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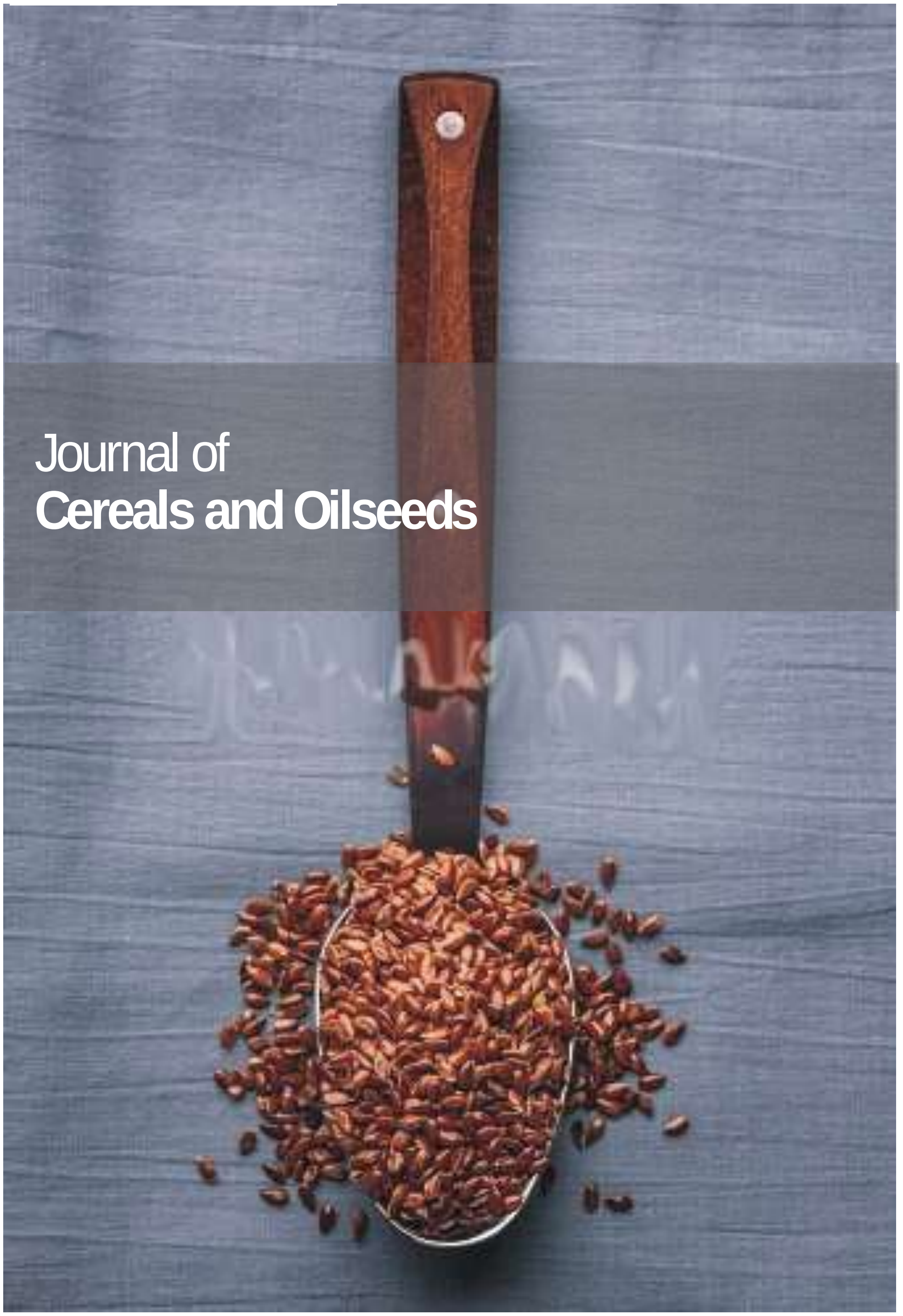

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Journal of Cereals and Oilseeds

Full Length Research Paper

Moisture requirement and water productivity of selected rainfed rice varieties grown under controlled water environment in Ifakara, Tanzania

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Moisture availability is a fundamental challenge to rice productivity in the rainfed environment. Most of the rice varieties released for cultivation under rainfed ecosystem in Tanzania are missing out on information about their moisture requirement under different soil moisture regimes. A pot experiment was conducted at Ifakara in a split-plot design. The main plots was assigned to water regimes of 100, 75, 50 and 25% based on saturated soil conditions, and the sub-plots were assigned to six rice varieties NERICA 1, NERICA 2, NERICA 4, TXD 306, Tai and Komboka. The results revealed that TXD 306 produced the highest grain yields after utilizing 36.91 kg water followed by Tai 30.24 kg water, Komboka 30.20 kg water and NERICA 4 27.47 kg water at 100% moisture saturation. NERICA 1 and NERICA 2 produced the highest grain yields at 75% moisture saturation transpiring 25.28 and 19.05 kg water, respectively. It was concluded that 100% moisture saturation in soils was the optimum moisture for TXD 306, Tai, Komboka and NERICA4 rice varieties since they produced the highest grain yields with highest productivity value than other moisture regimes investigated, and 75% moisture in soils was the optimum moisture requirement for NERICA1 and NERICA2 rice varieties at which they produced the highest grain yield and water productivity value. In the lower soil moisture contents of 50 and 25%, NERICA 2 and NERICA 4 rice varieties had higher grain yield and productivity value than the other varieties and are therefore recommended for cultivation in areas with moisture limited conditions.

Key words: NERICA, productivity, rainfed rice, soil moisture levels, water use.

INTRODUCTION

The term crop water requirement is defined as the amount of water required to compensate the evapotranspiration loss from the cropped field (USDA Soil Conservation Service, 1993). The ICID-CIID, (2000) describes it as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield. Moisture availability in rice production ecosystems has been changing with

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Table 1. Characteristics of the soils used in the pot experiment.

Soil texture class	Clay loam
Soil pH (H_2O)	5.4
EC (mS/cm)	0.18
OC (g/kg soil)	20.20
Total N (g/kg soil)	1.80
Available P (mg/kg)	43.40
	K = 0.35
Exchangeable Cations (meq/100 g soil)	Na = 0.39
	Ca = 9.04
	Mg = 4.53
CEC (Cmol/kg)	21.40

climatic environment worldwide. The rainfed rice ecology is the most affected of all ecologies (Boyer, 1982; Dey and Upadhyaya, 1996; Liming et al., 2006). Moisture uncertainty is among the major constraints of the rainfed ecosystems in Tanzania that hinders the performance of newly released rice varieties from achieving their yielding potentials (MAFSC, 2009, 2012).

Previous studies on moisture requirement (Borrell et al., 1997; Bouman and Tuong, 2001; Tabba et al., 2002; Belder et al., 2004) showed that most of the varieties tested maintained their production potential with less supplies of water for irrigation. These studies evaluated the moisture requirement for irrigated lowland and upland rice, using total water input (rainfall plus irrigation). Moreover, minimizing water usage in rice production was quantified in terms of water productivity (Bouman and Tuong, 2001; Kamoshita et al*.,* 2007). However, these studies provided limited information on the optimum moisture requirement for specific rice varieties based on the total cumulative transpired water under controlled water supply condition. Ouda et al*.* (2016) assessed water requirement for irrigating rice in Egypt and found that water required for irrigation in rice fields ranged between 1018 and 1162 mm, but under water stress scenarios was expected to increase by 10-14% in year 2040, reaching the range of 1124 to 1290 mm annually. It is reported that the yield of most rice declines in rainfed rice production when the soil moisture content becomes lower than the threshold value, and thus affects the socio-economic activities of farmers in rainfed rice ecosystem and food security in general (Tuong and Bouman, 2003). Amudha and Balasubramani (2011) reported moisture stress as the major constraint to the productivity of most rain-fed rice ecosystems, and that the yields of the rainfed ecosystem are always low and unsteady (GRiSP, 2013). Cultivation of upland rice has been reported as the most important strategy toward water-saving agriculture (Bouman, 2001), due to their lower moisture requirements in comparison to the lowland rainfed rice production systems. In this respect, Tanzania introduced upland NERICA rice varieties in 2005 as a strategy to solve the problem of moisture stress under rainfed upland rice ecosystem in the country. Five NERICA varieties were released in 2009 and disseminated to improve rice production in Tanzania (MAFSC, 2009). Two NERICA varieties (NERICA1 and NERICA2) have shown the ability to tolerate the problem of moisture stress and were found to have a higher capacity to absorb moisture and nutrient nitrogen in moisture-stressed and N deficient soils (Kitilu, 2011).

However, due to heavy reliance on rainfall for its agriculture production, Tanzania has been challenged with moisture availability in rice cultivation of which 72% is under rainfed lowlands with farmers averaged yields of between1.5 to 2.0 tons per hector, and 20% is under rainfed upland ecosystems with farmers' yields averaged between 0.8 to 1.0 tons per hectare (MAFSC, 2009; GRiSP, 2013). Of late, the rainy seasons in Tanzania have become erratic and unpredictable due to climate changes (URT, 2014; Moore and Lobell, 2014; IPCC, 2013), a situation which hampers rice productivity both in acreage and yield per unit area. Besides, the optimal moisture requirements and productivity for most recently released rice varieties including the NERICAs in Tanzanian are not known; therefore, the present study aimed at evaluating optimum moisture requirement and productivity of selected lowland and upland rice varieties under different soil moisture level.

MATERIALS AND METHODS

A pot experiment was conducted in Ifakara at KATRIN Agricultural Research Institute (08° 04' S and 36° 68' E), during the long rain season of 2017. The physicochemical characteristics of the soil used in the experiment are shown in Table 1. The experiment was carried out using 320 pots arranged in split plot using RCBD design with three replications. The main plots were assigned to four water regimes (100, 75, 50 and 25% soil moisture saturation condition), and the sub-plots were assigned to rice varieties including three upland rainfed varieties (NERICA 1, NERICA 2, and NERICA 4), and three lowland rainfed varieties (TXD 306, Tai and Komboka). Plastic pots (10-L capacity) were used by filling with soil collected from the upland and lowland fields to ¾ full. Five seeds of each variety were sown directly in the respective pots for each moisture saturation level. After germination, thinning was done to establish single seedling per pot. Opening and closing the vinyl plastic shade house was used in controlling direct entry of rainfall water. Other agronomic practices for example fertilization and weeding were adhered to.

Moisture regime management and measurement

The water regime management in the pot experiments followed the methodology used by Kitilu (2011), which involved estimation of moisture applied by calibrating the weights of soil filled pots before irrigating it to saturation. Then the moisture saturated pot for respective soil was used to estimate the amount of water to be applied to establish different levels of saturation in percentage, that is, weight of water at saturation was determined as the difference in weight of pot with moisture saturated soil minus the weight of pot with dry soil. Subsequently, the amounts of water to be supplied from the saturation point of 100%, (control), 75, 50, and 25% were established. Uniform saturation was maintained up to thirty days after the seedling emergence. Thereafter, seedlings were subjected to the four different water regimes gravimetrically calibrated at the beginning of irrigation. The purpose was to estimate the water requirements of each variety at different stages of growth. To get the total water lost by transpiring plants in pots, an identical pot but without a plant was placed in each replication as a control for water lost directly by surface evaporation. Then the difference between the total water lost by pots with plants and those lost in pots without plant was the total water used by the transpiring plant in pots (cumulative transpired water CTW or Tr). Irrigation and various measurements were accomplished daily from germination to maturity.

Data recording procedures

The number of tillers per plant

The number of tillers per plant was counted and recorded at vegetative, flowering and maturity according to Gomez (1972).

Above-ground biomass weights

The total above ground biomass weights at all sampling stages was obtained by the procedures described by Fageria (2010), whereby plants in pots were cut at 4 cm above the ground, sun-dried for three days and weighed using a weighing balance. Thereafter, the plants were threshed and the grain was weighed. Subsequently, straw was oven dried at 80ºC to a constant dry weight to get straw weights.

Water use efficiency (WUE)

The water use efficiency at vegetative, flowering and maturity stage was calculated by dividing the total above ground shoot dry weights (SDWt) sampled at vegetative (48 days after germination), 50% flowering and harvest maturity stages by the total cumulative transpired water Tr (CTW) at the respective growth stage according to de Wit (1958) and Kitilu (2011).

$$\text{Water use efficiency (WUE)} = \text{SDWt} / \text{Tr (CTW)} \qquad (1)$$

Yield and yield components

The grain yield and yield components were measured at harvest maturity. Two pots from each water regime treatment were harvested for yield and yield components analyses, whereby the numbers of panicles per plant, number of fertile and sterile spikelet per panicle were recorded by physical counting. In addition, a thousand grains were counted and weighed to get the 1000-grain weight at 14% moisture content following the procedure described by Gomez (1972). Thereafter, grain yields of the selected rice varieties were obtained from the relationship by Fageria et al. (1997) and Yoshida (1981).

$$GY= (P \times SP \times FS \times GW \times 10^{-5}) \qquad (2)$$

where;
GY= grain yield (tha^{-1})
P = number of panicles (m^{-2})
SP = number of spikelets per panicle
FS = percentage filled spikelet or grain
GW = 1000-grain weight (g)

Water productivity (WP_{ET} or WP_{CW})

For this study, water productivity and productivity efficiency were calculated with respect to the amount of water cumulatively transpired by rice plants from the vegetative to maturity stages in pots following method by Bouman and Tuong (2001) and Belder et al. (2004) relationships with a minor modification.

$$WP_{ET} = Y/ (ET – E) \text{ or simply } Y/CTW \qquad (3)$$

Where Y is the grain yield in kg per plant, E is evaporated water from the soil and pots surface, ET is evapotranspired water through plant tissues and soil surfaces and CTW is the difference between total water lost from pots with plants and water lost from empty pots, and all expressed in kg water per plant or pot as illustrated in methodology and Equation 1.

Data analyses

The data obtained in pots were subjected to analysis of variance (ANOVA) using GenStat 14th edition (2011) and Microsoft Excel for graphs and figures. Mean separation was accomplished using Tukey's significant difference test. The differences between treatments were compared at $P \leq 0.05$.

RESULTS

Effect of soil moisture saturation regimes on number of tillers of different rice varieties at different growth stages

Figure 1 shows the effects of varying soil moisture saturation on the number of tillers for the selected rice varieties. The number of tillers slightly increased from vegetative (maximum tillering) growth stage to the flowering stage at all soil moisture saturation levels. However, a decreasing trend in the number of tillers from flowering to maturity was observed in all tested varieties (Figure 1). At the vegetative stage, the number of tillers in lowland rice varieties was significantly higher than those of upland rice varieties tested. There were no significant differences among the lowland rice varieties in number of

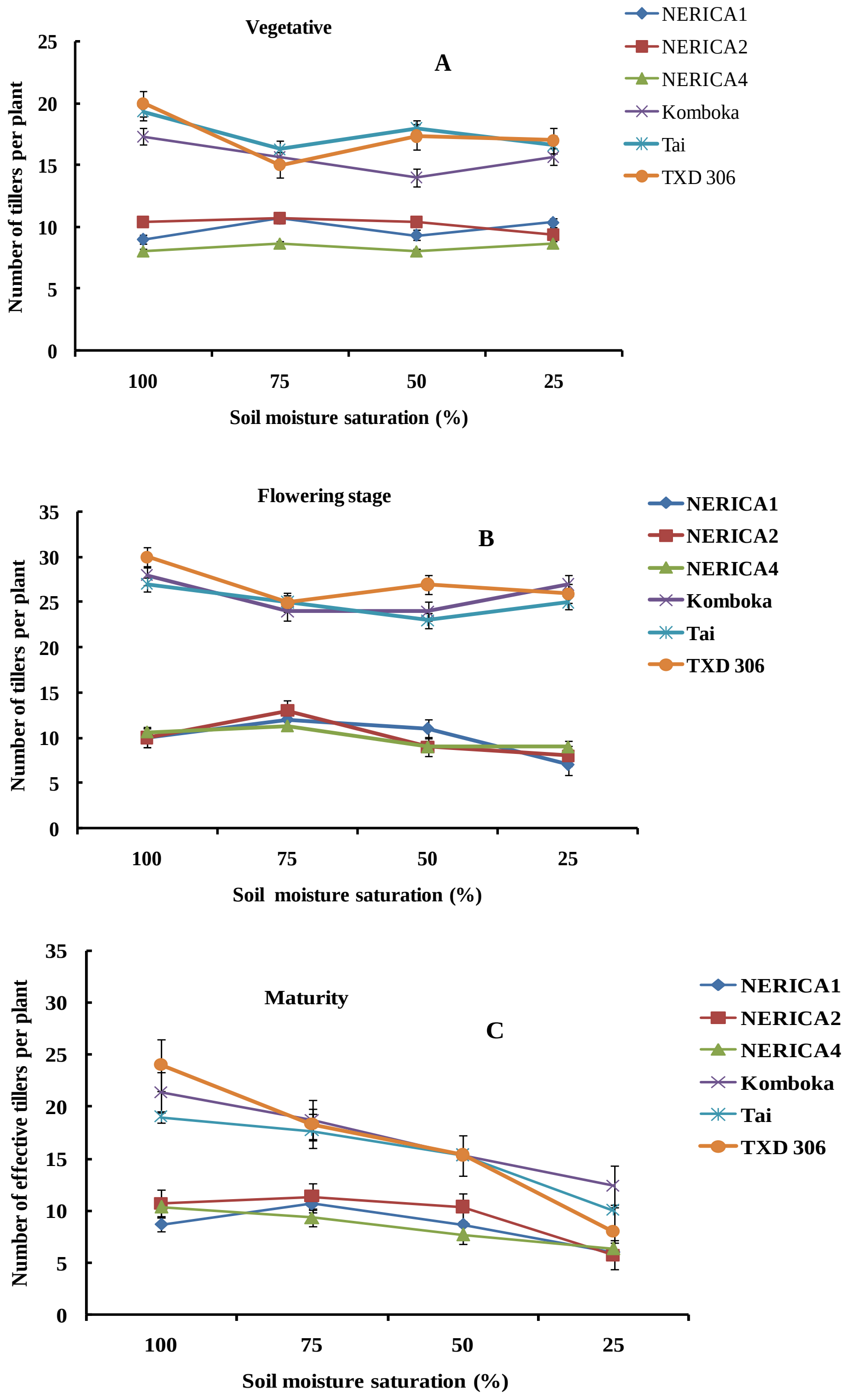

Figure 1. Effects of moisture stress on the number of tillers per plant for selected rainfed rice.

tillers per plant, although Komboka produced the smallest number of tillers at 50% soil moisture saturation (Figure 1A). For the upland rice varieties, NERICA2 and NERICA1 produced relatively a greater number of tillers than NERICA4 at 75 and 50% soil moisture saturation, although at 25% the number of tillers did not differ (Figure 1A).

The number of tillers at the flowering stage was relatively higher for all the rice varieties when compared to during vegetative and maturity growth stages, lowland rice varieties taking the lead (Figure 1B). TXD306 variety produced the largest number of tillers at 100 and 50%

soil moisture saturation than all other varieties. All upland rice varieties showed a relatively similar number of tillers per plant (Figure 1B).

At maturity stage, the numbers of effective tillers for all tested rice varieties highly declined with decreasing soil moisture saturation from 100 to 25%. The upland rice varieties NERICA1 and NERICA2 registered an increasing number of effective tillers from 100 up to 75% soil moisture saturation levels, and slightly decreased from 75% toward 25% soil moisture saturation levels (Figure 1C). However, the number of effective tillers was significantly higher in the lowland varieties than in the upland varieties at all moisture saturation levels (Figure 1C). TXD306 produced the highest number of effective tillers per plant at 100% soil moisture saturation level than all other rice varieties tested. The lowland varieties were highly declined in number of effective tillers at 25% soil moisture saturation level as compared to the upland varieties. The upland rice varieties NERICA2 and NERICA4 produced the highest number of effective tillers than NERICA1 at 100% (Figure 1C). It was also observed that the upland rice varieties recorded the least reduction in the number of effective tillers at 75 and 25% moisture saturation levels than the lowland varieties (Figure 1C).

Effects of soil moisture saturation regimes on shoot growth of different rice varieties at different growth stages

Results on the effect of moisture regimes on shoot growth assessed as shoot dry weights (SDWt) of rice genotypes are as shown in Table 2. Rice shoots growth significantly decreased with decreasing moisture from 100% to the lowest moisture saturation level of 25% during the vegetative, flowering and maturity growth stages. During the vegetative growth stage, Tai variety portrayed significantly less SDWt compared to Komboka while all other varieties tested showed no significant differences in SDWt at P≤0.05. At the flowering stage, significant differences in growth were observed, whereby TXD306, NERICA4, and Komboka had the highest shoot dry weights compared to NERICA2, Tai and NERICA1. At maturity stage, significant differences in shoot dry weights were observed between TXD306 and NERICA2, Tai, and NERICA1 although SDWt of TXD306 was not significantly different from that of NERICA4 and Komboka (Table 2). There was a significantly higher interaction between moisture treatment and the varieties on the shoot dry weights at flowering and maturity growth stages.

At 100% moisture saturation, the vegetative growth stage of all varieties tested showed no significant differences in SDWt at P≤0.05. However, Tai had the most SDWt in kg/plant (0.20), followed by TXD306 (0.018), NERICA1 (0.016), NERICA2 (0.015), Komboka (0.013), while NERICA4 had the least (Table 2). At the flowering stage, significant differences in growth as SDWt were observed among the varieties at P≤0.05. The lowland rice varieties grew significantly higher than the upland rice varieties which grew less in terms of SDWt (Table 2). TXD306 had significantly the most SDWt/plant (0.094) followed by Komboka (0.085) and Tai (0.081), although the latter two were not significantly different to NERICA1 and NERICA2 upland rice. NERICA4 had significantly less SDWt than other varieties tested, although its growth was not significantly different from those of NERICA1 and NERICA2 (Table 2). At the maturity stage, all lowland rice varieties (TXD306, Tai and Komboka) grew significantly higher in SDWt than all the upland rice tested. There were no significant differences in SDWt among the lowland rice varieties; although TXD306 had the most (12.93) followed by Komboka (10.84) and Tai (8.12) SDWt per plant. For the upland rice, NERICA4 had insignificantly bigger (6.44) than the other two upland rice varieties NERICA1 (5.84) and NERICA2 (5.81) SDWt per plant (Table 3).

At 75% moisture saturation, all varieties tested showed no significant differences in SDWt at P ≤ 0.05 during the vegetative stage. Tai had relatively bigger SDWt in kg/plant (0.022), followed by NERICA2 (0.015), NERICA4 (0.013), NERICA1 (0.013), Komboka (0.012), while TXD306, had less (0.010) SDWt (Table 3.3). At the flowering phase, significant differences in growth were observed among all the varieties in terms of SDWt at P ≤ 0.05. The lowland rice varieties had significantly more SDWt than the upland rice varieties (Table 3). For the lowland rice varieties, no significant differences were observed among the varieties, although Komboka grew significantly more (0.094), followed by TXD306 (0.073) and Tai (0.064), despite Tai being not significantly different from the upland rice varieties (Table 3). At maturity stage, TXD306 (8.55 kg) was associated with significantly more SDWt than all other varieties tested at P ≤ 0.05. However, all the remaining rice varieties Komboka, NERICA2, Tai, NERICA1, and NERICA4 showed respectively no significant differences in growth by respectively registering 6.08, 5.94, 5.40, 5.19 and 5.09 kg SDWt per plant (Table 3).

At 50% moisture saturation, all varieties tested showed no significant differences in SDWt at P ≤ 0.05 during the vegetative stage. Tai had higher SDWt in kg/plant (0.020), followed by Komboka (0.015), TXD306 (0.013), NERICA1 (0.013), NERICA4 (0.013) and NERICA2 (0.011) (Table 3). During the flowering growth phase, significant differences were observed among the varieties in SDWt at P ≤ 0.05. The lowland rice varieties had highest SDWt than the upland rice varieties (Table 3). Among the lowland rice varieties, no significant differences were observed although TXD306 showed significantly higher SDWt kg/plant (0.079), followed by Komboka (0.072) and Tai (0.064). The upland rice varieties indicated no significant differences in SDWt (Table 3), although NERICA4 and NERICA2 (0.048 kg each) indicated relatively higher in SDWt than NERICA1 (0.039). During

Table 2. Effect of moisture regimes and varieties on Shoot dry weights (SDWt), cumulative transpired water (CTW), and (WUE) of selected rice Varieties at different phases of growth.

Treatments		**SDWt (kg)**			**CTW (kg)**			**WUE x10^{-3}**		
Moisture(W)	**Varieties (V)**	**Vegetative**	**Flowering**	**Maturity**	**Vegetative**	**Flowering**	**Maturity**	**Vegetative**	**Flowering**	**Maturity**
100	NERICA1	0.016^{a}	0.058^{bcd}	5.10^{cdef}	7.89^{a}	16.71^{cde}	29.50^{b}	2.10^{a}	3.40^{cd}	171.70^{efg}
	NERICA2	0.015^{a}	0.058^{bcd}	5.84^{cde}	7.62^{ab}	15.06^{def}	27.75^{bc}	2.20^{a}	4.00^{cd}	200.00^{de}
	NERICA4	0.011^{a}	0.054^{cd}	6.44^{cd}	6.66^{ab}	14.91^{def}	27.47^{bc}	1.50^{a}	2.40^{d}	214.60^{cde}
	Komboka	0.013^{a}	0.085^{ab}	10.84^{ab}	5.75^{ab}	20.46^{ab}	30.20^{b}	1.90^{a}	5.70^{abc}	396.10^{a}
	Tai	0.020^{a}	0.081^{ab}	8.12^{b}	7.45^{a}	21.78^{ab}	30.24^{b}	3.50^{a}	4.00^{cd}	264.60^{abc}
	TXD 306	0.018^{a}	0.094^{a}	12.93^{a}	6.78^{ab}	25.51^{a}	36.91^{a}	2.80^{a}	3.70^{cd}	349.10^{ab}
75	NERICA1	0.013^{a}	0.058^{cd}	5.19^{cdef}	7.11^{ab}	14.59^{ef}	25.28^{bcd}	1.90^{a}	4.00^{cd}	205.10^{cde}
	NERICA2	0.015^{a}	0.061^{cd}	5.94^{cd}	6.21^{ab}	13.03^{fg}	19.05^{efg}	2.20^{a}	4.80^{bcd}	309.10^{abc}
	NERICA4	0.013^{a}	0.052^{cde}	5.09^{cdef}	6.06^{ab}	13.26^{fg}	23.19^{cde}	2.10^{a}	3.20^{cd}	207.40^{cde}
	Komboka	0.012^{a}	0.076^{ab}	6.08^{cd}	4.91^{b}	16.93^{cde}	25.11^{bcd}	2.20^{a}	5.80^{abc}	261.50^{abc}
	Tai	0.022^{a}	0.064^{bc}	5.40^{cde}	4.84^{b}	16.31^{cde}	25.40^{bcd}	4.70^{a}	3.80^{cd}	221.10^{bcd}
	TXD 306	0.010^{a}	0.073^{ab}	8.55^{ab}	4.98^{b}	20.39^{ab}	30.85^{ab}	1.90^{a}	3.60^{cd}	283.20^{abc}
50	NERICA1	0.013^{a}	0.039^{ef}	2.47^{def}	6.20^{ab}	11.39^{gh}	19.24^{efg}	2.20^{a}	3.60^{cd}	128.20^{fg}
	NERICA2	0.011^{a}	0.048^{de}	4.33^{cde}	5.89^{ab}	11.29^{gh}	18.53^{efg}	2.10^{a}	4.20^{bcd}	235.20^{cd}
	NERICA4	0.013^{a}	0.048^{de}	3.38^{def}	5.50^{ab}	10.74^{ghi}	18.58^{efg}	2.60^{a}	3.40^{cd}	166.90^{efg}
	Komboka	0.015^{a}	0.072^{bc}	3.36^{def}	5.02^{ab}	13.66^{efg}	20.72^{def}	3.00^{a}	6.80^{ab}	183.50^{defg}
	Tai	0.020^{a}	0.064^{bc}	3.53^{def}	5.43^{ab}	14.06^{ef}	21.50^{de}	4.20^{a}	4.70^{bcd}	183.60^{defg}
	TXD 306	0.013^{a}	0.079^{ab}	2.81^{def}	5.40^{ab}	18.80^{bc}	23.36^{cde}	2.50^{a}	4.20^{bcd}	122.40^{fg}
25	NERICA1	0.014^{a}	0.034^{ef}	0.97^{gh}	4.33^{b}	7.31^{i}	13.09^{hi}	3.50^{a}	4.40^{bcd}	81.00^{gh}
	NERICA2	0.010^{a}	0.030^{f}	1.44^{fg}	3.61^{bc}	6.48^{i}	10.29^{i}	2.90^{a}	4.60^{bcd}	146.90^{efgh}
	NERICA4	0.007^{a}	0.037^{ef}	1.58^{efg}	3.96^{bc}	6.84^{i}	12.07^{i}	1.70^{a}	3.80^{cd}	118.40^{efgh}
	Komboka	0.011^{a}	0.052^{cde}	0.78^{h}	2.79^{bc}	9.65^{hi}	14.92^{fgh}	3.10^{a}	9.70^{a}	69.00^{gh}
	Tai	0.012^{a}	0.050^{cde}	0.91^{gh}	3.64^{bc}	10.22^{gh}	13.94^{ghi}	4.60^{a}	5.30^{abc}	62.00^{gh}
	TXD 306	0.010^{a}	0.049^{de}	0.07^{i}	3.47^{bc}	13.71^{efg}	14.99^{fgh}	2.90^{a}	3.60^{cd}	4.60^{i}
ANOVA	W	NS	*	*	*	*	*	NS	*	*
	V	NS	*	*	NS	*	*	NS	*	*
	W x V	NS	*	*	*	*	*	NS	*	*
	CV (%)	37.0	17.1	29.6	28.3	11.8	4.1	56.2	20.0	31.5

Means bearing the same letter within the column do not differ significantly at 5% level of significance as analyzed by Tukey's significance test. W100, W75, W50, W25= moisture saturation levels, V = varieties, CV (%) = experimental Coefficient of variation and *** =** the significant difference level at $P \leq 0.05$ and **NS**= Non-significant.

Table 3. Effects of moisture and rice varieties on the yield and yield components of selected rice varieties in Ifakara.

Water regimes	Rice varieties (V)	Panicle length (cm)	Number of panicles/plant	Number of spikelet/panicle	Number of fertile spikelet/panicle	Number of sterile spikelet/panicle	% fertility grain	1000grain weight (g)	Grain yield in (kg)/plant
W100	NERICA1	26.0^{a}	9.0^{def}	209.3^{ab}	190.7^{ab}	18.7^{d}	91.1^{a}	30.2^{a}	5.0 ^{cdef}
	NERICA2	27.7^{a}	11.0 ^{cd}	223.7^{ab}	203.3^{ab}	20.3^{d}	90.9^{a}	27.5^{ab}	5.8^{cd}
	NERICA4	27.0^{a}	10.0 ^{cde}	221.7^{ab}	200.3^{ab}	21.3^{d}	90.5^{a}	29.9^{a}	6.4 ^{c}
	KOMBOKA	23.7^{ab}	21.0 ^{a}	309.0^{a}	248.7^{a}	60.3^{c}	80.2^{ab}	20.7^{abc}	10.7^{ab}
	TAI	22.3^{ab}	19.0 ^{ab}	221.3^{ab}	186.7^{ab}	34.7^{d}	83.8^{ab}	22.9^{abc}	8.0^{bc}
	TXD 306	23.3^{ab}	24.0 ^{a}	232.3^{ab}	202.0^{ab}	30.3^{d}	87.8^{a}	27.1^{ab}	12.9 ^{a}
W75	NERICA1	26.0^{a}	11.0 ^{cd}	181.3 ^{b}	164.3^{abc}	17.0^{d}	90.6^{a}	28.9^{ab}	5.1 ^{cdef}
	NERICA2	27.0^{a}	11.0 ^{cd}	219.3^{ab}	199.0^{ab}	20.3^{d}	90.0^{a}	26.8^{ab}	5.9 ^{cde}
	NERICA4	27.0^{a}	9.0 ^{def}	211.0^{ab}	185.7^{ab}	25.3^{d}	87.5^{a}	28.8^{ab}	5.0^{cdef}
	KOMBOKA	21.7^{ab}	19.0^{ab}	257.0^{ab}	188.7^{ab}	68.3^{bc}	67.3^{ab}	18.3^{abc}	6.0^{cd}
	TAI	26.3^{a}	18.0^{abc}	216.0^{ab}	126.0 ^{bcd}	90.0^{abc}	56.1^{abc}	24.3^{ab}	5.3^{cde}
	TXD 306	22.7^{ab}	18.0^{abc}	237.7^{ab}	186.3^{ab}	51.3^{d}	78.2^{ab}	25.4^{ab}	8.5^{ab}
W50	NERICA1	24.0^{ab}	9.0 ^{def}	160.0 ^{bc}	105.0 ^{cde}	55.0^{d}	65.7^{ab}	27.0^{ab}	2.4^{def}
	NERICA2	26.0^{a}	10.0^{cde}	201.0^{ab}	157.7^{abcd}	43.3^{d}	77.8^{ab}	26.0^{ab}	4.2^{cd}
	NERICA4	23.7^{ab}	8.0 ^{f}	198.7^{ab}	163.7^{abc}	35.0^{d}	82.4^{ab}	26.8^{ab}	3.3^{def}
	KOMBOKA	22.3^{ab}	15.0 ^{b}	167.3^{ab}	114.7^{bcde}	86.0^{bc}	69.4^{ab}	18.6^{abc}	3.3^{def}
	TAI	23.3^{ab}	15.0 ^{b}	192.7^{ab}	115.0^{bcde}	77.7^{bc}	58.4^{ab}	19.6^{abc}	3.4^{def}
	TXD 306	21.0^{ab}	15.0 ^{b}	147.3 ^{bc}	77.3 ^{cdef}	70.0^{bc}	44.0^{bc}	17.1^{bc}	2.8^{def}
W25	NERICA1	23.7^{ab}	6.0 ^{fg}	152.3^{b}	66.3 ^{de}	86.0^{bc}	43.6^{bc}	22.7^{abc}	0.9^{fg}
	NERICA2	25.3^{a}	6.0 ^{fg}	183.7^{ab}	98.3 ^{cde}	85.3^{bc}	53.9^{abc}	24.1^{ab}	1.4^{f}
	NERICA4	21.3^{ab}	6.0 ^{fg}	145.0 ^{bc}	91.3 ^{cde}	53.7^{d}	61.3^{ab}	25.0^{ab}	1.5^{ef}
	KOMBOKA	18.3^{c}	12.0 ^{bc}	198.3^{ab}	29.3^{e}	169.0^{ab}	16.0^{cd}	11.4^{cd}	0.7^{h}
	TAI	20.3^{b}	10.0 ^{cde}	247.0^{ab}	39.7 ^{e}	207.3^{a}	18.0^{cd}	11.7^{cd}	0.8^{fgh}
	TXD 306	18.3^{c}	8.0 ^{f}	176.3^{ab}	0.0^{f}	176.3^{ab}	0.0^{d}	0.0^{d}	0.0 ^{i}
ANOVA	W	*	*	*	*	*	*	*	*
	V	*	*	NS	*	*	*	*	*
	W x V	*	*	*	*	*	*	*	*
	CV (%)	10.2	24.2	23.1	30.1	53.8	19.4	17.3	30.3

Means bearing same letter(s) within the column do not differ significantly at 5% level of significance. W100, W75, W50, W25 indicates water regimes used to irrigate rice based on % saturated condition, V = varieties used in the experiment, CV (%) = Coefficient of variation and *** =** the significance different at P≤ ̲0.05 and **NS**= Non-significant.

the maturity stage there was no significant differences in SDWt among all rice varieties (Table 3), although variety NERICA2 had the highest SDWt in kg per plant (4.33, followed by Tai (3.53), NERICA4 (3.38), Komboka (3.36), TXD306 (3.81) and NERICA1 (2.47) (Table 3).

At 25% moisture saturation, all varieties tested showed no significant differences in SDWt at P ≤ 0.05 during the vegetative stage. NERICA1 had more SDWt (0.014), followed by Tai (0.012), Komboka (0.011), NERICA2 (0.010), TXD306 (0.010), while NERICA4 showed the least SDWt (0.007) (Table 3). During the flowering phase, the lowland rice Komboka, Tai and TXD306 grew relatively bigger than the upland rice (NERICA4, NERICA1, and NERICA4). Variety Komboka grew the biggest (0.052) followed by Tai (0.050), TXD306 (0.049), although no significant differences were found between the lowland and upland rice varieties NERICA4 (0.037) and NERICA1 (0.034). Lowland varieties differed significantly in SDWt with NERICA2 (0.030), although all other upland rice varieties tested were not significantly different in their SDWt (Table 3). At maturity stage, all the upland rice varieties plus the lowland rice variety Tai grew significantly bigger than the other lowland rice varieties Komboka and TXD306 (Table 3). The upland rice varieties NERICA4 (1.58) and NERICA2 (1.44) differed significantly with Komboka and TXD306 lowland rice varieties which grew less with 0.78 and 0.07 kg SDWt respectively (Table 3) although NERICA1 and Komboka did not significantly differ.

Effect of moisture saturation regimes on cumulative transpired water (CTW) of different rice varieties at different growth stages

In general, there was significantly higher interaction between moisture regime and rice varieties with regards to the cumulative transpired water (CTW) at vegetative, flowering and maturity growth stages as shown in Table 2. The mean (CTW) at vegetative, flowering and maturity growth stages were significantly decreased with decreasing soil moisture from the saturated regime of 100% to the lowest saturation regime of 25% (Table 2). No significant differences were observed among the varieties in mean CTW at their vegetative growth stages although NERICA1 transpired most followed by NERICA2, NERICA4, Tai, TXD306 and Komboka (Table 2). However, at flowering and maturity stages, significant differences in mean CTW were observed among the rice genotypes. The lowland rice genotypes (TXD306, Tai and Komboka) had the highest mean transpired water than the upland rice genotypes in all moisture regimes. At flowering, TXD306 variety significantly transpired most followed by Tai and Komboka although the later two varieties were not significantly different. The upland rice varieties (NERICA1, NERICA2, and NERICA4) transpired least and there were no significant differences observed between them; although NERICA1 transpired most followed by NERICA2 and NERICA4. At the maturity stage, TXD306 transpired the most compared to all other varieties tested, Tai and Komboka lowland rice varieties were not significantly different from the NERICA1 which transpired significantly higher than NERICA2 and NERICA4 in that order (Table 2).

At 100% moisture saturation, no significant differences were observed among the varieties in CTW at vegetative growth stages. Although NERICA1 transpired the highest quantity of water in kg/plant (7.89) followed by NERICA2 (7.62), Tai (7.45), TXD 306 (6.78) NERICA4 (6.66), while Komboka transpired the lowest (5.75). At flowering, TXD306 significantly transpired most (25.50) followed by Tai (21.78) and Komboka (20.46), although the latter two varieties were not significantly different. The upland rice varieties transpired least and there were no significant differences observed between them although NERICA1 transpired the highest quantity of CTW in kg/plant (16.71) followed by NERICA 2 (15.06) and NERICA4 (14.91) (Table 2). At the maturity stage, TXD 306 transpired most (36.91) compared to all other varieties tested. Tai (30.40) and Komboka (30.20) the two lowland varieties were not significantly different from NERICA1 which transpired relatively higher (29.50) than NERICA2 and NERICA4 which transpired 27.75 and 27.47 kg water per plant (Table 2) respectively. Generally, at flowering and maturity stages, significant differences in mean CTW were observed among the rice genotypes, whereby the lowland rice genotypes (TXD306, Tai and Komboka) had the highest transpired water than the upland rice genotypes (NERICA1, NERICA2, and NERICA4) (Table 2).

At 75% moisture saturation, all rice varieties transpired relatively equal CTW at vegetative growth stage although the upland rice varieties transpired the most than the lowland rice varieties tested. For the upland rice, NERICA1 transpired the most CWT in kg/plant (7.11) followed by NERICA2 (6.21) and NERICA4 (6.06), while TXD306 (4.98), Komboka (4.91) and Tai (4.84) transpired the least (Table 2). At flowering stage, TXD306 significantly transpired the most (20.39) than all other varieties tested, followed by Komboka (16.93) and Tai (16.31), although Komboka and Tai varieties were not significantly different. All the upland rice transpired least CWT compared to lowland rice varieties and there were no significant differences observed among them although NERICA1 transpired more (14.59) followed by NERICA4 (13.26) and NERICA2 (13.03). At maturity, TXD306 significantly transpired the highest quantity of CTW (30.85) compared to all other varieties investigated, followed by Tai (25.40), NERICA1 (25.28), Komboka (25.11), NERICA4 (23.19) while NERICA2 (19.05) transpired the least (Table 2).

At 50% moisture saturation, no significant differences were observed among the rice varieties in CTW during the vegetative phase of growth. The upland rice transpired relatively higher kg of water per plant (NERICA1 (6.20), NERICA2 (5.89) and NERICA4 (5.58) while the lowland rice transpired the least, that is, 5.43, 5.40 and 5.02 kg per plant for Tai, TXD306, and Komboka respectively (Table 2). During flowering, TXD306 significantly transpired the most kg of water per plant (18.80) than all other varieties tested followed by Tai (14.06) and Komboka (13.66), although the two later varieties were not significantly different. The upland rice varieties were not significantly different in their mean CTW, although NERICA1 transpired relatively higher kg of water per plant (11.39) followed by NERICA2 (11.29) while NERICA4 transpired the least (10.74) CWT per plant (Table 2). At maturity, there were no significant differences among the varieties in CTW, although TXD306 transpired the most kg of water per plant (23.36) followed by Tai (21.50) and Komboka (20.72), while upland rice varieties NERICA1, NERICA4 and NERICA2 transpired the least at 19.24, 18.58, 18.53 kg water per plant respectively (Table 2).

At 25% moisture saturation, all rice varieties relatively transpired insignificant amount of CTW at vegetative stage although NERICA1 transpired the most (4.33) followed by NERICA4 (3.96), Tai (3.64), TXD306 (3.47), NERICA2 (3.61) while Komboka transpired the least (2.79 kg water per plant). At flowering, TXD306 and Tai transpired the most 13.71 and 10.22 kg water per plant respectively followed by Komboka (9.65 kg). Nevertheless, Komboka was not significantly different from the upland rice NERICA1, NERICA4 and NERICA2 which transpired 7.31, 6.84 and 6.48 kg water per plant (Table 2) respectively. At maturity, the lowland rice varieties TXD306, Komboka and Tai transpired the most 14.99, 14.92 and 13.94 kg water per plant than the upland rice varieties which transpired the least CTW (13.09, 12.07 and 10.29 kg of water per plant for NERICA1, NERICA4 and NERICA2) respectively (Table 2).

Effect of moisture saturation regimes on Water use efficiency of different rice varieties at different growth stages

In general, results on water use efficiency (WUE) are shown in Table 2. WUE among the varieties were not significantly different at different soil moisture saturation regimes during the vegetative growth stages at $P \leq 0.05$. However, at the flowering stage, WUE at different moisture regimes was significantly different and increased from the maximum saturation level (100%) towards the lowest (25%) moisture level. At the maturity stage, the WUE at different soil moisture saturated regimes decreased with decreasing moisture saturation in the soils. There was significantly higher interaction between moisture saturation treatments and rice varieties on WUE at both flowering and maturity stages (Table 2).

At 100% moisture saturation, all varieties tested showed no significant differences in WUE at $P \leq 0.05$ during the vegetative stage. Tai, had the highest WUE (0.0035) followed by TXD306 (0.0028), NERICA2 (0.0022), NERICA1 (0.0021), Komboka (0.0019), and NERICA4 (0.0015) (Table 2). During the flowering phase, the lowland rice varieties showed relatively higher WUE than the upland rice varieties. Komboka variety showed the highest WUE (0.0057) followed by Tai (0.004) and NERICA2 (0.004), TXD306 (0.0037), NERICA1 (0.0034), while NERICA4 showed the lowest WUE (0.0024) (Table 2). At maturity, the lowland rice varieties showed significantly higher WUE than the upland rice varieties tested, although Tai was not significantly different from NERICA4 (Table 2). Among the lowland rice varieties, Komboka had the highest WUE (0.396) followed by TXD306 (0.349) and Tai (0.265), while for the upland rice varieties NERICA4 had relatively higher water use efficiency (0.215) followed by NERICA2 (0.200) and NERICA1 which had the lowest WUE (0.172) (Table 2). No significant difference among the upland rice varieties was observed at maturity stage.

At 75% moisture saturation, all the rice varieties did not differ significantly in their WUE at $P \leq 0.05$ during the vegetative phase (Table 2). Tai had the highest WUE (in kg of SDWt/kg of CTW) (0.0047) followed by NERICA2 (0.0022), Komboka (0.0022), NERICA4 (0.0021), while NERICA1 and TXD306 showed the lowest WUE 0.0019 and 0.0019, respectively. During the flowering stage no significant differences in WUE were observed among the rice varieties although Komboka showed the highest WUE (in kg of SDWt/kg of CTW) (0.0058) followed by NERICA2 (0.0048), NERICA1 (0.0040), Tai (0.0038), TXD306 (0.0036) while NERICA4 showed the lowest WUE (0.0032) (Table 2). At maturity phase, all the rice varieties tested had no significant differences in WUE at $P \leq 0.05$, although NERICA2 had the highest WUE (in kg of SDWt/Kg of CTW) (0.309) followed by TXD306 (0.283), Komboka (0.262), Tai (0.221), NERICA4 (0.207), while NERICA1 (0.205) had the least WUE (Table 2).

At 50% moisture saturation, no significant differences were observed among the rice varieties for WUE (Table 2). Tai had the highest WUE (in kg of SDWt/Kg of CTW) (0.0042) followed by Komboka (0.0030), NERICA4 (0.0026), TXD306 (0.0025), NERICA1 (0.0022), while NERICA2 was the least in terms of WUE (0.0021) (Table 2). During flowering stage, Komboka, a lowland rice variety had significantly higher WUE (in kg of SDWt/Kg of CTW) (0.0068) than NERICA4 (0.0034) and NERICA1 (0.0036) upland rice varieties, but it was not significantly different from Tai (0.0047), TXD306 (0.0042) and NERICA2 (0.0042) rice varieties (Table 2). Among the lowland varieties tested, Komboka had the highest WUE followed by Tai, TXD306, while the upland rice variety, NERICA2 had the highest WUE followed by NERICA1 and NERICA4 showed the lowest WUE. However, there were no significant differences in WUE among the upland rice varieties (Table 2). At maturity stage, NERICA2 had significantly higher WUE than NERICA1, NERICA4 and TXD306 rice varieties (Table 2). NERICA2 showed the highest WUE (in kg of SDWt/Kg of CTW) (0.235) followed by Tai (0.184), Komboka (0.184), NERICA4 (0.167), NERICA1 (0.128), while TXD306 had the lowest WUE (0.122) (Table 2). NERICA2, Tai and Komboka were not significantly different in their WUE, while NERICA 2 was observed to be significantly different from NERICA1, NERICA4 and TXD 306 (Table 2).

At 25% moisture saturation, there were no significant differences in WUE observed among the rice varieties (Table 2). At vegetative stage, Tai (0.0046) had the highest WUE followed by NERICA1 (0.0035), Komboka (0.0031), NERICA2 (0.0029), TXD306 (0.0029), while NERICA4 had the least WUE (0.0017) (Table 2). At flowering stage, Komboka had significantly higher WUE (0.0097) than all other lowland rice varieties tested followed by Tai (0.0053), and TXD306 (0.0036) while for the upland rice varieties there were no significant differences in WUE at ($P \leq 0.05$). NERICA2 had the highest WUE (0.0046) followed by NERICA1 (0.0044) and NERICA4 (0.0038) (Table 2). At maturity stage, TXD306 had significantly the lowest WUE (0.0046) compared to all other varieties tested (Table 2). Nonetheless, NERICA2 (0.147) had the highest, followed by NERICA4 (0.118), NERICA1 (0.081), Komboka (0.069) and Tai (0.062) (Table 2).

Effects of soil moisture saturation regimes on yields and yield components of selected rainfed rice varieties

Results of the effects of different soil moisture saturation regimes on the yield and yield components are shown in Table 3. The yields and yield components of selected rice varieties including the number and length of panicles per plant, total number of spikelets per panicle, number of fertile spikelets per panicle, percentage fertility grain ratio, 1000-grain weights and the total grain yields per plant were significantly affected by soil moisture saturation regimes and the rice genotypes investigated (Table 3). Most yield components significantly decreased with decreasing soil moisture saturation while the mean number of sterile spikelets per panicle significantly increased with decreasing soil moisture saturation (Table 3). The mean panicle length, percentage grain fertility ratio, and 1000-grain weights were significantly higher in upland rice varieties than in the lowland rice varieties at $P \leq 0.05$ (Table 3). The total number of panicles per plant, number of sterile spikelets per panicle, and the total grain yield per plant were significantly higher in the lowland rice varieties than in the upland rainfed rice varieties at ($P \leq 0.05$). There was a significantly higher interaction between soil moisture level treatment and varieties treatment on the total grain yields, and all yield components investigated at maturity growth stages (Table 3).

At 100% moisture saturation, all the lowland rice varieties TXD306, Tai and Komboka attained 24, 19 and 21 panicles per plant respectively which were also significantly higher than those of the upland rice NERICA1, NERICA2, and NERICA4 which had 9, 11 and 10 panicles per plant respectively. There were no significant differences in the total number of spikelets per panicle and number of fertile spikelets per panicle among the lowland and upland rice varieties due to different levels of moisture stress (Table 3). Panicle lengths, % fertile grain and 1000-grain weights of upland rice varieties were relatively higher compared to those of the tested lowland rice varieties. Komboka had a relatively higher number of sterile spikelets per panicle than all other varieties tested, although all lowland rice varieties had a relatively higher number of sterile spikelets per panicle than all the upland rice varieties (Table 3). The grain yields of all the lowland rice varieties at 100% moisture saturation level were significantly higher than those of the upland rice varieties. TXD306 had the highest grain yield (12.9 kg) per plant, followed by Komboka (10.7 kg), and Tai (8.0 kg per plant), although the later two were not significantly different in grain yield per plant (Table 3). For the upland rice, NERICA4 had relatively high grain yield per plant (6.4 kg) than the other two upland rice varieties NERICA1 (5.0 kg) and NERICA2 (5.8 kg), although these weights were not significantly different (Table 3).

At 75% moisture saturation, the lowland rice varieties were significantly higher in the number of panicles per plant and number of sterile spikelets per panicle than the upland rice varieties investigated (Table 3). The panicle lengths, % fertile grain and 1000-grain weights of upland rice varieties were relatively higher compared to the lowland rice varieties tested. Yield components including the total number of spikelets per panicle and number of fertile spikelets per panicle were not significantly different among the rice genotypes investigated. Grain yields per plant of the lowland rice variety TXD306 (8.5 kg) were significantly higher than all other varieties tested at $P \leq 0.05$, that is, Komboka, NERICA2, Tai, NERICA1, and NERICA4 which registered 6.0, 5.9, 5.3, 5.1 and 5.0 kg of grain yield per plant respectively (Table 3).

At 50% moisture saturation, the lowland rice varieties TXD306, Tai and Komboka had significantly higher number of panicles per plant (15 panicles each) and number of sterile spikelets per panicle 70, 78 and 86 respectively than the upland rice varieties NERICA1, NERICA2 and NERICA4, which produced significantly lower number of panicles per plant 9, 10, and 8 respectively as well as the number of sterile spikelets per panicle that is 55, 43 and 35, respectively (Table 3). NERICA2 and NERICA4 had the highest number of spikelets per panicle and number of fertile spikelets per panicle than all other rice varieties investigated, that is, 201 and 199 spikelets per panicle respectively as well as

Table 4. Moisture requirement (CTW or Tr), grain yields GY) and water productivity (WP) at different moisture regimes for selected upland and lowland rainfed rice.

Water regimes (W)	Varieties (V)	Total (CTW or Tr) in (Kg/plant)	(GY) produced (Kg/plant)	Water Productivity (WP)
W100	NERICA1	29.5^{b}	5.0^{cdefg}	0.17^{bc}
	NERICA2	27.8^{bc}	5.8^{cde}	0.21^{bc}
	NERICA4	27.5^{bc}	6.4^{cd}	0.23^{bc}
	Komboka	30.2^{b}	10.7^{ab}	0.36^{a}
	Tai	30.2^{b}	8.0^{bc}	0.27^{ab}
W75	TXD306	36.9^{a}	12.9^{a}	0.35^{a}
	NERICA1	25.3^{bcd}	5.0^{cdefg}	0.20^{bc}
	NERICA2	19.1^{efg}	5.9^{cde}	0.31^{a}
	NERICA4	23.2^{cde}	5.0^{cdefg}	0.22^{bc}
	Komboka	25.1^{bcd}	6.0^{cd}	0.24^{bc}
	Tai	25.4^{bcd}	5.3^{cdef}	0.21^{bc}
W50	TXD306	30.9^{b}	8.5^{bc}	0.27^{ab}
	NERICA1	19.2^{efg}	2.4^{defghi}	0.12^{ef}
	NERICA2	18.5^{efgh}	$4.2^{cdefghi}$	0.23^{ab}
	NERICA4	18.6^{efgh}	3.3^{defghi}	0.18^{bc}
	Komboka	20.7^{def}	3.3^{defghi}	0.16^{cd}
	Tai	21.5^{de}	3.4^{defghi}	0.16^{cd}
	TXD306	23.4^{cde}	2.8^{defghi}	0.12^{ef}
W25	NERICA1	13.1^{hi}	0.9^{ghi}	0.07^{fg}
	NERICA2	10.3^{i}	1.4^{fgh}	0.13^{de}
	NERICA4	12.1^{i}	1.5^{efg}	0.13^{de}
	Komboka	14.9^{fghi}	0.7^{hi}	0.05^{fg}
	Tai	13.9^{ghi}	0.8^{ghi}	0.06^{ef}
	TXD306	15.0^{fghi}	0.0^{i}	0.00^{g}
ANOVA	W	*	*	*
	V	*	*	*
	W x V	*	*	*
	CV(%)	4.1	30.3	31.5

W100, W75, W50, W25 = moisture regimes used based on % soil moisture saturated in the pot, Means bearing the same letter(s) within the column do not significantly differ at 5% level of significance by Tukey's significance test.

158, 164 fertile spikelets per panicle respectively (Table 3). The grain yield in kg/plant of NERICA2 (4.2) was significantly higher than all other varieties tested, followed by Tai (3.4), NERICA4 (3.3), Komboka (3.3), TXD306 (2.8) and NERICA1 (2.4) (Table 3).

At 25% moisture saturation, all upland rice varieties NERICA4, NERICA2 and NERICA1 as well as the lowland rice variety Tai had significantly longer panicle length, number of fertile spikelets, % fertility grain, 1000-grain weights and grain yields per plant than the lowland rice varieties Komboka and TXD306 (Table 3). However, the lowland rice varieties (TXD306, Tai and Komboka) had a significantly higher number of panicles per plant, number of spikelets per panicle and number of sterile spikelets per panicle.

Water productivity (WP) of selected upland and lowland rice varieties

The water consumption estimated from the total cumulatively transpired water (CTW or Tr) through the plants from germination to harvest, and the grain yield produced under different soil moisture regimes were used in calculating the water productivity efficiency (WP) summarized in Table 4.

At 100% soil moisture saturation, all lowland rice varieties recorded significantly high WP value compared to the upland rice varieties. From the lowland rice varieties, the improved varieties Komboka and TXD 306 portrayed the highest WP value of 0.36 and 0.35 respectively, while Tai variety was the least productive with WP value of 0.27 (Table 4). From the upland rice varieties, NERICA4 showed highest WP value of 0.23 among the upland rice, followed by NERICA2 with 0.21 and the least productive variety among the upland rice was NERICA1 with only 0.17 WP (Table 4).

At 75% soil moisture saturation, the improved rice variety for lowland, TXD 306 recorded high WP value of 0.27, followed by Komboka with 0.24 and Tai lowland variety was the least productive at this moisture saturation with WP value of only 0.21 (Table 4). For the upland rice varieties, NERICA2 indicated the highest water productivity efficiency value of 0.31, followed by NERICA4 which had WP value of 0.22, while NERICA1 recorded the least productivity efficiency value of only 0.20 (Table 4).

At 50% soil moisture saturation, the upland rice varieties NERICA2 and NERICA4 recorded the highest productivity ability with water productivity efficiency value of 0.23 and 0.18, respectively (Table 4). NERICA1 was the least productive variety at this soil moisture saturated condition with WP value of 0.12. For the lowland rice varieties, Tai and Komboka varieties had the highest WP value of 0.16 each, while TXD 306 was the least productive variety at this soil moisture regime with WP value of only 0.12.

At 25% soil moisture saturation, the upland rice varieties performed better compared to the lowland rice varieties in terms of water productivity. NERICA2 and NERICA4 recorded higher productivity ability with WP value of 0.13 each, while NERICA1 showed the least WP value of 0.07. Among the lowland rice varieties used, Tai had the highest productivity ability with WP value of 0.06, followed by Komboka with WP value of 0.05, while TXD306 did not produce any grain at all at this saturation levels (Table 4).

DISCUSSION

Water requirement of selected rice varieties

Water requirements for maximum productivity in many crops including rice are the functions of genotypes, management and environmental or atmospheric demand. The water requirements of upland rice varieties were lower than those of the lowland rice varieties regardless of the soil moisture levels, varieties and stage of growth. Considering the long vegetative growth duration of lowland rice between 78 - 87 days, and their high number of tillers per plant observed possibly were responsible for the higher water use rate of the lowland rice varieties tested. On the other hand, the short growth duration to maturity stages of between 95-98 days observed for the upland NERICAs rice varieties previously reported in Katrin (2013) and WARDA (2008) could have been responsible for saving on water consumption during the entire growth periods, leading to small amount of transpired water. A consistently decreasing trend in the total transpired water was found to follow the decreasing soil moisture saturation regimes in comparison to optimally saturated soil (100%) used as the control. These finding agreed with those of Sikuku et al. (2010) who reported on pot grown rice plants that were irrigated with one liter (1 L) of water at different intervals of irrigation to create different moisture levels and found a decrease in transpiration rate following a decrease in the soil moisture contents. Also, similar results were reported by El Hafid et al. (1998) in wheat.

In the present study, TXD 306 variety recorded significantly higher transpired water at all soil moisture saturation levels and maturity stages than all other rice varieties except at 25% where the transpired water was relatively the same as other lowland varieties Tai and Komboka and the upland rice variety NERICA1. The condition could be related to its long vegetative growth stage, large leaf area conferred by higher number of tillers at 100, 75 and 50% that might have contributed to higher water loss through plant body surfaces (Figure 1B and 1C). At higher soil moisture, the lowland rice variety Komboka and Tai were not significantly different from NERICA1, NERICA2 and NERICA 4 in the total transpired water possibly because there was no requirement for water conservation.

Assessment of the amount of water transpired based on growth stages revealed that the highest water transpired by the upland rice occurred from flowering to maturity or at grain filling growth stages, in contrast with the lowland rice varieties which showed their highest transpired water from the vegetative to flowering growth stages. This could be associated with increased photosynthetic activities during the grain filling growth stages for upland rice investigated, while in the lowland could be due to the increased number of tillers and panicle initiation activities which required a higher amount of water.

Similar results were observed by Kitilu (2011) who reported higher water uptake in upland NERICA rice varieties during the flowering to maturity or grain filling growth stages compared to other lowland and upland rice varieties which showed higher water uptake during vegetative to flowering growth stages under pot experiments. In this regard, long vegetative to flowering growth stages in lowland rice, and panicle initiation activities required higher amount of water for new panicle growth and development to attain their morphological and physiological functioning, while mobilization of dry matter accumulated in stem and leaves in rice required a lot of water for processing dry matter to move into spikelet for grain filing processes.

Water use efficiency

In the present study, water use efficiency (WUE) estimated from total above ground biomass dry weights per cumulative transpired water (CTW) in all selected upland and lowland rice varieties were constant during the vegetative stage while slight differences were observed at flowering and maturity growth stages regardless of moisture status. These results agreed with those reported by Kobata et al. (1996) and Kitilu (2011) who found that WUE calculated from dry matter increase per weight of transpired water was stable under diverse soil water conditions, but differed slightly between cultivars. According to Kobata et al. (1996), the varietal differences in WUE were associated to stomatal conductance which was observed to vary among genotypes and higher transpiration rates in some upland rice at flowering to maturity growth stages. Moreover, in other plant species, there were some observations which reported a high constant WUE calculated from dry matter increase per transpiration rate (de Wit et al*.,* 1958; Ludlow and Muchow, 1990).

The WUE at 50 and 25% moisture saturation in the upland rice varieties were found to vary between 0 - 53% from the 100% soil moisture saturation, while in the lowland rainfed rice varieties, WUE at 75 and 50% moisture saturation differed by 20 - 69% from the control moisture saturation regime. Current observations were in contrast with those of Kono et al. (1987) who reported that WUE of lowland and upland rice cultivars in drying soil hardly differed more than 20% compared to wet control plants. Moreover, WUE of all varieties tested under the same moisture saturation were reported to have no significant differences regardless of ecosystems (Kobata et al*.,* 1996).

Grain yields

In the present study, the grain yields of both lowland and upland rice varieties tested were higher at 100% moisture saturation regime than at the lower soil moisture saturation of 75, 50 and 25%. This was attributed to reduction in the number of panicles per plant, lower total number of spikelets per panicle, small number of fertile spikelets, and reduced grain filling resulting in lowered 1000-grain weights. These findings were also in line with those of Bouman et al. (2005) and Rahman et al. (2002) who reported yield reduction under upland condition due to lower number of spikelets per panicle in comparison with the yield performance in flooded conditions. Changing the soil moisture saturation from 100 to 75%, caused a significant reduction of about 34 - 44% in grain yields for lowland rice genotypes; while in the upland, rice genotypes reduction was less only 22% reduction in NERICA4. The other upland rice varieties NERICA1 and NERICA2 indicated a slight increase of up to 2% in grain yields with such decrease in soil moisture saturation attributed to favourable upland condition of the pots grown plants, which is the requirement of the upland improved rice varieties tested. A similar observation was reported by Yang et al. (2005), who compared yields of upland and lowland rice cultivars at (80 - 90%) soil moisture saturation and found the reduction of about 32% grain yields in both the upland and lowland varieties compared to the optimal soil moisture saturation.

Water productivity and efficiency

Varietal diversity on water productivity (WP_{CTW}) was observed between the lowland and upland rice varieties investigated. Water productivity of lowland rice decreased with decreasing soil moisture saturation from 100 to 25% soil moisture status, while the water productivity of upland rice varieties increased with decreasing soil moisture saturation from 100 to 75% and slightly decreased with decreasing moisture saturation in soils (Table 4). Water productivity of upland rice varieties was the highest at 75% moisture saturated condition with WP_{CTW} value ranging from 0.20 - 0.31 kg grain kg^{-1} water. While water productivity of lowland rice varieties was higher, at 100% soil moisture saturated condition with WP_{CTW} value ranged from 0.27 - 0.36 kg grain kg^{-1} water (Table 4). These findings were in contrast to the water productivity WP_{ET} reported by Bouman et al. (2005) that water productivity with respect to the amount of water evaporated and transpired (WP_{ET}) under saturation soil condition ranging from 0.0015 - 0.0021 kg grain kg^{-1} water, and in lower water saturation condition or aerobic condition WP_{ET} ranging from 0.001 – 0.0018 kg grain kg^{-1} water.

In the present study, high water productivity of about 37 - 40% in lowland rice varieties at 100% moisture saturation condition were reported compared to the upland rice tested implying that, the lowland rice varieties had high suitability to grow and yield in saturated soil water condition. However, at lower soil saturation condition the upland rice varieties had the highest productivity value of about up to 30% than those of lowland rice varieties. These observations imply that the upland rice varieties are highly adapted to low moisture environments in comparison to the lowland rice varieties, though the grain yield was slightly lower at lower moisture saturated condition. These finding agreed with the observation by Bouman et al. (2005) who reported that water productivity in the low soil moisture plots was up to 45% higher than those in the higher soil moisture saturation plots. Nevertheless, the grain yield was lower in the lower soil saturated condition than in the moisture saturated condition. Kato et al. (2006) also reported higher productivity of Nippon bare rice variety under the upland condition and that the water productivity of 2.4 to 5.1 times was more than the water productivity value of the same rice cultivar at 100% soil moisture.

Conclusion

From the present study, it was concluded that, TXD306, Tai and Komboka have higher moisture requirement and transpiration for optimal yields and that the soil moisture saturation regime at 100% was the optimal moisture for these rice varieties. While upland rice varieties have less moisture requirement and transpiration for optimal yield, 75% soil moisture saturation was the optimum moisture requirement for the upland rice varieties (NERICA1, NERICA2, and NERICA4). In the lower soil moisture regime of 25%, NERICA2 and NERICA4 had the highest water productivity of about 53.85 and 61.54% higher than that of Tai and Komboka lowland rice varieties respectively, with NERICA2 and NERICA4 having higher grain yield and water productivity value than all other varieties. Therefore, NERICA2 and NERICA4 rice varieties are the most recommended varieties under lower moisture condition. Among the lowland rice varieties, TXD 306 was the most susceptible rice variety to low moisture saturation and failed to produce any grain at 25% moisture saturation. In that regard, TXD306 is not recommended for rainfed production under moisture scarce conditions.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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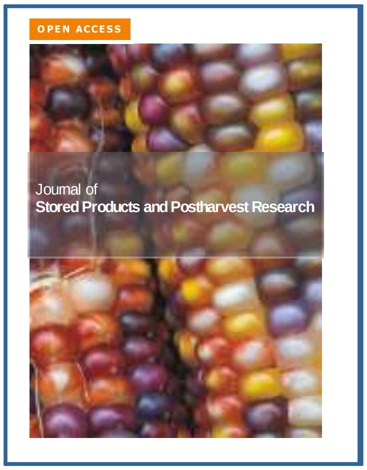
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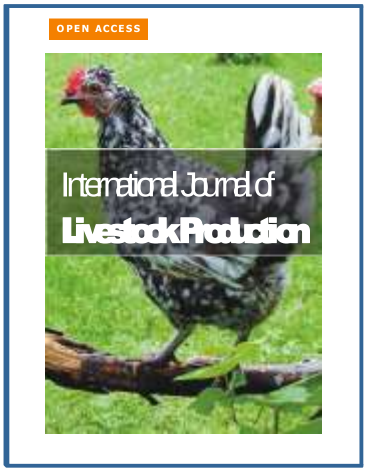
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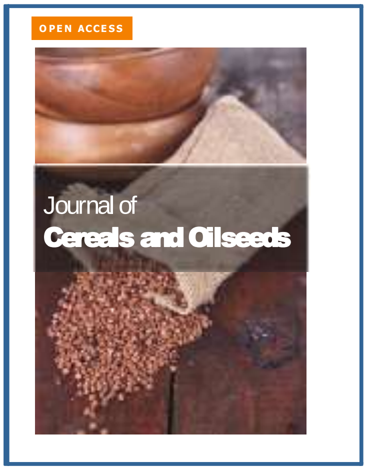
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