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RESEARCH PAPER

Water productivity and grain yield of hybrid rice under various moisture regimes in Potohar conditions of Pakistan

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Key Message: In this study water productivity of exotic rice hybrids was assessed in agro climatic conditions of Potohar region and it was found that the irrigation regime 50% less than normal flooded resulted in maximum total water productivity of rice hybrids.

Abstract: To prevent water loss and to maximize water productivity by hybrid rice using desirable water saving irrigation regimes, four rice hybrids were tested in three irrigation regimes (Normal flooded, 50% less than normal and 75% less than normal) during 2019 at Crop Sciences Institute (CSI), National Agriculture Research Center, Islamabad (latitude 33° 42 N' and longitude 73° 10' E) Pakistan. The experiment was conducted in RCB design with four rice hybrids and three irrigation treatments and three replications. Pooled analysis of variance depicted significant differences among the tested hybrids for most of the traits except thousand grain weight and canopy temperature. Plant height and number of tillers per plant revealed a negative trend when irrigation was reduced from normal level, however, this reduction in irrigation caused an increase in the number of grains per panicle, thousand grain weight and paddy yield of hybrid WDR and LP-2. Furthermore, by reducing irrigation to 50% and 75% less than normal, the NDVI values reduced, while, canopy temperature increased which indicates response of the tested hybrids to water deficit conditions. Even though the NDVI values obtained for the studied hybrids were in acceptable range (0.65-0.75) which showed the drought tolerant nature of these hybrids as well as desirability and effectiveness of the used irrigation regimes. Among hybrids, WDR (78.8 days), followed by LP2 (96.8 days) were early flowering, whereas, WDR was high yielding (13650.0 kg/ha, 13775.0 kg/ha and 14200.0 kg/ha, respectively) with maximum water productivity (0.158 kg L^{-1}, 0.160 kg L^{-1} and 0.165 kg L^{-1} respectively) across all irrigation regimes. Total water productivity of the rice hybrids was higher at 50% less than normal irrigation level and it is suggested that this irrigation regime shall be tested in future with greater number of rice hybrids.

Keywords: Canopy temperature, Irrigation regimes, NDVI, Rice hybrids, Water productivity

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Introduction

Rice (*Oryza sativa* L.) being a member of cereal family serves as a staple food for more than half of the global population (Jiang et al., 2020). It also plays a key role in alleviation of food scarcity in the current scenario of ever increasing demand for food with increase in global population. Among its rival's rice stands at 2nd position in terms of production after wheat crop (Jain et al., 2019). Worldwide production of rice is mostly dependent on irrigated lowland rice, thus it consumes greater share of irrigated water in comparison with other crops (Ofori & Anning, 2019). Among major constraints of reduced production and yield of crops, climate change is at the front of all, giving rise to several other calamities such as heat and drought stress, disease and insect outbreak and above all disturbance of the on-going cropping patterns. Rice is one of the crops that will be affected greatly due to current climatic change (Fahad et al., 2019).

Unrestrained population growth, increasing urban and industrial development is leading to drastic changes in natural ecosystems through increased temperature promoting water scarcity (Osipov, 2019). Fresh water reservoirs used for irrigation are depleting with the passage of time thus causing drought which ultimately affects yield of crops especially rice (Ayaz et al., 2019). In total global production of rice Asia contributes more than 90%, while consuming almost 90% of the total irrigation water (Bandumula, 2018). According to a report of International Rice Research Institute during 2003, it was estimated that by 2025, 15 million out of the total irrigated rice area might suffer from "Physical and economic water scarcity" (Pascual & Wang, 2017).

Pakistan is also among the climate change affected countries of the world. Agriculture sector of Pakistan is suffering huge losses due to biotic and abiotic stresses due to climate change. In Pakistan rice is an important staple food and cash crop which ranks second after wheat. Its importance in agriculture of Pakistan can be judged from its highest contribution to foreign exchange after cotton. It adds a share of 0.6 percent to GDP and 3.1 percent to value added in agriculture (Pakistan Economic Survey, 2020). During 2018-19, 3.1 percent reduction in area under rice cultivation was observed. This decrease in area of rice also decreased production by 3.3 percent which was 7.202 million tons against 7.450 million tons against last year due to water shortage, alleviated temperature and prevailing biotic stresses (Pakistan Economic Survey, 2019). In Pakistan, hybrid rice production is emerging and during the current year 500 tons of hybrid rice seed was imported from China. Furthermore, joint efforts of Pakistan and China have brought Pakistan's agriculture sector really close to development of hybrids in Basmati rice with an average yield of 80 mounds per acre (Lianqun, 2020). Rice is an exhaustive crop and its water requirement is more as compared to other crops but hybrid rice needs extra water and other inputs. In most part of the country rice is irrigated with canal water. Climate change has put water availability for irrigation at risk.

Rainfall patterns in many areas are becoming more unreliable, with extremes of drought and flooding occurring at unexpected times (Pascual & Wang, 2017). Traditional planting has been the most important and common method of crop establishment practice under irrigated lowland rice ecosystems in tropical Asia. Irrigated lowland rice varieties and hybrids not only consume more water but also cause wastage of water resulting in degradation of land (Ayaz et al., 2019). To save water losses and degradation of fresh water sources the farmers should move towards irrigation regimes that would conserve water without yield losses. To do so, a great deal of research work is required to identify the most desired level of irrigation to be provided to a rice field during a season that could conserve water or avoid drought stress without drastically affecting grain yield.

Water productivity (WP) is defined as yield produced in response to total water input by means of rainfall and irrigation. It is actually a relationship between input provided to rice in form of water and output obtained in form of yield (Kijne et al., 2003). Measurement of water productivity helps in devising more efficient water regimes with least reduction in yield that could conserve water losses in case of rice production. However, decreasing the amount of water supplied to a level surpassing threshold level may put the productivity of the irrigated rice at risk, therefore, various approaches should be sought out to save water and increase the water productivity of rice (Bouman et al., 2005). Water productivity under water-stress conditions can be improved by genetic improvement of the plants or by using eco-friendly agronomic practices.

Other than water productivity, the normalized difference vegetation index (NDVI) and plant canopy temperature can also be used as proxy indicators of drought stress (Kernieli et al., 2010). NDVI values range from -1 to +1, whereas; -1 to 0 stands for dead plants or no vegetation; 0 to 0.33 refers to unhealthy plants; 0.33 to 0.66 means moderately healthy plants and 0.66 to 1 means healthy plants (Cal et al., 2019). Plant canopy temperature increases with increasing drought; therefore, it can be used as an indicator or response to drought stress (Cal et al., 2019). These two parameters, along with water productivity can be used as indicators and tools for assessing the impact of different water regimes on production of rice. Keeping the given scenario in mind, the major aim of this study was to screen exotic rice hybrids in our local ecology for abiotic stress resistance, especially under water deficit conditions.

Materials and Methods

Experimental site and design

This research work was carried out at CSI, NARC (at coordinates of latitude 33° 42 N' and longitude 73° 10' E.) field during rice growing season 2019. Experiment Design comprised four rice hybrids and three different water regimes/treatments viz., normal irrigation, 50% less than normal and 75% less than normal were used to assess performance of four hybrids (three checks and one target drought tolerant Chinese Hybrid) used in this study with two replications in Randomized Complete Block Design, for yield and yield attributing traits. Details of hybrids used in this study are given in Table 1.

Table 1 List of rice hybrids used in the study

S. No.	Hybrids	Source
1	G-53	Local
2	LP-2	Local
3	Pearl Super	Local
4	WDR (Chinese drought tolerant hybrid)	Wuhan, China

Crop management practices

Nursery was raised using dry bed method during the third week of June 2019. Field was properly ploughed and after planking the field was divided into small sized beds with water channels for proper water removal. Organic manure (decomposed) and a small amount of inorganic fertilizer as basal dressing were applied in the field before sowing. Seeds were broadcasted in properly puddled and leveled beds which were covered with wheat straws for achieving successful germination. All beds were given the same level of irrigation and all other agronomic practices. After germination, three weeks old seedlings of each hybrid were carefully uprooted and taken to the field for transplantation. Before transplanting rice seedlings, the field was leveled through laser leveling followed by ploughing, flooding and puddling. Seedlings were transplanted after 24 hours of puddling. The whole field was divided into three main plots, each given different irrigations except initial irrigation provided in equal volume to all main plots for avoiding desiccation or wilting of seedlings through heat shock. Duration of water provided to each plot under each irrigation regime is given in Fig. 1. Depth of water at inlet and outlet of the water channel was measured by installing cut throat flumes. Half dose of nitrogen (Urea) and full doses of phosphorous and potassium were applied before transplanting, while rest of nitrogen was provided to the field during tillering and flowering initiation stage.

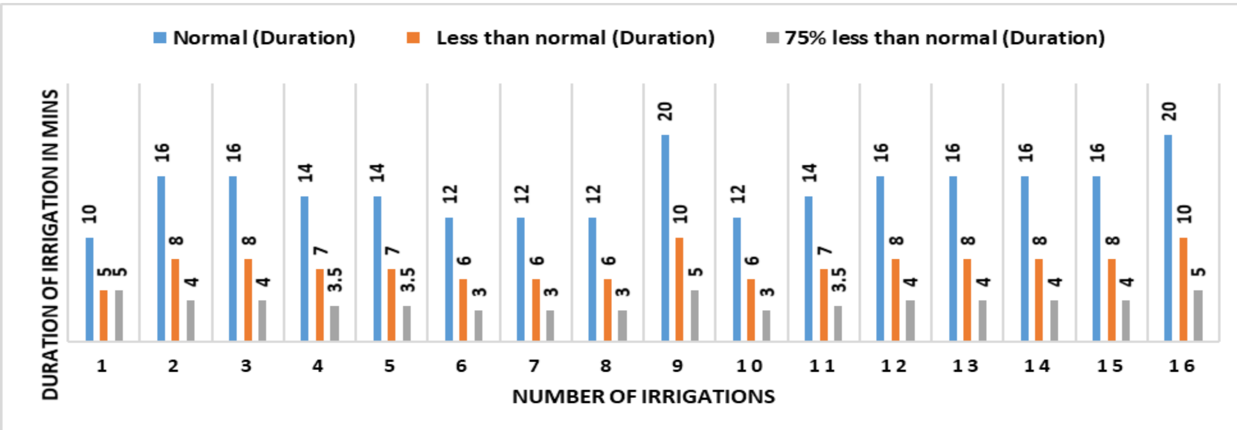

Fig. 1 Number and durations of irrigations under different water treatments

Parameters studied

For assessing agronomic traits, a sample comprising five plants were taken for each hybrid from all of the three treatments for comparative study. Grains per panicle of each hybrid under each treatment were threshed and counted as average of five samples per hybrid at crop maturity. Thousand grain weight of each hybrid under each treatment was also measured by taking thousand seeds from each hybrid at crop maturity, followed by weighing them through digital balance. Grain yield of each hybrid under each treatment was calculated as:

Grain yield (kg/ha) = Yield per plot (10 m^{-2}) × 1000 m^{-2}

The impact of the mentioned irrigation levels/regimes on physiology of rice hybrids under study were estimated through NDVI time series values and plant canopy temperatures (^{o}C) at different developmental stages of rice from germination to maturity.

Statistical analysis

The data obtained for the mentioned traits were subjected to pooled analysis of variance (ANOVA) as suggested by Annicchiarico (2002). Statistix 8.1 was used for ANOVA and descriptive calculations. Irrigation regimes were considered as fixed effects, while hybrids and replications were considered as random effects.

Grain yield of each hybrid under each treatment was associated with the volume of water provided through each irrigation regime by calculating water productivity (kg. L^{-1}). Water productivity was calculated as:

$$Water\ Productivity\ (Kg\ L^{-1}) = \frac{Yield\ in\ Killograms}{Total\ volume\ of\ Water\ in\ Litres}$$

Cut throat water flumes were installed for accurate measurement of the volume of water provided to each plot during each interval of irrigation.

Results

Impact of irrigation regimes on yield and yield related parameters

Variations among the tested rice hybrids across three different irrigation levels were found significant for days to flowering, plant height, tillers per plant, grains per plant, paddy yield and NDVI values, whereas hybrids depicted non-significant differences for thousand grain weight and canopy temperature (Table 2). Irrigation regimes resulted in non-significant differences for all of the studied traits, whereas, interaction between hybrids and irrigation regimes resulted in non-significant differences between rice hybrids for all traits except paddy yield (Table 2). The non-significant interaction between hybrids and irrigation regimes for most of the traits except paddy yield might have been resulted due to stability of the studied hybrids for these traits. It also indicates that irrigation regimes used in this experiment did not result in a huge impact on performance of these hybrids and non-significant interaction between hybrids and irrigation regimes pointed towards stable performance of the hybrids for all traits except paddy yield (Table 2). Furthermore, significant variation existed among rice hybrids for all traits except thousand grain weight and canopy temperature, which reveals differences in their genetic makeup (Table 2). Coefficient of variation calculated for all traits was within acceptable range indicating less chances of error or unidentified sources of variations in this study (Table 2).

Among the studied rice hybrids, WDR was earliest in flowering (78 and 79 days, respectively under normal, 50% and 75% less than normal with a pooled mean of 78.83 days), followed by LP2 (96.5, and 97 days each, respectively under normal, 50% and 75% less than normal irrigation with pooled mean of 96.83 days) (Table 3). In case of plant height, LP2 had shortest stature (119.5, 118 and 118.5 cm, respectively under normal, 50% and 75% less than normal irrigation with pooled mean of 118.67cm), whereas G53 had tallest plant stature (123.5, 120.5 and 121 cm under normal, 50% and 75% less than normal irrigation with pooled mean of 121.5cm) (Table 3). Maximum tillers per plant were produced by G53 (15, 13, 12 and 13.33 tillers under normal, 50% & 75% less than normal and pooled across all irrigations, respectively) (Table 3). WDR produced maximum grains per panicle then its adversaries (206.5, 223.5, 240 and 223.33g under normal, 50% & 75% less than normal and pooled across all, respectively) (Table 4). For thousand grain weight rankings of the hybrids changed from normal to 75% less than normal irrigation. Under normal and 50% less than normal irrigation Pearl Super produced heavier grains (39 g), however at 75% less than normal irrigation level WDR outcrossed Pearl Super (35 g) by producing seeds with thousand grain weight of 38 g (Table 4). Having maximum number of grains per panicle, WDR out yielded all other hybrids in terms of paddy yield (13650, 13275, 14200 and 13708 kg/ha under normal, 50% & 75% less than normal and pooled across all conditions, respectively) (Table 4).

In response to stress at 50% and 75% less than normal irrigation, days taken by each hybrid to initiate flowering increased (Table 3). Plant height and tillers per plant reduced by reducing irrigation from normal level (Table 3). Grains per panicle improved in almost all hybrids by reducing irrigation level except in G53 (Table 4). Thousand grain weight in case of G53 and WDR increased by reducing irrigation level, whereas it showed a negative trend in case of LP2 and Pearl Super (Table 4). Similarly, paddy yield of WDR, followed by LP2 increased by increasing water stress, whereas paddy yield of Pearl Super revealed a reducing trend. G53 behaved quiet different as its yield increased when irrigation was reduced to 50% less than normal but it reduced to its lowest on further reducing irrigation to 75% less than normal (Table 4). By virtue of current findings regarding thousand grain weight and paddy yield, we can summarize that WDR, followed by LP2 were high yielding as well as tolerant to drought stress, furthermore, instead of reduction in their yield and its attributes, they showed an improvement in these traits under water deficit conditions. Therefore, these hybrids are recommended for cultivation in areas with low rainfalls and limited irrigation reservoirs.

Table 2 Pooled mean squares for traits studied

SOV	DTF	PH	TPP	GPP	TGW	PY	NDVI	CPT
Replications	0.38	20.17	5.04	504.17	5.04	17604	4.2E-06	0.12
Irrigation regimes (IR)	1.79^{ns}	13.63^{ns}	3.17^{ns}	665.37^{ns}	1.55^{ns}	246979^{ns}	3.2E-04^{ns}	0.50^{ns}
Hybrids	521.38**	63.33**	4.71*	4750.28*	39.26^{ns}	3604549**	0.0066**	0.58^{ns}
H × IR	0.29^{ns}	3.46^{ns}	1.67^{ns}	647.82^{ns}	12.43^{ns}	627674*	1.7E-04^{ns}	0.07^{ns}
Error	0.56	9.80	1.31	1287.44	18.95	203968	2.1E-04	0.25
CV	0.80	2.58	9.52	19.47	12.45	3.58	2.06	2.11

SOV = Sources of variation; DTF = Days to flowering; PH = Plant height, TPP = Tillers per plant; GPP: Grains per panicle

Physiological impact of different water regimes on NDVI and canopy temperature of rice hybrids

NDVI values and canopy temperature were used as indicators of the impact of water stress on rice hybrids. In this study an unusual trend in case of NDVI and canopy temperature was observed that despite of significant differences resulting in these parameters as a response to difference in irrigation levels and interaction effects, we obtained non-significant differences (Table 4). However, hybrids depicted significant differences in their NDVI values across given irrigation levels (Table 4). By observing mean values of NDVI and canopy temperature calculated under each treatment, it can be clearly seen that NDVI values decreased, whereas, canopy temperatures for each hybrid increased with reduction in irrigation level (Table 4). It can also be concluded that the irrigation regimes used in this study were within threshold level and thus did not result in severe drought stress.

Table 3 Average performance of rice hybrids for the studied traits (Plant height, days to flowering and tillers per plant) under different irrigation regimes

Treatments	Hybrid	Days to flowering	Plant height	Tillers per plant
Normal	G53	97.5	123.5	15.0
	LP2	96.5	119.5	12.0
	Pearl super	96.5	128.5	12.0
	WDR	78.5	120.5	11.5
Mean		92.2	123.0	12.6
50% less than Normal	G53	99.0	120.5	13.0
	LP2	97.0	118.0	12.0
	Pearl super	97.5	126.5	12.5
	WDR	79.0	118.5	11.0
Mean		93.1	120.9	12.1
75% less than Normal	G53	98.0	121.0	12.0
	LP2	97.0	118.5	11.0
	Pearl super	98.0	123.0	11.0
	WDR	79.0	120.0	11.5
Mean		93.0	120.6	11.4
Pooled Data	G53	98.2	121.7	13.3
	LP2	96.8	118.7	11.7
	Pearl super	97.3	126.0	11.8
	WDR	78.8	119.7	11.3
Grand Mean		92.8	121.5	12.0

Table 4 Average performance of rice hybrids for the studied traits (Number of grains per panicle, 1000 grain weight and paddy yield) under different irrigation regimes

Treatments	Hybrid	Number of grains per panicle	1000 grain weight (g)	Paddy yield (Kg/ha)
Normal	G53	175.5	28.5	12150.0
	LP2	145.0	36.5	12625.0
	Pearl super	168.5	39.0	12550.0
	WDR	206.5	34.0	13650.0
Mean		92.2	173.8	34.5
50% less than Normal	G53	169.5	33.5	12750.0
	LP2	186.5	35.5	12850.0
	Pearl super	172.0	39.0	11975.0
	WDR	223.5	34.5	13775.0
Mean		93.1	187.8	36.4
75% less than Normal	G53	138.0	32.5	11175.0
	LP2	198.5	34.5	12925.0
	Pearl super	187.5	35.0	11900.0
	WDR	240.0	38.0	14200.0
Mean		93.0	191.0	35.0
Pooled Data	G53	161.0	31.5	12025.0
	LP2	176.6	35.5	12800.0
	Pearl super	176.0	37.7	12141.7
	WDR	223.3	35.2	13875.0
Grand Mean		92.8	184.2	34.9

Effect of irrigation levels on water productivity of rice hybrids

In order to identify which of three irrigation regimes conserved more water with least or no reduction in yield, we assessed water productivity of the four rice hybrids under each irrigation regime. WDR produced maximum water productivity across all irrigation regimes (0.158, 0.160 and 0.165 kg L^{-1}, respectively), followed by LP2 (0.146, 0.149 and 0.150 kg L^{-1}, respectively) (Table 5). Average water productivity calculated for all hybrids under all irrigation levels indicated that 50% less than normal irrigation produced maximum average water productivity (0.149 kg L^{-1}) and is thus the desired irrigation regime. In this study we found that WDR and LP2 performed better under drought than normal condition and thus these hybrids to be tolerant to drought stress. Furthermore, high water productivity obtained under 50% less than normal irrigation was because of the presence of these two hybrids in this experiment otherwise, reduction in irrigation would have resulted in reduction of water productivity such as reduction in yield observed in case of Pearl Super and G53 (Table 5).

Table 5 NDVI, canopy temperature and water productivity values pooled across all irrigation regimes

Treatment	Hybrid	NDVI	Canopy temperature	Water Productivity (kg/L)
Normal	G53	0.73	23.56	0.141
	LP2	0.75	23.26	0.146
	Pearl super	0.75	23.26	0.145
	WDR	0.67	23.79	0.158
Mean		0.71	23.47	0.148
50% less than Normal	G53	0.73	23.79	0.148
	LP2	0.74	23.32	0.149
	Pearl super	0.72	23.42	0.139
	WDR	0.66	23.96	0.160
Mean		0.70	23.62	0.149
75% less than Normal	G53	0.70	23.89	0.129
	LP2	0.72	23.86	0.150
	Pearl super	0.71	23.66	0.138
	WDR	0.65	24.12	0.165
Mean		0.69	23.88	0.145
Pooled Data	G53	0.72	23.75	0.139
	LP2	0.74	23.48	0.141
	Pearl super	0.73	23.45	0.146
	WDR	0.66	23.96	0.145
Grand Mean		0.71	23.66	0.158

NDVI = CT = Canopy temperature

Discussion

Utilizing and devising water-saving managements is a dire need under current climate change scenarios where availability of water for agricultural use is reducing, whereas continuous flooded irrigation under traditional practices in case of lowland rice is leading us to extreme water deficit conditions (Ullah et al., 2019). Among climate change affected plants, rice on one side is adding its share to water losses but on other hand it is a victim as well (Kontgis et al., 2019). In Asia, lowland rice cultivation and traditional irrigation needs the attention of agriculture scientists to devise new water saving regimes in order to enhance water productivity of rice (Mukherjee et al., 2019). In this study we aimed at devising water saving regimes using cut throat flumes to improve water productivity of rice hybrids. In our study, significant differences for the studied traits due to rice hybrids used in this experiment projected their genetic variability which resulted in their deferential performance across different irrigations. It shows that there is an ample scope for using these hybrids in future breeding programs for development of promising genotypes for yield and other economic plant traits with wider adaptability to water deficit conditions. Rice genotypes found across the globe are found to have greater amount of genetic variability which results in wider variability in their response to fluctuating environmental conditions (Ouk et al., 2006; Singh et al., 2006; Ishwar et al., 2007). Sabar and Arif (2014) also reported enough amount of genetic variability among eight local rice varieties which were being tested under a water deficit environment. The prevailing drought stress influenced the phenotypic performances of the tested rice varieties. They found significant differences among rice varieties for days to flowering, plant height, tillers per plant, thousand grain weight and paddy yield which are in coincidence with our findings.

Patel et al. (2010) also reported significant differences among high yielding rice varieties, tested across flooded and aerobic conditions, for days to flowering, plant height, grains per spike, and grain yield. In accordance with our results they also reported non-significant impact of the irrigation regimes on thousand grain weight and non-significant interaction effects on plant height, grains per spike and thousand grain weight. In contrast to our findings, they found non-significant differences among varieties for number of tillers and thousand grain weight; significant impact of irrigation regimes on all traits except thousand grain weight and significant interaction effect on days to flowering, number of tillers and grain yield. These differences in our findings are due to the difference in germplasm used in both experiments, nature of the water saving managements used and most importantly due to the difference in the ecologies where these experiments were conducted. Varieties in comparison with hybrids are having a broader genetic base and therefore, can possibly result in greater variations in response to changes in its environment, whereas, the hybrids tend to have a much uniform phenotype than varieties.

Ofori and Anning (2019) also found non-significant impact of irrigation regimes on plant height and grains per panicle, while studying the impact water saving managements on lowland rice in the Coastal Savannah Agro-ecology of Ghana. However, contrary to our results they found significant impact of the given irrigation treatments on the number of tillers produced by the rice genotypes when water saving management was applied only at maximum tillering stage in both seasons. This difference in our findings is because of two reasons. First of the two reasons is the difference between water saving managements used in both experiments. They used alternate wetting and drying at five different stages that resulted in a much serious drought stress by affecting performance of the studied genotypes for traits like number of tillers. On contrary, we used a bit flexible irrigation regimes for water conservation, where we provided same number of irrigations to each treatment but the duration for water flow was differentiated viz., the duration of water flow was reduced to 50% and 75%, respectively in former two irrigation regimes then the normal one. In this way water was efficiently conserved with least impact of reduced irrigation levels on the performance of rice hybrids.

In this experiment, interaction between hybrids and irrigation regimes was significant for paddy yield which is pointing towards the variable response of the tested hybrids across the tested irrigation levels. Significant interaction was responsible for changing the rankings of the hybrids for paddy yield under each treatment. Incidence of such results confirms that for effective identification of high yielding and drought tolerant rice germplasm we must assess their performance across a range of irrigation levels (Sabar & Arif, 2014). Selection under severe stress can result in better improvement of drought tolerance, however, identification of target stress level/environment is very important (Serraj et al., 2011; Venuprasad et al., 2011). It is evident from previous studies that drought stress imposed at vegetative stage greatly affects biomass production (plant height and number of tillers per plant), whereas drought stress applied at reproductive stage affects sink size (spikelet fertility, 1000 grain weight and seed yield) (Guan et al., 2010). In our study similar results were observed for plant height and number of tillers per plant, which revealed a decreasing trend when irrigation was reduced from normal level, however, an increase was observed in number of grains per panicle, thousand grain weight and paddy yield. These findings are pointing towards the severe impact of the water stress imposed on the studied hybrid at vegetative than reproductive stage.

NDVI values increase with a decrease in land surface temperature or canopy temperature, in vise versa (Pipin et al., 2016). Land surface temperature or canopy temperature increases with increase in drought stress and it causes a decrease in NDVI values. A Lower NDVI value refers to unhealthy or dry plants, which results due to ill effects of severe drought stress (Cal et al., 2019). Our results are in correspondence with previous findings. NDVI values of rice hybrids in our study showed a decreasing trend in which irrigation was reduced from normal level, whereas canopy temperature increased by increasing drought stress. Furthermore, despite of slight decrease, NDVI values of the rice hybrids at all irrigation levels remained higher (0.65-0.75), indicating that the studied hybrid was least affected under the applied water deficit conditions. This finding also suggests that instead of reducing the intervals of irrigations during a given rice growing season, we can efficiently save water by reducing the duration of water applied to the field under each irrigation level. These findings are an indication towards future possibility of growing rice in aerobic conditions like other cereals by providing alternate wetting and drying irrigation systems with effective weed control strategies.

For generations, rice has been deemed as an aquatic plant; however, this belief has been repeatedly confronted, as rice is capable of growing under both flooded and aerobic conditions (Pascual & Wang, 2017). Hybrids in our study, overall maximum water productivity of 0.149 kg L^{-1} was obtained under 50% less than normal irrigation regime in comparison with normal irrigation (0.148 kg L^{-1}). However, with further reduction in irrigation to 75% less than normal, overall water productivity reduced to its minimum (0.145 kg L^{-1}). Among hybrids, WDR produced maximum water productivity across all irrigation regimes (158, 160 and 165 kg L^{-1}, respectively), followed by LP2 (146, 149 and 150 kg L^{-1}, respectively). These findings are in conformity with Mishra & Salokhe

(2010); Zhang et al. (2010); Kima et al. (2014). He et al. (2020) also found a 34% increase in water productivity of rice by reducing irrigation to 40%.

Conclusion

Based on their unique behavior, WDR and LP2 were found high yielding as well as tolerant to drought stress. Furthermore, these hybrids had better performance for yield at reduced irrigation levels than normal irrigation and thus produced maximum average water productivity across all of the three irrigation regimes. In the current scenario of climate change where water conservation is inevitable, use of drought tolerant rice hybrids and varieties like WDR and LP2 is highly recommended. These hybrids can also open a new door towards a new era of developing drought tolerant varieties and hybrids for general as well as specific regions. In our study 50% less than normal irrigation resulted in maximum total water productivity and thus may be recommended to be used for growing rice in areas with water scarcity or deficit. From the findings of this study it can also be concluded that despite of using the conventional flooded irrigation system for growing rice we should shift to methods where we can reduce irrigation to an optimum level that could save water without resulting in any significant yield losses. To do so further work is required and experiments like this are needed to be designed where we could assess the impact of drought stress on our national rice gene pool in order to identify a base population having drought tolerance. This would pave a road towards development of rice genotypes with greater potential of competing the ill effects of water deficit conditions due to improved water use efficiency.

Authors Contribution Statement: Abid Majeed Satti planned, designed and monitored this research. Zabih Ullah helped in data analysis and write-up. Muhammad Shahzad helped in data recording. Shaukat Ali provided the germplasm and reviewed the manuscript. Syed Haider Abbas helped in preparing graphs and helped in crosschecking data analysis. Asma Akbar Khan helped in writing references and manuscript formatting. Zafar Islam helped in provision and installation of cut throat water flumes in field and assessed in water productivity calculation.

Conflict of Interest: The authors declare that they have no conflict of interest.

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