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Productivity and Economic Performance of NERICA Varieties under Two Harvest Modes and Rainfall Intensities in Uganda

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Authors' contributions

This work was carried out in collaboration among all authors. Author MGK designed the study, performed the statistical analysis, managed the literature and wrote the first draft of the manuscript. Author ME collected field data. All Authors read and approved the final manuscript.

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ABSTRACT

The productivity of upland rice is highly determined by the available soil moisture and nutrients. Droughts highly influence yields especially in the second 30 days growth period. A field experiment was conducted at the Uganda National Agricultural Research Institute, Ikulwe station during 2018B and 2019B seasons to determine the productivity and economic returns of four rice varieties under two harvest modes and rainfall intensities. The treatments included NERICA 1, 4 & 6 and NAMCHE 2 given 80 kg N and 30 kg P ha^{-1}. Treatments were replicated three times under a randomised complete block design. Data was collected on plant height, leaf number, leaf length, leaf width and number of tillers during vegetative stages in all treatments. The panicles m^{-2}, sink size, panicle filling percentage and grain yields were determined at harvest. All the yield attributes and grain yield reduced during the droughty 2018B relative to the rainy 2019B. On the contrary, the number of tillers reduced in 2019. Correlation coefficient (*r*) for spikelets per m^{-2} were significant ($\geq$8.0) and positive (0.86) to grain yield during 2018 but were lower (0.13) in 2019. The *r* values were also positive, but not significant, for panicles m^{-2} (0.76) and for percent filled panicles (0.23) with respect to grain yield during 2018 and 2019 respectively. NERICA 4 & 6 produced higher grain yield under both moisture stress and high rainfall conditions. The results indicate that NERICA 4 and 6 varieties

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could be adopted and harvested at 75 days after rice emergence (DAE) for NERICA 4 and at 75 DAE and 90 DAE for NERICA 6 under low (630 mm) rainfall or harvested once at 90 DAE given high (1,500 mm) rainfall to get higher yields and Returns on Investment.

Keywords: Correlation coefficient; NERICA; rainfall; returns on investment; yields.

1. INTRODUCTION

Rice is an important staple crop in sub-Saharan Africa (SSA) and ranked after wheat and maize in Uganda. Upland rice productivity is greatly influenced by soil moisture and nutrients and the New Rice for Africa (NERICA) have become the most popular cultivars in SSA. They are interspecific hybrids between the cultivated rice species *Oryza sativa* and *O. glaberrima* [1]. A notable characteristic of upland NERICA varieties is their amphibiousness. They grow well in upland and lowland ecosystems [2]. This makes NERICA desirable for the east African conditions where farm lands change between wetlands and dryland conditions depending on amounts and patterns of rainfall. The demand for rice has been increasing most rapidly among staple crops [3]. NERICA has attracted research attention and policy [4,5], because of its good performance. [6], reported NERICA varieties to have high yields (5-6 t ha^{-1}), protein content (10-12%) and good taste, tolerance to acidic soils, resistance to harsh growth conditions, pests and diseases [7,8] and early maturity (80-100 days. [9], however, reported reduced adoptions due to lower profitability of NERICA varieties relative to other crops. The availability of suitable fertile land and the high labor costs (466 person-days ha^{-1}) were reported to render NERICA technology pro-small holders [10,11]. These factors which are influenced by availability of soil moisture and nutrients during the cropping period, coupled with the cost and availability of labor greatly influence the productivity and commercial production of NERICA in SSA.

Nitrogen and Phosphorus are significant nutrients for higher rice productivity. Several studies have been conducted and recommendations made on nutrient and moisture requirements for rice in SSA. [12], found that the positive effects of N application on the yield of NERICA upland rice in P-deficient soils are limited unless P is applied. Nitrogen fertilizer was reported as one of the most important nutrients that determine rice yields. Several authors [13,14], similarly, reported N fertilisers to positively influence tiller development, yield and yield components. The significance of Phosphorus fertiliser in rice was reported by Mghase et al. [15]. The researchers observed that P-deficiency affected NERICAs at the early stages of plant growth because it limited the positive effects of nitrogen and retarded the number of panicles and spikelets. [16], found 30 kg P ha^{-1}, sufficient to rectify P deficiency in Uganda. The availability of soil moisture is central in upland rice production ecosystems. [17,18], reported water stress, during the meiosis-anthesis stage to increase spikelet sterility and reduce grain filling which substantially reduced yield. Sekiya et al. [19], noted that among NERICA varieties, higher water availability contributed to higher grain filing and increased rice yields. [16] found that rainfall in some or all of the three 40 day growth periods gave significant positive effects on spikelets, grain filling, grain weight and yield, but had no influence on the panicles. The researchers reported 1 mm increase in rainfall in the second growth period to increase yields by 0.45% or 10.4 kg ha^{-1}. Grain filling, spikelets and grain weight contributed most to the yield increase. [19,16], reported 3.4 kg ha^{-1} mm^{-1} and 8.3 kg ha^{-1} mm^{-1}, respectively as marginal effects of total seasonal rain on yield. Despite the studies on nutrient and moisture requirements for NERICA, there is meagre literature on the yield potential, harvest management options and profitability of NERICA cultivars having different maturity periods, under variable weather conditions. The main objective of this study was to reduce NERICA yield loses and optimize economic returns under drought and heavy rainy conditions on a Luvisol soil in Uganda. The specific objectives of the study were;

- To establish the growth and yield potential of popular NERICA varieties under different rainfall intensities.
- To determine the economic returns from NERICA using two harvest modes under variable weather conditions.

2. MATERIALS AND METHODS

2.1 Field Experiments

2.1.1 Site description

The experiment was conducted at Ikulwe Agricultural Research station, Uganda during

2018B and 2019B seasons. Ikulwe is located at 00°26'23.2''N 033°28'40.9''E, at 1209 meters above sea level. The rainfall at the site during the quarters; Jan – Mar (574 mm), Apr – Jun (1032 mm), Jul – Sep (456 mm) and Oct – Dec (628 mm) of 2018 totaled to 2,690 mm. During 2019 the total rainfall during Jan – Mar (449 mm), Apr – Jun (1,660mm), Jul – Sep (1,091 mm) and Oct - Dec (1,449 mm) was 4,649 mm as indicated in Figs. 1 and 2. The mean minimum and maximum temperatures during 2018 cropping season were 19.5°C and 32°C against the annual average temperatures of 18.3 and 31°C. During 2019 the mean cropping season minimum and maximum temperatures were 18.1°C and 28°C. The properties of the soil were determined before the study was conducted to establish the amount of organic matter (OM), available nitrogen (N), phosphorus (P), potassium (K) and the pH. The results indicated a Luvisol soil type with 3.2% OM, 0.15% available N, 5.04 mg kg^{-1} exchangeable P and 0.39me/100g exchangeable K. The pH of the soil was 5.3 with textural sand (56%), silt (20%) and clay (24%). The cropping seasons were October - December (B) during both years.

2.1.2 Experimental design and treatments

The treatments were arranged in a randomised complete block design with four treatments replicated three times. Each experimental unit measured 4 m x 5 m with 2 m between the plots. The four treatments included NERICA 1, NERICA 4, NERICA 6 and NAMCHE 2 rice varieties. Rice seed was planted by drilling method at a rate of 50 kg ha^{-1}, under spacing of 30 cm x 12.5 cm (2 seeds) in a clean field that had been ploughed twice and disc hallowed once. Nitrogen (N) and phosphorus (P) nutrients were applied as basal fertilisers (80 kg N & 30 kg P ha^{-1}). Two equal splits of N (60 N kg ha^{-1}) were applied into the soil uniformly in all the plots at 30 days after emergence (DAE) of rice and at panicle initiation stages as additional fertilisers. The sources of N & P were DAP (46: 18:0) and urea (46% N). The crops were thinned to 2 plants per hill at 14 DAE and hand hoeing was done uniformly twice on the same date at 21 DAE and 42 DAE in all the treatments. There were no pests and disease incidences, thus, no control measures were administered in all treatments. All other agronomic managements followed the recommended standards (NaCRRI, 2010).

2.1.3 Data collection

Five plants from individual net plots of each crop were randomly selected and tagged at 14 DAE for biometric observations during 2018 and 2019. The plant heights were measured from the ground to the base of the last fully opened rice flag leaf. The length and width of the plant leaves were taken by measuring the longest leaf and widest leaf parts, respectively. Data were also collected weekly on the number of tillers and green leaves of tagged plants in all the treatments. Data collection during the vegetative stage ended at 50% flowering of rice. Harvesting was done at 75 DAE during 2018 due to an early end of season drought in all the treatments. All the ripe panicles in 1 m x 1 m quadrant (40 hills) for each of the treatments were harvested in the centre of each plot to determine grain yield ha^{-1}. At 90 DAE, the same procedure was followed to harvest NERICA 6 panicles (65%), a late maturing cultivar that had registered only 35% mature panicles at 75 DAE. Ten rice panicles were harvested from an area adjacent to the quadrants to determine the number of panicles, filled panicles per plant, total spikelets and filled spikelets per panicle in all treatments. During 2019, a similar harvesting procedure was followed but harvesting was done at 90 DAE in all treatments. Data were collected on production costs, gross and net monetary returns per treatment. The economic benefit from rice growing per Uganda shilling investment was determined in the ratio of the net returns to the cost of production in each of the treatments [20]. The correlation coefficients (*r*) were calculated to establish possible linear relationships between the rice grain yield (dependent variable) and panicles m^{-2}, sink size, spikelets per panicle and filled panicles per plant as independent variables using the formulae;

$$r = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{\sqrt{[\Sigma(x-\bar{x})^2(y-\bar{y})^2]}}$$

2.1.4 Data analysis

All data collected were subjected to analysis of variance (ANOVA) using 13th edition, 2013 of Genstat software. Fischer's least significant differences (LSD) test was used to separate treatments means.

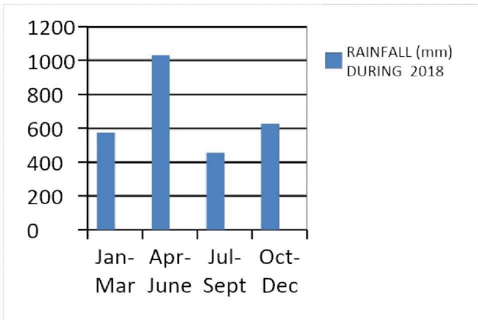

Fig. 1. Three months' interval rainfall (2018)

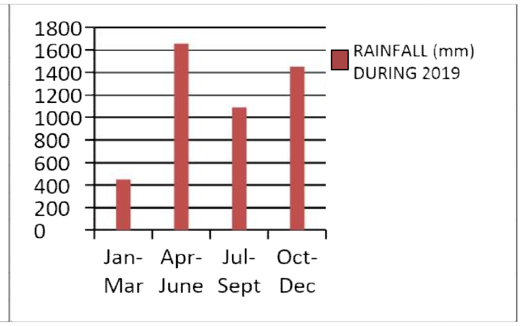

Fig. 2. Three months' interval rainfall (2019)

3. RESULTS

3.1 Growth and Yield at Ikulwe Research Station during 2018

3.1.1 Rice growth parameters

NERICA 1 produced significantly $P \leq 0.05$, taller plants (45.0 cm) than NERICA 4 (29.2 cm), NERICA 6 (33.9 cm) and NAMCHE 2 (30.3 cm) at 50% flowering (55DAE) of NERICA 1 (Table 1). The height of NAMCHE 2, NERICA 4 and NERICA 6, however, significantly ($P \leq 0.05$), increased (53 cm, 56 cm and 75 cm) at the corresponding 50% flowering stages of NAMCHE 2 (60 DAE), NERICA 4 (65 DAE) and NERICA 6 (75 DAE). NERICA 1 produced significantly $P \leq 0.05$, lower leaf length (31.3 cm) than NAMCHE 2 (44.8 cm) and longer leaves were produced by NERICA 4 (47.2 cm) and NERICA 6 (52.4 cm). NERICA 1 and NERICA 6 produced wider (1.7 cm & 2.0 cm) leaves than other varieties. The leaf number and number of tillers per plant were not significant among the rice varieties.

3.1.2 Yield attributes, grain yield and returns on investment

Rice crop harvesting was done at 75 DAE for all varieties and due to an early on-set of end of season drought. Additional harvest of NERICA 6 was done at 90 DAE due to its late maturity. NERICA 6 produced the highest spikelets (163 spikelets) per panicle (SPP) followed by NERICA 4 (127 spikelets). NAMCHE 2 and NERICA 1 produced lower (95 & 98 spikelets) SPP (Table 2). The sink size was bigger under NERICA 6 and NERICA 4 treatments but lower with NAMCHE 2 and NERICA 1. NAMCHE 2, NERICA 1 and NERICA 4 produced significantly ($P<0.05$), higher (74, 86 and 83%) filled panicles than NERICA 6 (55%). The unfilled panicles per square metre under NERICA 6 (102 panicles) at harvest (75 DAE) were significantly $P \leq 0.05$, higher than under other treatments (53 - 61 panicles). At harvest the grain yield was significantly $P \leq 0.05$, higher under NERICA 4 (3,435 kg ha^{-1}), followed by NERICA 1(2,388 Kg ha^{-1}) and NAMCHE 2 (2,340 Kg ha^{-1}). Lower yield was under NERICA 6 (1,805 kg ha^{-1}) under 35% mature panicles. At 90 DAE, additional grain yield (1,560 kg ha^{-1}) was harvested as some NERICA 6 panicles (65%) had not matured at 75 DAE. Significantly $P \leq 0.05$, higher total grain yield was produced under NERICA 6 (3,365 kg ha^{-1}) and NERICA 4 (3,435 kg ha^{-1}) and lower grain yield was under NERICA 1 (2,388 kg ha^{-1}) and NAMCHE 2 (2,340 kg ha^{-1}). The panicles were not significant.

3.2 Growth and Yield at Ikulwe Research Station (2019)

3.2.1 Growth parameters

The rice plant height at harvesting (90 DAE), was significantly ($P \leq 0.05$), higher under NERICA 6 (76 cm), NERICA 4 (72 cm) and NAMCHE 2 (74 cm). Lower plant height (56 cm) was recorded under NERICA 1 (Table 3). The leaf number was higher under NERICA 4 (4.4 leaves) and NERICA 6 (4.3 leaves) relative to lower counts under NERICA 1 (4.0 leaves) and NAMCHE 2 (4.2 leaves). NERICA 6 produced significantly ($P \leq 0.05$) longer leaves (44 cm) than NERICA 4 (37.1 cm) and NAMCHE 2 (35.6 cm). Shorter leaves were under NERICA 1 (29 cm). The leaf width was higher in the varieties; NERICA 1 (1.5 cm) and NERICA 6 (1.8 cm) and lower under NAMCHE 2 (1.3 cm) and NERICA 4 (1.4 cm). NERICA 4 produced more (3.4 tillers) tillers than NERICA 1 (2.9 tillers) and NAMCHE 2 (2.7 tillers). Significantly ($P \leq 0.05$) lower number (2.7 tillers) of tillers per rice plant were under and NERICA 6.

Table 1. Growth parameters for upland rice varieties at 55 DAE at Ikulwe station during 2018B

Rice variety	Plant height (cm) (50% flowering)	Leaf number (leaves)	Leaf length (cm)	Leaf width (cm)	Tillers plant^{-1} (tillers)
NERICA 1	45.03a	4.87	31.30c	1.69a	3.53
NAMCHE 2	31.50b	4.64	44.80b	1.42b	3.56
NERICA 6	33.87b	4.30	52.40a	2.00a	4.27
P-value	<0.001	0.16	<0.001	0.005	0.50
LSD (P ≤ 0.05)	4.63	NS	6.03	0.32	NS
CV (%)	14.5	3.0	7.80	20.0	18.3

Values with different letters in a column are significantly different at P≤0.05, NS = Not significant, DAE = Days after emergence, % = Percent, cm = centimeters

Table 2. Yield attributes, yield and returns on investment for upland rice at Ikulwe station (2018)

Treatments	PNC m^{-2} (Panicles)	SPK PNC^{-1} (Spikelets)	Sink size (SPK m^{-2})	Filled PNC (Percent)	Yield ADT (Kg ha^{-1})	Yield (Kg ha^{-1})	Total yield (Kg ha^{-1})
	75 DAE					**90 DAE**	
NERICA 1	149.7	98.0c	15,671c	86.0a	2,388.0b	-	2,388b
NAMCHE 2	159.7	95.0c	15,179c	74.2a	2,340.0b	-	2,340b
NERICA 4	155.7	126.7b	19,727b	83.3a	3,435.0a	-	3,435a
NERICA 6	158.7	162.7a	25,820a	55.0b	1,805.0c	1,560	3,365a
P-value	0.18	0.005	<0.001	0.009	<0.001	-	<0.001
LSD(P≤ 0.05)	NS	25.56	2.100	16.2	464.0	-	340.0
CV%	18.6	17.8	10.2	13.4	56.8	-	65.6

Values with different letters in a column are significantly different at P≤0.05, NS = Not significant, m^{-2} = Per metre squared, Kg ha^{-1} = Kilograms per hectare, DAE = Days after emergence of rice, ADT = Additional, - = No observations, SPK= spikelet, PNC = panicles

Table 3. Growth attributes at 75 days after germination of upland rice at Ikulwe station (2019)

Rice variety	Plant height (cm)	Leaf number (leaves)	Leaf length (cm)	Leaf width (cm)	Tillers plant^{-1} (tillers)
NERICA 1	56.13b	4.00b	29.00c	1.54a	2.87b
NAMCHE 2	73.63a	4.23b	35.63b	1.33b	2.74b
NERICA 4	72.20a	4.40a	37.07b	1.35b	3.40a
NERICA 6	75.73a	4.27a	44.13a	1.80a	2.67c
P-value	<0.001	0.14	<0.001	0.17	0.11
LSD (P≤ 0.05)	6.3	0.35	6.03	0.48	0.68
CV (%)	7.8	28.6	19.8	15.8	28.6

Values with different letters in a column are significantly different at P≤0.05, Plant^{-1} = per plant, cm = centimeters

3.2.2 Yield attributes and grain yield

NERICA 6 being a late maturing cultivar and given the drought conditions during 2018, the crop had two harvests, giving extra harvest labor costs. All treatments were harvested at once during the rainy 2019. The number of panicles per square metre was significantly (P≤0.05) higher under treatments with NERICA 1 (230 panicles), NAMCHE 2 (213 panicles) and NERICA 4 (247 panicles) as indicated in Table 4. The panicle density was lower under NERICA 6 (193 panicles). The filled spikelets per panicle recorded under NERICA 4 (119 spikelets) and NERICA 6 (116 spikelets) were significantly (P≤0.05), higher than under NERICA 1 (91 spikelets) and NAMCHE 2 (96 spikelets). The sink size was bigger under NERICA 4 than under NERICA 1, NAMCHE 2 and NERICA 6 cultivars. The filling of panicles under NERICA 1 (85%), NERICA 6 (84%), NAMCHE 2 (76%), NERICA 4 (80%) and the grain yield under different rice varieties were not significant.

3.3 Economic Returns and Correlation Coefficients

The gross returns and net returns were higher under NERICA 4 and NERICA 6 relative to NERICA 1 and NAMCHE 2 during the two seasons (Table 5). The returns per Uganda shilling investment (ROI) were all positive and higher indices were under NERICA 6 (1.5 & 2.8) and NERICA 4 (1.6 & 2.6) during 2018 and 2019. During 2018 the correlation coefficients (*r*) were positive and significantly high ($r \geq 8.0$) between rice grain yield and the yield attributes namely spikelets per panicle (0.86) and sink size (0.83). The *r* for panicles m^{-2} (0.76) was positive but not significant (Table 5). The percent filled panicles per plant recorded a non-significant negative and weak correlation (-0.23) with rice gain yield. In 2019 the *r* was positive for spikelets per panicle (0.13) and percent filled panicles per plant (0.23). The coefficient was however negative for panicles m^{-2} (-0.5) and sink size (-0.48).

3.4 Yield Changes during the Seasons

The grain yield in 2019 under all treatments was optimum for the NERICA varieties. During 2018, NERICA 1 recorded lower (54%) grain yield than in 2019. The grain yield also reduced under NAMCHE 2 (50%), NERICA 6 (45%) and NERICA 4 (39%) compared to 2019.

4. DISCUSSION

4.1 Growth Parameters and Yield Attributes during 2018

NERICA 1 matured earlier and produced taller rice plants than NERICA 4, NERICA 6 and NAMCHE 2 at 50% flowering. The late maturing treatments, however, gave significantly taller plants at their corresponding 50% flowering stages. The differences in plant height may be attributed to genetic characteristics for the cultivars. Matsumoto et al. [21], reported taller NERICA 4 than NERICA 1 at harvest. The expressed high vegetative growth rate for NERICAs, leads to early maturity, which is a useful trait to escape drought, compete with weeds and gives the cultivar possible diversification as intercrops or in crop rotation. The longer leaves under NERICA 4 and NERICA 6, relative to NERICA 1 and NAMCHE 2 and wider leaves under NERICA 1 and NERICA 6 could also be genetic characteristics of the cultivars. The leaf characteristics give higher photosynthetic area for solar radiation absorption, increased deposits of photosynthates into sinks of plants and results into higher growth rates, greater yield attributes and crop yields. WARDA [6], reported high yields by NERICA relative to other cultivars. The leaf number and tillers were not significant among rice cultivars. This may be attributed to lower nutrient (N & P) uptake, due to the reduced recorded rainfall (628 mm) to express their genetic potential coupled with possible higher and even solar radiation during the cropping season for all treatments. Peltonen et al. [22], observed tiller development and stem leaf growth to positively correlate with incident solar radiation. Onaga et al. [23], reported significantly higher number of tillers and panicles for NERICA 1 and NERICA 4 under increased application of N fertilizers.

4.2 Yield Attributes and Rice Grain Yield during 2018

Due to an early on-set of end of season drought, rice harvesting was done at 75 DAE for all varieties. An additional harvest was made at 90 DAE for late maturing NERICA 6. NERICA 4 and NERICA 6 produced higher spikelets m^{-2} than NAMCHE 2 and NERICA 1. This may be a genetic characteristic for the cultivars. Onaga et al. [23], reported higher spikelets per panicle under NERICA 4 than NERICA 1 and attributed the observations to higher nitrogen use efficiency coupled with genetic potential of NERICA 4. The higher percent filled panicles and grain yield recorded under NERICA 1, NAMCHE 2 and NERICA 4 relative to NERICA 6 at 75 DAE may be attributed to higher uptake of water and nutrients and tolerance to water stress at the meiosis-anthesis and panicle initiation stages, since the three varieties are early maturing. Manneh et al. [7], reported NERICA resistance to harsh growth conditions. In the current study, NERICA 1, NERICA 4 and NAMCHE 2 recorded reduced rice sink sizes with smaller numbers of spikelets per panicles that could have been more efficiently filled sinks with photosynthates. The results also relate to differences in plant traits since NERICA 6 matures late (100 DAE) and had only 35 percent panicles filled at harvest (75 DAE). Water stress at the grain filling stage was reported as most critical to yield components and yield by [21]. Matsumoto et al. [24], recorded higher yields of NERICA 1 and NERICA 4 (5,501kg ha^{-1} & 6,123kg ha^{-1}) during high rainfall and lower yields (3,018 kg $ha^{-}1$ & 2,826 kg ha^{-1}) under lower rainfall. Onaga et al. [23], reported no significant differences in the grain filling ratio of NERICA and NARIC varieties with similar traits given different N levels. NERICA 6 produced higher grain yield at 90 DAE when the 65% panicles had matured. The resultant high total yield for NERICA 4 and NERICA 6 could have resulted from the corresponding large sink sizes recorded under the two treatments and the longer grain filling period for NERICA 6. The number of panicles m^{-2} was not significant. This is attributed to the similar number of tillers recorded under all treatments since panicles arise from tillers. Tsuboi et al. [16], reported grain filling, spikelets and grain weight to have contributed most to the yield increase.

4.3 Economic Indices and Correlation Coefficients

All cultivars gave positive returns per Uganda shilling investment (ROI). The ROI under NERICA 4 and NERICA 6 were higher than under NERICA 1 and NAMCHE 2. The results implied that a timely harvest may be conducted at 75 DAE for NERICA 4 and two harvests at 75 DAE and 90 DAE are feasible for NERICA 6 to minimise field grain losses and maximize returns under a short cropping season. The correlation coefficients were high and positive for spikelets per panicle and panicles m^{-2} during 2018. The results are supported by Onaga et al. [23], who indicated panicles m^{-2} to give highest correlation with grain yield. During 2019, the spikelets panicle^{-1} and the filling of panicles recorded positive but non-significant correlation coefficients. The result may be associated with higher nutrient use efficiency under higher rainfall. From the results, spikelets panicle^{-1} linearly associated more to yield irrespective of amounts of rainfall. However, during both short and long rain seasons, the yield linearly associated with panicles m^{-2} and number of filled panicles per plant respectively. Panicles m^{-2} and the filling of panicles could have influenced yield, basing on the availability on water, nutrients and other environmental factors such as soil temperature. The factors affect tiller development at critical stages and hence number and filling of the panicles. Dobermann and Fairhurst [25], reported that the association of yield attributes and yield/ productivity is influenced by availability of nitrogen at critical stages of growth which is associated with increased demand for P and K. Tsuboi et al. [16] observed significant positive effects on spikelets, grain filling, grain weight and yield due to rainfall in some or all of the three 40 day growth periods but the panicles were not influenced. Weak and negative correlations were recorded between percent filled panicles per plant (r = -0.23) in 2018 and the number of panicles m^{-2} (r = -0.5) in (2019), with grain yields. The negative associations may be attributed to the non-significant number of panicles m^{-2} and percent filling of panicles, recorded during 2018 and 2019 respectively. The similar panicles m^{-2} relates to the non-significant number of tillers per rice plant among treatments during 2018. The similarity in percent filled panicles may be associated with availability of sufficient photosynthates to the sinks that resulted into similar yield under the high rains of 2019. Correlations coefficients are linear associations that may not indicate causation and if there is a relationship, it may be indirect.

4.4 Growth Parameters and Yield Attributes in 2019

NAMCHE 2, NERICA 4 and NERICA 6 produced significantly taller plants than NERICA 1 at harvesting. NERICA 4 and NERICA 6 produced more and significantly longer leaves than NERICA 1 and NAMCHE 2 while, NERICA 1 and NERICA 6 recorded wider leaves than NAMCHE 2 and NERICA 4. Similar results were observed under the same treatments in 2018 and associated with genetic variety inheritance. NERICA 4 produced more tillers than NERICA 1, NAMCHE 2 and NERICA 6. The higher tillers

Table 4. Yield attributes, yield and returns on investment at 90 DAE of upland rice at Ikulwe station (2019)

Treatments	PNC m^{-2} (Panicles)	SPK panicle^{-1} (Spikelets)	Sink size (SPK m^{-2})	Filled panicles (Percent)	Yield (Kg ha^{-1})
NERICA 1	230.00a	90.90b	20,907b	85.00	5,217
NAMCHE 2	228.30a	119.13a	27,198a	76.00	4,650
NERICA 4	246.70a	118.70a	29,283a	79.60	5,667
NERICA 6	193.30b	116.10a	22,407b	84.20	6,167
P-value	0.12	0.001	<0.001	0.18	0.27
LSD (P≤ 0.05)	45	12.05	2,307	NS	NS
CV (%)	22.3	21.0	15.2	16.4	78.0

Values with different letters in a column are significantly different at P≤0.05, NS = Not significant, m^{-2} = Per square metre, % = Percent, Kg = Kilograms, ha^{-1} = Per hectare, DAE = Days after emergence, PNC = panicles, SPK = spikelets

Table 5. Economic returns and correlation coefficients for upland rice during 2018 and 2019

Economic returns for rice varieties during 2018					Correlation coefficients for rice yield attributes during 2018	
Treatment	**Production costs ha^{-1} (Ush)**	**Gross returns ha^{-1} (Ush)**	**Net returns ha^{-1} (Ush)**	**ROI**	**Yield attributes**	**Correlation coefficients (r)**
NERICA 1	3,250,000	3,582,000	332,000	1.1	Panicles m^{-2}	0.76
NAMCHE 2	3,250,000	3,510,000	260,000	1.1	Spikelets $panicle^{-1}$	0.86
NERICA 4	3,250,000	5,152,500	1,902,500	1.6	Percent filled panicles	-0.23
NERICA 6	3,350,000	5,047,500	1,697,500	1.5	Sink size	0.83
Economic returns for rice varieties during 2019					**Correlation coefficients for rice yield attributes during 2019**	
NERICA 1	3,250,000	7,825,000	4,875,500	2.4	Panicles m^{-2}	-0.5
NAMCHE 2	3,250,000	6,925,500	3,675,000	2.1	Spikelets $panicle^{-1}$	0.13
NERICA 4	3,250,000	8,500,500	5,250,500	2.6	Percent filled panicles	0.23
NERICA 6	3,250,000	9,250,500	6,000,500	2.8	Sink size	-0.48

Note: 1 Us Dollar = Ush 3,700, Ush = Uganda shillings, ha^{-1} = per hectare. ROI = Returns on Investment, m^{-2} = per square meter under NERICA 4 are attributed to the high plant height, lower leaf length and width for NERICA 4, which are genetic factors observed in the study. The factors possibly allowed more light and high temperature to reach the base of the stems and resulted in active basal vegetative buds. The results are supported by Onaga et al. [23] who reported significantly higher number of tillers and panicles under NERICA 4 than NERICA 1 and the number of panicles and tiller numbers increased with application of N fertilizers. Tillering is species and cultivar dependent but the environment also plays an important role in modifying tiller performance [22].

4.5 Yield Attributes and Rice Grain Yield in 2019

Higher panicles per m^{-2} were under NERICA 1, NAMCHE 2 and NERICA 4 and the panicle density reduced under NERICA 6 cultivar. The increased number of panicles per square metre is attributed to the higher number of tillers per rice plant recorded under the three treatments relative to NERICA 6. The results could be associated with postulated increased water and nutrient uptake under the heavy rains of 2019. All the treatments in the study produced large sinks. This is indicated by the higher number of filled spikelets per panicle and panicle density recorded in the study. The filling of panicles was significantly higher under NERICA 1 and NERICA 6 than NAMCHE 2 and NERICA 4 cultivars. This may be attributed to the reduced sink size under NERICA 1 and lower panicle density under NERICA 6 that could be more efficiently filled. The grain yield was not significant, possibly due to the high panicle density under NERICA 1, NAMCHE 2 and NERICA 4, together with the large sinks under NERICA 4 and NERICA 6. The sink size is associated with the observed high number of spikelets per panicle. All the treatments recorded high efficiency in the filling of panicles with high yield attributes. The high attributes possibly resulted into the uniform high yield for the improved rice cultivars. The high yield could have been facilitated by the heavy rainfall received during the cropping season that possibly enhanced higher nutrient uptake. Onaga et al. [23] observed consistent performance of NERICA 1 and NERICA 4 between 0 N and 80 kg N ha^{-1}. Wang et al. [26], reported significant ($P<0.05$), differences in plant height and spikelets per panicle for NERICA1, NERICA 4 and NERICA 10 rice varieties, but the grain yield was not significant. The returns per Uganda shilling investment were positive for all the treatments but higher returns were under NERICA 6 and NERICA 4 similar to 2018. This is attributed to the higher yield under NERICA 6 and NERICA 4 treatments.

4.6 Comparison of Crop Performance during the Cropping Seasons

The lower (39 - 54%) grain yield during 2018, relative to 2019, may be attributed to the poor plant growth with lower plant height (29 - 45 cm) compared to taller (56 - 76 cm) rice during 2019. During 2018, the treatments also recorded reduced panicles m^{-2} (150 -158 panicles m^{-2}) and sink size (15,179 spikelets m^{-2}), relative to the larger panicle density (193 - 246 panicles m^{-2}), bigger sink size (20,907 - 29,283 spikelets per m^{-2}) and higher panicle filling (76 - 94%) in 2019. In the current study the spikelets per m^{-2} contributed most to grain yield. The lower plant height, yield attributes and yield during 2018 are associated with the lower amounts of rainfall (628 mm), possibly received at the critical second 30 day growth periods of the cropping season, compared to 2019 seasonal (1,449 mm) rainfall. Soil water enhances the absorption of nutrients and regulates photosynthesis, osmoregulation and transpiration processes that determine the amounts of photosynthates to be deposited in the sinks. The rainfall variation explains the yield variation for upland rice which depends on rainfall. [17,18], reported water stress during the meiosis-anthesis stage to raise spikelet sterility and reduce grain filling which substantially reduces grain yield. Onagaet al. [23] found that among NERICA varieties, higher water availability contributed most to the yield increase and the rainfall during the cropping season was above the threshold reported (400 mm $season^{-1}$) for NERICA varieties under a water application experiment in Uganda. Reports by several authors [20,16] indicated 3.4 kg ha^{-1} mm^{-1} and 8.3 kg ha^{-1} mm^{-1} respectively, as marginal effects of total seasonal rain on yield. [15], reported 1 mm increase in rainfall in the second growth period to increase yields by 0.45% or 10.4 kg ha^{-1}. In the drought year (2018) rice plants had longer (31 - 52 cm), wider (1.4 - 2.0 cm) leaves and higher number (2.7 - 3.4 tillers) of tillers. Rice crop developed shorter (29 - 44 cm) leaves that were not wide (1.3 - 1.8 cm) and the numbers (2.7 - 3.4 tillers) of tillers was lower during the heavy rainy season of 2019. The results may be attributed to increased trapped solar radiation with reduced shading effects on rice plants during 2018. Tiller development, stem leaf growth/ development positively correlate with incident solar radiation [22]. The filled spikelets per panicle reduced with increased rains in 2019. This may be attributed to possible lower pollination due to pollen drop under the heavy rains.

5. CONCLUSION

The plant growth parameters, yield attributes and rice grain yield for the upland NERICA varieties were determined. NERICA 1, NERICA 4, NAMCHE 2 and NERICA 6 varieties expressed poor plant growth, produced reduced panicles m^{-2}, smaller sink size, lower panicle filling percentages and grain yield during 2018 relative to 2019. The correlation coefficients to grain yield were high for spikelets per panicle (0.76) and spikelets per m^2 (0.86) during the drought 2018 year. During the rainy 2019, rice plants produced shorter and narrower leaves, lower number of tillers and less filled spikelets per panicle than in 2018. The correlation coefficients were positive in 2019 but reduced under spikelets per panicle (0.13) and percent filled panicles (0.23). Based on the results, both NERICA 4 and NERICA 6 recorded higher yields and Returns on Investment during the variable 2 years rainfall intensities and are hereby recommended using the 2 harvest modes at 75 and 90 DAE in areas with 620 -1,500 mm of rainfall, for higher economic returns.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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