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Assessing the Effects of Water Management Regimes and Rice Residue on Growth and Yield of Rice in Uganda

T. Awio[1], B. Bua[2*] and J. Karungi[1]

[1]Department of Agricultural Production, College of Agriculture and Environmental Sciences, Makerere University, P.O.Box 7062, Kampala, Uganda.
[2]Department of Agriculture, Faculty of Vocational Studies, Kyambogo University, P.O.Box 1, Kyambogo-Kampala, Uganda.

Authors' contributions

This work was carried out in collaboration between all authors. Author TA conducted the field and screen house trials, did data analysis and drafted the manuscript. Author BB and JK guided in design of the trials, data collection and analysis. All authors read and approved the final manuscript.

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ABSTRACT

Aim: This study was conducted to assess the influence of different water and rice straw management practices and rice genotypes on growth and yield of rice in Uganda.
Study Design: Field experimental design was a Randomized Complete Block Design while the screen house study design was a Completely Randomized Design.
Place and Duration of Study: The study was conducted in the field at National Crops Resources Research Institute (NaCRRI) Namulonge and in the screen house at Kyambogo University during the period of February-July 2013.
Materials and Methods: Ten rice genotypes obtained from the cereals program at NaCRRI Namulonge were grown under different water management regimes, with and without rice straw incorporation both in the field and screen house. Water management regimes used were alternate wetting and drying (AWD), continuous flooding (CF) and continuous drying (CD).

**Corresponding author: E-mail: boscobua@yahoo.com;*

Results: A significant variation in grain yield was observed among rice genotypes and under different water management regimes (P<0.001). Use of rice straw influenced rice yield in the screen house (P<0.001) but not in the field (P=0.23); interactions of water management x genotype and water management x rice straw x genotype influenced rice yield in the field (P=0.003) but not in the screen house (P=0.5). Higher yield gain was observed under the water-saving technology alternate wetting and drying compared to continuous flooding or drying.

Conclusion: This study has indicated significant variations in field performance of rice under different water management regimes and rice straw usage. These findings are therefore important because they suggest that efficient management of water resources and rice residues from rice fields coupled with the use of drought tolerant rice varieties could be an effective integrated approach to improve rice yield and an adaptation strategy to the observed climate variability.

Keywords: Alternate wetting and drying; continuous drying; continuous flooding; rice straw.

1. INTRODUCTION

Rice is a major cereal crop in the sub-Saharan Africa, providing up to 21% of the calorie intake. As such, rice is an important strategic component of food security and crucial element in the staple food economies of the region where it has gained prominence in the farming systems and diets in Africa [1,2]. Traditionally, rice has the potential to improve nutrition, boost food security, foster rural development and support sustainable land use in Africa. In Uganda, rice has also become an important food staple and source of income for a big portion of the populace [3,4].

Although much of the global rice acreage is in developing countries, rice yield per unit area is still very low, averaging 1.5t/ha for both lowland and upland rice compared to yield potential of 8 t/ha and 5 t/ha for lowland and upland rice, respectively [5]. The major reasons for these wide yield gaps is due to environmental stress, low inherent yielding varieties, poor management of rice fields, technology incompatibility and socio-economic factors. According to Mostajeran et al. [6], one of the main problems of rice cultivation and production in Africa is lack of water resources, especially during periods of low rainfall which affect the vegetative growth rate and yield. As such, drought is the most serious problem for rain fed dry land rice cultivation. Therefore, water management in rice production; whether in upland or lowland systems is an important aspect in ensuring increased rice production and environmental integrity. Additionally, crop residues are good sources of plant nutrients and are important components for the stability of agricultural ecosystems. In rice production, a large quantity of rice residues is left in the field after harvesting, which can be recycled for nutrient supply [7]. For some rice farmers, the rice residues are incorporated in to the soil during land preparation by ploughing while some farmers burn the rice residues during land preparation [7,8]. However, in Uganda there is no information on whether rice residue incorporation in to the soil results in any improvement in the growth and yield of rice. Moreover, there is also need to understand how different rice genotypes interact with water and rice residue management in influencing rice performance. Therefore, this study aimed at evaluating the effects of water management, rice straw use and rice genotypes on the growth and yield of rice in Uganda.

2. MATERIALS AND METHODS

This study was conducted both in the field at National Crops Resources Research Institute (NaCRRI) Namulonge, (1200 m above sea level, 0º32ºN 32º34ºE, 1300 mm average annual rainfall) and in the screen house at the Department of Agriculture, Kyambogo University, (1189 m above sea level, 0º20ºN 32º35ºE). Ten rice genotypes (namely; K5, NERICA-4, IR09A136, P27H14, P27H2, P33H3, P49H3, P55H17, P55H20 and P59H9) were used to assess the effects of water management régimes, rice straw use and rice genotypes on growth and yield of rice of rice both in the field and screen house.

2.1 Field Experiment

The study was conducted during the period of February to July 2013. The experimental design was a randomized complete block design arranged as a split-split plot with water regimes being the main plots, rice straw the sub-plots and rice genotypes made the sub-sub plots with three replications. During land preparation, all the surface residues (organic materials) were collected and disposed off without incorporating it into the soil. Rice straw was chopped into smaller pieces of about 1cm and then later incorporated into the soil two weeks prior to planting at a depth of 10-15 cm and at a rate of 8t/ha as described by Tadashiro et al. [9]. Treatments were as follows:

Main plots (water regimes)	Subplots (rice straw)	Sub-subplots (rice genotypes)
Alternate wetting & drying	8t/ha	All 10
Continuously dry (no flooding)	8t/ha	All 10
Continuous flooding	8t/ha	All 10
Alternate wetting & drying	None	All 10
Continuously dry (no wetting)	None	All 10
Continuous flooding	None	All 10

In alternate wetting and drying (AWD), irrigation water was applied by pumping water in the field using a water pump to flood the field for 7 days after which the field was drained and left dry for another 7 days. The field was alternately flooded and non-flooded for 7 days throughout the growth period of the rice crop.

Under continuous drying (CD), the field was solely dependent on rainfall and this was a rainy season which had atleast one rain per week. Where the rain was high and caused flooding of the field, the field was drained to keep it dry throughout the crop growth period. Under continuous flooding (CF), irrigation water was continuously pumped into the field to flood the field throughout the growth period of the crop.

During flooding, the water level was kept at 5cm above the soil surface. Plastic sheets were fixed around each treatment by digging 20 cm deep to restrict water movement from one treatment to another and a distance of 1.5 m was left between the treatments for easy monitoring. Rice straw rate of 8t/ha was used following the trials and recommendation of Tadashiro et al. [9].

Planting was by direct seeding, with a spacing of 20 cm x 20 cm. In the sub-sub plots, each genotype was planted in four rows, each row with 11 stands and each stand with two plants making a total of 88 plants per genotype. Agronomic data was collected on total number of tillers, number of productive tillers (panicles), crop height at harvest and grain yield. Data on total number of tillers, number of productive tillers and crop height were collected from 14 plants in the two middle rows, 7 plants from each row by counting all the tillers, counting all tillers that had panicles and measuring the height of the plants using a measuring tape, respectively and obtaining the average. Grain yield data was obtained by harvesting the grains from all the plants within a plot (treatment) and the total grain weight for each treatment was obtained (in grams) using an electronic weighing scale and later expressed in t/ha. All the data collected was subjected to Analysis of Variance (ANOVA) of the Genstat computer program (14th edition) and differences in means were determined using Least Significant Difference (LSD) at 5% probability level.

2.2 Screen House Experiment

This experiment was conducted concurrently with the field trial using 10 rice genotypes. The trial design was a completely randomized design with three replications. Rice paddy soil collected from the plough layer of a paddy field at NaCRRI as per Tadashiro et al. [9] was used. Plastic pots containing 8kg of the moistened soil samples were prepared for the treatments. Rice straw was chopped and mixed with the 8 kg of soil before filling in the pots at the same rate as in the field (32 g / 8 kg soil) [9]. Treatments were as follows:

Water regimes	Rice straw	Rice genotypes
Alternate wetting & drying	32 g	All 10
Continuously dry (no flooding)	32 g	All 10
Continuous flooding	32 g	All 10
Alternate wetting & drying	None	All 10
Continuously dry (no wetting)	None	All 10
Continuous flooding	None	All 10

For alternate wetting and drying, the pots were alternately flooded and non-flooded for 7 days throughout the growth period of the rice crop. In continuous drying, watering was done once every week throughout the trial to wet the soil while under continuous flooding, the pots were kept flooded throughout the crop growth period and water level was maintained at 5cm above the soil surface. For all treatments, each pot was then direct seeded with five rice seeds and thinning was later done to two rice plants per pot at the tillering stage. The pots were maintained in the screen house at temperature of 26ºC.

Weeding of pots was done twice during the trial, no artificial fertilizer was applied and all plants in each pot were harvested by cutting the panicles to obtain the grains. Data collection and analysis was the same as in the field experiment. The trial lasted from February to July, 2013.

3. RESULTS

3.1 Field Experiment

Water management significantly influenced plant height, number of productive tillers and yield (*P<0.001*) but not total number of tillers. All the growth and yield parameters measured varied significantly for rice genotypes (*P<0.001*); whereas incorporation of rice straw significantly (*P<0.001*) influenced number of productive tillers and total number of tillers, but not plant height and yield. The interactions of water management x genotype, water management x rice straw, rice straw x genotype and water management x rice straw x genotype was not significant for any of the growth parameters (P=0.5). Grain yield on the other hand was significantly affected by the water management x rice genotype (P<0.001), and the water management x rice straw x rice genotype interactions (P=0.003).

Genotypes K5 and IR09A136 had the highest average number of productive tillers per plant and the highest average total number of tillers per plant (Table 1). More productive tillers were recorded in AWD and CD than in the CF (Table 1). With regard to rice straw usage, there were more productive tillers recorded in plots without rice straw incorporated compared to plots which had rice straw incorporated (Table 1).

In regard to grain yield, K5 and P33H3 had the highest grain yield compared to other rice genotypes (Table 2). The highest grain yield was recorded under the CD water regime followed by AWD, and the least was from the CF regime, with no significant difference between AWD and CD (*P>0.05*; Table 2). Genotypes P33H3, NERICA-4 and K5 were among those that performed better under AWD and, K5 still performed well under CF. All the genotypes performed well under CD except for NERICA-4, IR09A136 and P49H3 (Table 2). With regard to rice straw usage, higher grain yields were recorded in plots without rice straw incorporation compared to those plots which had rice straw incorporated (Table 3).

3.2 Screen House Experiment

Results indicated that rice genotype significantly affected number of productive tillers and plant height (*P<0.001*) but not total number of tillers and grain yield. Water management regimes significantly (*P<0.001*) influenced all the studied variables except number of productive tillers. Rice straw incorporation significantly influenced yield and plant height (*P<0.001*) but not tillering. The interactions of water management x rice straw, water management x rice genotypes, rice straw x rice genotypes, and water management x rice straw x rice genotypes was not significant for any of the studied growth and yield variables in the screen house.

Table 1. Average number of productive tillers and total number of tillers under different water management regimes and rice straw usage in the field at NaCRRI

Genotypes	No. of productive tillers								Total no. of tillers
	AWD	CD	CF	LSD (5%)	With straw	Without straw	LSD (5%)	Mean	
K5	20	20	12		14	20		17	21
NERICA-4	10	9	5		7	9		8	11
IR09A136	16	20	9		13	17		15	19
P27H14	10	10	7		8	11		9	13
P27H2	12	13	7		8	14		11	14
P33H3	12	10	7		8	11		10	12
P49H3	13	9	9		9	12		11	14
P55H17	10	9	6		8	9		8	12
P55H20	9	8	7		7	9		8	11
P59H9	11	9	6		7	11		9	11
Mean	12	12	8	1.33	9	12	0.98	11	14
LSD (5%)								2.48	2.62

***(AWD**=Alternate wetting and drying **CD**=Continuous drying **CF**=Continuous flooding)*

Table 2. Yield of 10 rice genotypes grown under different water management regimes in the field at NaCRRI

Genotypes	Yield (t/ha)				
	AWD	CD	CF	Mean	LSD (5%)
K5	2.47	2.03	2.07	2.19	
NERICA-4	2.18	0.78	0.47	1.14	
IR 09A136	0.92	1.57	1.52	1.34	
P27H14	1.66	2.57	0.38	1.54	
P27H2	1.71	2.66	0.66	1.68	
P33H3	2.14	2.61	0.92	1.89	
P49H3	1.35	1.86	0.64	1.28	
P55H17	0.51	2.25	0.69	1.15	
P55H20	1.47	2.34	0.53	1.45	
P59H9	1.59	2.09	0.40	1.36	
Mean	1.60	2.08	0.83	1.50	0.84
LSD (5%)				0.47	

*(**AWD**=Alternate wetting and drying **CD**=Continuous drying **CF**=Continuous flooding)*

Table 3. Yield of 10 rice genotypes grown under different water management regimes and rice straw amendment in the field at NaCRRI

Genotype	Yield (t/ha)									
	AWD with straw	AWD without straw	Mean	CD with straw	CD without straw	Mean	CF with straw	CF without straw	Mean	LSD (5%)
K5	2.08	2.86	2.47	1.71	2.35	2.03	1.31	2.83	2.07	
NERICA-4	1.54	2.82	2.18	0.75	0.81	0.78	0.54	0.41	0.48	
IR 09A136	1.20	0.65	0.93	1.34	1.81	1.58	1.04	2.00	1.52	
P27H14	1.38	1.94	1.66	1.17	3.98	2.58	0.44	0.32	0.38	
P27H2	2.40	1.02	1.71	1.75	3.56	2.66	0.70	0.62	0.66	
P33H3	1.48	2.80	2.14	1.98	3.24	2.61	0.72	1.12	0..92	
P49H3	1.18	1.51	1.35	2.10	1.63	1.87	0.88	0.40	0.64	
P55H17	0.65	0.36	0.51	1.67	2.84	2.26	0.80	0.58	0.69	
P55H20	1.13	1.82	1.47	1.41	3.27	2.34	0.63	0.44	0.54	
P59H9	1.04	2.14	1.59	2.13	2.05	2.09	0.28	0.52	0.40	
Mean	1.41	1.79	1.60	1.60	2.55	2.08	0.73	0.93	0.83	1.50
LSD (5%)			0.82			0.82			0.82	

*(**AWD**=Alternate wetting and drying **CD**=Continuous drying **CF**=Continuous flooding)*

As in the field trial, K5 and IR09A136 had the highest number of productive tillers in the screen house (Table 4). Plant height varied significantly among genotypes with the tallest genotype, K5, measuring 0.9 m while the shortest genotypes, NERICA-4, P27H14, P33H3, P55H17 and P59H9 measured 0.7 m (Table 4).

With respect to grain yield and water management, the highest yield was recorded under CF followed by AWD and the least under CD, with no significant difference in grain yield between AWD and CD but CF differed significantly from AWD and CD (Table 5). Contrary to the field trial, higher grain yields were recorded in treatments amended with rice straw compared to those which were not (Table 5). The pooled yield data for rice genotypes over the different water management regimes and rice straw usage showed that genotypes K5, P33H3, P27H14 and P27H2 generally recorded the highest grain yields (Table 5).

4. DISCUSSION

The difference in yield observed among rice genotypes could have been due to the difference among genotypes in number of productive tillers (panicles). According to Hayashi [10], many high-yielding rice varieties are short and high tillering; characteristics exhibited by some of the high yielding genotypes such as P33H3, P27H2 and P27H14 used in this study. These results suggest that the most important factor for obtaining high yield is to get high number of productive tillers (panicles) per unit area.

Consequently, the difference in number of productive tillers / panicles among genotypes could be the main reason that contributed to the yield difference observed among genotypes. Additionally, the difference in grain yield could be attributed to the difference in water use efficiency among the rice genotypes and this could explain the significant interaction of genotypes and water regime on grain yield. Efficiency in water use by rice crops are factors that positively contribute to high yield of rice [11].

The high yield recorded under AWD during field trial compared to CD and CF may be attributed to the high number of productive tillers, moisture retention and efficient moisture use under AWD during the growing periods. The observed effect of AWD on grain yield is in agreement with several prior studies. According to Roderick et al. [12] and Tejendra et al. [13], AWD uses less water without significant reduction in grain yield, harvest index, number of productive tillers and plant height compared with conventional irrigation. Uphoff and Randriamiharisoa [14] and Uphoff [15] noted that keeping rice fields moist but not continuously saturated gives better results, both agronomically and economically, than flooding rice throughout its crop cycle. Bhuiyan and Tuong [16] concluded that a standing depth of water throughout the season is not needed for high rice yields. They added that about 40–45% of the water normally used in irrigating the rice crop in the dry season was saved by applying water in small quantities only to keep the soil saturated throughout the growing season without sacrificing rice yields.

The fact that most of the genotypes used in this study like P27H14, P27H2, P33H3, P55H20, P55H17 and P59H9 yielded relatively well under CD water regime implies that these genotypes can be grown under upland conditions. Since most of the genotypes used in this trial are being developed for upland rice environments, this shows suitability of these genotypes to be used as breeding materials for further breeding work for upland conditions or drought tolerant rice varieties. Developing drought tolerant rice varieties would help farmers adapt to the unpredictable weather patterns currently being observed.

The results of this study also indicated that rice straw significantly influenced rice yield in the screen house but not in the field during the trial. The results of this field study showed no effect of rice straw on rice yield. This contrasts previous studies [7,17] where application of organic materials such as rice straw, rice husks and plant residues significantly improved rice yields and soil productivity. Supapoj et al. [17] further noted that the residual effect of these materials also had a large impact on the growth and yield of rice, with rice straw having a higher residual effect on rice yields than rice husks and wheat straw. Additionally, Pandey [18] noted that using organic materials such as crop residues, green manure and organic wastes improve soil properties, give better crop yield and reduce costs. The result of this study on rice straw utilization shows that for high yield realization, there is need to appropriately manage water in rice fields and use the right rice genotypes.

Table 4. Number of productive tillers, total number of tillers and plant height of 10 rice genotypes grown in the screen house at Kyambogo University

Genotypes	No. of productive tillers	Total no. of tillers				Plant height (m)
		AWD	CD	CF	Mean	
K5	7	8	8	9	9	0.9
NERICA-4	6	9	7	11	9	0.7
IR 09A136	7	9	8	9	9	0.8
P27H14	6	11	9	13	11	0.7
P27H2	6	9	9	9	9	0.8
P33H3	6	9	8	9	9	0.7
P49H3	6	9	9	11	10	0.8
P55H17	6	10	7	10	9	0.7
P55H20	6	11	8	11	10	0.8
P59H9	6	9	8	10	9	0.7
Mean	7	10	8	10	9	0.8
LSD (5%)	0.6				1.4	0.06

*(**AWD**=Alternate wetting and drying **CD**=Continuous drying **CF**=Continuous flooding)*

Table 5. Yield of 10 rice genotypes under different water management regimes and rice straw amendment in the screen house at Kyambogo University

Genotypes	Yield (t/ha)					
	AWD	CD	CF	With straw	Without straw	Mean
K5	1.86	1.33	2.31	2.02	1.64	1.83
NERICA-4	1.14	1.25	1.64	1.49	1.20	1.34
IR 09A136	1.72	1.47	1.52	1.79	1.36	1.57
P27H14	1.89	1.87	1.72	1.97	1.68	1.83
P27H2	1.55	1.62	2.26	1.93	1.69	1.81
P33H3	1.82	1.71	2.40	2.05	1.89	1.97
P49H3	1.63	1.55	1.57	1.71	1.45	1.58
P55H17	1.77	1.35	1.89	1.76	1.58	1.67
P55H20	1.61	1.56	1.77	1.98	1.31	1.64
P59H9	1.57	1.40	1.92	1.87	1.39	1.63
Mean	1.66	1.51	1.90	1.86	1.52	**1.69**
LSD (5%)	0.21			0.17		**0.38**

*(**AWD**=Alternate wetting and drying **CD**=Continuous drying **CF**=Continuous flooding)*

Growing rice varieties that efficiently utilize the available nutrients released from rice straw decomposition and produce high grain yield could result to achieving high yield from rice fields with rice straw being used as the only nutrient source for the rice crops, a common practice with most of the rice farmers in rural areas who lack access to artificial fertilizers.

The significant interaction of water management by rice straw by genotype on rice yield suggests that yield under rice straw usage depends on the water management regime as well as the rice genotype. Varieties efficient in utilizing the available nutrients from straw decomposition under specific water regimes could have helped maintain rice productivity and yields. This could explain the consistent better performance of K5 across water regimes, P33H3 and NERICA-4 under AWD and, P27H14 and P27H2 under CD.

5. CONCLUSION

This study has shown a significant variation in growth and yield parameters among rice genotypes, water management regimes and rice straw usage. Rice yield varied significantly under different water management regimes and the two-way water management by genotype interaction; and the three-way water management by straw by genotype interaction significantly influenced rice yield. This implies that grain yields obtained from the rice genotypes depended on the water management regime and rice straw usage.

The study has demonstrated the possibility of AWD being a promising method of water management in rice cultivation since it offers the benefits of maintaining rice productivity compared with the conventional system of rice production (continuous flooding). This benefit is likely to be a critical factor that could make farmers and other stakeholders adopt the use of AWD in rice production. However, it is very important that other comparative experimental field studies be conducted in different environments or regions with different soil types, topography and climatic conditions in the country to validate these results. Additionally, genotypes used in this study need to be further evaluated for their suitability as genetic materials in breeding for drought tolerant or drought resistant rice varieties.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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