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Chapter 2

Performance dynamics of Upland Rice under Flooded Paddy Ecosystems

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Abstract

This study was conducted to determine the performance of three upland rice varieties; NERICA 4, NamChe 5 and PR 107 in flooded paddy ecosystems of Doho, Tororo and Kween paddy flooded sites in Uganda. The research was under in a Randomized Complete Block Design with three replications during March-June in 2022 and 2023. Data were collected once prior to planting on soil pH, organic matter, soil mineral nutrients and texture. At harvest the plant height, number of tillers plant^{-1}/ hill^{-1}, panicles plant^{-1}/ hill^{-1}, seeds panicle and grain yield were determined at harvest. Collected data were analyzed (ANOVA) using 13th Edition of GenStat statistical package and significant differences between treatments means, separated using Fischer's least significant difference test at $P < 0.05$. The pH range was slightly acidic (5.8-6.6) in all sites and the nitrogen levels were high under all treatments. Ngenge however, registered higher Phosphorus (70.4 Mgkg^{-1}) than Doho (17.1 Mgkg^{-1}) and Tororo (23.9 Mgkg^{-1}) sites. Similar potassium levels, were observed in Doho and Tororo (0.5-0.6 Cmol/ kg) but were higher in Ngenge (1.33 Cmol/ kg). The major soil textural class was sandy clay loam for Doho & Tororo and Ngenge had clay soil texture. At all the sites WITA 9 was significantly ($P > 0.05$) shorter (55 & 58 cm) than NamChe 5, NERICA 4 and PR 107 (76 & 82cm) during both seasons. WITA 9 at Doho and Tororo sites, produced significantly ($P > 0.05$) more) tillers plant^{-1} (8.8 tillers), tillers hill^{-1} (23 tillers), panicles m^2 (321 panicles), panicles hill^{-1} (23 panicles), seeds panicle^{-1} (189 &192 seeds and rice grain yield (5.0 & 3.6 Mt ha^{-1}) than other treatments during both seasons. In Doho the panicles hill^{-1} and number of tillers plant^{-1} for NERICA 4, NamChe 5 and PR 107 were at par during 2022. Similarly, NamChe and PR 107 treatments recorded similar numbers of tillers m^2 and panicles plant^{-1} during 2023. During 2022 the yield was high and similar for NERICA 4, NamChe 5 and PR 107 while lower and similar rice grain yields were recorded under the same rice treatments during 2023. In Tororo NamChe rice recorded significantly ($P > 0.05$) higher tillers hill^{-1} (9 tillers) than NERICA (6-8 tillers) rice during 2022. The panicles per unit area (209-211 panicles) and rice grain yield (3.0-3.2 Mt ha^{-1}) were at par for both varieties during the two seasons. NamChe 5 however, recorded significantly ($P > 0.05$) higher seeds per panicle (172-175 seeds) than NERICA 4 rice (157160 seeds) during both seasons. In Ngenge the growth attributes, yield attributes and yield for NERICA 4 and NamChe 5 were similar during the two years. Based on the findings under this study, NamChe 5, NERICA 4 and PR 107 Upland rice varieties could be adapted and adopted under smallholders flooded paddy conditions dependent on seasonal rainfall for reduced risks, increased rice production and productivity in similar ecologies.

Keywords: Adaptability, Paddy conditions, Performance, Rice varieties.

1. Introduction

As the population of the world is expected to increases to 9.8-10 billion people by 2050 (UN, Department of Economics and social Affairs; DESA) with rice serving as the major source of calories and nutrients for a significant portion of this population, provision of food is crucial to every country as it is desired to ensure global food security [1]. The key stakeholders to ensure food security include; international research centers, national governments, private sector, philanthropists and farmers. In Uganda the importance of rice (Oryza spp.) forced the government to join the Coalition for Africa Rice Development (CARD) formed in 2008 [2]. The goal of CARD was to double rice production for food security and incomes of smallholder farmers in Sub Saharan Africa (SSA) in a period of 10 years [2]. Rice is a commodity of

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strategic importance in the world considering area under cultivation and number of people who depend on it [3]. In 2022 the total world rice production was 776.5 m Mt and China was the world highest producer (208.5 m Mt) followed by India (196.2 m Mt [4]. The African countries that each produced over 1.0 m Mt of paddy rice included Egypt, Nigeria, Tanzania, Ivory coast, Sierra Leone, Senegal, Ghana and Democratic republic of Congo [4]. Rice is the most rapidly growing food source across the African continent due to the great urbanization relative to other regions in the world [5] and it is widely grown in the Eastern and Northern regions of Uganda [6].

Paddy rice production in Uganda increased by 95% from 373,000 Mt in 2020 to 727,000 Mt during 2021 (Uganda Statistical Abstracts, 2023). The increase was attributed to among other factors; development of high yielding, pests, disease and drought tolerant cultivars, introduction and adoption of improved agronomic practices, besides other technologies (Uganda Statistical Abstracts, 2023). Research on increasing global rice production focusses on the same factors but climate change poses a challenge to the goal. Most of the local paddy rice varieties grown in wetlands are sensitive to water stress [7]. The varieties are late maturing (120-140 days) and susceptible to diseases. The impact of rice cultivation on wetlands depends on wetland type, intensity of drainage and agronomic practices including the use of fertilizers. There is need to adopt and adapt improved varieties to the prevailing farming conditions. The Uganda government has shifted the emphasis from paddy cultivation to upland rice growing. The main reason for this shift is the growing concern over ways to prevent the fragile wetland ecosystems from further damage caused by paddy cultivation [2]. Upland rice is easier to cultivate compared to traditional paddy varieties, Upland rice typically requires less inputs like fertilizers and pesticides compared to traditional paddy rice and responds well to low rainfall as long as it is well distributed during growing phase [3].

Despite the commercialization of rice production with the establishment of rice schemes in Uganda, the output from Paddy ecosystems continues to lag behind demand in the country partly due to limited access to good paddy seed varieties, inadequate water management and seasonal variability [2]. Soil fertility has also declined, and increased the production costs [8], leading to overuse of fertilizers that may negatively impact on wetland ecosystems. In order to increase agricultural productivity worldwide, the current strategy is to enhance the resilience of rice plants to biotic and abiotic stresses. [9] reported that continued disturbance of wetlands is not only disastrous to the ecosystems, but also increases greenhouse gas (GHG) emissions into the atmosphere resulting in global warming, The researchers remarked that since the cultivation of late maturing paddy rice varieties is known to increase GHG emissions including CH_4, NO_2 and CO_2, strategies need to be sought to ensure optimal yields with reduction in GHG emissions. Adopting short term upland rice varieties with efficient water use under paddy conditions could also be one strategic option to reduce risks of crop failure due to weather variability. Farmers who grow upland rice varieties suited for paddy conditions have more flexibility, as they can adjust to different types of landscapes and climate conditions, reducing dependency on one farming method and diversifying risk. The farmers also have higher flexibility for rotation, second season planting and timely land preparation. Upland rice varieties that adapt to flooded paddy conditions may benefit from pest suppressing effects, leading to healthier crops, lower exposure to pests and diseases, lower inputs / costs and strike peak market prices if harvested early with lower postharvest losses. Given the changing climate, regions that were previously too dry for traditional paddy rice cultivation might benefit from upland rice varieties adapted to wetter conditions, allowing farmers to grow rice in new areas and maintain food security. Upland rice cultivation in paddy flooded conditions may allow for year-round rice cultivation, leading to more consistent food production in regions where seasonal rainfall is unpredictable or where paddy rice production was previously not feasible.

Organic matter (OM) is one of the key indicators of soil health as it plays a significant role in crop production and improves soil physical, chemical, and biological functions. Increasing the levels of organic matter aids soil structure, water-holding capacity, nutrient mineralization, biological activity and air infiltration rates. Soil OM improves the soil's capacity to store and supply essential nutrients and to retain toxic elements [10]. OM allows the soil to cope with changes in soil acidity and fastens the decomposition of soil minerals. The N ranges are very low ($< 0.05\%$), low (0.05-0.15%), medium (0.15-0.25%), high (0.25-0.5%) and very high (> 0.5 %). P is considered very low when it ranges between 0-1ppm, low when 12.5-22ppm, medium in the range 23-35.parts per million (ppm), high at 36-68ppm and very high when over 69 ppm.

Rice yellow mottle disease, caused by rice yellow mottle virus (RYMV), is a major challenge to rice production in Africa [11]. Nigeria, Ghana, Mali, Senegal, Cameroon, Chad and Central African Republic have reported significant out breaks. The disease has been reported in major rice producing East African countries like Uganda, Kenya and Madagascar especially under irrigated conditions. RYMV has not been reported in other continents of the world [12]. In Uganda the disease was first reported in 2000 by [13] as plants with yellow and mottling symptoms. The disease has since spread and varieties with good culinary properties including Super have been reported to be highly susceptible to the virus [14]. Development of RYMV resistance requires exploitation of natural resistance sources [15]. The disease affects rice under all types of cultivation systems including lowland and upland, rainfed rice [11]. The disease was initially described and named by [16]. RYMV primarily infects rice (Oryza sativa), but it can also infect several other grass species, including wild rice (Oryza longistaminata and Oryza barthii). Increased rice cultivation to meet the high demand for consumption across the continent due to the availability of water for sequential plantings throughout the year increases the spread of RYMV [17]. Sindano (IR22) and Basmati 217 rice varieties among others that were introduced into the African continent mostly proved to be highly susceptible to the virus [17]. Barnyard Grass (Echinochloa spp.) is very common in rice fields and can harbor the virus. Cutgrass (Leersia hexandra), which is often found in rice-growing regions, and Bermuda grass (Cynodon dactylon) are both known to be potential hosts [18]. Wild rice species can also serve as reservoirs for the virus [19]. The widespread distribution and ability to infect multiple hosts make RYMV a significant threat to rice production across SSA.

Uganda produces varieties of the New Rice for Africa (NERICA), namely NERICA 1, 4 and 10 developed by WARDA. NERICA rice is the product of interspecific hybridization between the cultivated rice species of Africa and Asia (Oryza sativa x O. glaberrima). NERICA 4 is the most adopted upland rice variety, grown in more than 10 countries in Sub-Saharan Africa (SSA). It gives good yield (3-6 Mt ha^{-1}), early maturing (85-100 days) and tolerant to biotic (pests,) and abiotic stresses like drought and soil conditions) which makes it suitable for SSA. NamChe 5 rice variety is not only high yielding (3-5 Mt ha^{-1}) under good management practices, but also of longer maturity (120-140 days), with mild aroma, good grain quality, high tillering ability and drought tolerant is being adopted in Uganda. The variety is also well suited for irrigated conditions. NARO rice 1 (PR 107) which is aromatic, high yielding (4-6 Mt ha^{-1}), resistant to RYMV, rice blast and Bacterial Leaf Streak and is also being adapted and adopted in Uganda and matures in 90-110 days). WITA 9 rice is a high yielding variety (4-7Mt ha^{-1}) depending on the environment and management conditions. It is resistant to many diseases including rice blast and bacterial blight but may require management for insect pests. WITA 9 has excellent grain quality, high milling recovery and good adaptability to both upland and lowland conditions. It matures in about 120-130 days and often used in commercial farming. The upland varieties are currently competing with the commonly grown paddy rice varieties because they are highly resistant to diseases, mature earlier (90-110 days), high yielding (potentially 46 Mt ha^{-1}) un-milled) and grows under moderate water availability [20]. The researchers further reported that upland rice is a promising better alternative to paddy rice for sustainable production and household income generation. Upland rice was also reported as a good substitute for partially submerged paddy rice in dry land, hillside land or low-lying areas where rainfall is stable but lacking irrigation [20]. Improved, high yielding upland rice varieties have been developed by the National Crop Resources Research Institute (NaCRRI) in Uganda in collaboration with other institutions [20]. Although farmers grow some of these improved upland rice varieties (NERICA and NamChe), their performance under paddy flooded conditions is not well known. The objective of this study therefore, was to evaluate the performance and possible adoption of three upland varieties under different ecological flooded paddy conditions as a viable alternative to cultivation of paddy varieties for increased rice production and productivity.

2. Materials and Methods

2.1. Study Sites

Location, rainfall and temperature

The study was conducted in Uganda at Doho scheme on Butaleja district, Tororo swamp in Tororo district and in Ngenge scheme in Kween district during the first rain seasons (March-June) of 2022 and 2023. Doho is located at 000 26’23.2N 0330 28’40.9E, at 1209 meters above sea level. The rainfall at the site during the cropping season was 652 mm during 2022 and 850.6 mm during 2023 Figure 1. During 2022 the mean cropping season’s minimum and maximum temperatures were 17.5°C and 33°C against the annual average temperatures of 18.2°C and 35°C. The mean minimum and maximum temperatures during 2023 cropping season were 18.4°C and 32.6°C respectively Figure 2. The Tororo site is found at 0044’59.99N 34004’60.99E, at 1199 meters above sea level. Rainfall received at the site during the 2022 cropping season was 753 mm and 840 mm were recorded during 2023 Figure 1. The mean cropping season’s minimum and maximum temperatures (2022) were 23°C and 31°C, relative to the annual average temperatures of 18.3°C and 32°C respectively. During 2023 cropping season the mean minimum and maximum temperatures were 22.8°C and 31.6°C respectively Figure 2. Ngenge site is situated 1031’59’N 34030’0’E, at 1276 meters above sea level. At the site the rainfall received during the cropping season was 732 mm during 2022 and 740.6 mm during 2023 Figure 1. In 2022 the mean minimum and maximum cropping season’s temperatures were 21°C and 34°C against the annual average temperatures of 20°C and 33°C. The mean minimum and maximum temperatures during 2023 cropping season were 20.4°C and 32°C respectively Figure 2.

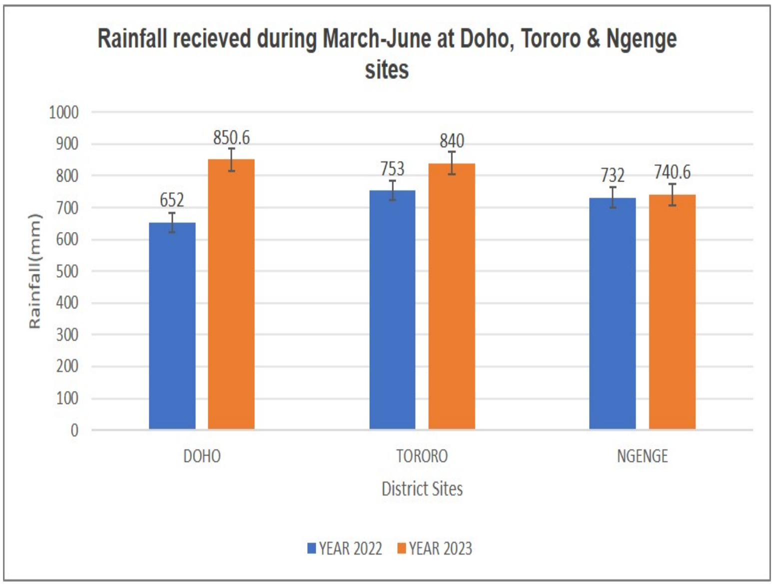

Figure 1: Rainfall received at Doho, Tororo and Ngenge sites during March-June 2022 & 2023

Plant Nutrients and soil texture

The pH, organic matter (OM), soil nutrients; nitrogen (N), phosphorus (P) potassium (K), sodium (Na) and texture were determined prior to the study.

Experimental design and treatments

The field experiment was conducted on each of 3 selected farms at Doho rice scheme in Butaleja district, Tororo farm in Tororo districts and on Ngenge rice scheme in Kween district during March - June of 2022 and 2023. Each of the treatments was applied in flooded lowland fields where rice had been previously planted for the past three years. The experimental plots measured 20m × 20m with inter plot spaces of 1m and arranged in a Randomized Complete Block Design, replicated three times. The rice varieties namely; NERICA 4, NamChe 5, PR 107 and WITA 9 collected from Uganda National Crops Resources Research Institute, Namulonge, were used. The treatments of rice adopted were the common varieties commonly grown in each of the districts at Doho (NERICA 4, NamChe 5, PR 107 & WITA 9); Tororo (NERICA 4, NamChe 5 & WITA 9) and Ngenge (NERICA 4 & NamChe 5). Pure 10 kg seeds of each of the four varieties were separately soaked and

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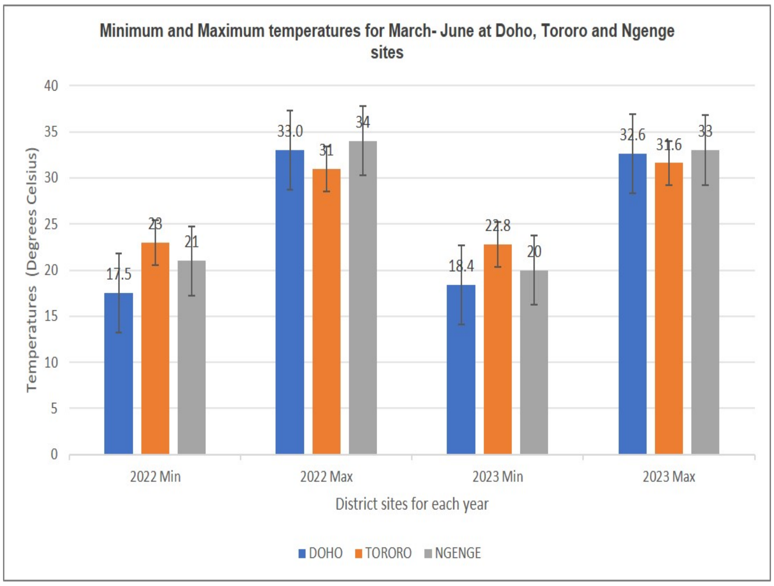

Figure 2: Minimum and maximum Temperatures at Doho, Tororo and Ngenge sites during 2022 & 2023

incubated for 24 hours at room temperature and then seeded on a well prepared nursery bed. Wet fields measuring 1,450 m^{-2} were divided into 3 replicates, ploughed, marked, leveled and puddled. Each of the replicates was divided into 4 equal plots, each measuring 100 m-2 with spacing of 1m between plots, considering the direction of water flow to be adjacent to the direction of replication. Rice was transplanted at 21 days after nursery establishment for all the varieties at a spacing of 30 × 12.5 cm. Fertilizers were applied to rice at 100 kg ha^{-1}, 60 kg ha^{-1}, 40 kg ha^{-1} of NPK in the form of Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP), respectively. The entire TSP and MOP were applied as basal at transplanting and Urea was top dressed in three equal splits at 15 days after transplanting (DAT), 25 DAT (tillering stage) and 30- 45 DAT (panicle initiation stage) to the rice crop.

2.2. Data Collection

Soil pH, Organic matter, mineral nutrients and texture

Soil litter was removed at the sampling spot and an auger driven to a depth of 15 cm to draw the soil sample from distinct randomly selected multiple locations in the experimental plots by zone sampling techniques at Doho, Tororo and Ngenge schemes. 10 samples were drawn from each sampling unit and placed in a bucket. The 10 samples from each experimental plot were thoroughly mixed and placed in a clean sample container. The sub samples were then taken to the soil laboratory for analysis. In the laboratories where the chemical elements were analyzed by loss on ignition method (organic matter), potentiometer (pH), Kjeldahl method (N), colorimeter (P) and an ion selective electrode for P. The soil texture was determined by soil sedimentation method.

Field biometric data

Strict data collection was carried out to compare the treatments. Two border rows in each plot and 5 border hills per row were not used for data collection and the remaining portion was considered as experimental plot. Plant height was measured from the base of the plant to the base of the flag leaf at panicle initiation, 30 days after transplanting (DAT) which coincided with the panicle initiation stage for NERICA, NamChe and PR 107 rice and at 45 DAT for WITA 9 rice. The mean numbers of leaves and tillers were counted per hill from panicle initiation till, full heading and at harvest on 10 tagged rice plants per treatment in the experimental plot. Data were collected on the incidences of Rice Yellow Mottle Virus (RYMV) disease in the experimental plots for all treatments at panicle initiation stage and before harvest. At maturity 10 hills were harvested in triplicates from 40 m^{-2} of the experimental plot for determination of mean yield components namely; seeds $panicle^{-1}$, tillers $hill^{-1}$, tillers $plant^{-1}$, panicles $hill^{-1}$, panicle m^{-2}, and grains $panicle^{-1}$. The grain yield was determined from a 40 m^{-2} net plot.

2.3. Data Analysis

The collected data was subjected to analysis of variance (ANOVA) using GenStat statistical package (13^{th} edition, 2013). The significant differences between treatments means were separated using Fischer's least significant difference (LSD) test at $P < 0.05$.

3. Results

The data on soil analysis for the 3 sites (Doho, Tororo and Ngenge) are indicated in Table 1.

Table 1: Soil Analysis for Doho, Tororo and Ngenge sites

Site/ Scheme	pH	O.M	N	P	K	Na+	Sand	Clay	Silt	Texture
		%		Mg/kg	Cmol/kg		%	%	%	
Doho	5.79b	6.07b	0.40a	23.9b	0.54b	0.04b	57.0a	24.0b	19.0b	Sandy clay loam
Tororo	6.07a	7.88a	0.34a	17.1c	0.58b	0.14a	55.0a	25.0b	20.0b	Sandy clay loam
Ngenge	6.62a	5.30c	0.26b	70.4a	1.33a	0.07b	27.5b	45.3a	27.0a	Clay
P. Value	0.04	<.001	0.04	<.001	0.005	0.004	<0.001	<0.001	0.01	
LSD (P≤0.05)	0.57	0.09	0.09	5.18	0.29	0.03	3.89	2.91	3.67	
CV (%)	2.7	3.4	9.2	4.4	11.3	12.0	3.6	3.9	5.2	

Note: Values with different letters in a column are significantly different at $P \leq 0.05$

PH Range, Soil Organic Matter content and Soil Texture

The pH ranged between 5.8-6.6 in all the study sites. The pH of the soil at the 3 sites was not adjusted before the study. The soil OM was high (7.9%) in Tororo, low in Doho (6.1%) and a lower level was found in Ngenge (5.3%).

Nitrogen, Phosphorus, Potassium and Sodium

The levels of N were high at all sites and at par in Doho (0.4%) and Tororo (0.34%) though significantly ($P > 0.05$) lower (0.26%) in Ngenge. Ngenge registered high levels of P (70.4 Mg/kg) and K (1.33 Cmol/kg) compared to Tororo and Doho sites. The Tororo site however recorded high levels of Na^+ (0.14 Cmol/kg) than the other 2 sites. The major textural class was sandy clay loam found at Doho and Tororo and Ngenge site had clay soil texture.

Rice plant height, tillers, panicles, seeds and yield for Doho during 2022 and 2023

The data on rice plant height, yield parameters and grain yield for rice planted in Doho irrigation scheme for WITA 9, NERICA 4, NamChe 5 and PR 107 rice during 2022 and 2023 season are presented in Table 2. All the parameters significantly (($P > 0.05$) differed for the treatments. WITA 9 was shorter (57 & 58 cm) than other treatments (76 & 82cm) during both seasons and at all sites but produced significantly ($P > 0.05$) more) tillers plant^{-1} (8.8 tillers), tillers hill^{-1} (23 tillers), panicles m^{-2} (321 panicles), panicles hill^{-1} (23 panicles), seeds panicle m^{-1} (189 & 192 seeds and rice grain yield (5.0 & 3.6 Mt ha^{-1}) during 2022 and 2023. The panicles per hill and number of tillers plant^{-1} for NERICA 4, NamChe 5 and PR 107 were at par during 2022. Similarly, NamChe and PR 107 treatments recorded similar numbers of tillers m^{-2} and panicles per plant during 2023. The yield for NERICA 4, NamChe 5 and PR 107 during 2022 was high and similar while lower and similar rice grain yields were recorded under the same rice treatments during 2023.

Rice plant height, tillers, panicles, seeds and yield for Tororo during 2022 and 2023

The data on rice plant height, yield attributes and yield for WITA 9, NERICA 4 and NamChe 5 rice obtained from a study conducted in Tororo swamp during 2022 and 2023 are indicated in Table 3. WITA 9 rice treatment was significantly ($P > 0.05$) shorter (55-56 cm) than other treatments that had similar height (77-78 cm). WITA 9 similarly produced significantly ($P > 0.05$) more tillers, panicles, seeds and grain yield than the other treatments during the two seasons. NamChe rice however, recorded significantly ($P > 0.05$) more tillers hill^{-1} (9 tillers) than NERICA (6-8 tillers) rice. The panicles per unit area (209-211 panicles) and rice grain yield (3.0-3.2 Mt ha^{-1}) were at par for NERICA 4 and NamChe 5 during the two seasons. NamChe 5 however, recorded significantly ($P > 0.05$) higher seeds per panicle (172-175 seeds) than NERICA 4 rice (157-160 seeds) during both cropping seasons.

Table 2: Height, Yield attributes and Yield of WITA 9, NERICA 4, NamChe 5 and PR IO7 under paddy flooded conditions in Doho during 2022 and 2023

Treatments	Plant height (cm)	Tillers hill^{-1}	Tillers m^{-2}	Panicles hill^{-1}	Panicles plant^{-1}	Seeds Panicle^{-1}	Yield Mt ha^{-1}
WITA 9 (2022)	57.83d	8.75a	-	321.3a	-	191.67a	4.99a
WITA 9 (2023)	57.33d	-	23.1a	-	22.5a	189.33a	3.55b
NERICA 4 (2022)	80.77a	6.40b	-	251.5b	-	149.67d	3.98b
NERICA 4 (2023)	76.23b	-	18.8a	-	18.5a	158.57c	2.97c
NamChe 5 (2022)	82.03a	5.73b	-	213.7b	-	162.50a	3.74b
NamChe 5 (2023)	79.00a	-	17.5b	-	16.2b	167.73b	2.83c
PR 107 (2022)	66.13c	6.20b	-	220.3b	-	158.67c	4.05b
PR 107 (2023)	64.50c	-	18.4b	-	16.9b	161.07a	2.63c
P-value	< 0.001	0.003	0.004	< 0.001	0.05	< 0.001	< 0.001
LSD ($P \leq 0.05$)	5.36	1.32	4.56	39.5	4.13	7.95	0.89
CV %	4.4	10.3	11.9	7.3	15.10	2.7	14.20

Note: Values with different letters in a column are significantly different at $P \leq 0.05$

Table 3: Growth parameters, Yield attributes and Yield of WITA 9, NERICA 4 and NamChe 5 in Tororo during 2022 and 2024

Treatments	Plant height (cm)	Tillers hill^{-1}	Panicles m^{-2}	Seeds Panicle^{-1}	Yield Mt ha^{-1}
WITA 9 (2022)	55.43b	8.53a	314.30a	193.00a	3.73a
WITA 9 (2023)	56.10b	8.56a	315.60a	192.20a	3.83a
NERICA 4 (2022)	76.60a	6.76b	225.10b	156.50c	3.24b
NERICA 4 (2023)	76.93a	6.07b	225.90b	159.80c	3.24b
NamChe 5 (2022)	77.60a	8.53a	208.50b	171.50b	3.07b
NamChe 5 (2023)	77.93a	8.56a	211.10b	174.80b	3.12b
P-value	< 0.001	< 0.001	< 0.001	0.001	0.04
LSD ($P \leq 0.05$)	4.69	0.88	24.68	11.90	0.54
CV %	3.80	6.90	5.50	3.80	9.10

Note: Values with different letters in a column are significantly different at $P \leq 0.05$

Rice plant height, tillers, panicles, seeds and yield for Ngenge during 2022 and 2023

The data on plant height, yield attributes and yield for NERICA 4 and NamChe 5 rice planted in Ngenge during 2022 and 2023 are presented in Table 4. The two treatments were not significantly ($P > 0.05$) different. NERICA 4 rice however, recorded numerically more tillers (8 tillers), panicles (292-295 panicles) and seeds per panicle (122-129 seeds) than NamChe 5.

Table 4: Growth parameters, Yield attributes and Yield of NERICA 4 and NamChe 5 in Ngenge during 2022 and 2023

Treatments	Plant height (cm)	Tillers hill^{-1}	Panicles m^{-2}	Seeds Panicle^{-1}	Yield Mt ha^{-1}
NERICA 4 (2022)	75.80	7.64	292.00	122.00	3.15
NERICA 4 (2023)	79.00	8.18	295.00	129.20	3.20
NamChe 5 (2022)	76.40	5.71	204.00	117.00	3.27
NamChe 5 (2023)	79.20	6.03	292.00	117.20	3.32
P-value	NS	NS	NS	NS	NS
LSD ($P \leq 0.05$)	15.86	1.72	76.80	24.17	0.47
CV %	13.30	16.20	20.10	12.80	9.50

Note: Values with different letters in a column are significantly different at $P \leq 0.05$, NS: Not Significant

Rice yellow mottle virus disease at Doho, Tororo and Ngenge during 2022 and 2023

The Rice yellow mottle virus (RYMV) disease was not observed in the all the treatments of rice at the 3 sites during 2022 and 2023 cropping seasons.

4. Discussion

PH Range, Soil Organic Matter content and Soil Texture

The pH range was found to be within the optimum range (5.2-7.0) for rice growing in all the study sites. The moderately acidic levels (5.8-6.6) therefore could have contributed to a conducive environment for nutrient uptake and crop growth. At low pH, many soil elements become less available to plants, while others such as iron, aluminum and manganese become toxic to plants. The pH of the soil at the 3 sites was therefore not adjusted before the study. The soil organic matter was adequate at all the 3 sites but Tororo had higher (7.9%) organic matter content followed by Doho swamp (6.1%) and the least (5.3%) OM was in Ngenge site. The high organic matter in Tororo site with sandy clay loam soil was probably due to reduced cultivation and could have resulted from accumulated root biomass and litter compared to Doho and Ngenge sites. The higher organic matter in both Tororo (7.9%) and Doho (6.1%) swamps contributed to the improved sandy clay loam soil structure that was observed at the two sites relative to Ngenge site that was characterized with clay soil texture with a poor structure. Organic matter improves soil aggregation, which enhances the ability of soil to retain water, allow better aeration, and facilitate root growth. [21] reported higher rice yields under long term organic and inorganic treatments than under NPK fertilizer. Soil organic carbon, total nitrogen, available nitrogen and available potassium with long term organic and inorganic treatments were significantly ($P \leq 0.05$), higher than in inorganic fertilizer (NPK) treatments. Organic matter provides essential nutrients for plants and promotes activities of soil organisms, such as earthworms and microbes, which further improve soil structure. Over time organic matter helps to create a loamy, well drained and fertile soil. Much as organic fertilizers increase crop yield and improve soil quality, they have disadvantages such as low efficiency, low nutrient content and high application rates. [22, 23] reported that application of long term combined organic and inorganic fertilizers maintained and improved crop yield and soil fertility. Poor structured soils exhibit poor infiltration and low water holding capacity. Soils with good structures like in Tororo and Doho (sandy clay loam) enhance root growth, resulting into better plant growth and movement of the soil nutrients such as nitrates to the roots.

Nitrogen, Phosphorus, Potassium and Sodium

The N levels were high (0.3-0.4%) under all treatments and the quantities were at par in Tororo (0.34%) and Doho (0.40%) sites though significantly, lower (0.26%) in Ngenge. Whereas, the recommended levels of Nitrogen were applied at all 3 sites, Tororo and Doho sites could have availed more N nutrients to the rice crop because of the higher OM and improved soil structure of sandy clay loam soils as reported by [22, 24, 25]. The significantly ($P < 0.05$) higher levels of P recorded in Ngenge (70.4 Mgkg^{-1}) relative to medium levels in Doho (24 0 Mgkg^{-1}) and lower quantities found in Tororo (17.1 Mgkg^{-1}), possibly contributed to the low yield attributes and yield of rice recorded in Ngenge in the 2 seasons. Excessive Phosphorus reduces the plant's ability to take up some nutrients like iron, zinc and Mn in the soil. The levels of K in the soils were low and at par in Doho and Tororo (0.5 Cmol/kg) but a high level was observed in Ngenge (1.33 cmolkg^{-1}). The K levels were lower than required for rice crop growth as the optimum level is 5-7 molkg^{-1}. Potassium is associated with improved photosynthesis, cell wall strength, regulation of water and nutrients movement and enzyme activation within the plants which influence protein synthesis [26]. It is implied that the applied K (40 kgha^{-1}) at planting could have improved the growth of rice at the 3 sites. Potassium enhances root development, disease resistance, better photosynthesis, regulates water balance, increases grain quality, nutrient uptake and transport. [24, 27, 28] observed that the rice grain yield and biomass of rice partly depended on plant K uptake. Due to the high cost of K fertilizers, farmers resort to applying more N fertilizer, resulting in significantly reduced rice yield and nitrogen use efficiency. Tororo recorded significantly ($P \leq 0.05$) higher sodium levels than the other 2 sites and the ions could have disrupted ion homeostasis that leads to ion toxicity in the leaves, nutrient imbalances particularly potassium and reducing water uptake due to osmotic stress.

Rice plant height, seeds, tillers, panicles and yield for Doho during 2022 and 2023

The significant differences in plant height for the different varieties could have been influenced by genetic potential, coupled with their inherent relative differences in utilizing the soil nutrient levels. The high number of tillers plant^{-1}, seeds per panicles and hill^{-1}, panicles m^{-2} and hill^{-1} and rice grain yield for WITA 9 during both 2022 and 2023 seasons may be attributed to the high N levels found in the soil Table 1 and increased absorption by the late maturing WITA variety (120-140 days). The positive influence of soil N on growth, development and rice yield at increased levels of N were noted by [29, 30]. Doho treatments could have also benefited from the relatively conducive minimum (18°c) and maximum (33°c) temperature Figure 2 and of rainfall received during 2022 (652 mm) and 2023 (850.6 mm) at Doho. The ideal temperature for rice which a water loving crop is 20-35°c. NERICA 4, NamChe 5 and PR 107 rice varieties had similar numbers of tillers and panicles per hill. This could be attributed to similar benefits from high nutrients released from the soil since the varieties exhibited similar maturity periods (90-100 days). This condition coupled with possible increased deposits of photosynthates to the sinks possibly contributed to the high and similar rice yield for the varieties during 2022 under the conducive sandy clay loam paddy soils. The lower and similar rice grain yields recorded under NERICA 4, NamChe 5 and PR 107 rice varieties during 2023 may be associated with the low Organic matter (6.1%) in Doho and high (850.6 mm) rainfall received with high maximum temperatures (33°c) experienced for the early maturing varieties during the cropping season. These varieties possibly succumbed to water shortage and high temperature at critical growth stages that could have hindered panicle formation and overall grain yield. There could also have been associated nutrient (NPK & micronutrients) deficiencies as a result of water stress to avail nutrients to the rice. Such conditions could have negatively influenced the uptake of nutrients by the rice crop, resulting into poor crop yields. High grain yield was recorded in the current study under NamChe 5 (3.74 Mtha^{-1}) in 2022 and in 2023 (2.83 Mtha^{-1}). This yield was higher than the rice yield (2.0-2.3 Mtha^{-1}) recorded by [31], under upland ecology for the same variety during 2022 in Uganda. The scientists also recorded high (3.8-4.4 Mtha^{-1}) rice grain yield from different weed control treatments of NamChe rice during 2023 in Uganda. The grain yield for NERICA 4 upland rice in this study during 2022 (3.89 Mtha^{-1}) was similarly, higher than the yield (3.2-3.6 Mtha^{-1}) reported in 2022 by [32]. The NERICA 4 grain yield (2.97 Mtha^{-1}) in 2023 under the current study was however; lower than the yield (4.9-5.73 Mtha^{-1}) recorded by [31] during 2024 for the same variety under upland conditions in Uganda. Growth parameters, yield parameters and yield for different crop varieties are inherent genetic characteristics of crop varieties. It is implied that NERCA 4, Namche 5 and PR 107 could have also responded to their genetic yield potential.

Rice plant height, seeds, tillers, panicles and yield for Tororo during 2022 and 2023

WITA 9 was shorter than other treatments possibly due to its genetic characteristics. The high number of tillers plant^{-1} seeds per panicles and hill^{-1}, panicles m^{-2} and hill^{-1} and rice grain yield during the 2022 and 2023 seasons for WITA 9 may be attributed to the high N levels tested in the soil that could have been absorbed by the late maturing WITA variety (120-140 days) over a longer duration. The high number of tillers per plant, panicles m-2, seeds per panicle and grain yield under WITA 9 during the two seasons may also be accredited to its longer extended the filling of the sinks relative to the other short maturing treatments (90-110 days). Shorter maturity crops like NamChe 5 and NERICA 4 rice varieties may avoid end of season climatic stresses, pests and diseases but get less period of exposure to solar radiation and nutrient uptake for deposition of synthates into the sinks leading to a lower yield potential because they have less time for tillering and grain filling. The lower vegetative growth of the early maturing crop varieties also reduces the number of panicles and size of grains. The significantly ($P > 0.05$) high panicles per unit area and rice grain yield for NamChe rice than NERICA rice could be ascribed to conducive site-specific soil conditions such as drainage, soil compaction and shading from weeds. Good sunlight exposure, soil aeration and good drainage encourage tiller development. The similar but low yield produced by NERICA 4, NamChe 5 and PR 107 during 2022 could be attributed to the lower levels of PK and high Na+ found at Tororo site. Low PK levels reduced photosynthesis, stress tolerance, cell structures and root development [24, 26–28] confirmed that PK are required for proper rice crop growth and development especially for the grain yield and biomass. The low yield of rice may also be attributed to disrupted ion homeostasis by the high levels of Na^+ ions found in Tororo. Sodium ions lead to ion toxicity in the leaves, causing nutrient imbalances particularly potassium and thus reducing water uptake due to osmotic stress. The grain yield was higher under WITA 9 (4.0 $Mtha^{-1}$) and lower under NamChe 5 and NERICA 4 (3.1-3.2 $Mtha^{-1}$) during the 2 seasons. This could be attributed to physiological processes of tiller development, panicle development, seed formation and filling of the sinks that were possibly influenced by photo-period and nutrient availability for the short maturity NamChe 5 and NERICA 4 (90-110 days) rice crops. The yield realized under the current study (3.0-3.2 $Mtha^{-1}$) for NamChe 5, NERICA 4 under paddy flooded conditions is similar to the grain yield (3.23 -4.0 $Mtha^{-1}$) that was reported by [33, 34] under upland conditions in Uganda.

Rice plant height, seeds, tillers, panicles and yield for Ngenge during 2022 and 2023

NERICA 5 and NamChe 4 treatments were not significantly ($P > 0.05$) different although NERICA 4 rice recorded numerically higher tillers, panicles and seeds per panicle than NamChe 5 during the two seasons. The similarity in growth, yield attributes and yield could be attributed to influences of the soil type and texture in Ngenge on nutrient uptake and assimilation of synthates into the sinks of rice plants. The high PK level in Ngenge soils possibly contributed to increased stress tolerance such as drought and extreme temperatures characterized in Ngenge, enhanced photosynthesis, regulated water balance and contributed to the observed similar tillers $plant^{-1}$, panicles per square metre, number of seeds per panicle and grain yield (3.1-3.3 $Mtha^{-1}$) under NERICA 4 than NamChe 5. This may have been influenced by amidst other factors the high mean maximum temperatures (33-340C) during both seasons. The observed grain yield in the current study at Ngenge was relatively high and similar to the yield (3.23 -4.0 $Mtha^{-1}$). [31, 32] reported for NamChe and NERICA rice respectively under upland conditions in Uganda. The relatively high yield for NERICA 4 than for NamChe 5 under the current study may be attributed to the high number of tillers per hill, panicles per square metre and seeds per panicle recorded. [35] reported higher (5.0-7.0 $Mtha^{-1}$) grain yield for NERICA 4 upland rice variety under paddy ecosystems. [36] observed 2.0-3.3 $Mtha^{-1}$ as the potential for NERICA 4 under rainfed conditions and [37] reported an average yield of 3.27 $Mtha^{-1}$ for NERICA 4 under upland ecosystem.

Rice yellow mottle virus disease at Doho, Tororo and Ngenge during 2022 and 2023

The results indicated that NERICA 4, NamChe% and WITA 9 rice varieties were not susceptible to RYMV disease. The resistance to RYMV in the treatments may be attributed to genetic resistance. Resistance genes can produce proteins that inhibit growth of the disease-causing organisms. Resistance may also arise from cellular and biochemical defenses of phytoalexins that inhibit pathogen penetration and growth or activate an immune or defense response in surrounding tissues and triggering programmed cell death to limit the spread of the pathogen. The results relate to reports by Africa Rice which noted that WITA 9 variety was not susceptible to RYMV. But another study found the presence of RYMV in leaf samples from WITA 9 suggesting susceptibility (http://scialert.net). The conflicting observations may arise from differences in environmental conditions, virus strain variations or research methodologies. Ndikuryayo et al., (2020) reported NAMCHE 2 rice variety as resistant to RYMV disease in Uganda while Muganyinka et al., (2015) similarly reported crosses with NERICA 1, 4 & 6 with best resistance to RYMV in Uganda. Studies by [38] indicated high resistance of WITA 9 to bacterial leaf blight, rice yellow mottling virus and rice blast. Several scientists have reported NERICA rice varieties as similarly tolerant to various biotic and abiotic stresses [33, 34, 39].

5. Conclusion

NERICA 4, NamChe 5 and PR 107 upland rice varieties recorded taller plants than WITA 9 paddy rice possibly due to their genetic inheritance. The upland varieties also produced high and similar number of seeds per panicles, tillers per plant, panicles per hill and grain yield. NERICA 4, NamChe 5 and PR 107 rice recorded on average similar to higher rice grain yield under flooded paddy conditions relative to the yields recorded from previous studies under upland ecosystems in Uganda. The three upland rice varieties therefore indicate high potential for successful cultivation and adaptation under traditional flooded paddy conditions in Uganda and similar ecosystems. Based on the current study, NERICA 4, NamChe 5 and PR 107 upland rice varieties matured earlier (100 days) than WITA 9 (130 days) and were not susceptible to RYMV disease or other biotic stresses like WITA 9. NERICA 4, NamChe 5 and PR 107 could therefore be recommended for flooded paddy rainfed ecosystems since they were resilient and their yield performance was similar to that under upland conditions. Further studies are recommended to explore irrigation and nutrient management strategies that optimize performance of the upland rice varieties in flooded paddy fields.

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