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Water Response of Upland Rice Varieties Adopted in Sub-Saharan Africa: A Water Application Experiment

Shunsuke Matsumoto[1], Tatsushi Tsuboi[2], Godfrey Asea[3], Atsushi Maruyama[1], Masao Kikuchi[1] and Michiko Takagaki[1]*

[1]*Graduate School of Horticulture, Chiba University, Chiba, Japan*
[2]*JICA Expert, JICA Uganda Office, Kampala, Uganda*
[3]*National Crops Resources Research Institute, Kampala, Uganda*

Abstract

Whether a rice Green Revolution in sub-Saharan Africa becomes a reality critically hinges on how far productive upland rice cultivation diffuses in the region. In order to quantify the drought tolerance, the rate of water response and the contribution of yield components to changes in yield due to water availability of upland rice varieties used in sub-Saharan Africa, we conducted water application experiments in Namulonge, Uganda, using NERICA 4, NERICA 10, NARIC 2 and Yumenohatamochi, with five different levels of water application. We found that the NERICA varieties were most drought tolerant, followed by NARIC 2. Yumenohatamochi did not withstand the lowest amount of water application of 378 mm. The results suggested that the minimum water requirement was around 311-400 mm per season for the three varieties used widely in East Africa, and around 420-600 mm for Yumenohatamochi, an upland variety in Japan famous in its drought tolerance. It was estimated that an additional water application of 1 mm increased rice yield by 11-12 kg /ha for the upland varieties tested. The high water response of upland rice was brought about by high water response of four yield components, among which the rate of grain filling contributed most to the increase in yield, followed by number of panicles/m^2, number of grains per panicle and 1000 - grain weight, in the order of the degree of contribution, for all the varieties tested.

Keywords: Drought tolerance; NERICA; Minimum water requirement; Uganda; Yield component

Introduction

Since a series of NERICA varieties (interspecific *Oryza sativa x O. glaberrima* progenie) were developed in the late 1990s by the Africa Rice Center (then WARDA), upland rice has been expected to catalyze a rice green revolution in sub-Saharan Africa where nearly 50% of land area planted to rice is upland, with the other half under rainfed lowland [1,2]. Such expectation has met mixed results due partly to the vulnerability of upland rice cultivation to drought [3,4].

There have been studies on the impacts of water deficit, water stress and drought on the growth and yield of upland rice [5-13], but all of them are conducted in Asia and Australia using *Oryza sativa* cultivars. Studies on the relationship between water and the yield of NERICA varieties in sub-Saharan Africa have been burgeoning, but reliable studies on drought tolerance and water response are still scarce in spite of its importance in promoting upland rice cultivation in the region. The yield response of NERICA varieties under different levels of water availability is reported [14,15], but the water application levels in these studies are 700-1200 mm per crop in the former and 1700-3000 mm per crop in the latter, both without controlling rainfalls.The relationship between yield and soil moisture using NERICA varieties is reported [16], but the soil moisture contents tested are 50-70%. Farmers in sub-Saharan Africa are attempting to plant upland rice in many upland areas that are prone to drought with rainfall less than 600 mm per crop season [2], and critical soil moisture contents for the growth of upland rice are 40% and below [8,13]. More studies that focus on lower levels of water availability are needed.A rice production manual for East African countries recommends upland rice cultivation using NERICA varieties in areas where 5-day rainfalls of 20 mm for about 90 days (360 mm /crop) are available, based on the results of experiments that test the effects of water application on the yield of NERICA 4, without presenting any detail of the experiments [17].

Information on the drought tolerance of NERICA and other upland rice varieties grown in sub-Saharan Africa and their response to water is critically important not only for rice research in the region, in particular for breeding drought-tolerant upland rice varieties [18], but also for developing adequate cultural practices suited to the environmental conditions in the region and disseminating upland rice cultivation among upland farmers there. With a basic purpose of reinforcing related information for researchers, extension workers and policy makers in sub-Saharan Africa, this paper reports the results of water-application experiments conducted in Uganda, aiming at clarifying the drought tolerance and water response of upland rice varieties adopted in sub-Saharan Africa. More specifically, this paper intends to (1) elucidate drought tolerance in terms of the minimum water requirement of upland rice varieties adopted widely in sub-Saharan Africa, (2) quantify how the upland rice varieties respond to changes in water availability, and (3) examine how yield components contribute to the increase in yield as water availability increases.

Materials and Methods

Experiments

Experiments were conducted from March to July 2012 (126 days) in the National Crops Resources Research Institute (NaCRRI) in Namulonge, Uganda (latitude 00°30’46.4N, longitude 32°38’03.6E, altitude 1120 m), using wooden boxes placed in a glass-roofed, screen-

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***Corresponding author:** Michiko Takagaki, Chiba University, Chiba, Japan, Tel: +81-47-308-8934; Fax: +81-47-308-8934; E-mail: mtgaki@faculty.chiba-u.jp

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walled greenhouse that shut out rainfall perfectly but kept sunlight and atmosphere the same as outside.

The planting boxes, measuring 1 m × 1 m × 0.7 m (width × length × depth), were made in such a way that the four walls were shielded by plastic sheet and the bottom was with holes the total area of which took one tenth of the bottom area, and filled up with soil taken from the top soil (0-50 cm deep from the soil surface) of an upland field in the NaCRRI. The soil composed of 55% of sand, 35% of clay and 10% silt, with pH of 5.6.

Upland rice varieties used in the experiments were NERICA 4 (henceforth denoted N4), NERICA 10 (N10), NARIC 2 (Naric), and Yumenohatamoti (Yume).The characteristics of the varieties used are found in previous studies[19-23]. N4, N10 and Naric are upland rice varieties formally released in Uganda [24], and hereafter grouped as 'African varieties' for the convenience of comparison with Yume, an upland variety in Japan famous in its drought tolerance.

Seeds were sown by dibbling 6 hills at a space of 30 cm ×15 cm (22.2 hills /m^2) and 4 varieties were planted in a box. Fertilization was conducted following the recommended rates: N-P-K = 60-30-30 kg / ha, 30 kg N, 30 kg P and 30 kg K applied as basal, 30 kg N applied at 30 days after sowing.Weeds were pulled out whenever emerged and no pest control was needed.

Five treatments for water application were adopted: T-1 = 21 mm /week (3 mm/day) x 18 (total water application = 378 mm), T-2 = 28 mm /week (4 mm /day) x 18 (504 mm), T-3 =35 mm /week (5 mm/day) x 18 (630 mm), T-4 = 42 mm/week (6 mm /day)x 18 (756 mm), T-5 = 49 mm /week (7 mm/day) x 18 (882 mm).The lowest water application treatment was set to be lower than the level of 4 mm /day, which is stated as the minimum rainfall for NERICA cultivation [17]. Actual water applications were made every Monday and Friday at the ratio of 4:3, for 18 weeks. Each water application treatment was replicated four times.

Data were collected on the following parameters: (1) total above-ground dry matter weight at harvest, (2) yield, (3) yield components; number of panicles /hill, number of grains /panicle, rate of grain filling and 1,000-grain weight, and (4) soil moisture content measured every day until 17th week after sowing by a soil moisture meter (DIK-312A; Daiki Rika Kogyo Co. Ltd.). Yield componentswere fully enumerated for all the six hills, and yield and above- ground dry matter weight were measured by uprooting the entire plants.

Methods

First, we examined the drought tolerance of the rice varieties by means of a simple correlation graph between yield and the total quantity of water applied, with fitted regression lines, distinguishing between 'African varieties' and Yume. Rough, but practically useful estimates of the minimum level of water required for the upland varieties were obtained by reading the coordinate in the graph of the intercepts made by the regression lines on the axis of the total quantity of water applied.

Second, in order to quantify the response of yield, total dry matter and the four yield components to the total quantity of water applied, we estimated linear water-response functions for these factors. Taking yield as an example, the water-response function we estimate is expressed as follows:

$$\mathrm{Y}_i = \alpha + \beta W_i + \left(\sum_{K=1}^{K} \gamma_k V_{k,i}\right) + \left(\sum_{K=1}^{K} \delta_k V_{k,i} W_i\right) + \in_i \quad \mathrm{i} = 1, 2, \ldots, N \qquad (1)$$

where$Y$ = yield (kg/ha), W = total water applied (mm), V_k = dummy variable for variety (V_k= 1 if k-th variety, = 0 otherwise), ε = random error, N = number of observations, and α,β,γ,δ are regression coefficients to be estimated. Note that Equation (1) has the same structure as the two-factors-with-cross-effect ANOVA model which can be expressed as $Y_{ikw} = \mu + \rho_k + \varphi_w + \omega_{kw} + \in_{ikw}$, where μ = overall mean, ρ_k =effect of variety, φ_w=effect of water application, ω_{kw}=interaction effect between variety and water application, ε_{ikw}= random error, k = four varieties, and w = five water treatments. A difference in Equation (1) from the ANOVA is that water is treated as a continuous variable, not categorical as in the ANOVA. Indeed, the estimation of Equation (1) performs what the ANOVA model is designed to perform, and in addition, quantifies the effects of water, variety and their cross-term on yield [25]. A simple rearrangement of Equation (1) gives:

$$\mathrm{Y}_i = \alpha + \left(\sum_{K=1}^{K} \gamma_k V_{k,i}\right) + \left(\beta + \sum_{K=1}^{K} \delta_k V_{k,i}\right) W_i + \in_i \qquad (2)$$

The second term in the right hand side of Equation (2) shows that the intercept of this water- response function could be different by variety (intercept dummies), and the third term shows that the effects of water on yield (the slope of the response function) could be different by variety (slope dummies). In the estimation, all the explanatory variables were 'centered' by converting all the observations to mean deviations in order to avoid multicolinearlity [25]. Note that the overall intercept term (α) in a 'centered' regression is the mean of dependent variable, yield in this example. The estimation of Equation (1) was made for all the varieties and for 'African varieties' separately. In the estimation for all the varieties, dummy variables were set for N4, N10 and Naric, using Yume as the base of comparison.In the estimation for 'African varieties', dummy variables were set for N10 and Naric, using N4 as the base of comparison.

Third, the contribution of changes in the yield components due to the changes in water availability to the change in yield is assessed by means of the additive decomposition of changes in a variable which is a product of other variables. Define yield as Y = P·S·R·G, where Y = yield, P = number of panicle/m^2, S = number of grains /panicle, R = rate of grain filling and G = 1000-grain weight. Differentiating Y with respect to the total quantity of water applied (W) and dividing through the differentiated equation by Y, we obtain $\left(\frac{dY}{dW}\right)/Y \left(\frac{dP}{dW}\right)/P \left(\frac{dS}{dW}\right)/S + \left(\frac{dR}{dW}\right)/R + \left(\frac{dG}{dW}\right)/G$, that is, the rate of change in Y is decomposed into the rates changes in P, S, R and G. Taking the derivative of Equation (2) with respect to W for P, S, R and G, and computing the rate of change for respective components for respective varieties, we can compute the relative contribution of these components to the changes in yield by variety. Since the decomposition equation is an approximation when differences (Δx) are used instead of differentials (dx), the left-hand side of the equation does not necessarily exactly tally with the right-hand side. For the computation of the percentage contribution of the components, we used the summation of the rates of changes in the right-hand side as the rate of change in yield. The decomposition was made for lower and higher water application levels separately, and for the 'mean' using the derivatives obtained from the estimated water response functions.

As will be presented in the next section, Yume did not withstand low levels of water application, resulting in no yield in five replications. Since the inclusion of zero-yield observations results in overestimations of water response, we excluded these five observations, which made the total number of observations used in the analyses 75. Throughout the paper, we adopted three levels of significance levels for hypothesis testing, $p<0.001$, $p<0.01$ and $p<0.05$, with the symbols of ‡, † and *, respectively.

Results and Discussion

The mean minimum daily temperature in the greenhouse during the period of the experiment was 15.7°C (standard deviation = 1.1°C), the mean maximum daily temperature was 28.4°C (1.3°C) and the average daily temperature was 22.1°C (0.9°C).

Weekly average soil moisture contents were shown in Figure 1 for T-1 (the lowest water application) and T-5 (the highest water application), which ranged 6.9 – 13.8% with the mean of 9.9% for T-1 and 10.1 – 20.0% with the mean of 14.5% for T-5. The trends of the moisture contents at the later stages of growth indicated that the rice plants reached the harvesting stage by 14th week (98 days) after sowing. These levels of soil moisture contents are comparable to those of a study that uses upland rice varieties obtained from IRRI grown in chambers [8] and those of a study that uses NERICA varieties grown in open upland fields at IITA, Nigeria [15], but lower than the levels of soil moisture contents reported by previous studies conducted in Australia and Asia [7,13].

The results of the experiment were shown in Table 1. At the lowest level of water application, N4 and N10 yielded 0.50 t /ha and 0.68 t /ha, respectively. Though very low, Naric also yielded 0.10 t /ha. However, Yume failed to reach the flowering stage. The yield of N4 and N10 jumped up to more than 3 t /ha at the second water application and that of Naric to 1.8 t /ha. In contrast, Yume gave no yield in one of replications at the second water application level, with the average yield in the rest of three replications of 0.35 t/ha, and it was at the fourth level of water application for the yield to exceed the 3 t /ha line. At higher levels of water application, yield reached around 6 t /ha for all the varieties tested. Total dry matter weight and all the four yield components also increased as the water application level went up.

Drought tolerance

Seventy five non-zero yield observations were plotted in Figure 2 against the total quantity of water applied, distinguishing 'African' varieties from Yume. Higher drought tolerance of 'African varieties' over Yume was apparent. The regression line for 'African varieties' intersected with the horizontal axis at 310 mm of water applied, and gave the yield of around 1 t /ha at the water availability of 400 mm per crop season. Taking into account the result that the rice plants reached maturity by 98 days after sowing (Figure 1), 311 mm (400 mm /126 days x 98 days) of water brought about the yield of around 1 t /ha for 'African varieties', which may be called the safe minimum water requirement. For Yume, the corresponding safe minimum water requirement was computed as 467 mm. These results suggested that 'African varieties' were more tolerant to drought than Yume by 33% in terms of the safe minimum water requirement. The results for 'African varieties' confirm that the recommended level of rainfall for NERICA cultivation of 360 mm per crop [17] is beyond the safe minimum level of 311 mm.

We failed to find out any literature on the minimum water requirement of upland varieties used in sub-Saharan Africa to compare with our results. For outside Africa, it is reported that the threshold rainfall for upland rice cultivation in Asia and Latin America is 200 mm/month, or 600 mm for a crop season of three months [26,27]. Comparing the results of water-application experiments for upland rice conducted in Australia [28,29], USA [30] and Asia [9,13,31], it is shown that the minimum water supply level tested is 419 mm /crop [12]. Though for rainfed lowland ecosystem, it is reported that rice production is virtually impossible with rainfall below 450 mm/crop [32]. These observations point to the high drought tolerance of 'African varieties', of N4 and N10 in particular.

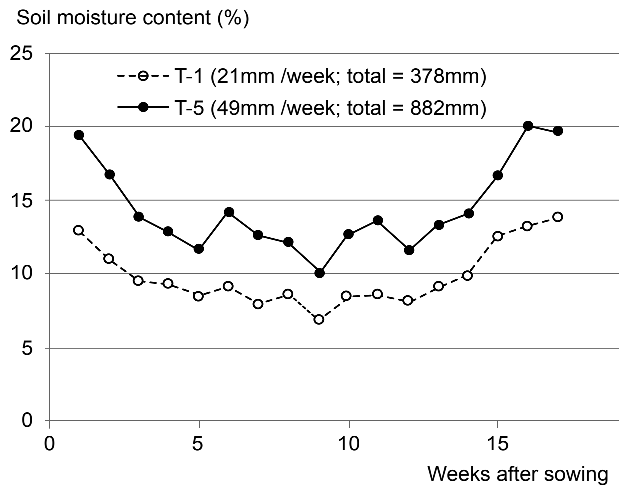

Figure 1: Soil moisture content of T-1 and T-5, measured at the depth of 10 cm from the soil surface, weekly averages of 4 replications.

It should be reminded that in our experiments water was applied regularly twice a week for 18 weeks.The distribution of rainfall during a crop season is not even as such. Since the water deficit at the reproductive stage affects yield more seriously than at the vegetative stage [5-7,12], a slight bias in rainfall distribution towards earlier or later stages could easily make the safe minimum water requirement of 311-400 mm for 'African varieties' out of range.

Water response

The results of the estimation of water response functions were presented in Table 2. Water was a positive, significant factor for all the 12 regression equations estimated. Remarkable were high significance levels at which the coefficients of water were estimated: Except for Regression VIII for which the significance level was 5%, it far exceeded 0.1% for all the rest.

First, let us look at the water response of yield for all the varieties (Regression I). The intercept of 3.46 t/ha showed the mean yield for the observations as a whole. The coefficient of water, 0.0123, the slope of the water response regression line for the base variety of Yume, indicated that a 1 mm increase in water availability increased yield by 12.3 kg /ha. The coefficients of three variety dummies for intercept were all positive and significant, indicating that the water response regression lines for these African varieties were located significantly above that of Yume, as shown in Figure 2 for 'African varieties' and Yume. The coefficients of two cross terms, Water x N4 and Water x N10, were negative and significant, indicating that the slopes of the water response regression lines for these NERICA varieties were less steep than that for Yume. These less-steeper slopes for N4 and N10 were resulted from their higher drought tolerance that kept their yields high relative to Yume at lower levels of water application. Regression VII, the water response function for yield estimated by using only the observations for 'African varieties', showed few differences in their water response regression lines, except for the cross-term between Water and Naric. The slope of the regression line was steeper for Naric for the same reason mentioned for Yume.

The estimated 11-12 kg/ha/mm of water response of yield is high compared to earlier studies. Linear water response functions estimated for upland rice grown in North China show 5.2 - 5.7 kg /mm of water response of yield [10]. The comparison of six water application studies mentioned above gives the rate of yield increase of 2.5 kg/ha/mm [12]. A study using rainfed rice farmers' field data reports that the rate is 1.2 kg /ha per 1 mm of total rainfall per season [33].

Regressions II and VIII show that the rate of water response of total dry matter did not differ significantly among the varieties tested, though N4 and Naric produced significantly more total dry matter than N10 and Yume. 'African varieties' varieties N10 produced total dry matter significantly less than others. Although total dry matter increased significantly as water availability increased (Table 2), its rate of increase was far less than that of yield (Table 1), implying that the harvest index increased at the rate closer to that of yield.

Number of panicle/m^2 and number of grains per panicle were significantly larger for 'African varieties' than Yume (Regressions III and IV), while opposite was the case for 1000 -grain weight (Regression VI). In contrast, there was no difference between 'African varieties' and Yume for the rate of grain filling, except for N10 that showed a significantly higher rate (Regression V). Also except for N10 for number of panicle /m^2 and number of grains per panicle, the rate of water response (the slope) was not significantly different between 'African varieties' and Yume. For 'African varieties', the water response functions of four yield components differed little among the varieties. There were two exceptions for this; the rate of grain filling was significantly higher for N10 (Regression XI) and 1000-grain weight was significantly heavier for Naric (Regression XII).

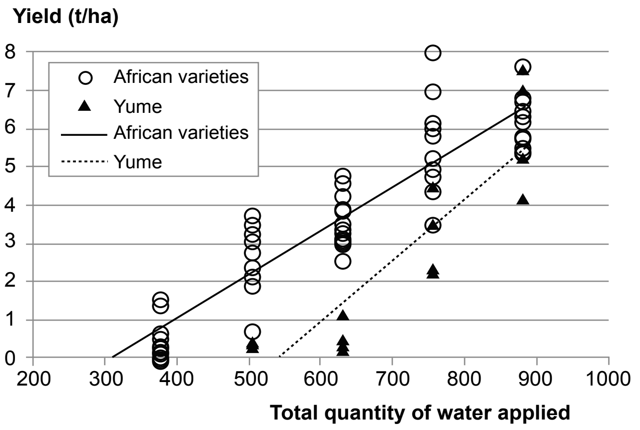

Figure 2: Correlation between yield and total quantity of water applied.

Contribution of yield components to yield increase

Yield increased significantly as water availability increased (Table 1). For 'African' varieties, the rate of yield increase was very high at lower levels of water application from T-1 to T-2 for N4 and N10 and from T-2 to T-3 for Naric, whereas for Yume, high rates of yield increase occurred at higher levels of water application from T-3 to T-5.The results of the decomposition of the yield increase were presented in Table 3. The decomposition based on the estimated water response functions in Table 2 (Mean) showed that the component that contributed most to the increase in yield was the rate of grain filling for all the varieties tested, followed by number of panicle/m^2, number of grains per panicle, and 1000-grain weight, in the order of the importance. The importance of the rate of grain filling was particularly large in the lower levels of water application. At higher levels of water availability, the contribution of number of panicles/m^2 remained to be an important contributing component and number of grains per panicle increased its importance.

These results are consistent with findings of earlier studies in Australia and Asia. It is found in Australia that water stress during panicle development reduces the rate of grain filling to zero [7]. It is found in Asia that the rate of grain filling is the key factor contributing to high harvest index of upland rice varieties under upland conditions [10], that decreasing water supply during 20-40 days before heading reduces the number of grains per unit area and harvest index [12],

	Water treatment^a	Yield (t/ha)	Total dry matter weight (t/ha)	No. of panicle /m^2	No. of grains /panicle	% grain filling	1000 grain weight (g)
N4	T-1	0.50	9.1	157	75.8	14.1	20.5
	T-2	3.04	11.2	317	102.2	37.1	25.4
	T-3	3.29	11.3	318	99.5	42.9	25.6
	T-4	4.47	13.4	349	115.2	43.0	26.2
	T-5	5.98	13.8	373	114.3	53.5	26.5
N10	T-1	0.68	4.3	177	84.5	19.5	22.8
	T-2	3.12	8.2	291	85.1	51.9	24.1
	T-3	3.71	9.0	307	101.2	49.9	24.1
	T-4	5.72	11.5	355	102.5	59.6	26.5
	T-5	5.77	12.1	354	103.2	62.7	25.5
Naric	T-1	0.10	7.0	128	62.9	5.2	22.1
	T-2	1.77	9.8	278	95.5	23.7	26.6
	T-3	3.75	12.1	334	95.5	44.2	27.3
	T-4	6.40	17.4	408	101.8	56.4	27.2
	T-5	6.69	16.3	376	113.6	55.5	28.8
Yume	T-1	0	0	0	0	0	0
	T-2	0.35	6.7	101	54.8	24.5	29.1
	T-3	0.55	8.6	141	38.9	31.6	31.1
	T-4	3.14	12.7	296	58.0	54.8	32.6
	T-5	5.97	13.1	299	101.6	58.7	33.4

Table 1: Yield, total dry matter weight, harvest index and four yield components of upland rice varieties by level of water applied.

a) The total quantity of water applied: T-1 (378 mm), T-2 (504 mm), t-3 (630 mm), T-4 (756 mm), T-5 (882 mm).

	Yield (t/ha)	Total dry matter (t/ha)	No. of panicle /m^2	No. of grains /panicle	% grain filling	1000 grain weight (g)
All varieties (base: Yume, n=75):	I	II	III	IV	V	VI
Intercept	3.46 ‡	11.0 ‡	284 ‡	90.3 ‡	41.7 ‡	26.6 ‡
Water (mm)	0.0123 ‡	0.0157 ‡	0.438 ‡	0.0810 ‡	0.0862 ‡	0.00956 ‡
N4	1.93 ‡	2.51 †	128 ‡	46.9 ‡	1.60	-6.04 ‡
N10	2.27 ‡	-0.141	122 ‡	40.4 ‡	12.3 *	-6.33 ‡
Naric	2.27 ‡	3.45 †	132 ‡	39.6 ‡	1.04	-4.45 ‡
Water x N4	-0.00613 †	-0.00902	-0.230	-0.067	-0.0332	-0.00121
Water x N10	-0.00584 †	-0.00332	-0.264 *	-0.094 *	-0.0258	-0.00507
Water x Naric	-0.00184	0.00241	-0.100	-0.0524	0.0052	-0.000121
R^2	0.861	0.607	0.741	0.595	0.696	0.703
African varieties (base:N4,n=60)	VII	VIII	IX	X	XI	XII
Intercept	3.67 ‡	11.1 ‡	301 ‡	96.9 ‡	41.3 ‡	25.3 ‡
Water (mm)	0.0114 ‡	0.0150 *	0.399 ‡	0.0668 ‡	0.0826 ‡	0.00913 ‡
N10	0.343	-2.73 ‡	-5.92	-6.08	10.60 †	-0.233
Naric	0.284	0.768	1.66	-7.55	-1.14	1.57 *
Water x N10	0.000285	0.00570	-0.0345	-0.0278	0.00740	-0.00386
Water x Naric	0.00429 †	0.0114 *	0.130	0.0141	0.0384	0.00109
R^2	0.876	0.632	0.689	0.417	0.695	0.456

Table 2: Water response functions of upland rice varieties: yield, total dry matter and four yield components.
a) Explanatory variables: Water = total quantity of water applied. N4, N10 and Naric are dummy variables that take 1 if the variety is N4, N10 or Naric and 0 otherwise, respectively. Water*N4, Water*N10 and Water*Naric are the products of Water and respective variety dummy variable. The symbols ‡, † and * show that the estimated regression coefficients are statistically different from 0 at the significance level of p<0.001, P<0.01 and p<0.05, respectively.

		Rate of change in yield (%)	Contribution to the change in yield (%)				
			Yield /ha	No. of panicle /m^2	No. of grains /panicle	% grain filling	1000 grain weight
N4	T-3 / T-1	363	100	28	9	56	7
	T-5 / T-3	60	100	29	25	41	5
	Mean	44	100	30	16	46	8
N10	T-3 / T-1	255	100	29	8	61	2
	T-5 / T-3	49	100	31	4	53	12
	Mean	40	100	30	10	55	5
Naric	T-3 / T-1	991	100	16	5	76	2
	T-5 / T-3	62	100	20	30	41	9
	Mean	60	100	29	15	49	7
Yume	T-3 / T-2	46	100	85	-63	63	15
	T-5 / T-3	367	100	31	44	23	2
	Mean	49	100	32	18	42	7

Table 3: Rate of change in yield and percentage contributions of yield components to yield increase due to changes in water applied
a) Rates of change between T-1 and T-3 and between T-3 and T-5 are computed from Table 1. For Yume, since T-1 gives no yield, the growth rate for the lower water application levels is taken between T-2 and T-3. Mean rates of change are obtained from regression equations in Table 2 by taking derivatives with respect to water applied. Regression equations used are Regression VII - XII for 'African' varieties and Regression I - VI for Yume. The rate of change in yield is calculated as the summation of the rates of change in four yield components.

and that the number of grains per panicle is the most important factor responsible for yield gap between aerobic and flooded rice [34].

It is stated that a high potential yield and harvest index, as well as yield stability under different water regimes, are important putative plant characters for developing new elite upland rice varieties [12]. In addition to this, our findings suggest it would be necessary that two different, yet closely related, breeding strategies have to be sought in developing new upland rice varieties suited to sub-Saharan Africa. To enhance drought tolerance for wider dissemination of upland rice cultivation in the region, it is critical to build in a higher ability for grains to reach maturity. To enhance the yield potential of upland rice varieties to be planted in areas with relatively favorable rainfall conditions, it is effective to build in a higher ability for forming larger sink size (number of panicles/m^2 and number of grains per panicle).

Conclusions

In view of the importance that upland rice varieties play in the rice Green Revolution in sub-Saharan Africa where many farmers are trying to plant rice in upland areas prone to drought, we conducted experiments in Namulonge, Uganda, to clarify water response of upland rice varieties using NERICA 4, NERICA 10, NARIC-2 and Yumenohatamochi with five different levels of water application. We found that the NERICA varieties were most drought tolerant, followed by NARIC-2. Yumenohatamochi did not withstand the lowest amount of water application of 378 mm that was applied evenly throughout the growing stages until harvesting. The results suggest that the minimum water requirement was 311-400 mm per season for three varieties used widely in East Africa, and about 420-600 mm for Yumenohatamochi. It was estimated that an additional water application of 1 mm increased rice yield by 11-12 kg /ha for the upland varieties tested. The high water response of upland rice was brought about by high water response of four yield components. Among the components, the contribution by the rate of grain filling was highest, followed by number of panicles /m^2, number of grains per panicle and 1000-grain weight, in the order of the degree of contribution, for all the varieties tested.

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