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Research Article

Relationship between physiological traits and yield of rice (*Oryza sativa* L.) under modified system of rice intensification

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Abstract
A field experiment was conducted to study influence of high-density planting on physiological parameters and yield of rice during late *Samba* (September-January) season of 2018-19. The treatments comprised of T_1 - 25 × 25 cm with 100% Recommended Dose of Fertilizer (RDF) (SRI), T_2 - 25 × 20 cm with 100% RDF, T_3 - 25 × 15 cm with 100% RDF, T_4 - 25 × 15 cm with 125% RDF, T_5 - 20 × 20 cm with 100% RDF, T_6 - 20 × 15 cm with 100% RDF, T_7 - 20 × 15 cm with 125% RDF and T_8 - Conventional cultivation with 100% RDF. Physiological parameters were recorded at four critical stages (active tillering, panicle initiation, flowering and maturity stages) of rice. The results revealed that photosynthetic rate (µmol $CO_2/m^2/s$), transpiration rate (mmol $H_2O/m^2/s$), stomatal conductance (mol $H_2O/m^2/s$) and chlorophyll index were increased in rice planted at a row spacing of 25 cm (T_1, T_2 and T_3) over other treatments in all the stages. Lower rates were noted in conventional method of planting (T_8) followed by T_6 and T_7. During 0600 hrs and 1000 hrs, closer spacing levels (T_5, T_6, T_7 and T_8) had higher leaf temperature, while during later at 1400 hrs and 1800 hrs, warmer leaf temperature (°C) was noted in wider spacing levels (T_1 and T_2) during all time of weekly observation. The grain yield of rice was higher with 20 × 20 cm spacing level compared to other closer and wider spacing levels with either 100% or 125% RDF. By correlation analysis, all parameter had a significant influence on yield.

Keywords: Chlorophyll index, High density planting, Leaf temperature, Photosynthetic rate, Rice, Stomatal conductance, Transpiration rate

INTRODUCTION

Rice (*Oryza sativa* L.) is India's pre-eminent crop and the most important edible starchy grain. It is the second largest cereal cultivated worldwide and staple food for almost 60 per cent of the global population. Due to the increased population, the demand for rice is expected to rise by 38 per cent within 30 years (Satyanarayana, 2005). The per capita availability of paddy in Asia has decreased from 54.7 kg in 2001 to 53.9 kg in 2019 (FAOSTAT, 2019).

The success of System of Rice Intensification (SRI) cultivation practices has been shown in over 50 countries, including the major rice producers in the world such as China, Vietnam, Cambodia and Philippines (Katambara *et al.,* 2013) as well as in India (Thakur *et al.,* 2013). However, due to wider spacing with lesser plant population per square metre in the SRI method, forcing the existing plants to produce more tillers. Hence, Modified SRI (MSRI) is one option in which the certain modifications are made in any of the principles or in management practices of SRI using best scientific knowledge for the benefit of farmers to get maximum yield and to adapt the local agro-ecological climatic condition (Thakur *et al.*, 2016). Increasing of production by way of reducing population, by following all SRI practices is one such modification which may increase the number of panicle/m^2 and in turn yield of rice.

Physiological parameters like photosynthetic rate, transpiration rate and stomatal conductance are highly influenced by planting density and also by climatic factors. Grain yield in rice is influenced by balance between respiration and photosynthesis and a key physiological parameter affected by the planting density and microclimate (Centritto *et al.*, 2009). Most of the carbon stored in the mature rice grains originates from CO_2 assimilation during the grain filling period is determined by the process of CO_2 assimilation in rice. Factors that lower the photosynthesis rate of the flag leaf during this period could affect the grain yield in rice. Lesser soil temperature affects the stomatal conductance and assimilation rate, which affects the plant growth (Dingkuhn *et al.*, 1989). The photosynthetic rate is more in rice following SRI method while comparing with the conventional method of cultivation (Hidayathi *et al.,* 2016). Since, in rice leaf appearance is controlled by temperature near the apical meristem and the optimum leaf temperature 2°C lower than the optimum air temperature affects phenological development (Ellis *et al*., 1993).

However, there are limited studies on physiological parameters under high density condition. Hence, this research was conducted to evaluate the effects of high density planting on the rice plant's physiological parameters, namely photosynthetic rate, transpiration rate, stomatal conductance, chlorophyll index and leaf temperature of rice in response to high density planting with SRI principles, comparing these with conventional rice cultivation methods.

MATERIALS AND METHODS

Location

A field investigation was carried out during the late *Samba* season of 2018-19 (September 2018 to January 2019) at Wetland farms of the Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore. The experimental site was situated in Semi-arid tropics of south India. Geographically, Coimbatore Western Agroclimatic zone at 11°83' N latitude, 76°71' E longitude is with an elevation of 426.7 m above mean sea level (MSL).

Soil characteristics

The soil of the experimental field was clay loam in texture with pH and EC of 8.2 and 0.5 dS/m, respectively. The nutrient status of the soil during the start of the experiment was low in nitrogen (22.68 kg/ha), medium in phosphorous (19.25 kg/ha) and high in potassium (571.1 kg/ha) with an organic carbon content of about 12.12 g/kg of soil.

Experimental details

The study was conducted using randomized complete block design having three replications. The treatments *viz.,* T_1 - 25 × 25 cm + 100% RDF (Recommended dosage of fertilizer) (SRI), T_2 - 25 × 20 cm + 100% RDF, T_3 - 25 × 15 cm + 100% RDF, T_4 - 25 × 15 cm + 125% RDF, T_5 - 20 × 20 cm + 100% RDF, T_6 -20 × 15 cm + 100% RDF, T_7 - 20 × 15 cm + 125% RDF) follows System of rice intensification (SRI) principles and T_8 - Conventional cultivation. Latest released rice variety from TNAU, Rice CO-52 with the field duration of 130-135 days was used in this field experiment.

Crop cultivation practices

Mat nursery was prepared for raising seedlings for T_1-T_7 treatments and conventional nursery for conventional method of planting (T_8). The main field was prepared by puddling and then, the buds were trimmed and plastered. The layout was taken as per treatment schedule after levelling the fields using a wooden leveller. The bunds were formed and seedlings were transplanted at 14 DAS for T_1-T_7 treatments and 30 DAS for treatment. Recommended dose of fertilizers (150: 50: 50 kg N: P_2O_5: K_2O/ha) were applied as urea, single super phosphate and muriate of potash to all the plots as per the treatment. Nitrogen and potassium were given in four equal split doses at basal, active tillering (50 DAT), panicle initiation (70 DAT) and flowering stages (100 DAT). A full dosage of phosphorus, 25 per cent of nitrogen and potassium were applied as basal prior to transplanting. Top dressing of nitrogen was done based on LCC observations in all plots. Excluding the conventional cultivation plots, weeding operation was done on 15, 25, 35 and 45 DAT using hand operated rotary weeder in both direction for square planted plots, while in one direction in all other plots. All other practices were followed as per Crop Production Guide (2012).

Measurement of physiological parameters

Physiological parameters like photosynthetic rate, transpiration rate and stomatal conductance were measured using Portable Photosynthetic System (PPS) - Model LCi-SD of ADC BioScientific Ltd., Great Amwell, Hertfordshire, UK. Rice leaf was inserted in a broad leaf chamber (6.25 cm^2) and the leaf area was set at 3.26 cm^2. Using the above PPS system, the observations were made at active tillering, panicle initiation, flowering and at maturity stages of rice from the third uppermost leaf at randomly selected five plants and calculated the mean value for each parameter.

Leaf temperature (°C) was measured on top unfolded leaves of rice in individual plots using infrared thermometer (Foopro, Raytek, USA). The time of observations was 0600 hrs, 1000 hrs, 1400 hrs and 1800 hrs and the observation were made at weekly interval *viz.,* 41 DAT, 48 DAT, 55 DAT, 62 DAT, 69 DAT, 76 DAT, 83 DAT¸ 90 DAT, 97 DAT, 104 DAT and 111 DAT.

Chlorophyll index was measured with SPAD meter (Model 502, Spectrum Technologies, Inc.). The readings were taken in the third uppermost leaf from randomly selected five plants and calculated the mean value at active tillering, panicle initiation, flowering and maturity stages.

Measurement of grain yield

The crop was harvested upon harvesting stage. The border rows in the plots were removed from the field. The net plot was then harvested, hand threshed, sun dried and weighed and allowed to 14 per cent moisture content. The grain yield was converted to kg/ha.

Statistical analysis

The data collected from field experiment at different growth stages were statistically analysed for Least Square Difference (LSD) at 5 per cent probability level as described by Gomez and Gomez (2010). The correlation analysis was done using R studio programming with statistical packages (RStudio, 2015).

RESULTS AND DISCUSSION

Effect of high density planting on photosynthetic rate of rice

The photosynthetic rate was altered significantly during each growth stages of rice under high density planting are presented in Table 1.

At the active tillering stage, significantly (at 5% level) higher photosynthetic rate (24.6 µmol $CO_2/m^2/s$) was noted in plant spacing level of 25 × 25 cm with 100% RDF (T_1) compared to all other treatments under testing but, it was on par with planting spacing of 25 × 20 cm with 100% RDF (24.3 µmol $CO_2/m^2/s$). A significantly lesser photosynthetic rate (21.8 µmol $CO_2/m^2/s$) was recorded in the conventional method of planting (T_8). Similarly, at the panicle initiation stage, the plant with a spacing of 25 × 25 cm with 100% RDF (T_1) registered significantly higher photosynthetic values (28.3 µmol $CO_2/m^2/s$) compared to other treatments. The least values on photosynthetic rate (23.6 µmol $CO_2/m^2/s$) was recorded in conventional method of planting (T_8). At flowering and maturity stages also, the same trend was noticed. By correlation analysis, photosynthetic rate is positively correlated with yield but not significantly. By regression fit analysis, a close relationship was observed between photosynthetic rate and observed chlorophyll index (Fig. 1). The photosynthetic rate depends upon the plant canopy structure which influences the amount of light profile absorbed by the leaf (Weiss *et al.,* 2004). Hence, higher photosynthetic rate in lower planting density was due to wider canopy structure and angle, broadly spreaded tillers and erect leaves, which reduced the self-shading to bottom leaf and mutual shading of leaves and enhanced better light utilization by the canopy (Hidayati et al., 2016). However, the photosynthetic rate is also depends on light energy absorbed by the chlorophyll (Maxwell and Johnson, 2000). Chlorophyll content is closely related to photosynthetic rate, because it provides the photosynthetic apparatus which allows plants to absorb energy from light and transfer it to the chlorophyll (Porra *et al.,* 1993). With a higher amount of chlorophyll in the leaves, a higher photosynthesis rate can be maintained (Kura-Hotta *et al*., 1987). From this study also, higher chlorophyll index was noticed in wider spacing compared to denser plant spacing. Lower photosynthetic rate was noted in denser plant spacing, was mainly due to the production of narrow leaves that reduces the sunlight absorption by leaves led to

Table 1. Effect of high density planting on physiological parameters of rice at different stages.

Treatments	Photosynthetic rate (µmol $CO_2/m^2/s$)				Transpiration rate (mmol $H_2O/m^2/s$)				Stomatal conductance (mol $H_2O/m^2/s$)			
	AT	PI	FL	MT	AT	PI	FL	MT	AT	PI	FL	MT
T_1	24.63	28.30	34.73	18.33	7.55	7.90	9.64	6.37	0.173	0.192	0.307	0.143
T_2	24.33	26.17	34.00	17.23	7.53	7.66	9.50	6.13	0.167	0.189	0.301	0.144
T_3	23.10	25.63	32.53	16.90	7.49	7.56	9.45	5.63	0.165	0.187	0.294	0.137
T_4	23.13	25.77	32.83	16.73	7.41	7.66	9.38	5.87	0.167	0.186	0.299	0.137
T_5	22.17	25.13	32.57	16.47	6.63	7.59	9.28	5.60	0.150	0.173	0.289	0.130
T_6	22.77	24.73	31.80	16.83	6.84	7.51	8.79	5.57	0.150	0.168	0.280	0.127
T_7	22.57	23.80	32.03	16.50	6.66	7.59	8.78	5.57	0.157	0.166	0.264	0.130
T_8	21.77	23.60	31.67	16.20	6.63	7.04	8.73	5.47	0.147	0.162	0.238	0.127
SEd	0.15	0.07	0.16	0.07	0.07	0.06	0.14	0.19	0.004	0.005	0.006	0.003
CD at 5% level	0.33	0.15	0.34	0.15	0.15	014	0.29	0.42	0.009	0.012	0.013	0.007

AT – Active tillering; PI – Panicle initiation; FL – Flowering stage; MT – Maturity stage; T_1 - 25 × 25 cm with 100% RDF (SRI); T_2 - 25 × 20 cm with 100% RDF; T_3 - 25 × 15 cm with 100% RDF; T_4 - 25 × 15 cm with 125% RDF; T_5 - 20 × 20 cm with 100% RDF; T_6 - 20 × 15 cm with 100% RDF; T_7 - 20 × 15 cm with 125% RDF; T_8 - Conventional cultivation with 100% RDF

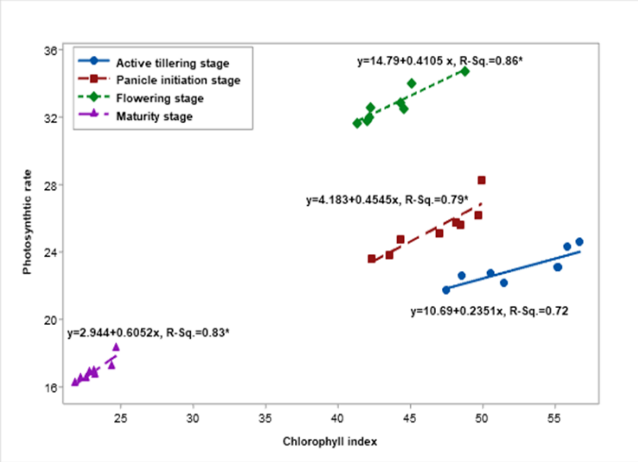

Fig. 1. *Relationship between photosynthetic rate and chlorophyll index of rice at different stages. (* significant at 5% level).*

reduced chlorophyll content in leaves that ultimately reduces the photosynthetic rate. Similar results were reported by San-oh *et al.* (2006) and Thakur *et al.* (2010).

Effect of high density planting on transpiration rate of rice

Mean data obtained on transpiration rate (mmol $H_2O/m^2/s$) of rice at active tillering, panicle initiation, flowering and at maturity stages are given under Table 1.

At the active tillering stage, the transpiration rate was varied significantly due to high density planting. The rice planted at a spacing of 25 × 25 cm with 100% RDF (T_1) recorded a significantly higher rate of transpiration (7.55 mmol $H_2O/m^2/s$) but, it was statistically on par with a spacing of 25 × 20 cm with 100% RDF (7.53 mmol $H_2O/m^2/s$) and 25 × 15 cm fertilized with 100% RDF (7.49 mmol $H_2O/m^2/s$) and 20 × 20 cm spacing with 100% RDF (T_5). All other spacing levels recorded a lower transpiration rate with the minimum of 6.63 mmol $H_2O/m^2/s$ recorded in conventional method transplanting (T_8). During panicle initiation stage, significantly higher rate of transpiration rate values (7.90 mmol $H_2O/m^2/s$) were recorded at spacing 25 × 25 cm with 100% RDF (T_1) than others. Lower transpiration rate (7.04 mmol $H_2O/m^2/s$) was observed in rice planted at conventional method of planting (T_8). At flowering stage, higher transpiration (9.64 mmol $H_2O/m^2/s$) was noted at spacing of 25 × 25 cm with 100% RDF (T_1) but it was on par with other 25 cm row spacing levels (T_2, T_3 and T_4). Significantly lower transpiration rate (8.73 mmol $H_2O/m^2/s$) was observed at conventional method of planting (T_8) and was par at 20 × 15 cm applied with 100% RDF (T_6) and 125% RDF (T_7). Wider plant spacing (25 × 25 cm and 25 × 20 cm) with 100% RDF (T_1 and T_2) did record significantly higher transpiration rate

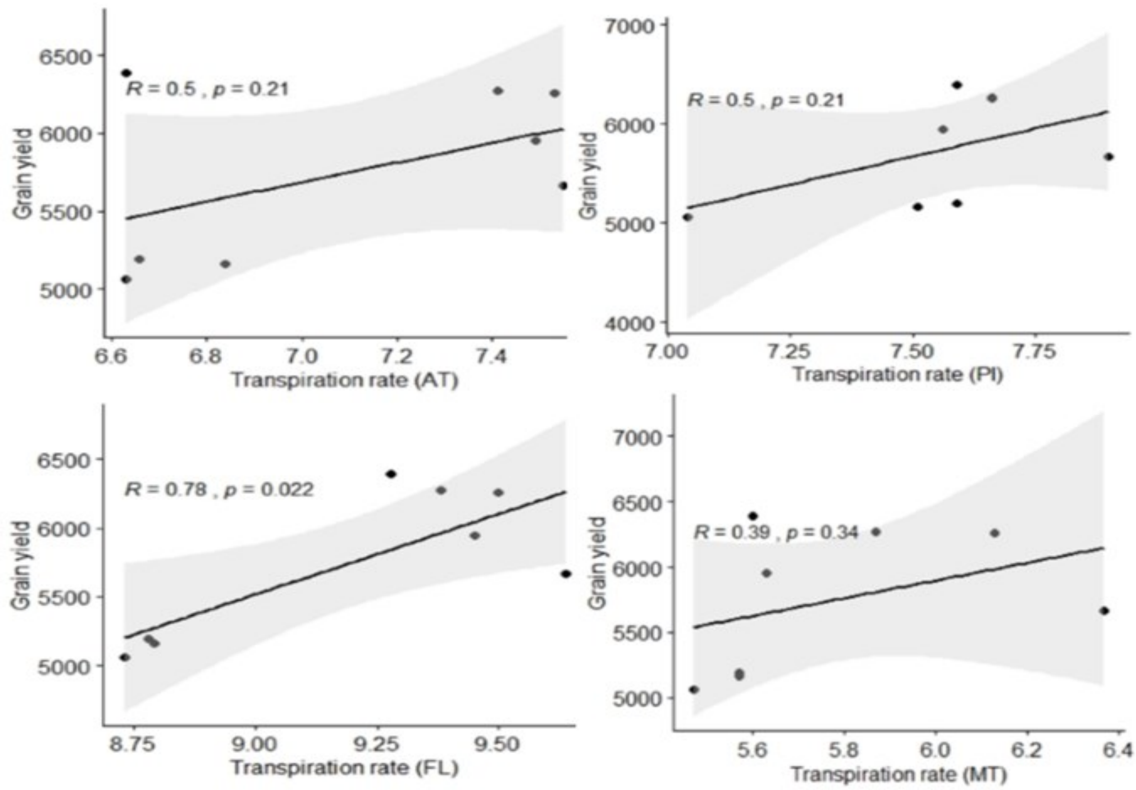

Fig. 2. *Transpiration rate vs grain yield of rice at different stages. AT- Active tillering stage, PI- Panicle initiation stage, FL– Flowering stage, MT- Maturity stage. (Scatter plot with correlation analysis).*

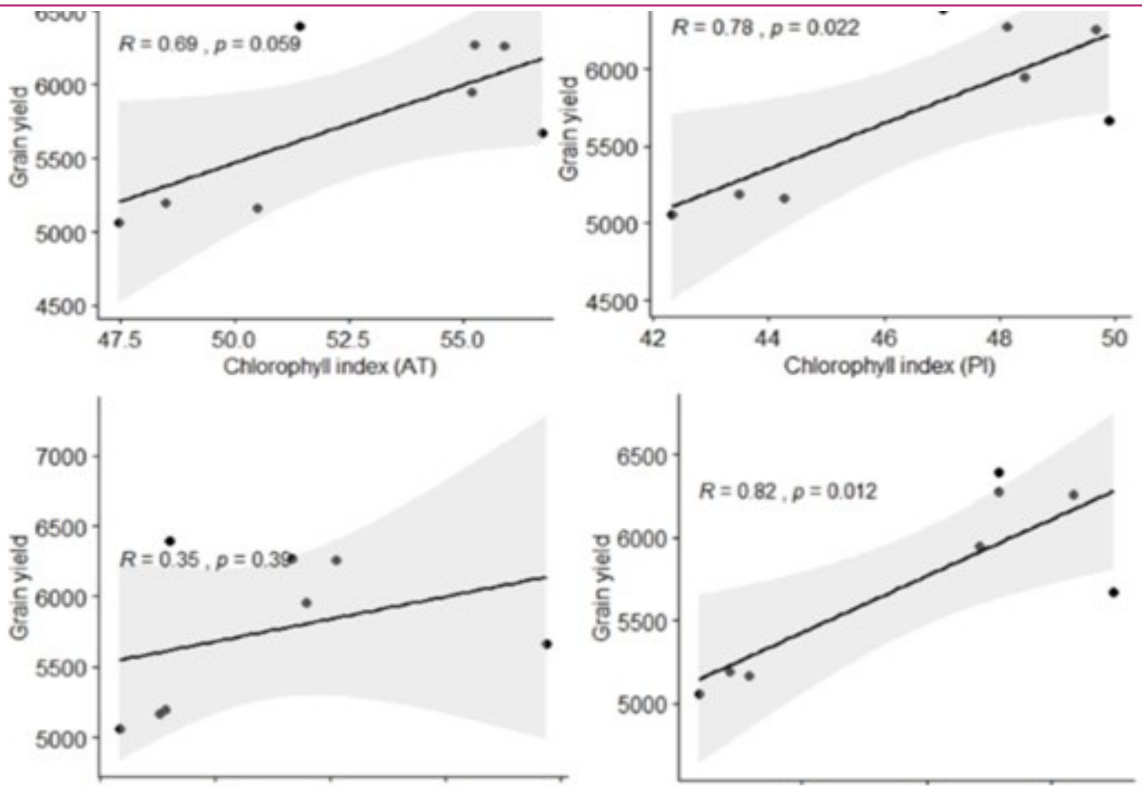

Fig. 3. *Stomatal conductance vs grain yield of rice at different stages. AT- Active tillering stage, PI- Panicle initiation stage, FL– Flowering stage, MT- Maturity stage. (Scatter plot with correlation analysis).*

(6.37 and 6.13 mmol $H_2O/m^2/s$, respectively) compared to all other treatments which were statistically on par with each other with the least transpiration rate (5.47 mmol $H_2O/m^2/s$) in conventional method of planting (T_8). The correlation analysis shows that transpiration rate influenced positively on the grain yield obtained and significantly correlated during the flowering stage (r=0.78*) of rice (Fig. 2). In wider spacing, the plant leaves are more exposed to sunlight due to lesser LAI and sparse crop canopy, which might have allowed the sunlight to fall on most of the leaves and would have enhanced the transpiration rate. The reason was due to the mutual shading of leaves due to dense canopy and higher LAI, which might not allow the sunrays to fall and penetrate to all leaves in closer spacing treatments. Wind speed form a thick lower boundary layer around the leaves which might reduce the transpiration rate in denser planting. This result is in agreement with the result by Farooq *et al.* (2009).

Effect of high density planting on stomatal conductance of rice

The stomatal conductance (mol $H_2O/m^2/s$) of rice as influenced by high density planting at active tillering, panicle initiation, flowering and maturity stages are represented in the Table 1.

At active tillering stage, the plants at a spacing level of 25 × 25 cm with 100% RDF (T_1) recorded significantly higher values (0.173 mol $H_2O/m^2/s$) but, it was on par

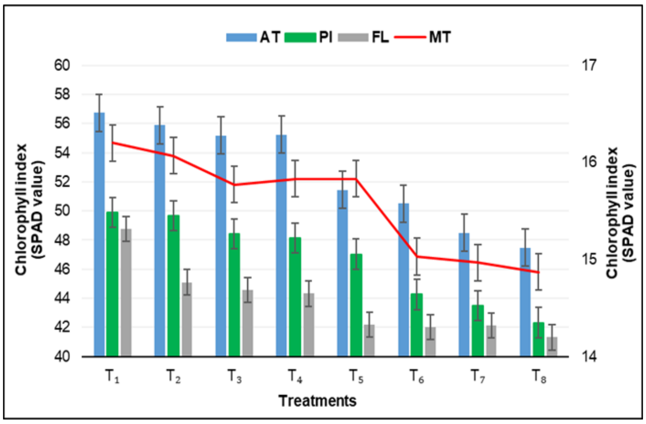

Fig. 4. *Effect of high density on chlorophyll index of rice. AT- Active tillering stage, PI- Panicle initiation stage, FL– Flowering stage, MT– Maturity stage. (The vertical line in bar chart represents standard error).*

with other wider spacing levels (25 × 20 cm and 25 × 15 cm) with 100% RDF and 125% RDF (T_2, T_3 and T_4). Significantly lesser stomatal conductance (0.147 mol $H_2O/m^2/s$) was observed in spacing of 20 × 10 cm with 100% RDF and was on par with all the row spacing levels of 20 cm (T_5, T_6 and T_7) with any of nutrient level. Similar trend of observation as like active tillering stage was recorded during panicle initiation and maturity stages. At flowering stage, significantly higher values (0.30 mol $H_2O/m^2/s$) of stomatal conductance were noted in 25 × 25 cm spacing level with 100% RDF (T_1), but it was statistically on par with level of spacing levels of

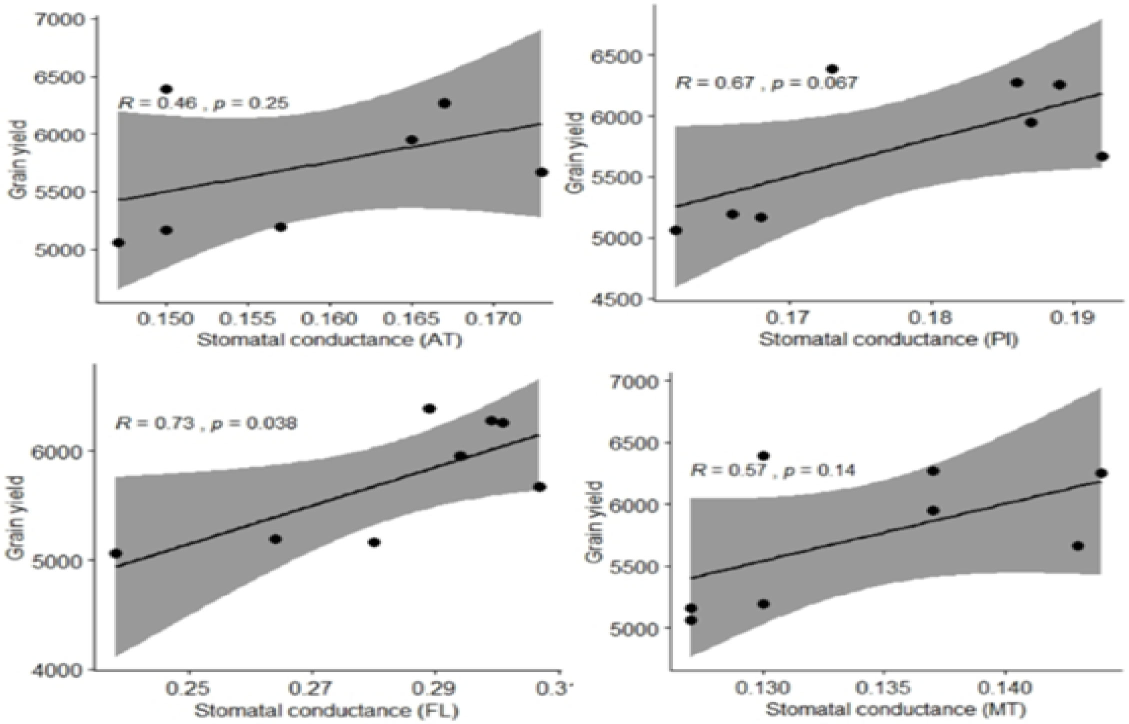

Fig. 5. *Chlorophyll index vs grain yield of rice at different stages. AT- Active tillering stage, PI- Panicle initiation stage, FL – Flowering stage, MT- Maturity stage. (Scatter plot with correlation analysis***).**

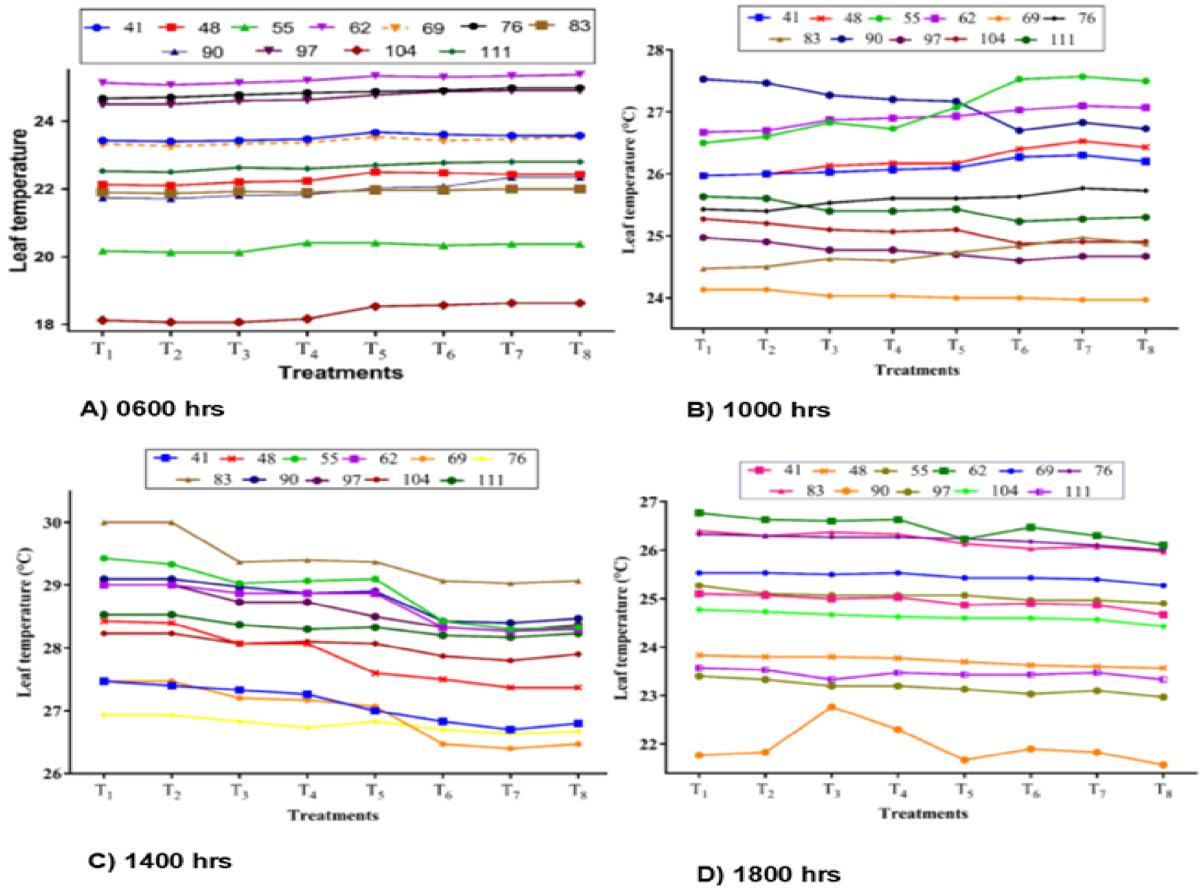

Fig. 6. *Weekly leaf temperature at different time intervals at 0600 hrs, 1000 hrs, 1400 hrs and 1800 hrs.*

25 × 20 cm with 100% RDF (T_2), 25 × 15 cm with 100% RDF (T_4) and 125% RDF (T_5). Significantly lower value on stomatal conductance (0.238 mol $H_2O/m^2/s$) was recorded in conventional method of planting than all others. Stomatal conductance at flowering stage was positively and significantly correlated to the grain yield obtained (r=0.73*) (Fig. 3). In general, stomatal conductance was more in wider spacing than closer spacing during all stages. The reason for higher stomatal conductance in wider spacing was due to more light profile at canopy level with higher temperature and lesser relative humidity as evidenced in the present study which might have promoted the stomata to open. However, lesser stomatal conductance was observed in closer spacing, due to partially closed stomata by low illumination level of light caused by mutual shading of leaves (Farooq *et al.,* 2010). Accumulation of more humidity due to denser canopy structure also expressed to universe relationship between relative humidity and stomatal conductance (Nobel, 1999).

Effect of high density planting on chlorophyll index of rice

The chlorophyll index (SPAD value) during active tillering, panicle initiation, flowering and maturity stages are given in Figure 4. During the active tillering stage, significantly higher SPAD value (56.73) were recorded at spacing of 25 × 25 cm with 100% RDF (T_1) than all other treatments. Conventional method of planting recorded the lowest chlorophyll index value (47.47). At the panicle initiation stage, rice planted at a spacing of 25 × 25 cm with 100% RDF (T_1) recorded higher chlorophyll index (49.90) over other treatment under study, however, it was on par with 25 × 20 cm with 100% RDF (T_2). Almost similar nature of results were noted at later (flowering and maturity) stages also. A positive correlation between grain yield and chlorophyll index at panicle initiation (r=0.78*) and flowering stages (r=0.82*) was recorded and is represented in Fig. 5. During all the stages, the chlorophyll index was significantly higher in wider plant spacing. This might be due to more spacing (lesser plant population), more solar radiation is observed by plant leaves which might increase the chlorophyll index in wider spacing plants. The lower value is due to mutual shading and denser plant population.

Effect of high density planting on leaf temperature of rice

Weekly leaf temperature recorded at different time intervals *viz.*, 0600 hrs, 1000 hrs, 1400 hrs and 1800 hrs are represented in Fig. 6. At 0600 hrs and 1000 hrs, closer spacing levels (T_5, T_6, T_7 and T_8) had higher leaf temperature during all time of weekly observation, while during later time of observation (1400 hrs and 1800 hrs), warmer leaf temperature (□) was noted in wider spacing levels (T_1 and T_2) over other treatments. In general, leaf temperature was higher in closer spacing compared to wider spacing at 0600 hrs. In closer spacing, where heat trapped inside the canopy during night hours might reflect on leaf surface as high leaf temperature at early hours. During 1000 hrs, 1400 hrs and 1800 hrs, wider spacing plants had more leaf temperature compared to closer spacing levels. The reason for warmer leaf surface in wider spacing treatments might be due to leaves of rice are more exposed to solar radiation, which would absorb the solar radiation as heat. The plants with lesser leaves can be easily heated than more leaves, hence lesser leaves in wider spacing, the leaf surface was high (Yang *et al.*, 2014). However, leaf structure and orientation play an important role in leaf temperature (Nobel, 1999). Cooler leaf temperature was recorded in closer spacing levels was mainly due to poor light illumination at lower level leaves which cause leaf surface cooler in rice. Correlation analysis between leaf temperature and grain yield shows negative

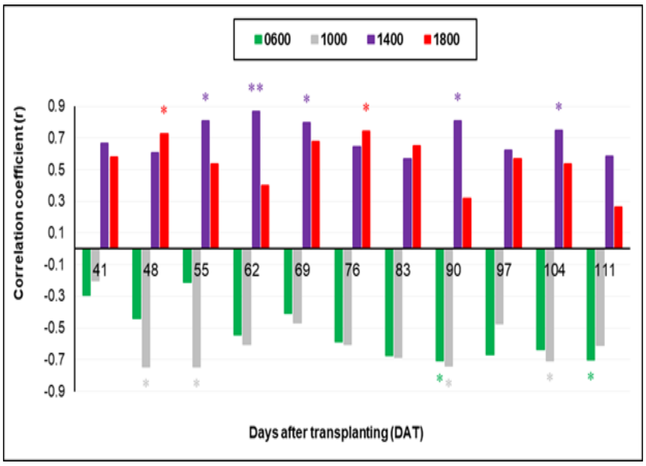

Fig. 7. *Correlation between leaf temperature and grain yield at weekly intervals (* significant at 5% level ** significant at 1% level).*

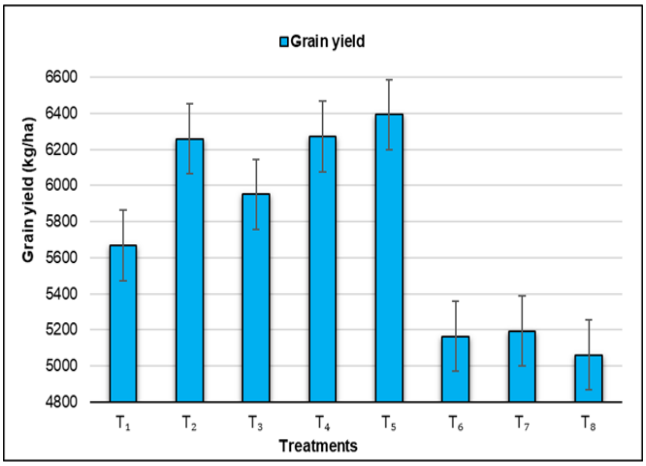

Fig. 8. *Effect of high density planting on grain yield of rice. (The vertical line in bar chart represents standard error).*

response during 0600 hrs and 1000 hrs, and positive response during 1400 hrs and 1800 hrs (Fig. 7).

Influence of high density planting on yield of rice

Grain yield was significantly influenced due to plant spacing (Fig. 8). A significantly higher grain yield was recorded under 20 × 20 cm (6392 kg/ha) planting geometry which was statistically on par with 25 × 20 cm (6259 kg/ha), 25 × 15 cm at 100% RDF (5951 kg/ha) and 25 × 15 cm at 125% RDF (6272 kg/ha). The yields obtained under the rest of the plant spacing levels were lower and statistically identical. The lowest yield was recorded under conventional method of planting (5061 kg/ha). The reason for higher yield might be due to more plant population compared to wider spacing with optimum canopy temperature and reduced competition for light, air and nutrients compared to other spacing levels. Similar results by Thakur *et al.* (2010) also reported that rice plant at a spacing level of 20 × 20 cm resulted in higher grain yield.

Conclusion

The study concluded that the photosynthetic rate, transpiration rate, stomatal conductance, and chlorophyll index were higher during the early growing period and decreased as rice grew at later stages. During all stages of rice, wider plant spacing levels had higher photosynthetic rate, transpiration rate, stomatal conductance and chlorophyll index, and also had positive correlation with the grain yield. Transpiration rate and stomatal conductance during the flowering stage significantly influenced the grain yield of rice. While leaf temperature was higher in closed spacing levels during 0600 and 1000 hours, a reversal trend was noticed during 1400 and 1800 hours. Grain yield shows a negative response during 0600 hrs and 1000 hrs, and a positive response during 1400 hrs and 1800 hrs with observed leaf temperature. The optimum level of observation was noticed in planting spacing of 20 × 20 cm, which might result in higher grain yield.

Conflict of interest

The authors declare that they have no conflict of interest.

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