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Yield response and heat unit accumulation in rice under different sowing dates

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ABSTRACT

An experiment was conducted to study the effect of sowing dates on grain yield of rice variety Prathyasa and also to work out the cumulative heat units required to attain various phenophases in direct seeded rice (Oryza sativa) in terms of growing-degree days (GDD), heliothermal units (HTU) and photothermal units (PTU). The experiment was conducted in two years during the kharif seasons of 2016 and 2017respectively and the treatments consisted of five sowing dates starting from 1st June to August 1st at fortnightly intervals.The other dates were June 15th, July 1st and July 15th respectively.The design of the experiment was Randomised Block Design (RBD) with three replications. The field experiment was conducted in the farmer's field at Kalliyoor Panchayat near College of Agriculture, Vellayani, Thiruvananthapuram, Kerala, India. The weather data recorded in the Class B observatory attached to College of Agriculture, Vellayani is used for the study. The heat units, i.e., growing-degree days (GDD), heliothermal units (HTU) and photothermal units (PTU) required for each sowing dates were computed using the formula for each phenophases based on the weather parameters recorded in the Class B agromet observatory. The heat unit efficiency (HUE) was also worked out from the dry matter production and GDD. The results revealed thatearly sowing inJune 1st resulted in more heat unit accumulation compared to late sowingin August 1stleading to higher grain yield in early sown crop.The grain yield was the highest in June 15th sowing (6443.28 kg ha-1) in first year and June 1st sowing in second year (5328.18 kg ha^{-1}). The HUE of the crop was found high in June 15th sowing in first year and June 1st sowing in second year. Similarly the heat unit accumulation in terms of GDD, HTU, and PTU were also found higher in June 1st sowing.

***Keywords* :** GDD, HTU, HUE, heat units, rice variety Prathyasa, PTU, sowing dates

Rice (*Oryza sativa* L.) is a staple food of more than 50 per cent of the world's population (Fageria, 2007) and supplies 20 per cent of total calories required by world and 31 per cent required by the Indian population (Anonymous, 2011). India holds second position in production of rice in the world with a production of 105.48 million tonnes from 43.90 million hectares, with a productivity of 2390 kg ha^{-1} during 2015 (Economic survey, 2015-16). Rice is adversely affected by temporal and spatial variation. Most relevant among them is the changing weather parameters. Temperature and sunlight are some of the most important factors determining the crop development and yield. To study the response of rice based on meteorological resources available, certain indices can be worked out and evaluated. Growing degree days is an agroclimatic index which is an indicator for the prediction of harvest date and also the suitability of a crop to a particular locality (Ketring and Wheless, 1989; Sandhu *et al*., 2013).The heat unit calculation of heliothermal and photothermal units also gives the response of crop based on the heat units accumulated and its effect on phenological stages and productivity of crop. Hence the study was conducted to find out the effect of sowing dates on yield and phenology of the crop and to compute the various agro-climatic indices of the crop.

MATERIALS AND METHODS

The field experiment was conducted in two years, i.e., *kharif* seasons of 2016 and 2017, respectively in farmer's field at Kalliyoor Panchayat near College of Agriculture, Vellayani, situated at $8^0$26.7622 N latitude and $77^0$0.1362 E longitude with an elevation of 29 m above mean sea level. The treatments were five dates of sowing starting from 1stJune (D_1) followed by June 15th(D_2), July 1st(D_3), July 15th(D_4) and August 1st (D_5) respectively in two years. The variety used was *Prathyasa,* a new short duration variety released from Rice Research Station, Moncompu, Kerala. The experiment was laid out in Randomised Block Design (RBD) with five sowing dates as treatments in three replications and plot size was 20 m^2. The recommended dose for fertilizers (70: 35: 35 kg N: P_2O_5: K_2O ha^{-1}) were supplied through urea, factomphos and muriate of potash in split doses (KAU, 2016). Direct seeding of the crop was done by broadcasting of pre-germinated seeds in the ploughed and leveled plots. Calculated

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quantity of seeds was broadcasted in each plot @ 100 kg ha^{-1}.

Observations on phenology of crop

Crop phenology was recorded based on visual observation. The phenological stages were closely observed and days taken for active tillering, panicle initiation, booting, heading, 50% flowering and physiological maturity were recorded (Table 1). The weather data recorded from the class B agrometeorological observatory attached to College of Agriculture, Vellayani was used for calculating the different indices.The following indices were computed as per the equations.

Growing degree days (GDD), ^{0}Cd

Growing Degree Days (GDD) in degree day hours was determined as per the equation by Nuttonson (1955).

$$GDD = T_{mean} - T_b$$

Where $T_{mean}$is the mean of maximum and minimum degree days

$$T_{mean} = \frac{T\,max + T\,min}{2}$$

T_b = Base temperature (For rice T_b is considered as 10^0C)

Heliothermal units (HTU), ^{0}Cd

Heliothermal units (HTU) was computed by taking the product of GDD and corresponding Bright Sunshine hours (BSS) for that day and summing up the value of each day to attain different phenophases according to the equation given by Rajput (1980) and Sasthry and Chakravarthy (1982) :

$$HTU = \sum_p \left(GDD \times BSS(n)\right)$$

Where GDD= Growing Degree Days

BSS(n)= Bright Sunshine hours (hrs)

Photothermal units (PTU), ^{0}Cd

Photothermal units (PTU) was computed by taking cumulative value of product of growing degree days and day length. PTU according to Major *et al.*(1975)is mathematically represented as:

$$PTU = \sum_p \left(GDD \times N\right)$$

Where GDD = Growing Degree Days

N = Maximum possible sunshine hours or day length

Heat use efficiency (HUE), g m^{-2} ^{0}Cd

The heat unit efficiency (HUE) was calculated for dry matter production per hectare at maturity as per the formula given by Rajput (1980)

$$HUE\ (gm^{-2}\ {}^0Cd) = \frac{DMP}{GDD}$$

Where, DMP = Dry Matter Production in kg ha $^{-1}$

GDD = Growing Degree Days

RESULTS AND DISCUSSION

Growing degree days (GDD)

The growing degree days or heat unit concept or thermal unit concept was developed assuming that there is a direct and linear relationship between crop growth and temperature. GDD accumulated by the crop at different phenophases were calculated and foundthat sowing dates had significant influence on degree days accumulated in both the years. The total growing degree days (GDD) required by the crop to reach maturity when sown at different dates ranged from 1634.8^{0}Cdto 1902.9 ^{0}Cdin first year and from 1718.94 ^{0}Cdto 1982.2 ^{0}Cdin second year (Table 2).Early sowing (D_1) accumulated the highest GDD and the GDD was in the order $D_1 > D_2 > D_3 > D_4 > D_5$.Similar results were reported by Khavse *et al*. (2015) and Sandhu *et al.* (2013).

Analysis of correlation between yield and GDD revealed significant positive correlation at active tillering stage (Table 3). The GDD accumulated during first year was more compared to second year resulting in higher yield in first year. Early sowing resulted in higher yield in both the years and this might be due to the significant positive correlation between yield and GDD at active tillering stage and the positive correlation between yield and GDD both at 50% flowering and physiological maturity stages.Late sowing resulted in lower yield due to less accumulation of GDD (Table 2).The negative correlation between yield and GDD at booting stage might be the reason for lower yield in second year as the GDD values were higher at this stage in second year compared to first year.

Heliothermal units (HTU)

Heliothermal units required for attaining different phenophases and the total HTU to reach maturity were calculated and found that sowing dates had significant influence on HTUaccumulated by the crop. Early sowing (D_1) accumulated the highest heliothermal units and late sowing (D_5) the lowest, during both the years. Similar results in rice were also reported by Hundal *et al.* (2005). HTU required at different sowing dates ranged from 15295.24 ^{0}Cdto 16954.92 ^{0}Cdin first year and from 13541.72^{0}Cd to 16072.86 ^{0}Cdin second year (Table 4).

Table 1: Effect of sowing dates on attaining various phenophases in rice *var.* Prathyasa

Phenophases	June 1st (days)		June 15th (days)		July 1st (days)		July 15th (days)		August 1st (days)		Mean (days)
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	
AT	36	35	35	34	34	34	31	31	30	31	33.10
PI	51	54	48	50	47	50	47	50	41	47	48.50
B	59	62	56	58	55	58	55	58	54	58	57.30
H	67	69	67	67	66	68	66	69	65.5	69	67.35
F	76	78	74	75	75	77	74	76	72	75	75.20
PM	105	110	99	105.5	92	105	92	100	90	99	99.75

Note: *Y1- 1st year (2016), Y2-2nd year (2017), AT-Active tillering, PI-Panicle initiation, B-Booting, H-Heading, F-50% flowering, PM-Physiological maturity*

Table 2: Growing degree days (GDD) accumulated by rice *var*. Prathyasa at various phenophases under different sowing dates

Crop phenophases	D1 (^{0}Cd)		D2 (^{0}Cd)		D3 (^{0}Cd)		D4 (^{0}Cd)		D5 (^{0}Cd)	
	Y1	**Y2**	**Y1**	**Y2**	**Y1**	**Y2**	**Y1**	**Y2**	**Y1**	**Y2**
AT	649.70	628.90	634.10	629.25	615.40	619.10	565.15	566.25	548.95	555.70
PI	272.70	341.65	233.00	296.35	239.75	289.10	291.15	337.50	199.25	290.75
Booting	142.40	150.10	147.00	143.70	146.35	157.70	145.35	165.10	2370.00	195.70
Heading	144.65	127.70	201.35	160.60	199.80	181.40	199.10	175.05	200.50	200.90
50% flowering	167.85	162.50	128.40	141.00	161.25	163.05	146.90	127.30	125.20	108.60
Physiological maturity	525.60	571.35	453.95	540.35	311.40	505.60	323.70	433.09	323.90	427.29
TOTAL	1902.90	1982.20	1797.80	1911.25	1673.95	1915.95	1671.35	1804.29	1634.80	1778.94

Note: Y1- 1st year (2016), Y2-2nd year (2017)

Table 3: Correlation between yield and heat units at different phenophases

Phenophases	GDD	HTU	PTU
Active Tillering	0.741**	0.409*	0.759**
Panicle Initiation	-0.260	-0.024	-0.227
Booting	-0.439*	-0.114	-0.269
Heading	-0.321	0.036	-0.264
50% flowering	0.327	0.490**	0.395*
Physiological maturity	0.320	0.623**	0.365*

*Note: *Significant at 5%, ** Significant at 1%*

Table 4: Heliothermal units accumulated by rice *var*. Prathyasa at various phenophases under different sowing dates

Cropphenophases	D1(^{0}Cd)		D2(^{0}Cd)		D3(^{0}Cd)		D4(^{0}Cd)		D5(^{0}Cd)	
	Y1	**Y2**	**Y1**	**Y2**	**Y1**	**Y2**	**Y1**	**Y2**	**Y1**	**Y2**
AT	5335.2	5122.6	5414.2	4930.4	5539.7	5339.4	5250.0	4975.5	5228.1	4467.4
PI	2442.8	2855.7	2089.2	2703.7	2302.1	2485.9	2758.5	2508.8	1851.8	2191.7
Booting	1233.5	1358.3	1412.8	1255.9	1397.9	1037.6	1344.7	1313.7	2234.8	1619.3
Heading	1360.8	1147.1	1912.3	1237.3	1861.1	1455.5	1887.8	1236.7	1847.8	1765.2
50% flowering	1617.4	1406.5	1231.5	1036.4	1525.0	1218.9	1372.6	1128.3	1221.7	760.1
Physiological maturity	4965.1	4181.9	4249.5	4233.7	2906.6	4168.3	3067.6	3206.6	2911.0	2738.0
Total	**16954.9**	**16072.1**	**16309.5**	**15397.4**	**15532.4**	**15705.6**	**15681.3**	**14369.6**	**15295.2**	**13541.7**

Table 5: Photothermal units accumulated by rice *var*. Prathyasa at various phenophases under different sowing dates

Cropphenophases	D1 (^{0}Cd)		D2 (^{0}Cd)		D3 (^{0}Cd)		D4 (^{0}Cd)		D5 (^{0}Cd)	
	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
AT	8110.2	7852.2	7891.5	7615.8	7629.0	7674.9	6982.0	6996.0	6755.7	6835.1
PI	3381.5	4008.3	2887.4	3669.1	2948.9	3555.9	3581.1	4140.2	2198.7	3489.0
Booting	1765.8	2087.5	1808.1	1767.5	1800.1	1722.0	1749.8	1981.2	3052.8	2348.4
Heading	1784.6	1570.7	2476.6	1975.4	2441.1	2203.5	2389.2	2100.6	2398.7	2381.4
50% flowering	2064.6	1998.8	1579.3	1734.3	1935.0	1956.6	1762.8	1527.6	1477.4	1281.5
Physiological maturity	6400.1	6930.2	5469.2	6500.4	3736.8	6023.0	3834.2	5117.7	3822.0	5016.9
Total	**23506.7**	**24447.7**	**22112.2**	**23262.4**	**20491.0**	**23135.9**	**20299.1**	**21863.3**	**19705.3**	**21352.3**

Table 6: Effect of sowing dates on heat unit efficiency (HUE) of rice *var*. Prathyasa

Date of sowing	HUE (Kg ha^{-1} ^{0}Cd $^{-1}$) for dry matter production		HUE (Kg ha^{-1} ^{0}Cd $^{-1}$) for grain yield	
	Y1	Y2	Y1	Y2
D_1	6.41341	5.67637	3.213485	2.688013
D_2	7.27242	5.39924	3.58398	2.457261
D_3	6.30389	4.00075	2.866854	1.614228
D_4	5.19566	3.65063	2.245107	1.491928
D_5	4.81378	4.58003	2.294733	1.985795
Correlation between yield and HUE	0.973**	0.987**	0.985**	0.992**

*Note: Y1- 1st year (2016), Y2- 2nd year (2017), *Significant at 5%,** Significant at 1%*

Analysis of correlation between yield and HTU revealed significant positive correlation during active tillering, 50% flowering and physiological maturity stagesrespectively leading to higher yield in early sown crops (Table 3). The negative correlation between yield and HTU during panicle initiation and booting stages resulted in less yield in second year as the HTU accumulated were higher at these stages in second year.Similarly the higher accumulation of total HTU during first yearand lesser accumulation during second year also might have contributed to the higher yield in first year and lower yield in second year.

Photothermal units (PTU)

Growth is basically controlled by day and night length and heat requirement varies widely with different photoperiodic conditions. In such situations the product of summation of day length and summation of temperature may provide a less variable unit to discuss the phenological stages than the temperature units alone (Lenka, 1998). Early sowing accumulated the highest PTU and PTU was in the order D_1> D_2> D_3>D_4>D_5. Delayed sowing resulted in less heat unitaccumulation and similar results were also reported by Sandhu *et al.* (2013).

The PTU accumulated by the crop to reach maturity ranged from 19705.32 to 23506.7 ^{0}Cdin first year and from 21352.31 to 24447.6^{0}Cd in second year (Table 5). Similar results in rice were also reported by Hundal *et al*. (2005). Among the different phenological stages, maximum PTU was accumulated from sowing to active tillering stage followed by 50% flowering to physiological maturity stage. As mentioned earlier in case of HTU, there was a significant positive correlation between yield and PTU at active tillering, flowering and physiological maturity stageswhich might have resulted in higher yield in early sown crops compared to late sown crops (Table 3). There was negative correlation at all other stages which might have contributed to the reduced yield in second year when compared to first year and the trend was similar to that in GDD and HTU.

Heat use efficiency (HUE)

As is seen in the table (Table 6), it is understood that sowing date had significant influence on heat unit efficiency of crop.When observing TDMP (total dry matter production), HUE was the highest in early sowings, i.e., June 15 (D_2) in first year and June 1st (D_1) in second year and the lowest in late sowingin first and second year (D_5 and D_4 respectively). This was in

Table 7: Effect of sowing dates on yield and yield attributes of rice *var.* Prathyasa

Date of sowing	Grain yield (kg ha $^{-1}$)			Spikelets panicle $^{-1}$		Filled grains panicle $^{-1}$		Productive tiller m $^{-2}$		1000 grain weight (g)		Chaff (%)		Sterility (%)	
	Y1	Y2	Pooled	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2	Y1	Y2
D_1	6114.9	5328.2	5721.6	101.6	96.7	87.7	83.0	485.3	464.0	28.1	31.3	13.9	13.7	15.8	16.4
D_2	6443.3	4696.4	5569.9	98.8	93.7	83.6	81.0	512.0	430.7	25.8	29.7	15.3	12.7	18.3	15.7
D_3	4799.0	3092.8	3945.9	82.7	80.3	65.8	63.7	490.7	385.3	28.5	29.8	16.8	16.7	25.6	26.3
D_4	3752.4	2691.9	3222.1	80.1	78.0	65.9	61.0	438.3	388.0	29.0	29.8	14.2	17.0	21.6	27.9
D_5	3751.4	3532.6	3642.0	90.6	88.0	75.0	73.3	495.8	392.0	28.1	30.5	15.6	14.7	20.8	20.0
SEm (±)	**161.83**	**117.11**	**107.12**	**1.16**	**3.29**	**1.27**	**2.42**	**8.97**	**10.18**	**1.56**	**0.69**	**0.76**	**2.19**	**1.23**	**3.06**
LSD (0.05)	**373.19**	**270.06**	**205.81**	**2.67**	**7.58**	**NS**	**5.58**	**20.67**	**23.47**	**NS**	**NS**	**1.75**	**NS**	**2.85**	**7.06**

accordance with the results of Diwan *et al*. (2017) and Praveen *et al*. (2013). When considering HUE of grains the same trend as in TDMP (Total dry matter production) was observed. There was significant positive correlation between HUE and yield. During first year, the HUE of TDMP and grains were the highest in June 15thsowing (D_2) resulting in the highest grain yieldin D_2(6443.28 kg ha^{-1}). During second year HUE was the highest in June 1st (D_1) resulting in the highest yield in D_1 (5328.18 kg ha^{-1}).At maturity stage, the highest heat use efficiency in June 1st (first year) and June 15th (second year) sowing might be due to better conversion of light into dry matter and better yield component in these sowings as compared to other sowing dates.Reduced heat use efficiency of late sown rice crop is in line with the findings of Sikder (2009) as observed in wheat.

Yield and yield attributes

Results revealed that yield attributes like productive tillers per m^2, spikelets per panicle, filled grains per panicle, chaff and sterility per cent were influenced by sowing dates (Table 7). Productive tillers, being an important trait deciding rice grain yield, number of productive tillers per m^2 was the highest in D_2 in first year (512) and D_1 in second year(464). Early sowing (D_1) recorded higher number of spikelets and filled grains per panicle during both the years. Spikelets per panicle ranged from 90.55 (D_5) to 101.56 (D_1) in first year and 88.00 (D_5) to 96.67 (D_1) in second year, whereas filled grains per panicle ranged from 65.84 (D_3) to 87.67(D_1) in first year and 61 (D_4) to 83 (D_1) in second year. These yield attributing parameters were low in late sowing. Late sowing resulted in higher amount of chaff and thereby leading to higher sterility percentage. The sterility percentage was higher in D_3 than in D_4 and D_5 and it was lower in D_1 and D_2. Sowing dates did not influence the 1000 grain weight.

The effect of sowing dates on yield attributes reflected on the grain yield during both the years. In first year (2016), grain yield was the highest in crop sown on June 15th (D_2) and was significantly superior to all other dates of sowing (Table 7). This was followed by the crop sown on June 1st (D_1) and grain yield was the lowest in delayed sowing (D_5). In second year, the highest yield was recorded by June 1st (D_1) followed by June 15th (D_2) sowing and late sowing (D_5) recorded the lowest yield. In first year the yield increase was up to 41.78 % in early sowing (D_1, D_2) and in second year it was up to 49.48 per cent compared to late sowing (D_3, D_4 and D_5). The number of productive tillers per m^2 has contributed to the higher yield in early sowing dates during both the years. These results are in agreement with the findings of Gangwar and Sharma (1997) who also observed more number of panicles in early transplanting than in late transplanting. This was due to the fact that rice sown earlier had longer period for their vegetative growth compared to those sown later (Safdar *et al.*, 2008). Lower sterility in early sowing was due to optimum photo period availed by these treatments for growth, development and starch filling in the grains (Dawadi and Chaudhari, 2013). These results are in line with that of Iqbal *et al.* (2008) and Dawadi and Chaudhari (2013) who reported that rice yield (4-5 t ha^{-1}) was the highest when rice crop was sown earlier in the season. According to Walia *et al.* (2014), the reduction in grain yield of direct sown rice with delayed sowing was due to shortening of overall growth period of crop. The results of this study also confirms the finding of Walia *et al.* (2014) as the total duration of the crop upto physiological maturity was reduced by 15 days in first year (90 days) and 11 days in second year (99 days) from the total duration of early sown crop (105 and 110 days respectively).Everywhere the highest rice yield is associated with sowing or planting within a specific period. The limits of source and sink development is so well related that late sowing or planting limits the development of one or both so that the yield decrease (Lenka, 1998).

As presented in table 7 it could be seen that with delayed sowing, yield reduced considerably as the crop duration as well as the days taken to attain each phenophases were reduced considerably without sufficient accumulation of heat units, the crop reached maturity. Early sowing accumulated sufficient heat units and GDD and hence the highest yield.

The results of the study revealed that optimum date of sowing is important for any crop to realize its full yield potential through its influence on various agro-climatic indices such as GDD, PTU, HTU and HUE of crop as sowing dates determine these indices. Hence the study recommends early sowing of the crop from June 1st to June 15th rather than going for late sowing up to August 1st so that the crop can utilize the weather parameters more effectively.

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