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Full Length Article

Root Traits Responses to Irrigation Intervals in Rice (*Oryza sativa*)

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Abstract

Drought is one of major abiotic stresses that effect rice production. Roots play vital role in absorption of water and nutrients from soil contributing for drought tolerance. The present study quantified the effects of different irrigation intervals on root development and agronomical traits of three Egyptian rice cultivars, Giza177, Giza178, Sakha107, IET1444 as a popular drought tolerant and Moroberekan as control genotype. Irrigation treatments were imposed 15 days after transplanting and applied for every 4, 8 and 12 days during 2018 and 2019 rice growing seasons. The results showed the reduction in root architecture traits with prolonged irrigation intervals. A significant decrease in plant height, number of panicles plant^{-1}, grain yield (t ha^{-1}) and relative water content, while sterility (%) and water use efficiency significantly increased over irrigation intervals. The highly significant and positive correlation was found among grain yield and root:shoot ratio, relative water content and number of panicles plant^{-1}, while the negative correlation was with root xylem vessel number and sterility. It was concluded that, the drought reduced the grain yield and its components due to poor developed root system. Moroberekan and IET1444 genotypes can be used as a donor parent for rice breeding program. Further studies are also required to identify factors that contribute to the high yield potential of both Giza178 and Sakha107 under different water stress condition.

Keywords: Cultivars; Drought; Grain yield; Irrigation regimes; Root traits

Introduction

Rice (*Oryza sativa* L.) is staple of more than 3.5 billion people to obtain 20% of their daily calorie intake. Water is essential for growth and development of rice plants (Yang 2012; Ghoneim 2020). More than 75% of the world rice is produced under continuous flooding practices (Van *et al.* 2001). Rice production area in Egypt changes yearly based on the available irrigation water and occupies about 20% with the total cultivated area of 660 thousand hectares with the total production of 5.5 million tons. About one-third of total cultivated area is exposed to water shortage annually in Egypt (Abdallah *et al.* 2016). Hence, irrigation water is the most limiting factor for expanding rice cultivation area in Egypt.

Breeding for drought tolerance in rice can be a sustainable approach to reduce the adverse effects of drought stress. Drought tolerance can be assessed through morphological, physiological and agronomical traits (Farooq *et al*. 2009; Hussain *et al*. 2018). Rice roots play a crucial role in the understanding of water stress, its acquisition, water stress adaptation and tolerance (Geng *et al.* 2018). Considerable variation in root traits is regulated by multiple genes and many studies report that selection for root traits in improving drought tolerance. For instance, roots with increasing penetration rate have an advantage for moisture absorption from deeper soil layers (Hussain *et al.* 2019). Increased rooting depth, root shoot ratio, root density, root pulling force and penetration ability through hardpans contribute to drought tolerance and have a direct association with the rice root systems (Upriser *et al.* 2004; Clark *et al.* 2011; Hazman and Brown 2018).

Likely, xylem vessels play an essential role in plant adaptation to drought stress. Root anatomical features of xylem vessels, including the extraction of nutrients and water from the soil, have a significant impact on plant function and therefore of major importance in understanding plant adaptation to drought stress (Bhugra *et al.* 2017).

The root length with surface area can determine the uptake of soil resources and young root tips are the key regions of water absorbed. The diameter of xylem vessels affects the hydraulic conductivity of the root and eventually determines the productivity of the plant under drought stress. Breeding strategies to decrease the root xylem diameter can lead to a decrease in hydraulic conductance under adequate accessibility of moisture (Kim *et al.* 2020). Drying of the soil surface layer could lead the roots to search deep in the soil profile for available moisture.

The water resources in Egypt are limited to the share flow of the Nile River by 55.5 billion m^3, the deep groundwater in the deserts and small amounts of rainfall in the northern coastal area. Egypt has pioneered various water-saving irrigation technologies to achieve more water-efficient irrigation for rice and deficit irrigation is most practiced. In this method, soil is dried out to some degree in between irrigation intervals (Ghoneim 2020) and has been effective breeding method for plants with lower root length density in shallow layers of soil and high root length density in medium and deep layers. The hierarchical structure of the root system could promote hydraulic lift, helping water uptake from deep soil profiles. Large-diameter xylem vessels may be useful in raising the axial hydraulic conductivity of roots growing in deep soil layers if deep root systems may increase crop productivity (Kim *et al.* 2020). Relative water content (RWC), water use efficiency (WUE) and panicle characteristics of rice genotypes are multivariate traits in response to varying degrees of water stress (Cha-Um *et al.* 2010).

Drought stress at the reproductive stage can cause huge impacts on yield and its components. Extreme water stress during grain-filling stage accounts for 48–94% economic yield losses. If drought stress develops soon after panicle initiation, the number of spikelets developed are declined and this may result in reduction of yield (Sharma *et al.* 2018; Ikmal *et al.* 2021). Water scarcity has also been reported to delay or earlier the appearance of panicle and flowering (Shamsudin*et al.* 2016a, b; Kang and Futakuchi 2019; Ikmal *et al.* 2019). Panicle length, number of spikelets per panicle and grain yield are significantly reduced by drought (Abdel-Hafez *et al.* 2017).

Therefore, production of cultivars with both high yield potential and tolerant to drought are key objectives of the rice breeding program. Until today, many drought tolerant rice cultivars have been introduced for increasing productivity per unit area under drought as well as normal conditions, such as BRRI Dhan-56 and -57 (Bangladesh), Hanhui3T (China), Sahbhagi dhan (India), Sukha dhan-1, -2 and -3 (Nepal), Sahod ulan-3 and Katihan-8 (Philippines), and MRIA1, MNR151 and MNR152 (Malaysia) (Ahmed *et al.* 2016; Li *et al.* 2018; Sobri *et al.* 2020). Hence, this study was carried out to understand the changes in root and other morpho-physiological traits induced by irrigation interval and to determine the most important criteria for effective selection of drought tolerant rice genotypes.

Materials and Methods

Plant materials

Five rice genotypes including three Egyptians cultivars, namely Giza177, Giza178, Sakha107, IET1444 from India and Moroberekan from Republic of Guinean were used in this study. The pedigree information and types of the rice genotypes are presented in (Table 1).

Experimental site and soil properties

A field experiment was conducted at Rice Research and Training Centre, located at Kafr EL-Sheikh Governorate (31 09° N Latitude and 30 68° longitude) during 2018 and 2019 growing seasons. The air temperature (°C), relative humidity (RH, %) and evaporation (mm day^{-1}) during the 2018 and 2019 growing seasons are presented in (Table 2). Representative soil samples were taken in bulk from 0–20 cm and 20–40 cm depth before the growing season. The soil samples were air-dried, ground and passed through 2-mm sieve. Composite soil samples were taken and analyzed for physical and chemical characteristics of the soil including electrical conductivity (EC,) pH, organic matter (OM), $CaCO_3$, cations and ions following the standard methods (Page *et al.* 1982). The physico-chemical characteristics of the soil are given in (Table 3).

Experimental design and treatments

Field experiment was carried out in a strip-plot design using three replications. The main plots were devoted to the three irrigation intervals, 4, 8, and 12 days with 6 cm water depth ahead, while five rice genotypes were allocated to subplots. The horizontal plots were surrounded by deep ditches to prevent any lateral movement of water. Pre-germinated seeds were sown on 1st May in both growing seasons. The 28 days old seedlings of all genotypes were transplanted at inter-row distance of 20 cm with one seedling per hill. Nitrogen fertilizer was applied at 165 kg ha^{-1} as urea (50% as basal, 30% at initial tillering and 20% at panicle initiation). Phosphorus fertilizer was applied at 36 kg P_2O_5 ha^{-1} using superphosphate (15.5% P_2O_5) as basal during soil preparation. The irrigation intervals were imposed at 15 days after transplanting till harvesting. Water pump was used to irrigate the experiment and amount of water applied throughout the experiment was measured. Water use efficiency (WUE) was calculated as follows:

$$\mathrm{WUE} = \text{Grain yield (kg)}/\text{amount of applied water } (m^3)$$

Relative water content (RWC) was calculated for flag leaf using following formula:

$$\mathrm{RWC}\ (\%) = ((\mathrm{FW}) - (\mathrm{DW}) / (\mathrm{TW} - \mathrm{DW})) * 100$$

Where, FW is flag leaf fresh weight, DW is flag leaf dry weight and TW is flag leaf turgid weight.

Table 1: Pedigree, origin, type and some remarks of the studied genotypes

Genotypes	Pedigree	Origin	Type
Giza177	Giza 171/Yomji No.1 // Pi No. 4	Egypt	Japonica
Giza178	Giza 175/Milyang 49	Egypt	Indica/Japonica
Sakha107	Giza 177 x BL1	Egypt	Japonica
IET1444	(TN 1/CO 29)	India	Indica
Moroberekan	IR 8-24-6-(M307 H5)	Republic of Guinean	Japonica

Table 2: Monthly relative humidity (RH, %), temperature (°C), and Pan evaporation (mm day^{-1}) recorded during the 2018 and 2019 rice growing seasons

Months	Relative humidity (%)		Temperature (°C)		Pan evaporation (mm d^{-1})	
	2018	2019	2018	2019	2018	2019
May	44.9	44.2	26.1	26.2	6.49	6.63
June	50.1	51.9	28.3	28.1	6.78	6.89
July	53.3	53.1	28.3	28.7	6.14	6.35
Aug.	59.0	58.7	30.2	30.8	5.19	5.49
Sep.	56.4	56.4	27.5	27.2	3.17	3.18

Table 3: Pre-sowing physico-chemical analysis of experimental soil

Property	2018		2019	
	0-20 cm	20-40 cm	0-20 cm	20-40 cm
EC (dS m^{-1})	2.00	2.10	2.00	2.20
pH	8.20	8.30	8.00	8.10
OM (%)	1.30	1.30	1.20	1.20
$CaCO_3$ (%)	3.70	3.10	3.80	3.20
Soluble ions (meq L^{-1}):				
Ca^{++}	5.10	4.80	5.40	5.20
Mg^{++}	2.10	2.00	2.40	2.30
Na^{+}	12.00	13.10	11.8	12.30
K^{+}	0.40	0.50	0.60	0.50
HCO_3^{-}	3.50	3. 80	3.70	4.20
Cl^{-}	14.80	14.90	15.20	15.90
SO_4^{--}	1.30	1.70	1.20	1.90
Available-P (mg kg^{-1})	12.60	12.00	14.20	14.30
Available-Zn (mg kg^{-1})	0.69	0.70	0.88	0.80
Available-Fe (mg kg^{-1})	5.20	5.10	6.10	6.00
Available-Mn (mg kg^{-1})	2.10	2.30	2.50	2.10

EC= Electric conductivity; OM= organic matter; $CaCO_3$= Calcium carbonate

Assessment of root parameters

Root traits were measured using five plants/genotype at 24 days after stress imposition. A 38 mm (inner diameter) steel tube was placed next to a hill with less than 1 cm between the nearby tiller and the tube. The soil column was sampled at 45 cm deep, collected and cut the soil to a depth of 0–45 cm. Soil samples were placed on 1 mm mesh screen and roots were washed to take out soil using tap water (Pantuwan *et al.* 1997). Roots were dried in an oven at 70°C for 48 h and weighed to record dry weight. Root length was measured from the base of the plant to the tip of the main axis of primary root. Root volume (cm^3) was measured by water displacement technique by placing all the roots in a measuring cylinder and obtaining the displaced water volume. Number of roots plant^{-1} was assessed by the counting roots. Root:shoot ratio, percentage of the root dry weight (g) to the shoot dry weight (g). Root thickness was the average thickness (mm) of the tip portion (about 1 cm from the tip) of three random secondary roots at the mid position of the root plant^{-1}.

Root xylem and its area measurement

Root sample of two cm was taken between 1 cm and 3 cm from the nodal root tip for each root. The samples were immediately subjected for fixation and storage to FAA (formalin at 10% volume, acetic acid at 5% volume, ethyl alcohol at 50% volume and distilled water at 35% volume). Root samples were dehydrated with 50, 70 and 95% ethanol in subsequent steps. The paraffin system was used for penetration and embedding, which was followed by sectioning, removal of xylem and alcohol paraffin. Every embedded root was placed in a microtome which used to cut perpendicular cross sections (10 mm slice thickness) at a 20 mm distance from the root tip (Reichert-Jung, Model 1130/Biocut). After staining with safranine and fast green as counter staining (Bhugra *et al.* 2017), pictures of the root cross sections were taken by a microscope (Olympus BX51) whereby one pixel represented 0.47 mm. The average xylem vessel number of roots was counted under the light microscope. The average xylem vessel diameter was measured under ocular microscope at 10x magnification. The average diameter of all xylem vessels of the three roots/plant were transformed to area by using the formula:

$$\text{Area} = \pi r^2$$

Where, π = Pi (3.14), r = radius.

Assessment of yield and its components

At harvesting, rice grain yield was estimated and adjusted to 14% moisture content. Ten panicles were selected randomly from each plot to measure length of panicle, number of filled and unfilled grains panicle^{-1}, 100-grain weight and sterility.

Statistical analysis

The statistical analysis was done using analysis of variance technique by means of Genes computer software package (Gomez and Gomez 1984). The means of treatment were compared using the Duncan's multiple range test (Duncan 1955). Correlations among these characteristics were also calculated.

Results

Root traits characteristics

All root traits were affected significantly by irrigation intervals, rice genotypes and interaction among them (Table 4). The plants irrigated with 4 days interval recorded the highest mean values for all root traits in both rice growing

Table 4: Effect of irrigation intervals and rice genotypes on root traits of rice

Treatments	Root length (cm)		Root volume (cm^3)		Number of roots plant^{-1}		Root: shoot ratio		Root thickness (mm)		Root xylem vessel number		Root xylem vessel area (mm^2)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Irrigation intervals (days)														
4	30.64^{a}	31.01^{a}	66.68^{a}	65.77^{a}	252.00^{a}	252.53^{a}	0.77^{a}	0.76^{a}	0.86^{a}	0.87^{a}	5.35^{a}	5.36^{a}	0.25^{a}	0.26^{a}
8	26.60^{b}	26.32^{b}	50.04^{b}	50.84^{b}	228.33^{b}	231.87^{b}	0.69^{b}	0.69^{b}	0.81^{b}	0.80^{b}	5.20^{b}	5.24^{b}	0.23^{b}	0.23^{b}
12	24.97^{c}	23.87^{c}	44.94^{c}	44.57^{c}	210.67^{c}	210.80^{c}	0.62^{c}	0.63^{c}	0.76^{c}	0.76^{b}	5.07^{c}	5.10^{c}	0.20^{c}	0.21^{c}
F-Test	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Rice genotypes														
Giza177	21.72^{e}	21.08^{e}	36.78^{e}	37.21^{e}	180.22^{e}	187.89^{e}	0.67^{c}	0.62^{c}	0.77^{b}	0.76^{b}	3.84^{e}	3.85^{e}	0.16^{e}	0.15^{e}
Giza178	23.70^{d}	23.20^{d}	54.79^{c}	54.19^{c}	221.00^{c}	219.89^{b}	0.71^{ab}	0.69^{b}	0.68^{c}	0.68^{c}	4.00^{d}	4.00^{d}	0.18^{d}	0.18^{d}
Sakha107	25.51^{c}	25.37^{c}	44.58^{d}	45.82^{d}	192.22^{d}	193.89^{c}	0.69^{abc}	0.70^{b}	0.78^{b}	0.78^{b}	4.30^{c}	4.32^{c}	0.20^{c}	0.21^{c}
IET1444	31.90^{b}	31.73^{b}	62.07^{b}	61.53^{b}	327.44^{a}	332.33^{a}	0.72^{a}	0.77^{a}	0.68^{c}	0.69^{c}	5.09^{b}	5.10^{b}	0.23^{b}	0.24^{b}
Moroberekan	34.15^{a}	33.95^{a}	71.22^{a}	69.90^{a}	230.78^{b}	224.67^{b}	0.68^{bc}	0.69^{b}	1.14^{a}	1.15^{a}	8.83^{a}	8.85^{a}	0.37^{a}	0.38^{a}
F-Test	**	**	**	**	**	**	**	**	**	**	**	**	**	**
Interaction (I × G)	**	ns	**	**	**	**	*	*	*	*	**	**	**	**

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test
*= Significant at 0.05; **= Significant at 0.01; ns= Non-significant

seasons, while the lowest root traits values were obtained when irrigated at 12 days interval. The highest root traits values including root length, root volume, root thickness, root xylem vessel number and root xylem vessel area were observed for drought tolerant check, Moroberekan while, the IET1444 exhibited superior values for number of roots plant^{-1} and root:shoot ratio in both rice growing seasons. The lowest mean values for all root traits except root thickness were observed for Giza177 while the lowest values were recorded for Giza178 genotype in both rice growing seasons.

Regarding interactive effects, the highest value of root length, root volume, root thickness, xylem vessel number and xylem vessel area were recorded for Moroberekan when irrigated with 4 days interval while the highest number of roots per was observed for IET144 across the two growing seasons. On the other hand, Giza177 under recorded the lowest number of roots plant^{-1} when irrigated at 12 days interval in both growing seasons. The interaction between irrigation intervals and genotypes was also significant for root:shoot ratio. The highest and lowest root:shoot ratio was recorded for IET1444 at 4 days interval and Giza177 at 12 days interval, respectively in both rice growing seasons (Table 5).

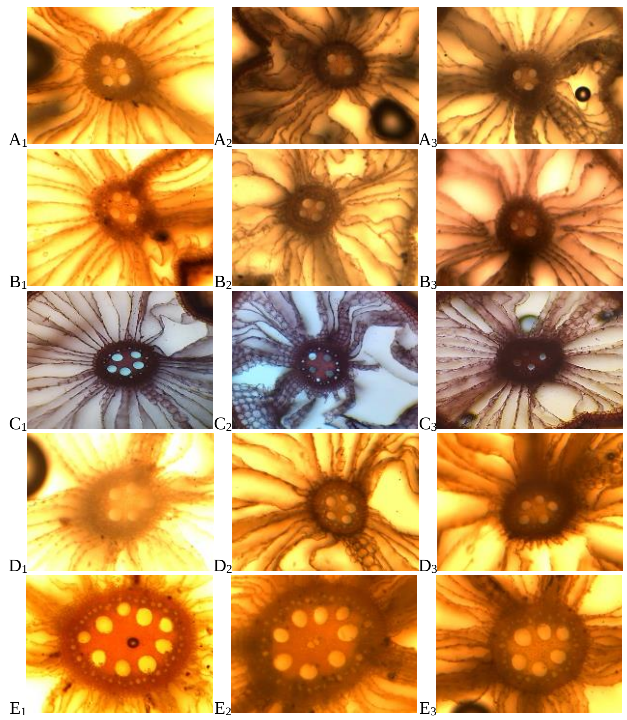

Fig. 1: Rice root cross section illustrated xylem vessel number and area for genotypes under irrigation intervals whereas, A_1, A_2, A_3 is Giza177; B_1, B_2, B_3 is Giza178; C_1, C_2, C_3 is Sakha107; D_1, D_2, D_3 is IET1444; E_1, E_2, E_3 is Moroberekan at 4, 8 and 12 irrigation intervals, respectively

Root cross sections

Root cross sections in indicated the significant differences in root xylem vessel number and area for all genotypes under different irrigation intervals (Fig. 1). All rice genotypes showed xylem vessel number and area decreased by increasing irrigation intervals. The lowest xylem vessel number and area was obtained for Giza177 when irrigated at 12 days interval. In general, least effects of irrigation intervals were observed for Moroberekan thus confirm the high drought tolerant level of this genotype. IET1444 also shown little effects compared to other Egypt rice genotypes under different irrigation intervals. Sakha107 was indicated more tolerance to drought stress compared to Giza178, whereas the decrease in root xylem vessel number and area in Sakha107 was lower than Giza178 at 8- and 12-days irrigation intervals (Fig. 1).

Relative water content

The significant effect was found among irrigation intervals on RWC. The results indicated that, RWC decreased with prolonged irrigation intervals in both growing seasons

Table 5: Interactive effects of irrigation intervals and rice genotypes on root traits of rice

Irrigation intervals (days)	Genotypes	Root length (cm)	Root volume (cm^3)	Number of roots plant^{-1}	Root: shoot ratio	Root thickness (mm)	Root xylem vessel number	Root xylem vessel area (mm^2)
4	Giza177	24.84^{d}	48.35^{d}	220.67^{f}	0.74^{bc}	0.82^{d}	4.00^{e}	0.19^{e}
	Giza178	27.93^{c}	63.70^{b}	257.00^{d}	0.79^{ab}	0.7^{e-h}	4.00^{e}	0.19^{e}
	Sakha107	30.57^{b}	66.78^{b}	208.67^{g}	0.73^{bc}	0.83^{d}	4.60^{d}	0.22^{d}
	IET1444	33.19^{b}	75.38^{a}	349.67^{a}	0.82^{a}	0.71^{e-h}	5.17^{c}	0.25^{d}
	Moroberekan	36.71^{a}	79.17^{a}	224.00^{f}	0.77^{abc}	1.25^{a}	9.00^{a}	0.40^{a}
8	Giza177	20.96^{fg}	35.26^{e}	165.00^{j}	0.64^{ef}	0.76^{def}	3.84^{f}	0.15^{fg}
	Giza178	22.8^{def}	52.06^{d}	206.00^{g}	0.70^{cde}	0.68^{fgh}	4.00^{e}	0.17^{f}
	Sakha107	24.06^{de}	36.01^{e}	191.67^{h}	0.72^{cd}	0.78^{de}	4.30^{d}	0.20^{e}
	IET1444	31.88^{b}	58.14^{c}	332.33^{b}	0.7^{cde}	0.67^{fgh}	5.08^{c}	0.23^{d}
	Moroberekan	33.3^{b}	68.75^{b}	246.67^{e}	0.66^{def}	1.14^{b}	8.84^{ab}	0.36^{b}
12	Giza177	19.37^{g}	26.73^{f}	155.00^{k}	0.61^{f}	0.74^{efg}	3.67^{f}	0.12^{h}
	Giza178	20.4^{fg}	48.60^{d}	$200.00g^{h}$	0.63^{f}	0.66^{gh}	4.00^{e}	0.15^{g}
	Sakha107	21.9^{ef}	30.94^{ef}	176.33^{i}	0.61^{f}	0.74^{efg}	4.00^{e}	0.18^{f}
	IET1444	30.71^{b}	52.68^{d}	300.33^{c}	0.62^{f}	0.64^{h}	5.00^{c}	0.21^{e}
	Moroberekan	32.45^{b}	65.75^{b}	221.67^{f}	0.61^{f}	1.04^{c}	8.67^{b}	0.33^{c}

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test

Table 6: Effect of irrigation intervals and rice genotypes on relative water contents, yield related traits and water use efficiency of rice

Treatments	RWC (%)		Number of panicles plant^{-1}		100-grain weight (g)		Sterility (%)		Grain yield (t ha^{-1})		WUE (kg m^3)	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Irrigation intervals (days)												
4	82.30^{a}	82.70^{a}	25.10^{a}	25.60^{a}	2.58^{a}	2.56^{a}	7.82^{c}	7.65^{c}	10.25^{a}	10.58^{a}	0.79^{c}	0.77^{c}
8	78.40^{b}	77.80^{b}	20.10^{b}	20.30^{b}	2.42^{b}	2.45^{b}	18.10^{b}	17.65^{b}	8.57^{b}	8.64^{b}	0.84^{b}	0.83^{b}
12	73.60^{c}	73.60^{c}	18.30^{c}	18.60^{b}	2.31^{c}	2.32^{c}	21.60^{a}	21.02^{a}	7.77^{c}	7.72^{c}	0.91^{a}	0.91^{a}
F-Test	**	**	**	**	**	**	**	**	**	**	**	**
Rice genotypes												
Giza177	65.10^{c}	63.87^{d}	18.94^{b}	18.77^{b}	2.70^{b}	2.75^{b}	25.83^{a}	26.81^{a}	7.79^{b}	7.60^{d}	0.72^{c}	0.70^{c}
Giza178	79.23^{b}	78.13^{c}	23.13^{a}	23.13^{a}	2.22^{c}	2.21^{c}	15.09^{b}	13.99^{b}	9.38^{a}	9.67^{a}	0.91^{a}	0.87^{b}
Sakha107	80.80^{b}	81.36^{b}	24.00^{a}	24.86^{a}	2.60^{b}	2.66^{b}	13.40^{c}	13.55^{b}	9.32^{a}	9.43^{b}	0.91^{a}	0.95^{a}
IET1444	81.03^{b}	81.26^{b}	22.60^{a}	22.92^{a}	2.23^{c}	2.28^{c}	13.32^{c}	12.32^{c}	7.53^{c}	7.95^{c}	0.89^{a}	0.85^{b}
Moroberekan	84.09^{a}	85.72^{a}	17.10^{c}	18.00^{b}	3.19^{a}	3.26^{a}	11.60^{d}	10.53^{d}	7.63^{c}	7.89^{c}	0.80^{b}	0.82^{b}
F-Test	**	**	**	**	**	**	**	**	**	**	**	**
Interaction I × G	**	**	**	*	**	**	**	**	**	**	**	**

Means within a column followed by the same letter do not differ significantly ($P<0.05$) according to Duncan's Multiple Range Test

*= Significant at 0.05; **= Significant at 0.01; ns= Non-significant

(Table 6). Moroberekan and IET1444 genotypes showed the higher RWC while Giza177 showed the lowest RWC in both growing seasons. Highly significant effects of interaction between irrigation intervals and genotypes on RWC were also observed in this study, whereas Moroberekan expressed the highest RWC at 4 days irrigation interval. The lowest RWC were recorded for Giza177 at 12 days irrigation interval in both growing seasons.

Water use efficiency

Irrigation intervals, rice genotypes and interaction among them has significant effect on WUE of rice in both years of study (Table 6). The highest WUE value was observed at 12 days irrigation interval, while the lowest values were recorded for 4 days irrigation interval in both growing seasons. The higher WUE values were found in Sakha107 and Giza178 indicating that these genotypes had high water productivity under drought stress. Regarding interaction, highest mean value of WUE was recorded for Sakha107 at 12 days irrigation interval. Conversely, the lowest WUE value was observed for Giza177 at 12 days irrigation interval over the two growing seasons (Table 7).

Grain yield and its components

Irrigation intervals, rice genotypes and interaction among them has significant effect on number of panicles plant^{-1}, 100-grain weight, sterility and grain yield in both years of study (Table 6). Grain yield and its components were significantly decreased under at 12 days irrigation interval in both growing seasons. The highest sterility percent was recorded for at 12 days irrigation interval in both growing seasons, meanwhile the lowest mean values were obtained when irrigated at 4 days interval (Table 6). Giza178 and Sakha107 recorded the highest grain yield and number of panicles plant^{-1} in both growing seasons. Meanwhile, Giza177 produced the highest values of sterility but lowest values of grain yield for both rice growing seasons. Moroberekan recorded lowest values of number of panicle plant^{-1} and sterility, but highest values for 100-grain weight over the two growing seasons. Meanwhile, Giza178 recorded the lowest values of 100-grain weight over the two growing seasons (Table 6).

With respect to interaction among irrigation interval and rice genotypes, the highest number of panicles plant^{-1} was recorded for Giza178 at 4 days irrigation interval,

Table 7: Interactive effect of irrigation intervals and rice genotypes on relative water contents, yield related traits and water use efficiency of rice

Irrigation intervals (days)	Genotypes	RWC (%)	Number of panicles plant^{-1}	100-grain weight (g)	Sterility percentage (%)	Grain yield (t ha^{-1})	WUE (kg m^{3})
4	Giza177	71.63^{f}	24.84^{bc}	2.39^{d}	8.56^{g}	38.63^{cd}	0.82^{cd}
	Giza178	82.06^{b-e}	26.09^{abc}	2.25^{hi}	8.12^{gh}	46.03^{a}	0.87^{b}
	Sakha107	84.53^{abc}	28.33^{a}	2.36^{e}	9.17^{g}	43.17^{b}	0.81^{cd}
	IET1444	84.94^{ab}	27.44^{ab}	2.30^{f}	7.24^{gh}	40.71^{c}	0.78^{d}
	Moroberekan	88.06^{a}	18.68^{fgh}	3.58^{a}	6.01^{h}	36.59^{de}	0.66^{e}
8	Giza177	68.67^{f}	17.42^{gh}i	2.28^{fg}	33.09^{b}	30.50^{h}	0.68^{e}
	Giza178	78.88^{de}	22.04^{de}	2.23^{ij}	16.58^{d}	36.03^{ef}	0.89^{b}
	Sakha107	79.67^{cde}	23.67^{cd}	2.26^{gh}	14.29^{e}	35.45^{efg}	0.90^{b}
	IET1444	80.65^{b-e}	20.66^{ef}	2.22^{j}	14.22^{e}	35.70^{efg}	0.90^{b}
	Moroberekan	83.87^{a-d}	16.63^{hi}	3.12^{b}	12.13^{f}	33.60^{efg}	0.84^{bc}
12	Giza177	54.98^{g}	14.5^{7i}	2.10^{l}	35.85^{a}	24.39^{i}	0.67^{e}
	Giza178	76.75^{e}	21.25^{def}	2.18^{k}	20.58^{c}	30.48^{h}	0.97^{a}
	Sakha107	78.19^{e}	20.00^{efg}	2.23^{ij}	16.74^{d}	33.25^{fgh}	1.01^{a}
	IET1444	77.48^{e}	19.70^{efg}	2.18^{k}	18.50^{d}	34.93^{efg}	0.99^{a}
	Moroberekan	80.32^{b-e}	16.00^{hi}	2.87^{c}	16.68^{d}	32.61^{gh}	0.91^{b}

Means within a column followed by the same letter do not differ significantly ($P < 0.05$) according to Duncan's Multiple Range Test
RWC= Relative water contents; WUE= Water use efficiency

Table 8: Correlation coefficient among yield and root traits

Parameters	Root length (cm)	Root volume (cm^{3})	No. of roots plant^{-1}	Root thickness (mm)	Root: shoot ratio	Root xylem vessel No.	Root xylem vessel area	RWC (%)	No. of panicles plant^{-1}	100- grain weight (g)	Sterility (%)	Grain yield (t ha^{-1})
Root volume (cm^{3})	0.90**											
Number of roots plant^{1}	0.66**	0.61**										
Root thickness (mm)	0.60**	0.52**	-0.14^{ns}									
Root: shoot ratio	0.63**	0.66**	0.64**	0.08^{ns}								
Root xylem vessel number	0.76**	0.67**	0.18	0.90**	0.11^{ns}							
Root xylem vessel area	0.87**	0.77**	0.30*	0.88**	0.33*	0.97**						
RWC %	0.77**	0.81**	0.49**	0.40*	0.63**	0.54**	0.69**					
Number of panicles plant^{-1}	0.03^{ns}	0.14^{ns}	0.39*	-0.49**	0.70**	-0.50**	-0.31*	0.28^{ns}				
100-grain weight (g)	0.36*	0.23^{ns}	-0.35*	0.92**	-0.05	0.70**	0.68**	0.12^{ns}	-0.53**			
Sterility (%)	-0.71**	-0.77**	-0.53**	-0.32*	-0.79**	-0.38*	-0.57**	-0.87**	-0.47**	-0.11^{ns}		
Grain yield (t ha^{-1})	0.02^{ns}	0.21^{ns}	0.03^{ns}	-0.19^{ns}	0.59**	-0.37*	-0.18^{ns}	0.36*	0.81**	-0.20	-0.55**	
WUE (kg m^{3})	-0.11^{ns}	-0.11^{ns}	0.10^{ns}	-0.31*	-0.23^{ns}	-0.11^{ns}	-0.12^{ns}	0.30*	0.08^{ns}	-0.45**	-0.21^{ns}	0.03^{ns}

*= Significant at 0.05; **= Significant at 0.01; ns= Non-significant

while the lowest number of panicles plant^{-1} was recorded for Moroberekan at 12 days irrigation interval in both growing seasons. Consequently, the heaviest 100-grain weight was observed for Moroberekan at 4 days irrigation interval while the lightest 100-grain weight was recorded for Giza178 at 12 days irrigation interval in both growing seasons. The highest sterility percent was observed for Giza177 at 12 days irrigation interval. On the other hand, the lowest sterility was recorded for Moroberekan at 4 days irrigation interval in both growing seasons (Table 7).

Correlation analysis

The highly significant positive correlation was found among root length and root volume, number of roots plant^{-1}, root:shoot ratio, root thickness, root xylem vessel number, root xylem vessel area, RWC and 100-grain weight (Table 8). The positive and highly significant correlation was shown among root volume and number of roots plant^{-1}, root:shoot ratio, root thickness, root xylem vessel number, root xylem vessel area and RWC, whereas the highly negative correlation and significant was found between root volume and sterility. The highly significant positive correlation was found between number of roots plant^{-1} and root:shoot ratio, root xylem vessel area, RWC and number of panicle plant^{-1} while, the negative correlation and significant was found between number of roots plant^{-1}, 100-grain weight and sterility. The highly significant positive correlation was illustrated between root thickness and root xylem vessel number, root xylem vessel area, RWC and 100-grain weight, but the highly negative correlation and significant was found between root thickness and number of panicle plant^{-1}, sterility and WUE (Table 8).

The highly significant positive correlation was observed among root:shoot ratio and root xylem vessel area, RWC, 100-grain weight and grain yield, therefore, the negative correlation and significant was found with sterility. Root xylem vessel number had highly significant and positive correlation with root xylem vessel area and number of panicles plant^{-1}, whereas the negative correlation and significant was shown with number of panicles per plant, sterility and grain yield. Concerning the root xylem vessel area was correlated positive and highly significant with RWC and 100-grain weight, otherwise negative correlated and significant with number of panicles plant^{-1} and sterility. Regarding RWC was correlated positive and significant with grain yield and WUE, however, the negative and highly significant correlation was confirmed with sterility (Table 8).

Discussion

This study focused on root architecture of five rice varieties under different irrigation intervals to understand its relationship with drought tolerance mechanisms. The root traits decreased by increasing irrigation intervals. Rice cultivars irrigated with 12 days interval had the highest negative effect on root length, root volume, number of roots plant^{-1}, root:shoot ratio, root thickness, root xylem vessel number and root xylem vessel area. The genotypes performance also varied under water deficit as each genotype had different genetic background. Henry *et al.* (2012) reported that Aus rice genotype Dular was drought tolerant based on its deep root growth and the highest drought response index.

Most of the root length was extended to 21.08 to 34.15 cm in top layer of the soil in both Giza177 and Moroberekan, respectively. The restricted root growth in lowland shallow top-soil zones is a result of the hardpan that develops by pudding and maybe due to the limitation of the supply of oxygen in soil depths under anaerobic lowland conditions (Kato *et al.* 2013). The shallow nature of the root system, genotypic difference in root volume or length is rather limited. Moroberekan and IET1444 had significant higher root length and root volume at 15–30 cm soil depth and longer than other genotypes. These two genotypes also had desired root traits compared to other three genotypes. Meanwhile, Giza177 with the lowest yield performance also expressed poor root performance of all traits and thus considered as drought susceptible genotype.

It was predicted that high level of drought tolerant can be obtained for rice genotypes with deep root systems than genotypes with shallow roots systems at the 30 cm deep. According to Ikmal *et al.* (2019), deep and coarse root is an important avoidance strategy in rice to reduce adverse effect of drought on yield. An enormous root system could be able to extract more water from the soil, but this does not essentially result in higher yield under limited water condition (Sahebi *et al.* 2018). Larger root system might have resulted in more rapid extraction of available water and therefore, faster development of water shortage could have an adverse effect on grain yield. Moreover, the roots traits like root length, root thickness, root volume, total number of roots, root length density, root dry weight and root:shoot ratio are imperative to induce drought tolerance (Ganapathy *et al.* 2010). Pushpam *et al.* (2018) also reported that the drought resistant genotypes had higher root thickness, root volume and deep root system than the sensitive genotypes. Hence, these root characteristics could be utilized for a reliable selection for drought stress.

The results in present study showed the important correlation between RWC, WUE and grain yield and its components performance under different irrigation intervals. However, the grain yield components decreased gradually by increased water shortage period, also the same trend with RWC while, the WUE increased by increasing irrigation intervals. The RWC reduced under alternative wetting and drying including saturated to one cm flooding saved about 45% of fresh water which are similar to alternative wetting and drying over control (Khairi *et al.* 2015). Under limited water condition, Moroberekan and IET1444 had higher RWC due to well root system that capable to absorb more water from depth soil and maintained water from losses through transpiration.

Interestingly, Giza178 and Sakha107, genotypes without good rooting system compared to Moroberekan and IET1444 showed high yield potential under irrigation treatments. This shows the capability of this genotype to stand well under water limited condition but this capability was not contributed by the root factor. Therefore, further studies should be conducted to identify traits associated to drought resistance mechanism in these genotypes and traits such as stomatal traits, and transpiration and photosynthesis efficiencies should be prioritized. Terra *et al.* (2010) reported that, the Quebra Cacho cultivar, have the lower drought index and morpho-physiological traits for drought tolerance. The spikelet sterility presented large difference among cultivars, with higher sterility under water stress condition. Remarkably, the 100-grain weight for all genotypes had low response under irrigation intervals. The rice breeders for drought tolerance are concerned to have genotypes with high WUE values companied with high grain yield, this was also observed in this study for Sakha107 and consequently, we recommended using this cultivar for breeding to drought tolerance. Terra *et al.* (2010) found that lower number of panicles plant^{-1} in some cultivars was noted under water stress conditions. Yield advances under water scarcity condition might occur, even high osmotic adjustment and good root thickness and depth should be combined through breeding.

The correlation coefficient is important factor to identify the relationship among the studied root traits with water status, grain yield and its components under different irrigation treatments. Highly significant and positive correlations between grain yield with root:shoot ratio, RWC and number of panicles plant^{-1} as well as negative correlation of grain yield with sterility indicates that the root system and water relation have direct contribution to drought tolerance and achieved high yield performance under high WUE. Watanabe *et al.* (2020) illustrated that, significant and positive correlation was found between the root system traits and the surface area but not for the other component roots. Pushpam *et al.* (2018) and Ikmal *et al.* (2019) reported that drought resistant genotypes posed higher root volume, root thickness and deep root system than the susceptible genotypes. Furthermore, negative correlation between grain yield and root xylem vessel number and area could indicate that these two root anatomical traits were also associated with drought tolerance in rice. Various studies have also reported on the significant effects of root xylem vessel on the water relations and drought resistance in rice (Richards and Passioura 1989; Henry *et al.* 2012).

Conclusion

All genotypes responded to drought stress with decreases yield and related traits, and RWC along with increase in sterility and WUE and reduction in root architecture traits when the plants were gradually stressed. Moroberekan and IET1444 have the best root architectural traits and can be manipulated in the development of drought-tolerant rice varieties. In addition, Giza178 and Sakha107 can be classified as drought-tolerant genotypes due to their ability to produce high yield under water stress condition but contributing factors other than root traits should be studied further.

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Author Contributions

AMG, MIG, HMM and RMS designed and supervised the study, MAG conducted the experiment, collected data and drafted first draft, AMG, HR and NAAS critically reviewed and improved the manuscript.

Conflict of Interest

The authors declare no competing interests

Data Availability

The data will be made available on acceptable request to the corresponding author.

Ethics Approval

Not applicable.

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