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Influence of Water Stress on Canopy Temperature and Yield Contributing Characteristics of Wet Seeded Rice

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ABSTRACT

Canopy temperature (CT) is one of the indices for evaluating water stress. The study has been taken to correlate water stress with CT and to evaluate effect of water stress on crop and yield performance of wet seeded rice (WSR). The canopy temperature of rice at vegetative and flowering stages were investigated under different soil water stresses. The field experiment was conducted at IRRI (International Rice Research Institute) during dry season, 2011. Three levels of water stress (-10, -20 and -40 kPa) were applied at 3-leaf (3L) to panicle initiation (PI), PI to flowering (FL) and FL to physiological maturity (PM) stages. One non-stressed treatment, i.e., continuously flooded puddled transplanted rice (PTR-CF) was used as a control. Soil water tension was measured using a 30-cm long gauge tensiometer and a handheld infrared thermometer was used to measure CT. Canopy temperatures were recorded from 3L to PI and PI to FL stages. In both the stages, CT was within the range of marginal stress. Canopy temperature depression (CTD) was higher in the stressed condition than that of the non-stressed. At the PI stage, leaf area index (LAI) was significantly lower in WSR than PTR-CF. LAI was comparatively lower in WSR with -20 kPa and -40 kPa than WSR with -10 kPa and PTR-CF when water stress imposed during PI-FL. Decreasing grain yield was observed when irrigation threshold increased from -10 to -40 kPa during PI to FL and FL to PM, but the differences were not significant. Yield components of WSR with different stresses were not significantly different. But spikelet fertility (%) and grain weight (g) of WSR was significantly higher than that of PTR-CF. The yield of PTR-CF was similar to the yield of WSR. Panicle/m^2 correlated negatively with CT under a stressed condition. Yield and all yield components except spikelet per panicle were positively correlated with CT at 60 days after seeding (CT_{60}). Under stressed condition, CT correlated negatively with the grain yield. Results revealed that CT correlated positively with grain yield under non-stressed condition (CT_{35} and CT_{60}). Spikelet fertility percentage (SF%) correlated negatively with CT_{35} and CT_{46}. It has been concluded that CT and CTD may be used for water stress evaluation.

Key words: Wet seeded rice, canopy temperature, water stress, crop performance

INTRODUCTION

Plant growth and development (Boonjung and Fukai, 1996; Kato *et al*., 2007) mainly depends on water. Rice plant is sensitive to water stress. Effect of water stress on one or all growing stages have considerable influence on plant growth and development. Declining leaf expansion rate and decreasing plant height, leaf area and biomass production reduced interception of photosynthetically active radiation (PAR) of rice when water stress imposed during vegetative phase (Inthapan and Fukai, 1988). Tiller abortion also increased due to water stress at vegetative phase. Kumar *et al*. (2006) reported that dry matter partitioning increased significantly from leaf and stem to grain due to water stress imposed at reproductive stage. Physiological activities of root, leaf photosynthesis, dry matter accumulation and transpiration rate of rice plant impeded by water stress at heading stage (Cai *et al*., 2002; Tao *et al*. 2004; Wang *et al*., 2006). Moderate water stress at the heading and filling stages significantly

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increased spikelet fertility percentage and grain weight (Wang *et al*., 2004). After heading, water stress had negligible effect on the yield of rice (Zheng *et al*., 2006). Parveen *et al.* (2017) reported that grain weight decreases with water stress at -40 kPa imposed during the whole growing season.

Water stress effects on canopy temperature (CT). Therefore, CT may be used as an indicator for crop water stress (Jackson *et al*., 1981). Generally, CT is lower than the atmospheric temperature due to leaf cooling process by transpiration. Soil water availability in the root zone reduced by water stress limits transpiration rate. Thus, leaf cooling process hampered, and heat injury occurred. Mackill and Coffmam (1983) and Xu *et al.* (1999) described heat injury and resistance to heat injury by panicle temperature and canopy temperature. Slight heat injury occurred by lower panicle temperature while resistance to heat injury happened by lower canopy temperature. Burke (1996) categorized the range of CT as non-stressed ($CT_{mean}<27^oC$), marginally stressed ($27^oC<CT_{mean}<29^oC$) and highly stressed ($CT_{mean}>29^oC$) temperatures, respectively. Parvaze *et al.* (2019) reported significant correlation with grain yield and canopy temperature depression (CTD). CTD represents the reduction of CT to the ambient temperature.

Scientists are now using the canopy temperature measurement as a screening technique under water stress condition. However, the correlations of CT with LAI, biomass, grain yield and yield components of WSR are lacking. Therefore, the aim of this study to figure out correlation of water stress with CT and to determine the effect of water stress on crop and yield performance of wet seeded rice (WSR).

METHODOLOGY

The field research was conducted at the International Rice Research Institute (IRRI), Los Baños, Philippines ($14^0 11'$N, $121^0 15'$E), from January to May 2011. The climate is tropical with a dry season (starts in January and ends in May) followed by a wet season (continues until December). However, rainfall during the dry season (January to April) varies greatly from year to year, ranging from a total of 43 mm in 1993 to 630 mm in 2009. The long-term average annual rainfall is around 2000 mm, of which 92% occurs from May to December. Monthly mean potential evaporation greatly exceeds mean rainfall during January to April, while mean rainfall is well in excess of potential evaporation during June to December. Average monthly potential evaporation ranges from 103 mm in December to 190 mm in April. Solar radiation increases from a monthly mean of 13.8 $MJm^{-2}day^{-1}$ in January to a maximum of 20.9 $MJm^{-2}day^{-1}$ in April and then decreases to a monthly mean of 12.2 $MJm^{-2}day^{-1}$ in December. Mean monthly maximum temperature varies from 28.3^0C in January to 33.0^0C in May. Variation in mean monthly minimum temperature is even smaller, ranging from 22.8^0C in December to 24.1^0C in September. The relative humidity is high throughout the year, with monthly averages ranging from 82.1% in May to 87.6% in September. Average wind speed is low, ranging from 1.1 to 1.8 ms^{-1}, with the lowest values during the rainy season.

The topsoil (0 - 15 cm) is silty clay with 1.45% organic carbon and neutral pH (Table 1 and Table 2). The subsoil is silty clay to 30 cm, overlying clay, and clay loam. There is a hard pan starting at 18 - 20 cm depth which has lower hydraulic conductivity (Ksat, 35 $cmday^1$) and higher bulk density than the rest of the soil profile. Up to 75 cm soil depth Ksat ranged from 35-53 $cmday^{-1}$. Below 60 cm, Ksat was much higher (around 200 $cmday^{-1}$) due to the presence of gravel.

Table 1. Soil physical properties at the experimental site.

Depth (cm)	Texture			Textural Class	Bulk density[A] (gcm^{-3})	Ksat[A] ($cmday^{-1}$)
	Clay (%)	Sand (%)	Silt (%)			
0-15	53	12	35	Silty clay	0.93 (0.02)[B]	46 (6.3)
15-30	53	13	34	Silty clay	1.01 (0.1)	35 (5.3)
30-45	49	20	31	Clay	0.90 (0.09)	48 (2.5)
45-60	39	30	28	Clay loam	0.93 (0.02)	53 (7.9)
60-75	31	40	29	Clay loam	1.07 (0.12)	200 (14.7)
75-90	20	54	25	Sandy clay loam		

[A]Determined in the middle 5 cm of each soil layer i.e., at 5-10, 20-25, 35-40, 50-55, 65-70, 80-85 cm.
[B] standard error in parentheses.

Table 2. Chemical properties of topsoil at the experimental site prior to puddling in 2011.

Soil layer	pH (1:1in H_2O)	Organic C (%)	Olsen P (mg/kg)	Exch. Ca ($meq100g^{-1}$)	Exch. K ($meq100g^{-1}$)	Kjeldahl N (%)
0-15 cm	7.0	1.45	18	25.5	1.07	0.161

Wet seeded rice (WSR) was grown with three levels of soil water deficit stress (-10, -20 and 40 kPa) applied during three growth stages: 3-leaf to panicle initiation (3L-PI), panicle initiation to flowering (PI-FL) and flowering to physiological maturity (FL-PM) (Table 3). One treatment included continuously flooded puddled transplanted rice (PTR-CF) in the experiment. The experiment was laid out with four replications in a randomized complete block design and plot size was 10 m × 5 m. To minimize seepage flows between treatment plots, the bunds were lined with plastic sheet, which was installed up to the hard pan, to a depth of about 20 cm below the soil surface, and individual treatment plots were separated by buffer plots. The buffer plots were irrigated at the same time as the driest adjacent treatment plot.

For the establishment of the experiment, the soil was ploughed using an animal drawn mould-board plough followed by a hydrotiller/rotavator powered by a 2-wheel tractor with cage wheels (3 passes) and levelled by a manually drawn wooden plank. The soil was then left to settle for one day prior to basal fertilizer application and wet seeding. The rice variety NSIC Rc222 (seed to seed growth duration 120 days) was used. Seeding was done on 14 January 2011. Prior to seeding, the seed was soaked for 24 hrs, drained, then incubated for 24 hrs by storing in a hessian bag in a dark and warm (45-50^{0}C) room. For the WSR, the pre-germinated seed was sown at the rate of 60 kg dry seed ha^{-1} using a manually pulled drum seeder. This rate is equivalent to about 255 $seedsm^{-2}$.

Table 3. Treatments of the field experiments.

Treatment	Crop establishment method[1]	Irrigation threshold during each crop stage[4] (kPa)		
		3L-PI	PI-FL	FL -PM
10-10-10	WSR[1]	10	10	10
10-20-10	WSR	10	20	10
10-40-10	WSR	10	40	10
10-10-20	WSR	10	10	20
10-10-40	WSR	10	10	40
CF-CF-CF	PTR[2]	CF[3]	CF	CF

[1]WSR-wet seeded rice; [2]PTR- Puddled Transplanted rice; [3]CF-continuously flooded
[4]3L= 3-leaf stage, PI= panicle initiation, FL= flowering and PM= physiological maturity

For the puddled transplanted rice (PTR), the pre-germinated seeds were sown in a raised seedbed on the same day that the WSR was sown. Transplanting was done 17 days after sowing (DAS) when the plants had reached to the three-leaf stage. There were 2-3 seedlings per hill in rows 20 cm apart with hill-to-hill spacing within the row of 20 cm. At the time of transplanting, the soil surface was flooded with a shallow layer of water (1 to 2 cm deep). During the first week after transplanting, the soil surface was allowed to dry for molluscicide application and was re-irrigated for seven days after molluscicide application.

Fertilizer was applied at a rate of 160-41-80-5 kgha^{-1} of N-P_2O_5-K_2O-Zn, respectively, each year. Diammonium phosphate (DAP) was the source of P and some of the N, the remaining N was applied as urea. Muriate of potash (MOP) was the K source, and Zn was applied as zinc sulphate. The full doses of Zn and P_2O_5, 30 kgha^{-1} of the N, and half of the K were applied as basal by broadcasting 24 hr before wet seeding or transplanting. Nitrogen top dressing was split as 50-50-30 kgNha^{-1} at maximum tillering, PI, and heading, respectively. The other half of the K was applied at PI.

Soil tension was measured using 30-cm long tensiometers installed in all replications for each treatment. The tensiometers were installed in between two plant rows, and the middle of the ceramic cup was placed at 15 cm below the soil surface. A handheld infrared thermometer (Model TECPEL 513, TAIWAN), with a field view of 100 mm to 1000 mm, was used to measure CT. CT was measured at 35, 46, 50, 60, 67, 71, and 73 DAS. The data were taken from the four sides of each plot at 1 m distance from the edge and approximately 50 cm above the canopy at an angle of 30^{o} to the horizontal. Readings were taken between 1300 hr and 1500 hr on sunny days (Guendouz, 2012).

GenStat V.14.1 was used for data analysis. Data were analyzed for determination of analysis of variance (ANOVA). Treatment means were compared by 5% level of significance (LSD). Factorial analysis was done for interaction between water stress treatment and growth stages. Pearson’s correlation coefficient was analyzed by Ssx stat programme at the 5% level of significance.

RESULTS AND DISCUSSIONS

Effect of water stress on canopy temperature of rice

Canopy temperature (CT) was increased with the increase in water stress (Fig. 1). At 3L to PI stage (35 DAS) canopy temperature ranges from 27.8 to 29.5^{0}C at -10 kPa stress due to prevailing high air temperature (32.3^{o}C). Due to removing stresses at 46 DAS, canopy temperature decreased and ranges from 22.7 to 23.6^{o}C. Water stress at PI to FL, the highest canopy temperature (28.3^{o}C) was recorded at -40 kPa which was followed by -20 kPa. Increased canopy temperature under water stress condition might have occurred due to increase in respiration and decrease in transpiration as a result of stomatal closure. Chuan *et al.* (2012) found that leaf temperature of rice was increased by water stress significantly under severe water stress. The minimum canopy temperature (24.9^{o}C) was recorded in flooding condition (PTR-CF). CT was found less than air temperature. The evaporative cooling involve in transpiration might cool the leaf below ambient air temperature.

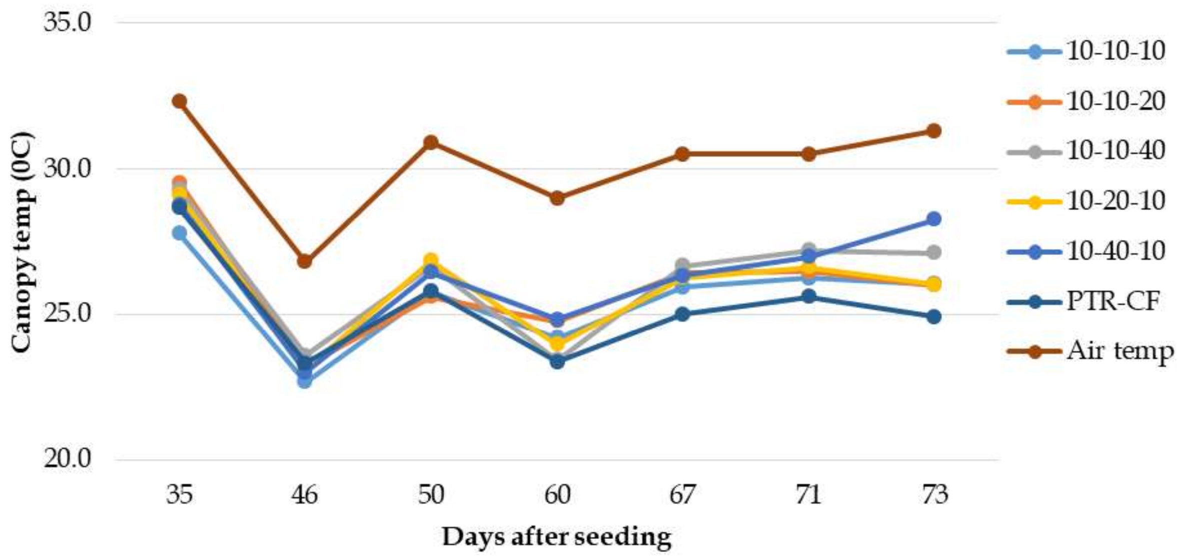

Fig. 1. Canopy temperature in different water stress treatment

CT has the positive relation with water stress (Table 4). Higher water stress increases the CT. Water stress (WSR 10-40-10) shows the higher (R^2 = 0.2168) relation with CT. Water stress index responded with CT and vapor pressure deficit. Turner *et al*. (1986) found that the temperature difference between the canopy and the air increased with the decline of soil moisture. Some researchers made it simple for farmers (Kacira *et al*., 2002) that require only measures of CT.

Effect of water stress on growth and development of rice

Table 5 presents the LAI influenced by water stress. LAI was significantly lower in WSR than PTR-CF at PI. The higher LAI (4.65) was found in PTR-CF and lower (2.60) in WSR. At FL, LAI did not significantly differ with water stress, but comparatively higher in WSR with -10 kPa and PTR-CF than WSR with -20 kPa and -40 kPa. LAI had significant differences at PI, but no such trend was observed at PM.

Table 4. Relation of canopy temperature with water stress at vegetative and flowering stage.

Treatment	Relation of canopy temperature with water stress
WSR 10-10-10	Positive association (R^2 = 0.1335)
WSR 10-10-20	Positive association (R^2 = 0.0677)
WSR 10-10-40	Positive association (R^2 = 0.0124)
WSR 10-20-10	Positive association (R^2 = 0.0337)
WSR 10-40-10	Positive association (R^2 = 0.2168)

Table 5. Effect of water stress on leaf area index (LAI) at key stages.

Treatment	3 L	PI	FL	PM
WSR 10-10-10	0.09	3.27	3.35	0.78
WSR 10-20-10	0.07	3.03	3.12	0.44
WSR 10-40-10	0.08	2.83	2.92	0.61
WSR 10-10-20	0.10	2.60	3.31	0.53
WSR 10-10-40	0.07	3.59	3.81	0.58
PTR-CF	0.03	4.65	3.78	0.47
$LSD_{0.05}$	ns	1.25	ns	ns

3L= three leaf stage, PI= panicle initiation stage, FL= flowering stage, PM= physiological stage
WSR= wet seeded rice, TR-CF= transplanted rice with continuously flooded

Water stress had no significant effects on biomass (Table 6). But lower biomass was obtained in PTR than WSR. However, lower biomass (7.9 tha^{-1}) within WSR was obtained with -40 kPa water stress imposed during PI-FL.

Yield and yield components under water stress condition

Yield was not significantly different with water stress in both WSR and PTR-CF (Table 7). But there was a decreasing trend of grain yield with increasing water stress. Water stress imposed as -10, -20 and -40 kPa during PI-FL and FL-PM decreased the grain yield. The higher grain yield (5.9 tha^{-1}) was obtained from WSR-10-10-10. Whereas the lower grain yield (4.4 tha^{-1}) was found in WSR 10-40-10. Yield of PTR-CF was similar to WSR. This was due to compensate of significantly lower spikelet fertility and grain weight with non-significantly higher panicle density and more spikelet per panicle. Yield components between the WSR and water stress were not significantly different.

CT ranges from 22.8 to 29.1°C showed no significant correlation with spikelet fertility%. This result can be justified by the findings of Straussberger (2015) who reported that rice spikelet fertility significantly decreased with over 33°C threshold.

Parveen *et al*. (2017) reported the lowest average grain weight (20.1 mg) with a water stress of -40 kPa during FL-PM only. Grain filling stage determine the grain weight and the lower biomass at flowering determines the grain weight and yield (Zhang et al., 2016). Parveen *et al*. (2017) results of the lowest grain weight were similar to the findings of Yoshida (1981) and Castillo *et al*. (2006). However, the present study has no effect on grain weight with imposing -40 kPa water stress.

Table 6. Effect of water stress on biomass (t/ha) at key stages.

Treatment	3 L	PI	FL	PM
WSR 10-10-10	0.06	2.9	8.0	15.6
WSR 10-20-10	0.06	2.1	8.1	11.7
WSR 10-40-10	0.06	2.5	7.9	10.7
WSR 10-10-20	0.08	3.0	8.4	13.7
WSR 10-10-40	0.06	2.5	9.0	13.3
TR-CF	0.04	2.4	7.4	11.5
$LSD_{0.05}$	ns	ns	ns	ns

[A]3L= 3-leaf stage, PI= panicle initiation stage, FL= flowering stage, PM= physiological stage
WSR= wet seeded rice, TR-CF= transplanted rice with continuously flooded

Table 7. Effect of water stress on yield and yield components of WSR.

Treatment	$Panm^{-2}$	$spikeletpan^{-1}$	spikelet fertility%	1000 grain weight (g)	Straw yield (tha^{-1})	HI	GY (tha^{-1})
WSR 10-10-10	379	81.5	88.5	23.7	5.3	0.49	5.9
WSR 10-20-10	428	60.3	84.3	23.9	4.8	0.48	5.3
WSR 10-40-10	319	66.2	89.3	23.3	5.0	0.44	4.4
WSR 10-10-20	340	86.3	89.3	24.5	5.1	0.49	5.6
WSR 10-10-40	389	82.4	85.8	23.4	5.1	0.48	5.5
PTR-CF*	422	91.9	78.4	22.0	4.3	0.49	5.1
$LSD_{0.05}$	ns	ns	6.5	1.3	ns	ns	ns

* WSR= wet seeded rice, PTR - CF= Puddled transplanted rice with continuously flooded, HI=Harvest index

Correlations between CT, LAI, and BM

LAI was negatively correlated with CT at PI and FL except CT_{60} at FL (Table 8). There was no consistent trend of LAI correlation with CT at PM. Correlation of BM with CT showed no consistent trend at PI, but there was a strong negative correlation of CT_{46} with BM at PM stage.

Correlations between CT, grain yield and yield components

Paniclem^{-2} correlated negatively with CT under stressed condition (Table 9). CT at 60 days after sowing (DAS) was in non-stressed condition. Therefore, yield and yield components were positively correlated with CT_{60} except number of spikelet per panicle. Under stressed condition, canopy temperature (CT) correlated negatively with grain yield (r=-0.937**). Result revealed that CT correlated positively with grain yield under non-stressed condition (CT_{35} and CT_{60}). Spikelet fertility% (SF%) correlated negatively with CT_{35} and CT_{46}. Rest of the CT was correlated positively with yield and yield components.

CONCLUSIONS

Correlation of water stress was examined with CT. Three levels of water stress (-10, -20 and -40 kPa) were imposed at three crop growth stages. CT was recorded during vegetative and flowering stages. This study shows that water stress had influence on canopy temperature and grain yield. Grain yield was not significantly different with water stress but decreasing trend was observed with higher water stress during panicle initiation to flowering. Grain yield was negatively correlated (r=-0.937**) with CT.

Table 8. Correlation between CT (different days after sowing) and LAI and BM under different water stressed conditions.

	LAI at PI	LAI at FL	LAI at PM	BM at PI	BM at FL	BM at PM
CT_{35}	-0.362	-0.432	-0.76	-0.537	0.098	-0.763
CT_{46}	-0.017	-0.385	-0.602	-0.526	-0.365	-0.964**
CT_{50}	-0.499	-0.151	0.078	0.508	0.459	-0.049
CT_{60}	-0.238	0.149	-0.022	-0.205	0.745	0.378
CT_{67}	-0.870*	-0.656	0.130	-0.011	0.593	-0.061
CT_{71}	-0.710	-0.468	0.202	0.052	0.643	-0.122
CT_{73}	-0.335	0.010	0.269	-0.012	0.810*	0.046

LAI: Leaf area index, BM: Biomass, CT: Canopy temperature
*p<0.05, **p<0.01, ns= not significant

Table 9. Correlation between canopy temperature (CT) (different days after sowing) and yield and yield components under different water stressed conditions.

	Panm^{-2}	Spikeletpan^{-1}	SF%	1000 GW	SW	HI	GY
CT_{35}	-0.099	-0.576	-0.0016	0.199	-0.278	-0.467	0.593
CT_{46}	-0.206	-0.392	-0.195	-0.311	-0.545	-0.691	-0.937**
CT_{50}	-0.846*	0.149	0.597	0.368	0.391	-0.390	-0.245
CT_{60}	0.393	-0.297	0.140	0.499	0.420	0.316	0.563
CT_{67}	-0.531	-0.719	0.779	0.724	0.668	-0.578	-0.186
CT_{71}	-0.663	-0.525	0.743	0.515	0.633	-0.695	-0.321
CT_{73}	-0.369	-0.260	0.487	0.267	0.575	-0.455	-0.0999

Panm^{-2}: panicle per m^2 area, Spikelet pan^{-1}: Spikelet per panicle, SF%: Spikelet fertility%, 1000 GW: 1000 grain weight (g), SW: Straw weight (t/ha), HI: Harvest index, GY: Grain weight (t/ha), *p<0.05, **p<0.01, ns= not significant

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REFERENCES

Boonjung, H and S Fukai. 1996. Effects of soil water deficit at different growth stages on rice growth and yield under upland conditions. 2. Phenology, biomass production and yield. *Field Crops Research,* 48: 47-55.

Burke, J J. 1996. Personal communication to S. R. Evett from the USDA-ARS. *Crop Stress Research Laboratory, Lubbock, TX.*

Castillo, E G, T P Tuong, U Singh, K Inubushi, J Padilla. 2006. Drought response of dry-seeded rice to water stress timing and N-fertilizer rates and sources. *Soil Science and Plant Nutrition,* 52**:** 496-508.

Chuan, Yan, Heyun Chen, Tianyun Fan, Yifeng Huang, Shouwu Yu, Shnyu Chen and Xiaofu Hong, 2012. Rice flag leaf physiology, Organ, and canopy temperature in response to water stress. Plant Prod. Sci. 15(2): 92-99.

Guendouz, A, S Guessoum, K Maamri, M Benidir and M Hafsi. 2012. Canopy temperature efficiency as indicators for drought tolerance in Durum Wheat (*Triticum Durum* Desf.) in semi- arid conditions. *Journal of Agriculture and Sustainability*, 1(1):23-38.

Inthapan, P and S Fukai. 1988. Growth and yield of rice cultivars under sprinkler irrigation in south-eastern Queensland. II. Comparison with maize and grain sorghum under wet and dry conditions. *Aust. J. Exp. Agric.*, 28:243-248.

Jackson, R D, S B Idso, R J Reginato and P J Pinter, Jr. 1981. Canopy temperature as a crop water stress indicator. Water resources research, 17(4):1133-1138.

Kacira, M, P P Ling, T H Short.2002. Establishing crop water stress index (CWSI) threshold values for early, non-contact detection of plant water stress. *Trans. ASAE*, 45 (3):775–780.

Kumar, R, A K Sarawgi, C Ramos, S T Amarante, A M Ismail, L J Wade.2006. Partitioning of dry matter during drought stress in rainfed lowland rice. *Field Crops research,* 98 **:**1-11.

Parvaze, A S, A Ara, M Gull and K Rehman. 2019. Canopy Temperature Depression as an Effective Physiological Trait for Drought Screening, Drought - Detection and Solutions, Gabrijel Ondrasek, IntechOpen, DOI: 10.5772/intechopen.85966. Available from: https://www.intechopen.com/books/drought-detection-and-solutions/canopy-temperature-depression-as-an-effective-physiological-trait-for-drought-screening

Parveen, S, E Humphrey, and M Ahmed. 2017. Effect of Water Deficit Stress on Yield Performances in Wet Seeded Rice. Bangladesh *Rice J*, 21 (1): 1-12.

Pearson's Correlation Coefficient. 2008. *In:* Kirch W. (eds) Encyclopedia of Public Health. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-5614-7_2569

Straussberger, Lisa. 2015. Disaggregating the Effect of Drought and Heat Stress During Flowering on Spikelet Fertility in Rice. Theses and Dissertations.1372. http://scholarworks.uark.edu/etd/1372

Turner, N. C., O'toole, J. C., Cruz, R. T., Namuco, O.S. and Ahmad, S. 1986. Response of seven diverse rice cultivars to water deficits. I. Stress development, canopy temperature, leaf rolling and growth. Field Crops Res. 13: 257-271.

Yoshida, S. 1981. Fundamentals of rice crop science. *International Rice Research Institute, Los Baños, Philippines,*1-63.

Zhang W, Z Cao, Q Zhou, J Chen, G Xu, J Gu, L Liu, Z Wang, J Yang, H Zhang. 2016. Grain filling characteristics and their relations with endogenous hormones in large- and small-grain mutants of rice. *PLoS ONE* 11(10): e0165321. doi:10.1371/journal. pone.0165321