the requirement of crop protection measures, and can be manipulated to regulate weed composition under field conditions. Delayed planting can reduce weed burden (Buhler and Gunsolus, 1996). In field crops; a yield penalty, often proportional to duration of delayed period is an assumption once the planting is done beyond an optimum limit. The tradeoff between weed suppression and crop yield reduction warrants the need to optimize sowing time before its manipulation as a weed management tool in DSR.

Phenology is the study of timing of developmental events in relation to calendar. Knowledge of phenological development seems indispensable to understand crop growth and yield potential besides prediction of events of developments of the crop. Such an information can be crucial for identification of a growth stage that is particularly sensitive to biotic and/or abiotic stress. Factors regulating the phenological development of DSR can alter crop-weed interactions and their knowledge is essential in making decision for weed management. Phenological properties of rice cultivars determine their yield potential (Fageria, 2007) and assessing the impact of weed competition on these requires detailed description of developmental events that reflect the success in capturing growth resources during crop life cycle (Ghersa, 2000). Thermal and photoperiodic conditions have a profound effect on rice phenological development and hence growth and yield. Rice plants require certain amount of heat units (growing degree days; GDD) often designated as thermal time to get through one stage to another in the growing season. When grown at a mean temperature of 25ºC, a rice crop may accumulate 2000-4000 GDD in 80-160 days depending upon environment × genotype interaction (Yoshida, 1981).

Although tillage and sowing time play vital role in determining the competitive outcome of rice-weed interactions, consequences of these factors for crop phenological developmental have not been described earlier. Thus, assessing the impact of these two factors in conjunction with different durations of weed competition in DSR forms an important area of research. The present study was therefore undertaken to ascertain the phenological development of DSR as influenced by tillage systems, sowing times and different durations of weed competition.

MATERIALS AND METHODS

Site description: The proposed study was conducted at the Agronomic Research Farm, University of Agriculture Faisalabad, (31.25° N, 73.09° E, 184 m a.s.l.), Pakistan. The soil of the experimental site belongs to Lyallpur soil series (Aridisol-fine-silty, mixed, hyperthermic Ustalfic, Haplargid in USDA classification and Haplic Yermosols in FAO classification). The pH of saturated soil paste was 7.7 and total soluble salts were 0.79 dS m^{-1}. Organic matter, total nitrogen, available phosphorus, and potassium were 0.74%, 0.055%, 7.1 ppm, and 183 ppm, respectively. Due to high evapotranspiration, Faisalabad features an arid climate with mean annual rainfall of about 200 mm. The meteorological data during the course of crop growth are presented in Fig. 1.

Experimentation: The experiments were conducted during the summer of 2010 and 2011 to appraise the influence of tillage and sowing time on phenological development of DSR subjected to different durations of weed competition. Treatments comprised of tillage (T) practices as zero tillage (ZT) and conventional tillage (CT), sowing times (ST) as 15th June and 7th July and different durations of weed competition (WC)–20, 30, 40, 50 days after sowing (DAS). Season long weed competition (weedy check) and weed free plots were maintained for comparison under each tillage system and sowing time. A randomized complete block design (RCBD) with split-split arrangement employing three replications was used. Tillage systems were kept in main plots, while, the sowing times and durations of weed competition were assigned to the sub- and sub-sub-plots, respectively. The net plot size was 7 m × 2.2 m. In all there were 72 experimental units during both the years.

Under field, the CT was accomplished by cultivating the soil with a disc plough for residue incorporation and then thrice with a tractor mounted cultivator followed by planking each time. Sowing in ZT plots was performed using a single row hand drill into undisturbed seed bed in a single pass operation. The previous crop in all tillage systems was wheat that followed the same tillage practices as for the preceding rice crop. The ZT plots received glyphosate (Roundup, Monsanto Agritech, Pakistan) at 20 days before sowing to curtail established weeds that otherwise were killed through cultivation in CT. Seed of popular rice *cv.* Super basmati was obtained from Rice Research Institute, Kala Shah Kaku, Sheikhupura, Pakistan. A soaking irrigation (10 cm) was applied 10 days before rice planting to keep ZT plots soften and moist while bring CT plots to working conditions to prepare the root and seed bed. A fertilizer dose of 114 kg N, 65 kg P_2O_5 and 50 kg K_2O ha^{-1} was applied in the form of urea (46% N), diammonium phosphate (18% N, 46% P_2O_5) and sulphate of potash (50% K_2O). The whole phosphorus and potassium and

one third of nitrogen (38 kg) were applied at the time of sowing. The remaining (76 kg) nitrogen was top dressed in two equal splits at tillering (30 days after sowing; DAS) and panicle initiation (65 DAS). Crop was sown on the respective sowing times during both the years at seeding rate of 50 kg ha^{-1} with a single row hand drill in 20 cm spaced rows. The first irrigation (3 acre-inch) was applied 5 DAS and the crop was irrigated subsequently as and when needed. Irrigation was applied only when soil showed drying signs after the water from previous irrigation have been consumed in the process of evapo-transpiration. There was no water ponding at any stage and hence complete aerobic conditions prevailed throughout the growing season. Irrigation was skipped if there was effective rainfall at that time. In all, 14 irrigations were given to the crop sown on 15th June and 12 to the crop sown on 7th July. To safeguard the crop against insect pests, carbofuron (Furadan 3G) at 22.5 kg ha^{-1} was used as a sand mixture just after irrigation at 60 DAS. For protection against paddy blast (*Pyricularia oryzae*), Topsin-M 70WP (thiophenate methyl) was used twice at 1250 g ha^{-1} prior to panicle initiation and at 14 days after panicle initiation.

Data collection and statistical analyses: The number of days taken from emergence to heading was calculated when 50% heading was achieved in respective plots. Heading time was assessed from three random sites in each plot and average was computed. Time taken from heading to maturity was recorded as the time period lapsed between complete heading to maturity for each plot. Days from heading to maturity were calculated from three sites for each plot applying 90% criterion and averaged. Phenological development was assessed based on thermal time (GDD) instead of calendar time as it has been suggested biologically more meaningful estimate of time required for growth and development. The GDDs were accumulated from the seeding date for each sowing time, and time of crop emergence was used as a reference point for the accumulation of the GDDs (Anwar *et al*., 2012). The GDDs were computed as under;

$$\mathrm{GDD} = \frac{\sum(T_{max} + T_{min}}{2} - T_b$$

where T_{max} and T_{min} are daily maximum and minimum air temperature (ºC), and T_b is the base or threshold temperature (10ºC for rice; Sarma *et al*., 2008) below which physiological activities are inhibited.

The data on GGDs accumulation was further used to calculate heat use efficiency index (HUEI; Rajput, 1980) as under;

$$\mathbf{HUEI} = \boldsymbol{Yield}\ (\boldsymbol{kg\ ha^{-1}})/\boldsymbol{GDD}$$

The data collected were subjected to the Fisher's analysis of variance and the Tukey's honest significance difference (HSD) test at $P \leq 0.05$ was employed to compare the treatments' means (Statistix 8.1, Analytical software, Statistix; Tallahassee, FL, USA, 1985-2003). Statistical analyses revealed that year effect was significant and hence, data are presented separately for two years. Graphical representation of the data was carried out using MS-Excel (Microsoft Corporation, USA).

RESULTS AND DISCUSSION

Thermal time requirement for phenological development of DSR: Thermal time required from sowing to emergence was significantly affected by sowing time during both the years. The DSR crop sown on 7th July accomplished an early emergence with lesser accumulation of thermal time (25 and 18 GDDs during 2010 and 2011, respectively) from sowing to emergence than 15th June sowing (Table-1). This was presumably due to higher soil moisture available for July sown crop due to rains in that period (Fig. 1). The effect of tillage was significant only during 2010 and CT plots recorded delayed emergence by accumulating more heat units from sowing to emergence (Table-1). Tillage systems had no effect on thermal time required from sowing to emergence in 2011. Regarding thermal time accumulation from emergence to heading, main effects of the tillage, sowing time (Table-1) and duration of weed competition were significant during 2010 (Table-2) . Crop sown under CT accumulated more (2038 GDDs) than ZT (2019 GDDs). The June sown crop accumulated more (440 GDDs) to reach heading than those observed for the July sowing. Requirement of higher thermal time in early sown rice crop for completion of heading corroborates the previous work of Singh *et al*. (2012) in transplanted rice. The June sown crop in present study availed more time of hot summer months than did July sown crop and hence accumulated more thermal time. Kobayashi *et al*. (2010) concluded that higher air temperature and incident radiation tend to advance anthesis in rice. Though the results of their study were significant, yet these two environmental variables explained only 40% variation in flowering time. Rice is a short day plant (Dingkuhn and Miezan, 1995) and less accumulation of the heat units for heading might be in part due to the seasonal transition in July sown crop after panicle initiation. The effect of sowing time on heading is associated with photoperiod sensitivity (Fukai, 1999) and Super Basmati has been characterized as a photoperiod sensitive rice cultivar (Safdar *et al*., 2008). Moreover, increasing durations of weed competition delayed time taken from emergence to heading in DSR and plots subjected to the season long weed competition required more (54.44 GDDs) heat units to reach heading than did the season long weed free plots. The interactive effect of tillage systems with sowing time was significant in 2011 (Table-1) and crop sown under ZT on 15th June accumulated more thermal time followed by CT under

the same sowing time. Nevertheless, the plots sown under CT on 7th July accumulated less thermal time showing an early heading. Contrarily, Kato *et al*. (2007) documented a delay in heading under CT. Such contrasting results may be due to variable genotype × environment interaction and variable cultural practices that prevailed under these studies. The main effects of the duration of weed competition were also significant in 2011 (Table-2), each successive increase in the duration of weed competition delayed heading, and hence, brought about an increase in the thermal time required to reach this stage. Difference in thermal time requirements between weedy check and season long weed free plots amounted to 77 GDDs, though overall accumulation of thermal time to reach heading was less than the previous year. Under severe weed competition, flowering time in rice was delayed by several days (Fukai, 1999). This suggested that under conditions of insufficient weed control or heavy weed infestation, as it normally happens with DSR, early flowering is diminished, thus exposing rice to lower temperature at later stages resulting in sterility (Sie´ *et al*., 1998). A delay in heading under weed competition in DSR also had implications for its agronomic fitness into the rice-wheat cropping system as sowing of the preceding wheat crop would be delayed if the rice remains in field for longer span of time. Thus, sustainable weed control in DSR seems obligatory for overall system productivity.

Although the effect of sowing time on thermal time accumulation from sowing to emergence and from emergence to heading was significant, nonetheless, its influence on thermal time accumulated between heading to maturity was non- significant during both the years (Table-1). However, tillage systems differed significantly and ZT plots took more thermal time to reach maturity in 2010 (Table-1). The effect of duration of weed competition on thermal time requirements from heading to maturity was quite opposite to that observed for emergence to heading, increased duration of weed competition caused accumulation of less heat units from heading to maturity (Table-2). Singh *et al*. (2012) documented that delayed transplanting accumulated less heat units between anthesis to maturity. The plots subjected to season long weed competition accumulated minimum heat units (376.13 GDDs) as against maximum (417.60 GDDs) observed for season long weed free plots. During 2011, the response of thermal time accumulation under different tillage systems varied as a function of sowing time due to significant interaction and ZT plots sown on 7th July took maximum GDDs to reach maturity (Table-1). Duration of weed competition depicted similar pattern as was observed in 2010 (Table-2).

Total thermal time accumulated from sowing to maturity differed between tillage systems, sowing times and duration of weed competition (Table-1&2). DSR sown under CT accumulated more thermal time than ZT. Likewise, the June sown crop had more GDDs (2824.61) on its credit than July (2350.04) sown crop. Thermal time requirement was slightly higher than season long weed free plots as duration of weed competition exceeded 20 DAS in 2010. In 2011, the crop sown on 7th July had lower value of cumulative GGDs than 15th June sowing (Table-1) irrespective of the tillage system. The weed competition duration increased the thermal time required to reach maturity (Table-2).

Heat use efficiency index of DSR: Regarding heat use efficiency, three-way interaction of tillage systems, sowing time and duration of weed competition was significant during 2010 (Fig. 2a). The significant interaction suggested that under ZT, HUEI of season long weed free plots was statistically similar between 15th June and 7th July sowing. However, in case of CT, 7th July sowing had significantly higher HUEI (1.34) than 15th June sowing. Increasing the duration of weed competition lowered HUEI, and when weeds were allowed to compete with the DSR crop for 30 DAS, HUEI of plots sown under CT on 15th June was significantly less (0.73). The July sowing under ZT had significantly higher HUEI (0.82) than June sowing under the same tillage system at weed competition duration of 50 DAS. Nevertheless, under season long weed competition, HUEI was statistically similar (0.29-0.42) between sowing times under both the tillage systems. In 2011, only the interaction of the sowing time with duration of weed competition was significant for HUEI. Highest HUEI (134 and 1.24) was recorded in season long weed free plots at both sowing times. The HUEI observed under weed competition duration of 20 DAS for June sowing was statistically similar with that observed for DSR growing in season long weed free plots of July sowing. Reduced HUE under increased weed competition suggested that although crop accumulated more thermal time under field condition yet it was unable to convert the accumulated heat efficiently into yield. This might be due to reduced assimilatory surface (leaf area index) available for intercepting incident radiation and duration of photosytnthetic activity ((leaf area duration; data not shown) under weed competition and July sowing. Reduced heat use efficiency of late sown rice crop is in line with the previous findings of Sikder (2009) as observed in wheat.

It is concluded that a DSR crop should preferably be sown by mid-June and weeds must be controlled before 20 DAS to avoid delay in heading and curtailed accumulation of heat units from heading to maturity. Late sown DSR crop exposed to weed competition was less efficient in converting accumulated heat units into economic yield. Hence, a DSR crop should preferably be sown by mid-June and weeds must be controlled before 20 DAS to avoid delay in heading and reduction in accumulation of heat units from heading to

maturity so that the crop gets an appropriate grain filling period.

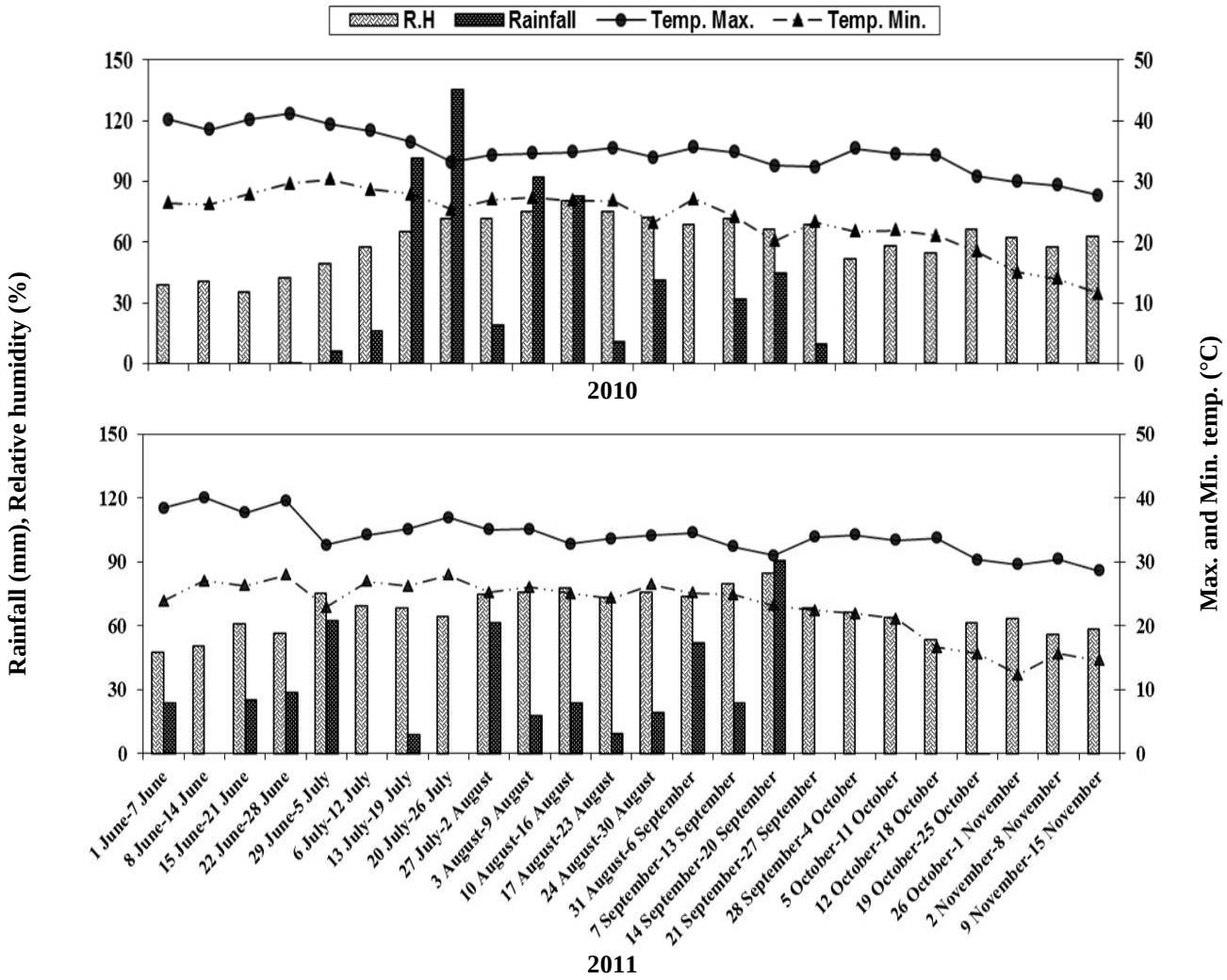

Fig. 1. Metrological data during the course of present study (Source: AgroMet Observatory, Department of Crop Physiology, UAF)

Table 1. Influence of different tillage systems, sowing times and their interaction on thermal time (GDDs) accumulation by direct seeded fine rice

	2010			**2011**		
	Sowing to emergence (S-E)					
	Tillage systems			**Tillage systems**		
Sowing time	ZT	CT	**Mean**	ZT	CT	**Mean**
15th June	160.72^{ns}	178.50	**169.61^{A}**	170.43^{ns}	178.13	**174.28^{A}**
7th July	142.92	147.28	**145.10^{B}**	150.14	162.26	**156.20^{B}**
Mean	**151.82^{B}**	**162.89^{A}**		**160.28^{ns}**	**170.19**	
	Emergence to heading (E-H)					
	Tillage systems			**Tillage systems**		
Sowing time	ZT	CT	**Mean**	ZT	CT	**Mean**
15th June	2240.51^{ns}	2256.30	**2248.41^{A}**	2127.97^{a}	2106.01^{b}	**2116.99^{A}**
7th July	1797.76	1819.04	**1808.40^{B}**	1768.24^{d}	1802.44^{c}	**1785.34^{B}**
Mean	**2019.14^{B}**	**2037.6^{A}**		**1948.10^{ns}**	**1954.23**	
	Heading to maturity (H-M)					

	Tillage systems			Tillage systems		
Sowing time	ZT	CT	**Mean**	ZT	CT	**Mean**
15th June	417.00^{ns}	396.18	**406.59**	364.32^{a}	364.86^{b}	**364.59^{ns}**
7th July	401.89	391.19	**396.54**	380.18^{b}	346.69^{c}	**363.44**
Mean	**409.44^{A}**	**393.69^{B}**		**372.25^{ns}**	**355.78**	
	Sowing to maturity (S-M)					
	Tillage systems			**Tillage systems**		
Sowing time	ZT	CT	**Mean**	ZT	CT	**Mean**
15th June	2818.23^{ns}	2830.98	**2824.61^{A}**	2662.72^{a}	2649.00^{a}	**2655.86^{A}**
7th July	2342.57	2357.51	**2350.04^{B}**	2298.56^{b}	2311.40^{b}	**2304.98^{B}**
Mean	**2580.40^{B}**	**2594.2^{A}**		**2480.64^{ns}**	**2480.20**	

Main effect and interaction means not sharing a letter in common differ significantly at 5% probability level by Tukey's HSD test. ns: non-significant

Table 2. Influence of different durations of weed competition on thermal time (GDDs) accumulation by direct seeded fine rice

	S-E		E-H		H-M		S-M	
	2010	**2011**	**2010**	**2011**	**2010**	**2011**	**2010**	**2011**
Season long weed free	161.00^{ns}	164.92^{ns}	2005.86^{D}	1911.23^{F}	417.60^{A}	388.35^{A}	2579.63^{B}	2464.50^{E}
Competition for 20 DAS	163.83	164.92	2018.15^{CD}	1925.71^{E}	408.19^{B}	381.27^{A}	2583.63^{B}	2471.90^{D}
Competition for 30 DAS	161.00	164.92	2022.82^{C}	1944.46^{D}	405.83^{B}	367.15^{B}	2588.57^{A}	2476.52^{C}
Competition for 40 DAS	168.83	164.96	2026.03^{BC}	1962.56^{C}	405.90^{B}	358.90^{BC}	2590.30^{A}	2486.42^{B}
Competition for 50 DAS	158.83	166.81	2038.15^{B}	1974.79^{B}	395.15^{C}	349.54^{CD}	2589.80^{A}	2491.15^{A}
Season long competition	163.83	164.92	2059.42^{A}	1988.25^{A}	376.73^{D}	338.88^{D}	2592.03^{A}	2492.04^{A}

Main effect and interaction means not sharing a letter in common differ significantly at 5% probability level by Tukey's HSD test. ns: non-significant

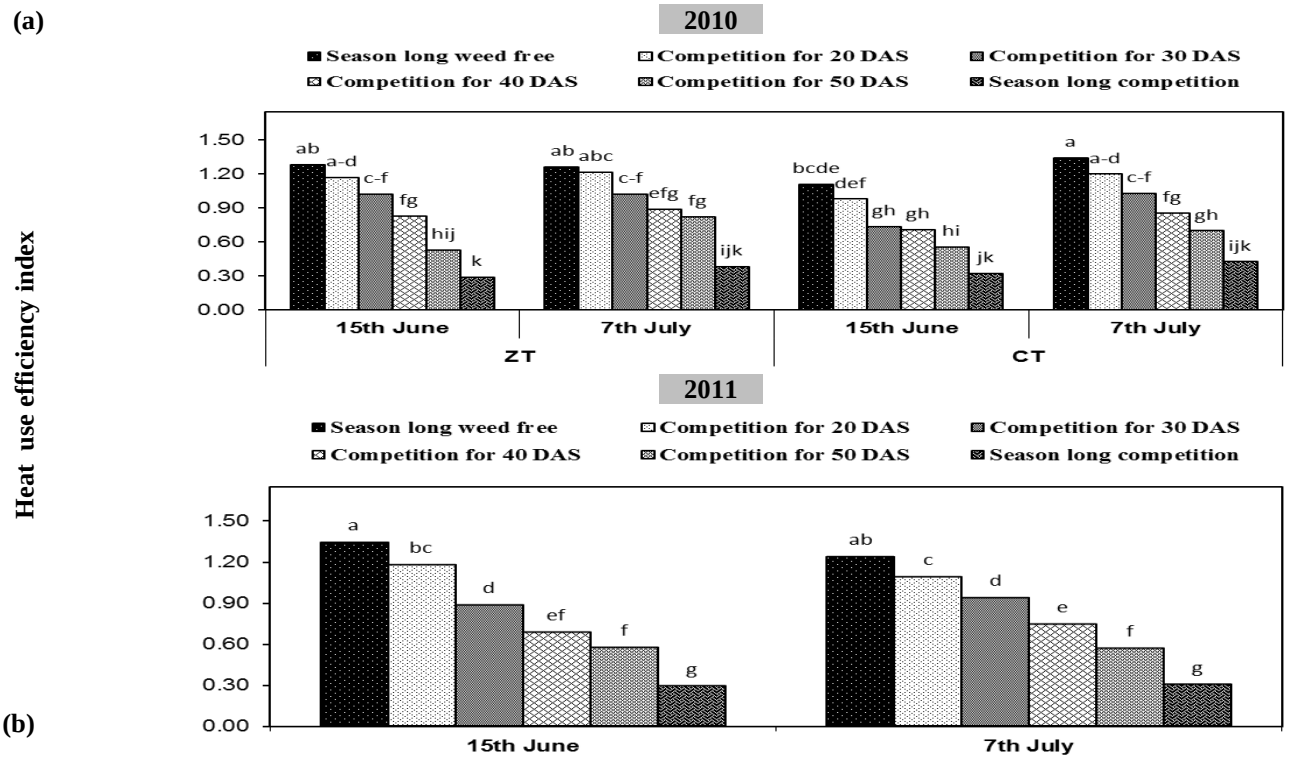

Fig. 2. Interaction of different tillage systems, sowing times and weed competition durations on heat use efficiency index in direct seeded fine rice during 2010 and 2011. Interaction means not sharing a letter in common differ significantly at 5% probability by Tukey's HSD test.

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