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Research Paper

Growth performance and agrometeorological indices of rice under different establishment methods

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ABSTRACT

The field experiment was conducted to study the growth performance and agrometeorological indices of rice cultivars i.e. PR 122, PR 126 and Pusa 44 grown under direct seeded rice (DSR) and puddled transplanted rice (PTR) conditions during *kharif* 2020 and 2021 at Punjab Agricultural University, Ludhiana. Results revealed that the accumulated growing degree days (AGDD), accumulated helio-thermal units (AHTU) and accumulated photo thermal units (APTU) were higher in PTR than DSR, while radiation use efficiency (RUE) was higher in DSR in terms of dry matter production but in terms of grain yield RUE was higher in PTR. Heat use efficiency (HUE) was also higher in DSR. AGDD, AHTU and APTU were also higher in Pusa 44, however, RUE and HUE were higher in PR 126 in terms of grain yield and dry matter. Among nitrogen levels, N_3 (Leaf colour chart-based nitrogen application) gives at par yield with N_1 (Recommended) and N_2 (125 % of recommended). Optimum nitrogen level is helpful to get higher light interception rate and RUE while HUE was highest in N_2 followed by N_1 and N_3.

Keywords: Direct seeded rice, Puddled transplanted rice, Heat use efficiency, Radiation use efficiency, Agrometeorological indices, Stress degree days

Rice (*Oryza sativa* L.) is one of the significant grain crops, structuring the staple eating routine of more than 60 per cent of the global population (Yu *et al.,* 2020). In India, rice is grown over widely diverse ecologies, such as irrigated uplands, rainfed lowlands, and rainfed uplands with the lowest productivity under rainfed ecology. India is major producer and consumer of rice after China, which accounts for 21 per cent of the world's total rice production (APEDA, 2021). In Punjab, rice crop occupied the 31.45 lakh hectares with total paddy production 203.71 lakh tones during *kharif* 2021-22 (Anonymous, 2023).

Rice is established mainly by two methods i.e. puddled transplanted rice (PTR) and direct seeded rice (DSR). In PTR, which is predominant in South and Southeast Asia, seedlings are transplanted from a nursery into a puddled field. On the other hand, DSR involves establishing rice without nursery raising, achieved either by using dry seeds in non-puddled soil (Dry-DSR) or pre-germinated seeds in puddled soil (Wet-DSR). DSR reduces the cost of cultivation and GHG emissions, and increases farmer's income without yield penalty. Based on a meta-analysis, DSR has reduced methane emissions from 40 to 63 % compared to PTR especially dry-DSR, because of less flooding and more aerobic conditions which prevents methanogenesis and therefore methane emissions (Kumar *et al.,* 2018).

Nitrogen is vital for plant growth, impacting cell development and photosynthesis. However, excessive nitrogen uses by farmers, coupled with improper synchronization of application, leads to significant environmental losses, including emissions of nitrous oxide (N_2O) and ammonia (NH_3), and leaching of nitrate (NO_3^-). Real-time nitrogen management in rice relies on assessing leaf nitrogen content using chlorophyll meters etc. Leaf color chart-based nitrogen management has shown positive results in enhancing nitrogen use efficiency and profitability in rice cultivation. Improved nitrogen management can help to mitigate environmental impacts associated with nitrogen losses, promoting sustainable agricultural practices (Coskun *et al.,* 2017).

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Heat and radiation use efficiencies in terms of dry matter or yield are important aspects, which have great practical application. The total heat and radiant energy available to any crop is never completely converted to dry matter under even the most favourable agroclimatic conditions. Efficiency of conversion of heat and radiant energy in to dry matter depends upon genetic factors, sowing time and crop type (Rao *et al.,* 1999). Total dry matter accumulation was found to be linearly related with the RUE in terms of biomass (Kar and Kumar, 2016). Therefore, the relationship between dry matter and intercepted radiation may vary during crop growth. The SDDI is an index, which shows the soil moisture as well as plant water status in unison. As it is the difference between canopy temperature and air temperature estimated at 12.00 h, higher degree of negativity will indicate the low canopy temperature with a low water stress (Chakravarti *et al*., 2010). In view of these, an attempt has been made to understand the intricate relationship between various agrometeorological parameters and growth and yield of rice in Punjab.

MATERIAL AND METHODS

The field experiment was conducted at the Research Farm of Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana during *kharif* season of 2020 and 2021. Ludhiana station is located at latitude of 30°54' N and longitude of 75°48' E with an altitude of 247 m above mean sea level, which is placed in the central plain region of Punjab under Trans-Gangetic agro climatic zone of India. The experiment was laid out in Factorial Split Plot Design with three replications comprising two crop establishment methods and three varieties in main plots and three nitrogen levels in sub-plots. Three varieties viz; PR 122 (long duration), PR 126 (short duration) and Pusa 44 (long duration) were planted with puddled transplanted method and direct seeding with conventional seed drill. Three nitrogen levels viz; recommended dose of nitrogen (N_1), 125 % of recommended dose of nitrogen (N_2) and according to leaf color chart (LCC, N_3) were taken. The drill sowing of all three varieties was done at 20 cm row spacing using treated seed on seed-bed prepared in respective main plots on 28th May. For puddled transplanting, nursery was raised by sowing on the date of direct seeding and transplanted manually with 30 days old seedlings at 20 cm×15cm spacing. For transplanted crop the N_1 (225 kg urea ha^{-1}) and N_2 (281.25 kg urea ha^{-1}) doses of nitrogen were applied after 7, 21 and 42 days (35 days for PR 126) after transplanting (PAU, Ludhiana package of practices). In N_3, 62.5 kg ha^{-1} basal dose of urea was applied and after 14 days of transplanting first fully exposed leaf from top was continuously matched with 4th strip of LCC at 7 days interval upto flowering initiation and 62.5 kg ha^{-1} was applied when 6 from 10 leaves shows light colour then LCC strip. For direct seeded crop the N_1 (325 kg Urea ha^{-1}) and N_2 (406.25 kg Urea ha^{-1}) doses of nitrogen as recommended by Punjab Agricultural University Ludhiana were applied after 4, 6 and 9 weeks of sowing. In N_3, 25 kg urea was applied after 4 weeks of sowing. After 6 weeks of sowing first fully exposed leaf from top was continuously matched with 4th strip of LCC at 7 days interval up to flowering initiation and 75 kg ha^{-1} was applied when 6 from 10 leaves shows light colour then LCC strip. The weather prevailed during both the seasons are presented in Fig. 1.

Growth and yield parameters i.e. dry matter accumulation, chlorophyll content and grain yield were recorded. Chlorophyll content was recorded at 30 days interval with the help of the chlorophyll content meter model CCM-200 plus portable leaf greenness meter. Chlorophyll content index was measured in the presence of sun light, on clear sunny days. The chlorophyll content was presented as chlorophyll content index of leaf surface after calculating from five leaves. Agrometeorological indices i.e. growing degree days (GDD), helio-thermal units (HTU) and photo-thermal units (PTU) were computed (Sreenivas *et al.,* 2010). Photosynthetically active radiation (PAR) was also recorded by using a line quantum sensor to measure the amount of incoming, reflected and transmitted PAR at 15 days interval. The incoming and reflected radiation measurements were made above the canopy while transmitted radiation was recorded at the base of canopy. Data collected from this observation was used to calculate the PAR interception:

$$\text{PAR interception (\%)} = \frac{\text{Incoming PAR} - [\text{Transmitted PAR} + \text{Reflected PAR}]}{\text{Incoming PAR}} \times 100$$

$$\text{Radiation use efficiency (RUE)} = \frac{\text{Dry matter production/Grain yield (g m}^{-2})}{\text{IPAR (MJ m}^{-2}\text{ day}^{-1})}$$

$$\text{Heat use efficiency (HUE)} = \frac{\text{Dry matter production (kg ha}^{-1})}{\text{Accumulated growing degree day (° Cday)}}$$

The average canopy and air temperature difference (Tc-Ta) values were used to determine the accumulated stress degree days by using the following formula by Jackson *et al*., (1977):

$$\text{Accumulated SDD} = \sum(\text{Tc-Ta})$$

RESULTS AND DISCUSSION

Dry matter production, grain yield and APAR

During *kharif* 2020 and 2021, dry matter accumulation (g m^{-2}) was 2.66 % higher in DSR method than PTR method up to harvesting and difference was statistically significant during *kharif* 2021, as data presented in Table 1. That might be due to transplanting shock to transplanted crop and a well-established crop in DSR method. Rate of dry matter production was more in DSR method than PTR method up to 90 DAS and after that similar or less than PTR. Although DSR took 7-8 days less than PTR to reach maturity but rapid leaf area growth rate at early vegetative stage, LAI before heading and high stem number resulted in higher intercepted radiation before heading compared to PTR and accumulated more dry matter. Xu *et al.,* (2022) also reported similar findings for rice crop in China. Among varieties, dry matter was significantly higher in Pusa 44 than PR 122 (5.31 %) and then PR 126 (13.88 %) at the time of harvesting. During early stages dry matter of PR 126 increased at higher rate than the other two varieties due to its short life span. Among nitrogen levels, dry matter was significantly higher in N_2 than N_1 (1.61 %) and N_3 (5.63 %) at harvesting. These findings in respect of effect of nitrogen level on dry matter production in rice crop were also in conformity with Xu *et al.,* (2022).

During *kharif* 2020, non-significant results were found for

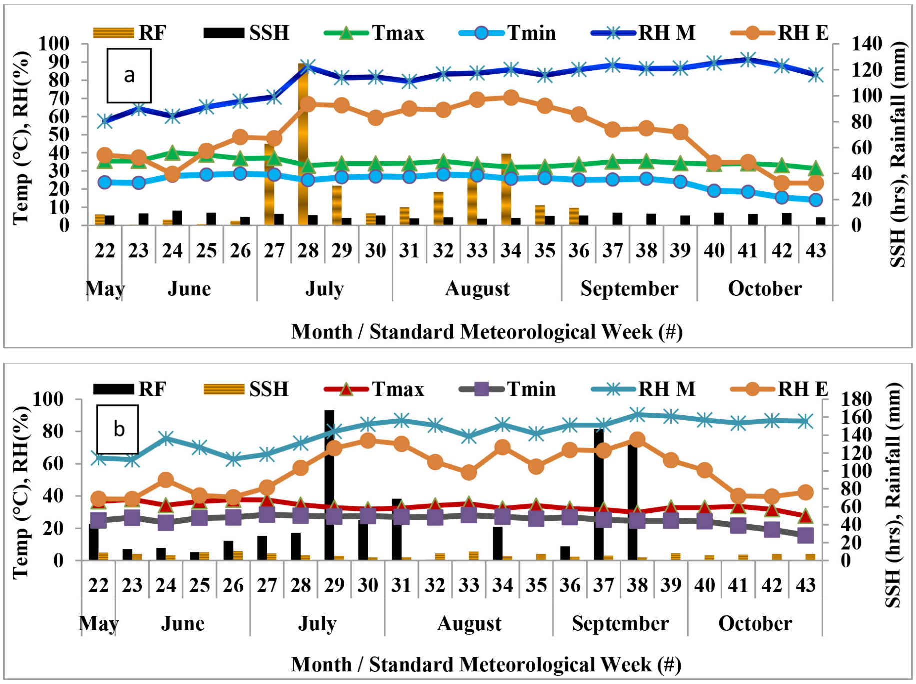

Fig. 1: Weekly meteorological data during rice crop season, (a) *kharif* 2020 and (b) *kharif* 2021

Table 1: Dry matter production, grain yield and HUE of rice as varied by establishment methods, varieties and nitrogen levels during *kharif* 2020 and 2021

Treatments	Dry matter accumulation (g m^{-2})		Grain yield (q ha^{-1})		HUE	
	2020	2021	2020	2021	2020	2021
Establishment methods						
DSR (Direct seeded rice)	1187.02	1174.67	60.20	58.36	4.36	4.28
PTR (Puddled transplanted rice)	1156.19	1133.20	61.80	59.49	4.12	4.02
CD (0.05%)	NS	36.42	NS	NS	0.16	0.20
Varieties						
PR 122 (V_1)	1180.27	1162.78	60.45	58.37	4.13	4.00
PR 126 (V_2)	1091.54	1075.37	59.60	58.02	4.39	4.34
Pusa 44 (V_3)	1243.00	1223.64	62.95	60.38	4.20	4.10
CD (0.05%)	44.18	44.61	NS	NS	0.18	0.23
Nitrogen levels						
Recommended Dose (N_1)	1180.09	1158.65	60.76	58.64	4.26	4.15
125 % of Recommended dose (N_2)	1199.15	1183.39	62.45	60.21	4.30	4.21
Leaf colour chart (N_3)	1135.58	1119.76	59.80	57.92	4.16	4.08
CD (0.05%)	45.39	30.55	NS	NS	NS	NS

grain yield among all treatments as presented in Table 1. However, in Transplanting method 61.80 q ha^{-1} grain yield was recorded which was 2.65 % higher than DSR method i.e. 60.20 q ha^{-1}. Among different varieties, Pusa 44 (62.95 q ha^{-1}) was recorded with 4.13 % and 5.32 % higher yield than PR 122 (60.45 q ha^{-1}) and PR 126 (59.60 q ha^{-1}), respectively. Among different nitrogen levels, grain yield in N_2 (62.45 q ha^{-1}) was 2.78 % and 4.43 % higher than N_1 (60.76 q ha^{-1}) and N_3 (59.80 q ha^{-1}), respectively. During *kharif* 2021, due to cloudy weather and rains at the time of flowering lowered the grain yield in all treatments and statistical results were similar to *kharif* 2020 as shown in Fig. 2. Kaur and Singh (2015) also found that DSR gave statistically at par yield with PTR method however yield might be slightly more in PTR method.

The accumulated photosynthetically active radiation (APAR) was 0.6 % higher in PTR (755.66 MJ m^{-2}) than DSR (751.59 MJ m^{-2}) during *kharif* 2020 due to its long duration. Among varieties, APAR was highest in Pusa 44 (805.96 MJ m^{-2}) by 5.67 % and 16.37 % than PR 122 (762.66 MJ m^{-2}) and PR 126 (692.55 MJ m^{-2}), respectively. Among nitrogen levels, APAR was higher in N_2

Table 2: Influence of establishment methods, varieties and nitrogen levels on chlorophyll content in rice crop during *kharif* 2020 and 2021

Treatments	Chlorophyll content							
	2020				2021			
	60 DAS	90 DAS	120 DAS	At harvest	60 DAS	90 DAS	120 DAS	At harvest
Establishment methods								
DSR (Direct seeded rice)	10.89	22.87	16.85	10.85	11.15	23.02	17.46	11.45
PTR (Puddled transplanted rice)	8.67	20.72	17.18	11.76	9.05	21.48	17.96	12.50
CD (0.05)	0.37	0.89	NS	NS	0.57	1.28	0.45	0.36
Varieties								
PR 122 (V_1)	9.05	20.13	18.93	10.89	9.44	20.52	19.70	11.60
PR 126 (V_2)	11.03	24.37	11.65	11.17	11.30	24.82	12.26	11.77
Pusa 44 (V_3)	9.26	20.87	20.48	11.85	9.57	21.40	21.17	12.56
CD (0.05)	0.45	1.09	1.14	NS	0.70	1.57	0.55	0.44
Nitrogen levels								
Recommended dose (N_1)	9.88	21.70	16.65	10.86	10.13	22.17	17.42	11.59
125% of recommended dose (N_2)	9.80	23.20	18.89	12.50	10.28	23.86	19.71	13.23
Leaf colour chart (N_3)	9.66	20.48	15.51	10.55	9.90	20.72	15.99	11.12
CD (0.05)	NS	0.66	0.74	0.74	NS	1.99	1.07	0.50

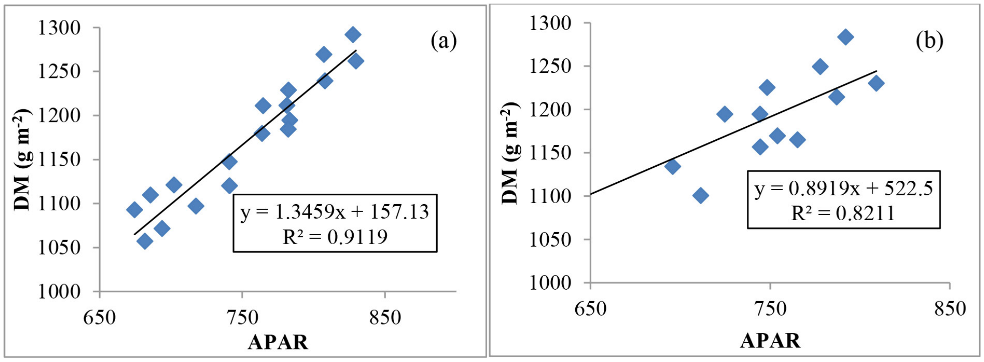

Fig 2: Relationship between cumulative APAR and dry matter production (DM)during *kharif* (a) 2020 and (b) 2021

(773.74 MJ m^{-2}) than N_1 (753.84 MJ m^{-2}) and N_3 (733.59 MJ m^{-2}) by 2.64 % and 5.47%, respectively. During *kharif* 2021, although all treatments took more days to reach maturity but due to cloudy weather and less sunshine hours APAR was lower than *kharif* 2021 and shows similar trend as 2020. The total dry matter accumulation was found to be linearly related with the cumulative absorbed PAR with the R^2 value of 0.91 and 0.82 during *kharif* 2020 and 2021, respectively (Fig. 2). Grain yield also showed linear relationship with cumulative absorbed PAR with the R^2 value of 0.63 and 0.47 during *kharif* 2020 and 2021, respectively (Fig. 3). Kar and Kumar (2016) also reported that total AGDB (above ground dry biomass) accumulation was linearly related with the cumulative absorbed PAR with the R^2 value of 0.84.

Heat use efficiency (HUE)

HUE was calculated as the ratio of total dry weight to heat units utilized as presented in Table 1. During *kharif* 2020, HUE was significantly higher in DSR than PTR by 5.83 %. That might be due to more dry matter production in DSR method in 7-8 days short growth period than PTR method. Among varieties, HUE in PR 126 was significantly higher than Pusa 44 (4.52 %) and PR 122 (6.29 %), while HUE of these both varieties was statistically at par. That also might be due to 25-30 days short growth period of PR 126 than PR 122 and Pusa 44. PR 126 produced comparable dry matter to both varieties in short growth period. Among nitrogen levels, HUE in N_2 was higher than N_1 (0.09 %) and N_3 (3.36 %), however results were statistically non-significant. All treatments produced less dry matter in *kharif* 2021 with higher AGDD consumption as compared to *kharif* 2020 due to poor sunshine hours so HUE was also lower in *kharif* 2021 than *kharif* 2020 and statistically trend was similar among the treatments. Aggarwal *et al.,* (2015) also reported that the accumulated GDD and HUE increased significantly with each successive increase in nitrogen dose from 0 to 150 kg ha^{-1} which might be due to corresponding significant increase of days taken to maturity and in grain yield.

Chlorophyll content

Chlorophyll content increased progressively with successive stage of crop growth as presented in Table 2. During *kharif* 2020, Chlorophyll content was significantly 10.37 % higher in

Table 3: Influence of establishment methods, varieties and nitrogen levels on AGDD (°Cday), AHTU (°C day) and APTU (°C day) at physiological maturity of rice during *kharif* 2020 and 2021

Treatments	AGDD		AHTU		APTU	
	2020	2021	2020	2021	2020	2021
Establishment methods						
DSR (Direct seeded rice)	2725	2753	21688	19509	35944	36233
PTR (Puddled transplanted rice)	2813	2827	22344	20222	36946	37080
CD (0.05%)	87.0	NS	NS	NS	NS	NS
Varieties						
PR 122 (V_1)	2861	2905	22904	20830	37514	37975
PR 126 (V_2)	2488	2481	19528	17301	33234	33131
Pusa 44 (V_3)	2958	2984	23617	21466	38587	38863
CD (0.05%)	106.6	119.5	1075.4	959.9	2006.1	2677.5
Nitrogen levels						
Recommended dose (N_1)	2773	2797	22066	19931	36490	36741
125 % of Recommended dose (N_2)	2795	2819	22203	20082	36736	36986
Leaf colour chart (N_3)	2739	2754	21780	19584	36109	36243
CD (0.05%)	NS	NS	NS	NS	NS	NS

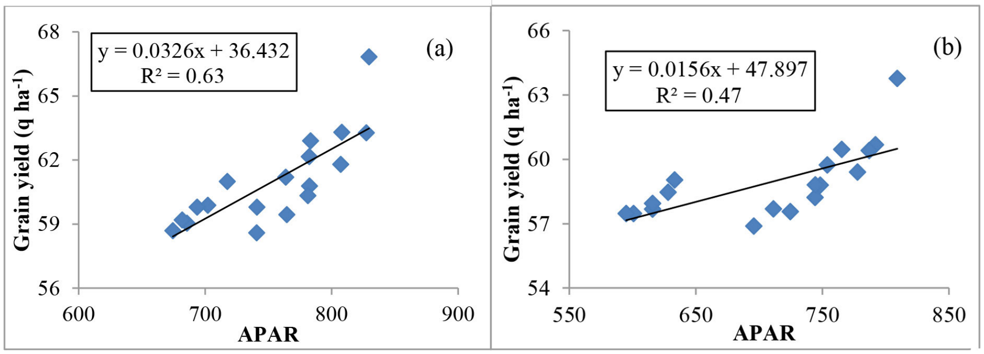

Fig 3: Relationship between cumulative APAR and grain yield (q ha^{-1}) during *kharif* (a) 2020 and (b) 2021

DSR than PTR at 90 DAS, that might be due to transplanting shock to transplanted crop and a well-established crop in DSR method. After 90 DAS chlorophyll content started declining in both the methods but rate of decline was higher in DSR as compared to PTR method. Among varieties, Chlorophyll content increased at higher rate in PR 126 upto 90 DAS and was significantly higher than Pusa 44 (16.77 %) and PR 122 (21.06 %) due to its short duration. PR 126 attained its peak value at 90 DAS while Pusa 44 and PR 122 attained their peak value at 105 DAS and at 120 DAS, chlorophyll content of PR 126 was significantly lower than the other two varieties. Among nitrogen levels, Chlorophyll content was significantly higher in N_2 than N_1 and N_3 from 60 DAS to harvest. Due to cloudy weather in *kharif* 2021, chlorophyll content was higher in *kharif* 2021 than *kharif* 2020 however statistically analysis was almost similar among all treatments.

Accumulated -growing day degree (AGDD)

During *kharif* 2020, PTR (2812.8 °C days) accumulated significantly higher growing degree days than DSR (2725.3 °C days) by 3.21 %. Among varieties, PR 126 (2488.3 °C days) accumulated significantly lower AGDD than Pusa 44 (2957.7 °C days) and PR 122 (2861.2 °C days) by 15.81% and 13.03% respectively. While N_2 (2794.7 °Cday) accumulated 0.08 % and 2.02 % higher AGDD than N_1 (2773.2 °Cday) and N_3 (2739.3 °Cday), respectively however results were statistically non-significant. During *kharif* 2021, as all treatments took a greater number of days to reach maturity so AGDD were higher in *kharif* 2021 than *kharif* 2020 while statistical analysis was similar in both years except establishment methods as given in Table 3.

Accumulated helio-thermal units (AHTU)

Accumulated helio-thermal units to attain maturity under various treatments are shown in (Table 3). During *kharif* 2020, 3.68% higher AHTU were accumulated by PTR (22344 °Cday hour) than DSR (21688 ºC day hour) and was statistically at par. Among varieties, PR 126 (19528 °C day hour) accumulated significantly 17.31% and 14.75% lower AHTU than Pusa 44 (23617 °C day hour) and PR 122 (22904 °C day hour), respectively. While N_2 (22203 °C day hour) accumulated 0.06% and 1.94% higher AHTU than N_1 (22066 °C day hour) and N_3 (21780 °C day hour), respectively

Table 4: Influence of establishment methods, varieties and nitrogen levels on radiation use efficiency (RUE) in rice crop during *kharif* 2020 and 2021

Treatments	2020				2021			
	Grain yield	90 DAS	Upto harvesting	Total	Grain yield	90 DAS	Upto harvesting	Total
Establishment methods								
DSR (Direct seeded rice)	0.804	1.543	1.598	1.581	0.836	1.887	1.441	1.676
PTR (Puddled transplanted rice)	0.824	1.422	1.643	1.539	0.840	1.679	1.512	1.595
CD (0.05%)	NS	0.07	NS	NS	NS	0.08	0.06	0.08
Varieties								
PR 122 (V_1)	0.795	1.360	1.751	1.552	0.797	1.650	1.538	1.588
PR 126 (V_2)	0.862	1.638	1.470	1.579	0.941	1.947	1.442	1.744
Pusa 44 (V_3)	0.785	1.451	1.640	1.549	0.777	1.753	1.449	1.575
CD (0.05%)	0.04	0.09	0.10	NS	0.05	0.09	0.08	0.09
Nitrogen Levels								
Recommended Dose (N_1)	0.817	1.499	1.652	1.583	0.832	1.800	1.465	1.637
125 % of Recommended dose (N_2)	0.818	1.499	1.611	1.567	0.832	1.795	1.460	1.631
Leaf colour chart (N_3)	0.826	1.449	1.680	1.566	0.854	1.754	1.518	1.646
CD (0.05%)	NS	NS	NS	NS	NS	NS	NS	NS

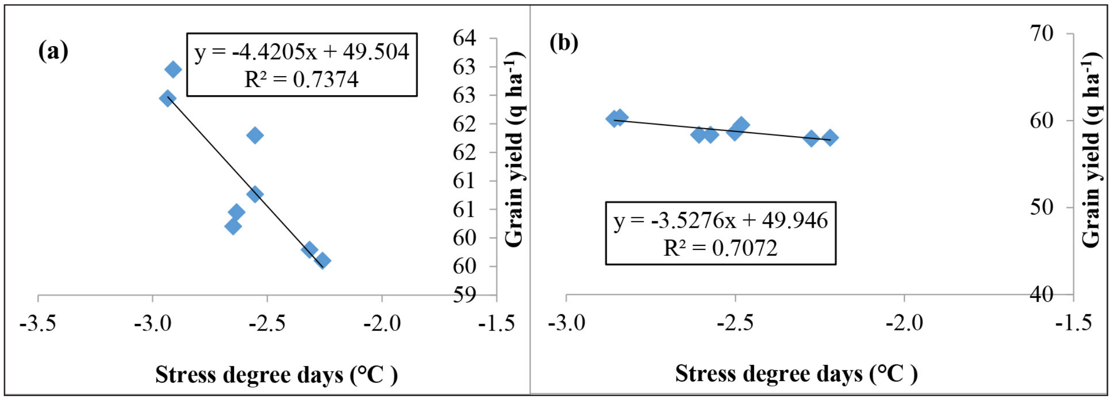

Fig. 4: Regression relationship between stress degree day and grain yield in during *kharif* (a) 2020 and (b) 2021

and results were statistically non-significant. During *kharif* 2021, although all treatments took a greater number of days to reach maturity but due to less sunshine hours as compared to *kharif* 2020, AHTU was lower in *kharif* 2021 however statistical analysis was similar during both years given in Table 3. Sreenivas *et al*., (2010) also reported that short duration (125 days) cultivar Jagtiala Sannalu has accumulated less growing degree days and helio-thermal units than medium duration (135 days) cultivar Polasa Prabha.

Accumulated photo-thermal units (APTU)

Accumulated photo-thermal units to attain maturity under various treatments are shown in (Table 3). During *kharif* 2020, 2.78% higher APTU were accumulated by PTR (36946 °C day hour) than DSR (35944 °C day hour). Among varieties, PR 126 (33234 °C day hour) accumulated significantly 13.87 % and 11.40 % lower APTU than Pusa 44 (38587 °C day hour) and PR 122 (37514 °C day hour), respectively. While N_2 (36736 °C day hour) accumulated 0.07% and 1.73% higher APTU in N_1 (36490 °C day) and N_3 (36109 °C day), respectively. During *kharif* 2021 as duration of all treatments was longer than *kharif* 2020, so APTU were higher in *kharif* 2021 than *kharif* 2020 with similar statistical trend as given in Table 3.

Radiation use efficiency (RUE)

RUE was calculated as the ratio of total dry weight/grain yield to intercepted radiation during the entire growing season as presented in Table 4. During *kharif* 2020, RUE was higher in PTR than DSR by 2.61% in respect of grain yield and was statistically at par. In respect of dry matter production, RUE was significantly higher in DSR than PTR by 8.43% at 90 DAS but from 90 DAS to harvesting, RUE in PTR was 2.88% higher than DSR method and was statistically non-significant. RUE in DSR was non significantly more than PTR method by 2.66% in overall dry matter production. High canopy intercepted radiation and RUE were responsible for higher biomass accumulation of DSR over PTR method before heading (about 90 DAS). After heading, intercepted radiation of DSR was comparable to or higher than that of PTR, and there was no consistent difference in RUE between DSR and PTR. DSR took 7-8 days less than PTR to reach maturity. Reduction in total growth duration would reduce the total amount of incident solar radiation for producing biomass through canopy photosynthesis. However, rapid leaf area growth rate at early vegetative stage, LAI before heading and high stem number which contributed to higher intercepted radiation before heading and resulted in higher biomass production in DSR method. Xu *et al.,* (2022) also reported similar findings for rice crop in China.

Among varieties, RUE was significantly higher in PR 126 than PR 122 (9.11 %) and Pusa 44 (9.39 %), in respect of grain yield. That might be due to short duration of PR 126, because in less no of days this variety gives at par yield with PR 122 and Pusa 44. Up to 90 DAS in respect of dry matter, RUE of PR 126 was significantly higher than Pusa 44 (12.35 %) and PR 122 (21.25%). From 90 DAS to harvesting, RUE in Pusa 44 and PR 122 was significantly higher than PR 126 by 12.17% and 18.39 %, respectively. In overall dry matter production, RUE was higher in PR 126 than Pusa 44 and PR 122 by 1.47% and 2.33%, respectively and result was non-significant. Kar and Kumar (2016) also reported effect of different varieties on RUE. Effect of different nitrogen levels was statistically non-significant among nitrogen levels, N_3 gives highest RUE in terms in respect of grain yield and RUE was approximately similar in N_1 and N_2. In terms of dry matter production, RUE in N_3 was lower than N_1 and N_2 but after 90 DAS, RUE was highest in N_3 followed by N_1 and N_3. Overall RUE was highest in N_1. During *kharif* 2021, as dry matter production and grain yield was lower than *kharif* 2020 but APAR was also lesser in all treatments, so RUE was higher during *kharif* 2021 in all treatments than *kharif* 2020 with similar statistical trend except N_3 which gives highest RUE among nitrogen levels in terms of dry matter production as presented in Table 4. Swarna *et al.,* (2017) also considered 180 kg N ha^{-1} as optimum for improved growth and RUE of transplanted rice than 240 kg N ha^{-1} and 300 kg N ha^{-1} in South Telangana Region of Telangana State. Li *et al.,* (2012) also reported that optimal nitrogen rate is helpful to get higher light interception rate, RUE, and harvest index.

Regression relationship between the stress degree day and grain yield

During both years, a negative and polynomial regression relationship between the grain yield and stress degree days under different treatments was analyzed, which showed that with increase in canopy temperature, grain yield decreased and vice-versa (Fig. 4). Chakravarti *et al*., (2010) also reported that SDDI had a significant negative correlation with the dry matter production as well as yield of groundnut.

CONCLUSIONS

Radiation use efficiency and heat use efficiency were higher in direct seeded rice (DSR) as compared to puddled transplanted rice (PTR). As direct seeded rice took 7-8 days less than puddled transplanted rice so it consumes less accumulated growing degree days, helio-thermal units and photo thermal units than puddled transplanted rice but gives statistically at par yield with puddled transplanted rice. DSR is an environment friendly method of rice as it eliminates the major drawbacks of PTR i.e. indiscriminate use of water and methane emissions due to skipping of puddling and standing water conditions. Among the varieties, PR 126 had higher radiation and heat use efficiency than Pusa 44 and PR 122 in respect of grain yield and dry matter production due to its ability to produce comparable yield and dry matter in short duration. Among the nitrogen levels, N_3 (Leaf colour chart-based nitrogen application) gives statistically at par results with higher nitrogen levels for grain yield, radiation and heat use efficiency. The potential advancements in LCC-based nitrogen management can lead to reduced environmental impacts, insect-pests attack and enhanced profitability for farmers.

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