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GROWTH AND YIELD RESPONSES OF RICE GENOTYPES SUBJECTED TO WATER DEFICIT IN VARIED SOIL TYPES

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Abstract

Inconsistent results were obtained on the yield of rice genotypes established along the soil toposequence thus the need to validate these under controlled environment with rice genotypes. This investigation hypothesised there could be variation in the growth and yield of rice genotypes in different soil types under soil water deficit. A pot experiment was established in an open screen house, Ibadan. The treatment consisted of rice varieties (IR 64, IR 77298-14-1-2-B-10, NERICA 4 and WAB 56-104), soil ecologies [hydromorphic (H), lowland (L) and upland soils (U)] and soil moisture regime (Control and water deficit stress), in completely randomised design replicated three times. Growth in rice genotypes were significantly higher under optimum water supply than under water deficit. Conversely, rice genotypes under water deficit flowered later and had significantly higher spikelet sterility than under optimum water supply. Number of tillers plant^{-1} was in the order H > L > U. However, 1000 grain mass was in the order U > H > L. IR 64 had the highest grain yield. Similar pattern was observed on the shoot biomass, number of tillers and number of panicles. In different soil ecologies under water deficit, IR 64 and IR 77298-14-1-2-B-10 had significantly the highest number of panicles plant^{-1}. These evidences suggested that high number of tillers observed in hydromorphic soil is associated with the duration of vegetative growth. Isohydric behaviour was not maintained by rice genotypes used as reflected in the variation in number of panicles under water deficit in the soil types.

Keywords: drought tolerance, grain yield, interspecific rice hybrid, rice ecologies, toposequence

INTRODUCTION

The condition where the supply of water is less than its demand possess serious production constraints to the growth and development of rice. In Africa the order of importance among the investigated abiotic stresses during rice production on the field was drought (33%) > iron toxicity (12%) > cold (7%) > salinity/sodicity (2%) (Van Oort, 2018). This problem is further exacerbated by global climate change (Madadgar *et al.*, 2017) and the competing need for fresh water for industrial and domestic use (Ouyang *et al.*, 2020). Rice had been characterised as a semi-aquatic crop that is highly sensitive to evaporative demand (Peng *et al.*, 2006). It was posited that this could be linked with its low epicuticular wax that is 20% of that of sorghum (Farooq *et al.*, 2009) and shallow root system. The effect of water deficit on rice depends on the cultivar, time, intensity and duration of water deficit. Rice is grown in varied agroecologies, namely upland, lowland (irrigated and rainfed) and the mangrove. Irrigated rice is the wide spread ecosystem comprising 55 percent of the overall production area and the most productive system accounting for 75 percent of global production (Bernier *et al.*, 2008). Similar pattern was observed in Africa, where in terms of area under cultivation rainfed lowland rice constitutes 40% of cultivated area among rice agroecologies in sub-Sahara Africa (SSA). This was closely followed by rainfed upland rice (34%), with 22% and 4% of cultivated rice area in SSA dedicated to the production of irrigated rice and those from other agroecologies respectively (Diagne *et al.*, 2013). It was reported that 75% of rice production in Nigeria is from the lowland (Oyediran and Wakatsuki, 1999). The yield of the lowland rice is greater than rice grown in other agroecologies. Upland rice is produced under aerobic conditions without irrigation and without pudding (Sritharan *et al.*, 2015). It can be found in a range of environments from low-lying valley bottoms to steep sloping lands with high runoff (Singh *et al.*, 2017). Many factors limiting grain yield in upland rice ecosystems includes drought (Bernier *et al.*, 2008) and weed competition (Touré *et al.*, 2013). It is essentially a low-input ecosystem, which results in poor paddy yield of about 1 t ha^{-1} (Bernier *et al.*, 2008). The rainfed lowland ecology accounts for 43–53% of the total rice production (Imolehin and Wada, 2000). Hydromorphic occur from the mid- slope to the valley bottom in the topo-sequence (Norman and Otoo, 2003). The rice crop here may obtain water from three sources – direct rainfall, high water table and surface water depending on its location in the topo-sequence. The main hydraulic characteristic of this ecosystem is the fluctuating water table, caused by cyclical swelling and receding water levels of rivers during the rains (Ogban and Babalola, 2009). It is estimated that a total of 130 million ha of inland valleys are available for cultivation in Africa, 19 million ha of which (i.e. 14.6 percent) occur in West Africa (Norman and Otoo, 2003). This variation in the yield from varied agroecologies of rice production could be ascribed to the availability of water predominantly. Rice grown in the inland valley could be found in other fringes like the hydromorphic and upland soil. This would have implication on the availability of water and nutrients and the modification of the physico-chemical properties of the soil. The variations observed in water availability along the toposequence of lowland ecology have been associated with the topology and prevailing climatic condition of the environment. Oyediran and Wakatsuki (1999) reported that the clay, silk and water holding capacity of the inland valley were significantly higher than those of the upland and hydromorphic soils. Similar pattern was observed on the soil acidity, except exchangeable cation exchange capacity and Bray-1 P that were observed to be lower than the aforementioned soils.

There were inconsistent reports on the performance of lowland rice along the toposequence of inland valley in the Southeast Asia (Boling *et al.*, 2008). This could have been confounded by the water and nutrient gradients together with the modification of the soil physico-chemical properties. These gradients would have implications on the root architecture of rice genotypes and their tolerance or otherwise to water deficit. Van Oort (2018) further opined that with regards to drought in Africa focus should be more on the local variation along the hydromorphic zones than large scale climatic variation, further reinforcing the earlier reports made by Boling *et al.* (2008) on variations along the topo-sequence in the inland valley and its implications on crop performance. It had earlier been reported that rice from varied agroecologies displayed isohydric behaviour within the water potential range of 0–0.6 MPa (Parent *et al.*, 2010). It was indicated that leaf elongation rate and its water status were less sensitive to water deficit at the aforementioned soil water potential among rice genotypes from different agroecologies (Parent *et al.*, 2010). Differences in the sensitivities of rice to soil water deficit were linked with the variations in the root system. Considering that root system of rice from different agroecologies will vary, there is no information on the implications of this on their sensitivities to water deficit in different agroecologies. However, it must be highlighted that Poorter *et al.* (2016) posited that there are modifications in the root system of plants grown under controlled condition. To what extent this modification would vary in rice grown in different agroecologies and their sensitivities to water deficit remains unknown. Furthermore, the observation reported by Boling *et al.* (2008) was executed under field condition with its attendant confounding factors, there is the need to disentangle the effect of water deficit from that of the variations in the nutrient composition along the toposequence in the inland valley.

This investigation aimed to investigate the growth and yield responses of rice genotypes subjected to water deficit in different soil ecologies.

MATERIALS AND METHODS

Description of Experimental Site

A pot experiment was established, in an open screen house at International Institute of Tropical Agriculture (IITA), Ibadan sub-Station (Latitude 7º 30‘8’‘N and Longitude 3º 54‘37’‘E), Nigeria.

Experimental Treatment and Design

The treatments consisted of four rice varieties (IR 77298-14-12-B-10, NERICA 4, WAB 56-104 and IR 64), three soil ecologies (hydromorphic, lowland and upland) under water regimes (water deficit and well-watered). The experiment was in completely randomised design, replicated three times. IR 77298-14-12-B-10 is a lowland variety developed at International Rice Research Institute (IRRI) (Moumeni *et al*., 2015). It is an adapted near-isogenic line derived from IR 64, highly tolerant to drought. NERICA 4 is an interspecific hybrid between *O. sativa* × *O. glaberrima*. It is upland adapted variety developed by Africa Rice Centre (Fofana *et al*., 2010), highly tolerant to drought. It was adopted in 14 countries in sub-Saharan Africa in 2007 (Kaneda, 2007). WAB 56-104 is a moderately drought tolerant variety bred at Africa Rice (Fukuta *et al*., 2012; Ndjiondjop *et al*., 2012). It is an *O. sativa* japonica type, adapted to upland conditions (Kaneda, 2007). IR 64 is a semi-dwarf, high yielding indica line developed for irrigated lowland conditions and is highly drought-susceptible (Venuprasad *et al*., 2008; Venuprasad *et al*., 2007).

Cultural Practises

Pots (buckets) used were 52 cm wide (diameter) at the surface, 64 cm deep and 100 litres in volume. A total of 72 pots were used. Upland, lowland and hydromorphic soils were sourced from Ikenne (Nigeria), Cotonou (Benin Republic) and IITA, Ibadan (Nigeria) respectively. The soils were air dried for 72 hours and sieved to remove soil clods and foreign particles such as stones and plant remains. Ninety-six (96) kg each of soil types were used to fill each pot. Pre-planting soil physico-chemical properties were determined as described by Sakariyawo *et al*. (2020). Twenty-one-day-old seedlings were transplanted into the bucket on 18th of April 2014. Two seedlings per hill were transplanted at a spacing of 25 cm apart in two perpendicular rows. The two hills per row were later thinned to one seedling per hill a week after transplanting. The quantity of fertilizer applied was 100 kg ha^{-1} of N-P-K (15-15-15) at sowing. Top dressings of 50 kg ha^{-1} of urea (46% N) at tillering/panicle initiation (21-30 DAS) and 50 kg ha^{-1} of urea (46% N) at panicle exsertion/grain filling (42-50 DAS) were done.

Water deficit was imposed on seven weeks old seedlings in the water stress environment. To induce drought, the soils were watered to full field capacity (the percentage of water present in the soil after the gravitational water was drained away) and the excess water was drained using adjustable water stopper (drainer) until all the free moisture are fully drained. Water deficit stress was maintained until all the leaves of the susceptible varieties (IR 64) were fully rolled. Pots were afterwards fully irrigated to field capacity and another cycle of stress developed (the screening protocol used was cyclic drought stress). Plants in the control environment were well watered throughout the experiment. Manual weeding was done regularly in order to keep the buckets weed. Harvesting was done manually using a sickle to cut the panicles when the grains had reached harvest maturity (when the panicles turned golden brown).

Sampling and Data Collection

Growth (plant height, number of tillers, shoot biomass), yield components (number of panicles, spikelet sterility, 1000 grain weight, harvest index) were determined at harvest maturity. Days to 50% flowering were determined when 50% of the plants in each pot flowered. The aforementioned variables were measured adopting standard measurement procedures developed at International Rice Research Institute (IRRI, 2002). Grain yield/plant was determined at harvest maturity and dried to 9% moisture content and were weighed.

Data collected were subjected to Analysis of Variance, fixed model. The treatment structure consisted of variety, soil type and water regime, while replicates were placed in the block structure. Significant treatment means were separated using Least Significant Difference (LSD) at 1% probability level. Genstat 12th Edition Statistical Package was used (Payne *et al*., 2009).

RESULTS

The soil pH was in the order lowland > hydromorphic > upland soils. Soil organic carbon was moderate (1.58–1.69%) for the soil types. The total nitrogen content (1.58–1.60%) in both lowland and the upland soils was medium, while in hydromorphic soil it was medium (0.228%). Concentration of available P was in the order lowland > upland > Hydromorphic soil. Iron concentration was the highest in lowland soil (149.89 mg kg^{-1}), with the least observed in the upland soil (66.74. Hydromorphic soil had Fe concentration in the same range as the lowland soil (Tab. I).

Soil types had significant effects ($P < 0.05$) on the number of tillers, days to 50% flowering and 1000 grain mass (Tab II). The effect of soil types on the number of tillers per plant was in the order hydromorphic > lowland > upland soil. Rice sown in hydromorphic soils flowered later (90.25 days) than those sown in other agroecologies. Rice sown in upland agroecology required 87 days to flower, while those sown in the lowland ecology required the least number of days to flower (83.5 days).

Rice sown under optimum water regime was significantly taller (106.7 cm) than those sown under water deficit (100.2 cm). Similar pattern was observed on number of panicles per plant, harvest index, 1000 grain mass and grain yield per pot. Conversely, rice sown under water deficit flowered (90.33 days) later than those sown under optimum water regime (83.50 days). Spikelet sterility followed similar pattern (Tab. I).

Significant varietal differences were observed on the plant height (Tab. II). Among the investigated varieties WAB 56-104 was the tallest (123.10 cm), while the shortest (90 cm) was IR 77298-14-1-2-B-10. Rice cultivar IR 64 had significantly the highest number of tillers per plant (51.69), the least was observed in NERICA 4 (18.15). Similar pattern

I: *Pre-planting physico-chemical properties of the soil types*

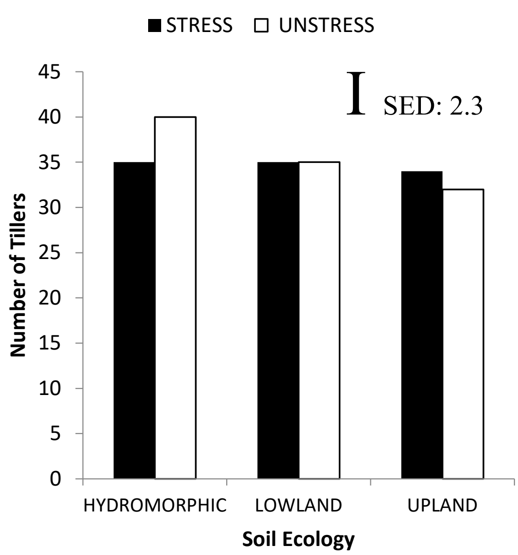
Parameters	Unit	Hydromorphic soil	Lowland soil	Upland soil
pH (in water)	-	5.8	6	5.6
Organic carbon	%	1.69	1.58	1.6
Total nitrogen	%	0.228	0.154	0.161
Available phosphorus	ppm	4.7	142.33	12.4
		Exchangeable		
- Calcium	mg kg^{-1}	4.72	4.86	3.9
- Magnesium	mg kg^{-1}	0.92	0.92	0.72
- Potassium	mg kg^{-1}	0.16	0.33	0.23
- Sodium	mg kg^{-1}	0.14	0.13	0.11
ECEC	mg g^{-1}	5.93	6.25	4.98
- Zinc	mg kg^{-1}	44.59	22.55	24.75
- Copper	mg kg^{-1}	2.01	1.43	0.55
- Molybdenum	mg kg^{-1}	66.95	6.05	120.49
-Iron	mg kg^{-1}	139.18	149.89	66.74
Particle size	mg kg^{-1}			
- Sand	%	63	73	77
- Clay	%	16	6	6
- silt	%	21	21	17
Textural class	-	Sandy clay loam	Sandy loam	Loamy sand

Source: IITA

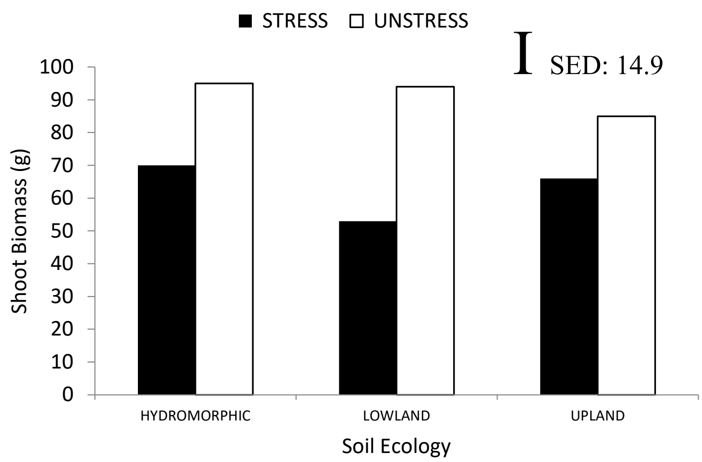
was observed on the shoot biomass, days to 50% flowering, number of panicle per plant and grain yield pot^{-1}. NERICA 4 had significantly the highest 1000 grain mass (272.8 g) compared to other rice varieties. The least was observed in rice variety IR 64 (232.1 g).

Significant interaction of soil type × water regime was observed on the number of tillers $plant^{-1}$ (Fig. 1). Number of tillers per plant was significantly lesser in rice grown under water deficit in hydromorphic soil than under optimum water regime. Conversely, number of tillers per plant was significantly higher in rice under water deficit in upland ecology than those sown under optimum water regime. In lowland soils rice sown under both water regimes had similar number of tillers per plant. In all the soil types rice sown under water deficit had significantly lower shoot biomass than those sown under optimum water regimes (Fig. 2). Conversely, in all the soil types rice sown under water deficit flowered later than those sown under optimum water condition (Fig. 3). Significant interaction of soil type × variety was observed on the number of tillers $plant^{-1}$ (Fig. 4). Number of tillers per plant of rice sown in hydromorphic soil was in the order IR 64 > IR 77298-14-1-2-B-10 > WAB 56-104 > NERICA 4. Number of tillers $plant^{-1}$ of rice in both lowland and upland was in the order IR 77298-14-1-2-B-10 > IR 64 > NERICA and WAB 56-104.

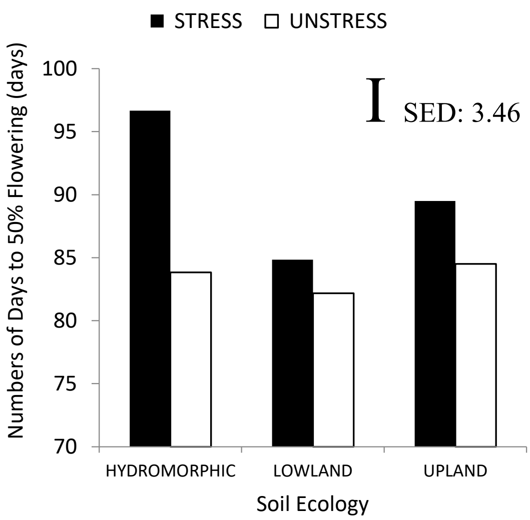
Significant interaction of soil type × water regime × variety was observed on the number of panicles (Fig. 5). Number of panicles $plant^{-1}$ in rice sown in soil types under water deficit was significantly lower than those sown under optimum water regime. The number of panicles $plant^{-1}$ of rice sown in hydromorphic soil, under water deficit indicated



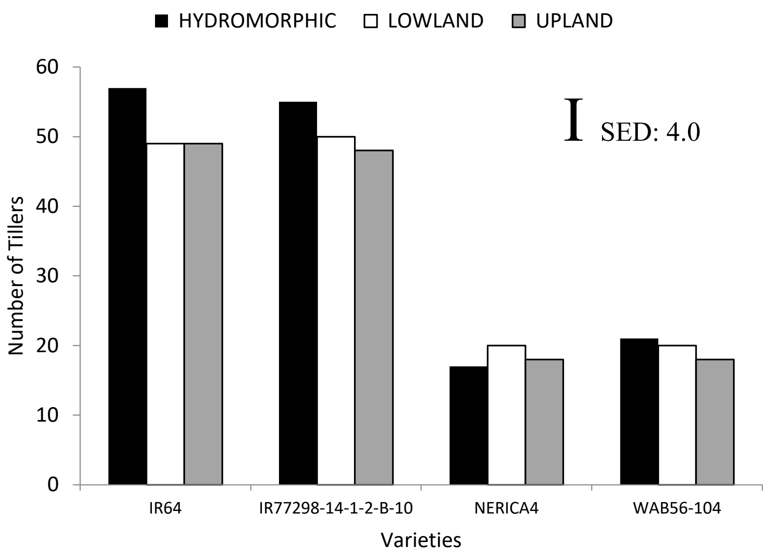
1: *Interactions of soil ecology and water stress on number of tillers of drought tolerant rice varieties*



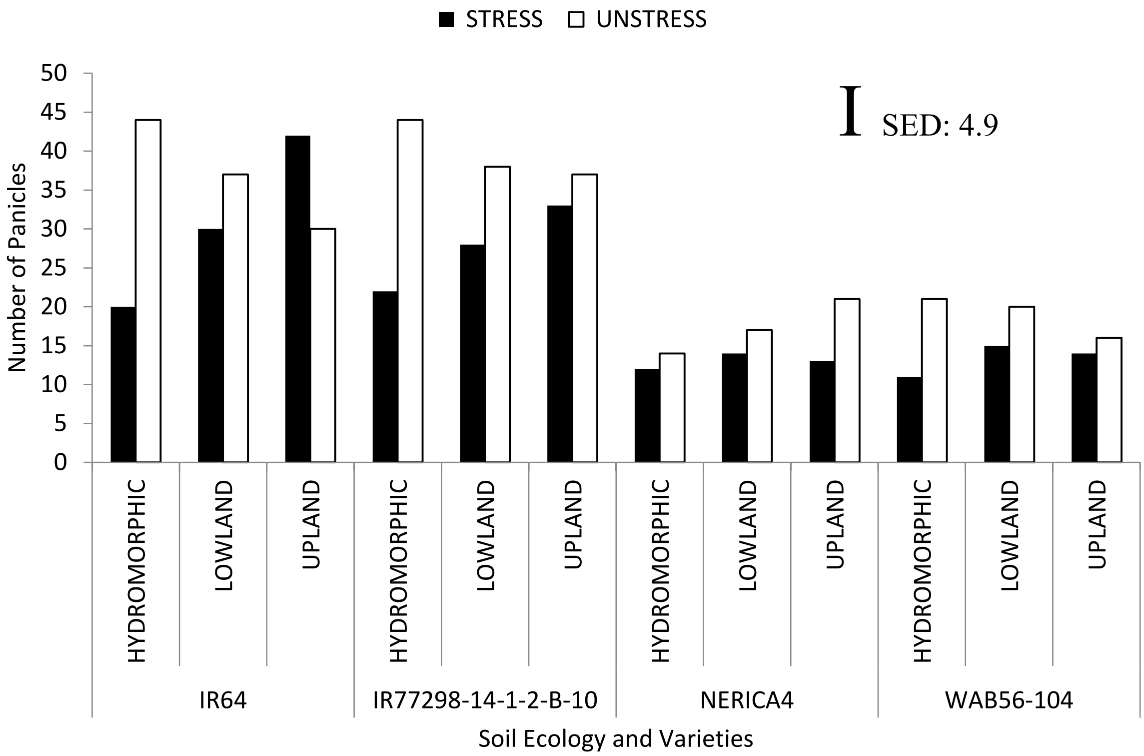
2: *Interactions of soil ecology and water stress on shoot biomass of drought tolerant rice varieties*



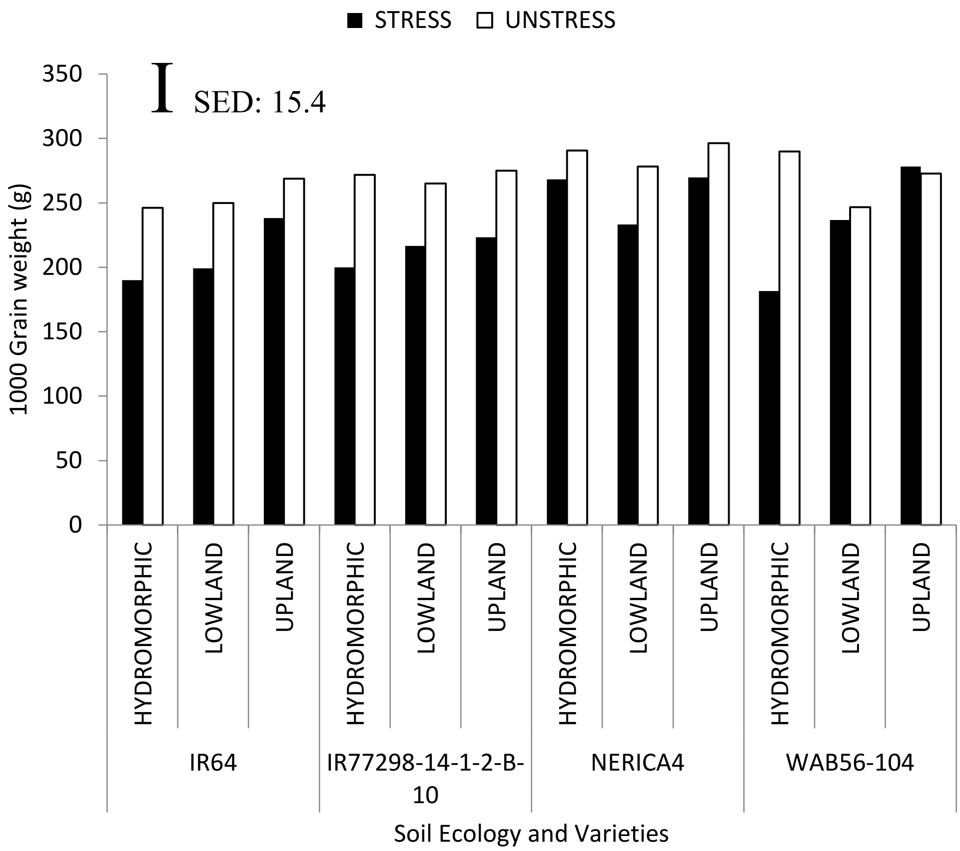
3: *Interactions of soil ecology and water stress on number of days to 50% flowering of drought tolerant rice varieties*



4: *Interaction of soil ecology and varieties on number of tillers of drought tolerant rice varieties*



5: *Interactions of soil ecology, variety and water stress on number of panicles of drought tolerant rice varieties*



6: *Interactions of soil ecology, water stress and variety on 1000 grain weight of drought tolerant rice varieties*

II: *Effects of soil ecology and water stress on plant height (cm), tiller number, shoot biomass (g), 50% flowering (days), spikelet sterility (%), panicle number, 1000 grain weight (g), grain yield pot^{-1} (g) and harvest index of drought tolerant rice varieties*

Treatment	Plant Height (cm)	Number of Tiller plant^{-1}	Shoot Biomass (g)	50% Flowering (days)	Spikelet Sterility (%)	Number of Panicle plant^{-1}	1000 Grain mass (g)	Grain Yield (g pot^{-1})	Harvest Index
Soil Ecology (SE)									
HYDROMORPHIC	106.6	37.64	82.6	90.25	59.9	23.49	242.3	112.9	1.154
LOWLAND	100.1	34.72	73.2	83.5	55.7	24.75	240.8	117.9	1.52
UPLAND	103.7	33.19	75.5	87	49.5	25.6	265.3	125.9	1.594
LSD 1%	NS	**	NS	**	NS	NS	**	NS	NS
Water Stress (WS)									
Water Deficit Stress	100.2	34.62	62.8	90.33	64.2	21.09	228	51.3	0.851
No Water Deficit	106.7	35.75	91.4	83.5	45.8	28.13	270.9	186.5	1.994
LSD 1%	*	NS	**	**	**	**	**	**	**
Variety (V)									
IR64	90.3	51.69	87	93.61	57.7	33.58	232.1	135.2	1.387
IR77298-14-1-2-B-10	90	51.35	82.5	86	50.5	33.57	241.9	131.9	1.504
NERICA4	110.4	18.15	60.3	79.5	53.7	15.2	272.8	102.5	1.569
WAB56-104	123.1	19.56	78.5	88.56	58.1	16.09	251	106.1	1.231
LSD 1%	**	**	**	**	NS	**	**	NS	NS
SE × WS	NS	*	*	**	NS	**	*	NS	NS
SE ×V	NS	*	NS	NS	NS	NS	NS	NS	NS
WS × V	NS	NS	NS	NS	NS	NS	NS	NS	NS
SE × WD × V	NS	NS	NS	NS	NS	**	*	NS	NS

Soil Ecology (SE), Water Deficit Stress (WS), Variety (V), LSD least Significant Difference, NS not significant, * 1% probability, ** 5% probability that variety IR 77298-14-1-2-B-10 had the highest number of panicles plant^{-1} compared to others, while the least number of panicles per plant under these conditions was observed in rice variety WAB 56-104. In rice varieties sown in lowland soil, under water deficit number of panicles plant^{-1} was in the order IR 64 > IR 77298-14-1-2-B-10 > WAB 56-104 > NERICA 4. Similar pattern was observed in rice established in upland under water deficit except that rice variety WAB 56 had significantly the least number of panicles plant^{-1}. Significant interaction of soil type × water regime × variety was observed on the 1000 grain weight (Fig. 6). In all soil types, under optimum water supply, 1000 grain weight of rice varieties was significantly higher than those established under water deficit. In both lowland and upland soils, under soil water deficit rice variety WAB 56-104 had significantly the highest 1000 grain weight compared to other rice varieties except when sown in hydromorphic soil under water deficit where it was observed it had the least significant 1000 grain weight compared to other rice varieties. Rice varieties sown in hydromorphic soils under soil water deficit 1000 grain mass was observed to be highest in NERICA 4 compared to others.

DISCUSSION

Growth in plant is associated with carbon budgeting process. This process provides a feedback mechanism for the process of carbon assimilation. It is not surprising that the occurrence of water deficit could limit photosynthesis through negative feedback mechanism provided by reduced growth under water deficit. Considering the aforementioned premises improved growth of rice under optimum water regime could have suggested functional photosynthesis that could have aided shoot biomass accumulation and taller rice under this condition. Yin *et al.* (2007) posited that the reduced plant height observed under water deficit in rice was associated with reduced panicle exsertion. The increased number of panicle plant^{-1} under optimum water regime could be linked with its reduced spikelet sterility. The increased spikelet sterility under water deficit in rice had been associated with inhibition of anther dehiscence, reduced fertilisation and increased abortion (He and Serraj, 2012). Peng *et al.* (2006) had earlier posited that in upland rice spikelet number under drought is a major limiting factor. This could have explained the observed improved yield of rice genotypes under optimum water regime. Other yield components (1000 grain weight, harvest index) could have contributed significantly to the observed grain yield of rice genotypes under optimum water regime considering their comparatively higher value than rice genotypes established under sub-optimal condition. However, the relative contribution of these yield components under optimal water regime is still not clear. Matsumoto *et al.* (2014) had earlier observed that upland rice under water deficit the contribution of the yield components to the yield was in the order rate of filling > panicle/m^2 > number of grains per panicle > 1000 grain weight. Though not validated in this study it is possible to infer that the reduced yield observed in rice genotypes under water deficit could be attributed to the higher spikelet sterility and the reduced number of panicle plant^{-1} than under optimum water supply. The observed grain yield response of rice genotypes to the availability of water could be premised on the effect of water on its performance. Matsumoto *et al.* (2014) observed that each unit of water (1 mm) lead to 11–12 kg ha^{-1} of grain yield in the East Africa, where the minimum requirements of water was approximately in the range 311–400 mm per cropping season. Rice cultivars established under sub-optimal water condition experienced delayed days to maturity compared to the observations of Sikuku *et al.* (2010), where it was faster. This could be attributed to the ecologies used in both investigation and the choice of varieties used. The delayed days to maturity here could be associated with reduced rate of grain filling as described by Matsumoto *et al.* (2014). He posited that the rate of grain filling was the yield contributing factor in rice under water deficit.

The performance of IR 64 rice genotype could be linked with the number of tillers plant^{-1} and the number of panicle plant^{-1}. Number of tillers per plant in IR 64 could have contributed significantly to higher shoot biomass than other rice cultivars used in this investigation. Other evidences for the aforementioned in IR64 could be associated with delayed time to flowering. This could have suggested increased accumulation of biomass. The observed grain yield of NERICA 4 despite its significantly higher 1000 grain mass and HI than other rice genotypes could be linked with its reduced number of panicle plant^{-1}. The observed pattern of shoot biomass and days to 50% flowering in IR 64 was consistent with the position of Donald and Hamblin (1976). They posited that high shoot biomass and harvest index could decrease HI in cereals. These properties were more the reflection of the competitive ability of rice plant than the attributes that could confer high performance. Though in a pure stand grain yield is more associated with the HI than biomass accumulation, which is what is more pronounced in the mixture. WAB 56 with taller canopy than others also had the least harvest index. Corroborating the aforementioned observation by Donald and Hamblin (1976). What is not clear is why in IR 64 HI did not contribute to the grain yield considering the varieties of rice used were in pure stand. One possible explanation could be that the cultivars experienced stress during its ontogeny that facilitated the association between the grain yield of IR 64 with the biomass accumulation. This would need to be empirically validated further.

High yield observed in flooded lowland and hydromorphic soils had earlier been associated with biomass accumulation (Saito *et al.*, 2010). Though not observed in this study it could be speculated that increased biomass accumulated in those agroecologies could have been as a result of increased number of tillers and delayed flowering. Saito *et al.* (2010) observed that growth duration and efficiency of translocation of assimilates were responsible for the high yield in hydromorphic soils. This corroborated the findings in this investigation, where days to 50% flowering were delayed. The reduced number of tillers in the upland ecology could have been associated with the availability of water and nutrients. Conversely, earliness observed in rice established in this agroecology could have been an escape mechanism to forestall the negative impact of nutrient and moisture stress. Patel *et al.* (2010) observed that number of panicles per m^2 is what was responsible for the yield gap between the rice grown in the lowland and upland agroecologies. This finding could have corroborated the observed pattern here on the number of tillers plant^{-1}. Saito *et al.* (2010) observed that high yield of rice in aerobic soils of upland agroecology is related to high HI. Though not empirically validated in this investigation, it could be inferred that 1000 grain weight of rice sown in upland agroecology compared to others could have a bearing on the harvest index observed in their study.

The interaction of soil ecology × water regime indicated that number of tillers and shoot dry matter were lesser under water deficit than under optimal water regime. The reduced shoot biomass could have been associated reduced number of tillers, despite the delayed flowering period. The high number of tillers plant^{-1} in rice genotypes IR 64 and IR 77298-14-1-2-B-10 in all the soil types could have suggested that these genotypes are more adapted to all agroecologies examined in this investigation than other rice genotypes. Parent *et al.* (2010) had earlier posited that rice in varied agroecologies displayed isohydric behaviour within certain range of soil water potential. He ascribed this to similarities in their root system. Both rice varieties have earlier been reported to be adapted to lowland agroecologies. However, rice genotype IR 64 is more susceptible to water deficit than other rice genotypes as reported in the literature (Mackill and Khush, 2018). One could infer that the range of the water potential in this investigation was not severe enough to facilitate their relative adaptability to all agroecologies. Both rice genotypes IR 77298-14-1-2-B-10 and IR 64 in all soil types and under water deficit were able to main comparatively higher number of panicles than other rice genotypes. However, in both lowland and upland soils, under water deficit both IR 77298-14-1-2-B-10 and IR 64 could not sustain their 1000 grain mass except in hydromorphic soils where soil organic carbon and total nitrogen with favourable soil texture that could positively affect soil water holding capacity could provide enough nutrients and water to sustain their 1000 grain mass even under water deficit. Other explanation could be the trade-off observed between number of panicles plant^{-1} and 1000 grain mass under stress conditions. It had been reported under stressful condition hierarchy of phenotypic plasticity favours the conservation of 1000 grain mass compared with number of panicles m^2 (Sadras and Slafer, 2012).

CONCLUSION

Rice cultivars grown in hydromorphic soils had more number of tillers than those in other soil types, which could be explained by their prolonged vegetative growth. The observed low 1000 grain mass of rice cultivars grown in the lowland ecology could be linked to its short duration to optimise growth resources. Spikelet sterility and prolonged days to flowering were more pronounced in rice cultivars grown under sub-optimal water condition. The observed performance of IR 64 could be attributed to the number of tillers plant^{-1}, number of panicles plant^{-1}, shoot biomass and the prolonged duration of flowering, probably to optimise growth resources. However, a trade-off was observed with the 1000 grain mass, suggesting the susceptibility of this cultivar to stress due to competition for growth resources with the increasing number of tillers. Shoot biomass in rice cultivars was significantly depressed under sub-optimal water supply in all soil types, with prolonged days to reach flowering. This could have contributed to more tillers plant^{-1} in rice cultivars grown in upland ecology with a converse pattern for those established in hydromorphic soils. When grown under different soil types with sub-optimal water supply rice cultivar 77298-14-1-2-B-10 was observed to be the most promising and drought tolerant considering its reproductive growth. The only exception was its significantly lower 1000 grain mass when established in an upland ecology under water deficit compared to other rice cultivars.

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REFERENCES

BERNIER, J., ATLIN, G. N., SERRAJ, R., KUMAR, A. and SPANER, D. 2008. Breeding UPLAND rice for drought resistance. *Journal of the Science of Food and Agriculture*, 88(6): 927–939.

BOLING, A. A., TUONG, T. P., SUGANDA, H., KONBOON, Y., HARNPICHITVITAYA, D., BOUMAN, B. A. M. and FRANCO, D. T. 2008. The effect of toposequence position on soil properties, hydrology, and yield of rainfed lowland rice in Southeast Asia. *Field Crops Research*, 106(1): 22–33.

DIAGNE, A., AMOVIN-ASSAGBA, E., FUTAKUCHI, K. and WOPEREIS, M. C. S. 2013. Estimation of cultivated area, number of farming households and yield for major rice growing environments in Africa. In: WOPEREIS, M. C. S., JOHNSON, D. E., AHMADI, N., TOLLENS, E. and JALLOH, A. (Eds.). *Realising Africa's Rice Promise.* CABI, pp. 35–45.

DONALD, C. M. and HAMBLIN, J. 1976. The Biological Yield and Harvest Index of Cereals as Agronomic and Plant Breeding Criteria. *Advances in agronomy*, 28: 361–405.

FAROOQ, M., WAHID, A., KOBAYASHI, N., FUJITA, D. and BASRA, S. M. A. 2009. Plant drought stress: Effects, mechanisms and management. *Agronomy for Sustainable Development*, 29: 185–212.

FOFANA, M., CHERIF, M., KONE, B., FUTAKUCHI, K. and AUDEBERT, A. 2010. Effect of water deficit at grain repining stage on rice grain quality. *Journal of Agricultural Biotechnology and Sustainable Development*, 2(6): 100–107.

FUKUTA, Y., KONISHO, K., SENOO-NAMAI, S., YANAGIHARA, S., TSUNEMATSU, H., FUKUO, A. and KUMASHIRO, T. 2012. Genetic characterization of rainfed upland New Rice for Africa (NERICA) varieties. *Breeding Science*, 62(1): 27–37.

HE, H. and SERRAJ, R. 2012. Involvement of peduncle elongation, anther dehiscence and spikelet sterility in upland rice response to reproductive-stage drought stress. *Environmental and Experimental Botany*, 75: 120–127.

IMOLEHIN, E. D. and WADA, A. C. 2000. Meeting the rice production and consumption demands of Nigeria with improved technologies. *International Rice Commission Newsletter*, 49: 33–41.

IRRI. 2002. *Standard evaluation system for rice*. Manila: International Rice Research Institute.

KANEDA, C. 2007. Breeding and Dissemination Efforts of “NERICA”. *Japanese Journal of Tropical Agriculture*, 51(4): 145–151.

MACKILL, D. J. and KHUSH, G. S. 2018. IR64: A high-quality and high-yielding mega variety. *Rice*, 11(1): 18.

MADADGAR, S., AGHAKOUCHAK, A., FARAHMAND, A. and DAVIS, S. J. 2017. Probabilistic estimates of drought impacts on agricultural production. *Geophysical Research Letters*, 44(15): 7799–7807.

MATSUMOTO, S., TSUBOI, T., ASEA, G., MARUYAMA, A., KIKUCHI, M. and TAKAGAKI, M. 2014. Water response of upland rice varieties adopted in sub-Saharan Africa: A water application experiment. J Rice Res, 2: 121.

MOUMENI, A., SATOH, K., VENUPRASAD, R., SERRAJ, R., KUMAR, A., LEUNG, H. and KIKUCHI, S. 2015. Transcriptional profiling of the leaves of near-isogenic rice lines with contrasting drought tolerance at the reproductive stage in response to water deficit. *BMC Genomics*, 16(1): 1110.

NDJIONDJOP, M.-N., SECK, P. A., LORIEUX, M., FUTAKUCHI, K., YAO, K. N., DJEDATIN, G., SOW, M. E., BOCCO, R., CISSE, F. and FATONDJI, B. 2012. Effect of drought on Oryza glaberrima rice accessions and Oryza glaberrima derived-lines. *Asian Journal of Agricultural Research*, 6(4): 144–157.

NORMAN, J. C. and OTOO, E. 2003. Rice development strategies for food security in Africa. In: *Proceedings of the 20th Session of the International Rice Commission.* Bangkok, Thailand, 23–26th July, 2002, pp. 235–250.

OGBAN, P. I. and BABALOLA, O. 2009. Characteristics, classification and management of Inland valley bottom soils for crop production in subhumid southwestern Nigeria. *Agro-Science*, 8(1): 1–13.

OUYANG, W., YIN, X., YANG, J. and STRUIK, P. C. 2020. Comparisons with wheat reveal root anatomical and histochemical constraints of rice under water-deficit stress. *Plant and Soil*, 452(1): 547–568.

OYEDIRAN, G. O. and WAKATSUKI, T. 1999. Hydromorphic soils of two inland valley swamps in the rain forest zone of Nigeria. I some physical and chemical Properties. *Agrosearch*, 5(1–2): 21–37.

PARENT, B., SUARD, B., SERRAJ, R. and TARDIEU, F. 2010. Rice leaf growth and water potential are resilient to evaporative demand and soil water deficit once the effects of root system are neutralized. *Plant, Cell & Environment*, 33(8): 1256–1267.

PATEL, D. P., DAS, A., MUNDA, G. C., GHOSH, P. K., BORDOLOI, J. S. and KUMAR, M. 2010. Evaluation of yield and physiological attributes of high-yielding rice varieties under aerobic and flood-irrigated management practices in mid-hills ecosystem. *Agricultural Water Management*, 97(9): 1269–1276.

PAYNE, R. W., HARDING, S. A., MURRAY, D. A., SOUTAR, D. M., BAIRD, D. B., GLASER, A. I., CHANNING, I. C., WELHAM, S. J., GILMOUR, A. R., THOMPSON, R. and WEBSTER, R. 2009. *Genstat for Windows 12th Edition: Introduction*. VSN International.

PENG, S., BOUMAN, B., VISPERAS, R. M., CASTAÑEDA, A., NIE, L. and PARK, H.-K. 2006. Comparison between aerobic and flooded rice in the tropics: Agronomic performance in an eight-season experiment. *Field Crops Research*, 96(2–3): 252–259.
POORTER, H., FIORANI, F., PIERUSCHKA, R., WOJCIECHOWSKI, T., VAN DER PUTTEN, W. H., KLEYER, M., SCHURR, U. and POSTMA, J. 2016. Pampered inside, pestered outside? Differences and similarities between plants growing in controlled conditions and in the field. *New Phytologist*, 212(4): 838–855.
SADRAS, V. O. and SLAFER, G. A. 2012. Environmental modulation of yield components in cereals: Heritabilities reveal a hierarchy of phenotypic plasticities. *Field Crops Research*, 127: 215–224.
SAITO, K., AZOMA, K. and SOKEI, Y. 2010. Genotypic adaptation of rice to lowland hydrology in West Africa. *Field Crops Research*, 119(2–3): 290–298.
SAKARIYAWO, O. S., OYELEDUN, K. O., ADEYEMI, N. O. and ATAYESE, M. O. 2020. Nitrogen use efficiency and performance of maize (Zea mays L.) cultivars as influenced by calcium carbide and inorganic nitrogen application rates in a derived savanna. *Journal of Plant Nutrition*, 43(6): 784–797.
SIKUKU, P. A., NETONDO, G. W., MUSYIMI, D. M. and ONYANGO, J. C. 2010. Effects of water deficit on days to maturity and yield of three NERICA rainfed rice varieties. *ARPN Journal of Agricultural and Biological Science*, 5(3): 1–9.
SINGH, C. V., MANDAL, N. P. MAITI, D. 2017. Upland rice technologies: A brief overview. *ICAR-Central Rainfed Upland Rice Research Station (NRRI), Hazaribag, Jharkhand, India*.
SRITHARAN, N., VIJAYALAKSHMI, C., SUBRAMANIAN, E. and BOOMIRAJ, K. 2015. Supremacy of rice genotypes under aerobic condition for mitigating water scarcity and future climate change. *African Journal of Agricultural Research*, 10(4): 235–243.
TOURÉ, A., SOGBEDJI, J. M. and GUMEDZOÉ, Y. M. D. 2013. The critical period of weed interference in upland rice in northern Guinea savanna: Field measurement and model prediction. *African Journal of Agricultural Research*, 8(17): 1748–1759.
VAN OORT, P. A. J. 2018. Mapping abiotic stresses for rice in Africa: Drought, cold, iron toxicity, salinity and sodicity. *Field Crops Research*, 219: 55–75.
VENUPRASAD, R., CRUZ, M. S., AMANTE, M., MAGBANUA, R., KUMAR, A. and ATLIN, G. N. 2008. Response to two cycles of divergent selection for grain yield under drought stress in four rice breeding populations. *Field Crops Research*, 107(3): 232–244.
VENUPRASAD, R., LAFITTE, H. R. and ATLIN, G. N. 2007. Response to direct selection for grain yield under drought stress in rice. *Crop Science*, 47(1): 285–293.
YIN, C., GAN, L., NG, D., ZHOU, X. and XIA, K. 2007. Decreased panicle-derived indole-3-acetic acid reduces gibberellin A1 level in the uppermost internode, causing panicle enclosure in male sterile rice Zhenshan 97A. *Journal of Experimental Botany*, 58(10): 2441–2449.

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