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Effect Of Moisture Levels And Fertilizer Rates On Growth, Yield And Water Use Efficiency Of Upland Rice

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Abstract: Introduction of NERICA (New Rice for Africa) upland rice has been projected to transform rice farming in stress-afflicted ecologies by producing high yield with minimum inputs. This has not been realized due to the vulnerability of upland rice cultivation to yield limiting constraints such as inadequate water control and low soil fertility particularly in sub-Saharan Africa. The study was carried out in a greenhouse environment to determine the effect of water levels, fertilizer rates and Water use efficiency of NERICA 1 rice variety at KALRO-Mwea in two cropping seasons of 2017. Two water levels; 3.5mm day^{-1} , 7.00mm day^{-1} and sixteen fertilizer rates encompassing four levels of phosphorus; 0, 20, 40, 60 kg P_2O_5 ha^{-1} from Triple super phosphate and four levels of potassium; 0, 10, 20, 30 kg K_2O ha^{-1} from murate of potash were applied. The experiment was laid up in split plot design with three replications with water levels assigned in the main plot and fertilizer rate in sub-plot. Growth parameters measured were, plant height, number of tillers and number of leaves while yield indicators used were panicle weight, spikelet fertility, 100 grain weight, grain length & width plus grain yield. The data collected was summarized in MS Excel and analyzed using SPSS version 23 for ANOVA and post-hoc tests at $\alpha = 5\%$. Water levels significantly affected growth parameters, grain yield and WUE. The highest grain yield of 4.535.57 kgha^{-1}and 2,705.1kgha^{-1} was attained with 7.00mm/day while 3.5mm/day significantly gave higher WUE of .75 kgha^{-1}m^{-3} and .53 kgha^{-1}m^{-3} in season 1 and 2 respectively. Highest grain yield of 3.745.41kgha^{-1} was attained by P_1K_2 (0 kgha^{-1} P_2O_5 + 0 Kgha^{-1} K_2O) fertilizer rate, P_3K_3 (40 kgha^{-1} P_2O_5+20 Kgha^{-1} K^2O) fertilizer rate gave the highest WUE of .69 kgha^{-1}m^{-3} average of the two seasons. $P_3K_3W_2$ (40 kgha^{-1} P_2O_5+20 kgha^{-1} K_2O)-7.00mm/day water fertilizer interaction significantly gave highest grain yield of 4,114.2 kgha^{-1}and highest WUE of .86 kgha^{-1}m^{-3} was attained in the interaction $P_1K_2W_1$ (0 kgha^{-1} P_2O_5 + 10 kgha^{-1} K_2O-3.5mm day^{-1}). With (3.5mm day^{-1}) it is possible achieve over 75% grain yields as can be attained with rainfall of 833 mm (7.0mm day^{-1}) in soils not deficient of phosphorus and moderate Potassium plus sustained Nitrogen supply of 60 kg ha^{-1}. While considering the economics, WUE, growth and yield parameters, application of P_1K_2 (0 kgha^{-1} P_2O_5 + 10 kgha^{-1} K_2O) with 3.5mm/day appears to the viable option for NERICA 1 rice in loam sandy soils of Kirogo -Mwea.

Key words: Upland rice, Water Use Efficiency, Water –fertilizer interaction, Kirogo-Mwea.

1. Introduction

For half of the world's population, Rice (Oryza sativa) is the major food supplying 20% of the calories consumed globally (World Rice Statistics, 2000, Fageria and Baligar, 2003). Rice has grown to be most rapidly grown food source in sub-Saharan Africa (SSA), over the past decade (Sohl, 2005). The crop is the third most important staple food in Kenya after maize (Zea mays L.) and wheat (Triticum aestivum L.). According to MoA, (2009) Kenya report, the national rice consumption is estimated at 540, 000 tonnes. The growth has been gradual at an average rate of 12% compared to wheat 4% and maize 1% per year, perhaps due to introduction of NERICA. Introduction of NERICA upland rice has been projected to catalyze a rice green revolution in sub-Saharan Africa where nearly 50% of land area planted to rice is upland (Balasubramanian et al., 2007). This has not been achieved due partly to the vulnerability of upland rice cultivation to drought (Kijima et al., 2011) and other yield limiting constrains such as insufficient water control, low soil fertility and soil acidity. Research indicates that among the abiotic constraints, poor soil fertility is the most vital soil linked constraint, while drought and flooding are the utmost key climate-related constraints. Previous studies revealed that proper use of fertilizer can increase the yield and increase the quality of rice considerably (Ahmed et al., 2005, Oikeh et al., 2008). Nitrogen, phosphorus, and potassium are key elements ingested by the rice plant and are important in promoting a high yields. Nitrogen is the most limiting essential element in many tropical soils followed by potassium that is why NPK fertilizer is essential in order to get good yield (Abe et al., 2009). Many upland soils have low N availability and are extremely P-fixing (Becker and Johnson, 2001; Miyamoto et al. (2012) reported that in intensified systems in Uganda, continuous rice cropping reduced rice yield, compared with rotation systems. Fertilizer application is more effective in high-rainfall environments, whereas fertilizer application is less helpful in drought-prone systems, so different fertilizer application approaches are required in such conditions (Sokei et al., 2010). In rain-fed rice regions, drought stress is a severe restrictive factor to rice production and yield stability. Matsumoto et al. (2014) showed that an additional water application of 1 mm increase rice yield by 11-12 kg ha^{-1} for the upland varieties .The contribution by the rate of grain filling was highest, followed by number of panicles m-2, number of grains per panicle and 1000-grain weight, in the order of the degree of contribution. Water use efficiency (WUE), measured as the biomass produced per unit transpiration, defines the relationship between water use and crop production. WUE is defined as the ratio between grain yield and the amount of water used (Borrel et al., 1997). This implies that, high WUE can be attained either by increasing grain yield without reducing water input, by reducing the quantity of water used by the crop while sustaining yield, or combinations of both (Tabbal et al., 2002). Improving water use efficiency or improving agricultural water productivity is a critical response to growing water scarcity. With expanded population, considerably more well-organized production from a smaller irrigation water resource will be necessary. It will also necessitate substantially higher water-use efficiency from rainfed agriculture, which remains the main means of food production for most farmers in most countries. De Vries et al. (2010) also in an experiment conducted in Africa concluded that it is possible to achieve main savings of irrigation water with little yield penalties in a Sahelian surroundings. In water-limiting environments, it would be vital to produce a high quantity of biomass, which contributes to crop yield, using a little or limited volume of water. Studies have showed that upland rice cultivation has greater water-saving space and productivity than that of conventional flooding irrigation (Bouman et al., 2001; Cheng et al., 2006). Low yields in rice can be improved when upland cultivars adapted to water and nutrient supply limitations are used under improved agronomic practices. This involves applying fertilizers and moisture when least susceptible to losses and applying the right amount based on immediate plant requirements to well adapted upland rice cultivar. It is therefore possible to reverse the rice supply shortfall to one of abundance, if proper agronomic practices are documented and together with adapted upland rice cultivars availed to the farmers. Studies on the relationship between water and the yield of NERICA varieties and effect of different nutrients uptakes on rice varieties in sub-Saharan Africa have been growing. Little has been done on interaction of water and fertilizer variations on performance and water use efficiency of rice in promoting upland rice cultivation in Kenya. The study was therefore carried out with the following objectives; determine the performance of NERICA under different moisture regimes, investigate the interaction of moisture and fertilizer levels on growth and yield of NERICA and determine the water use efficiency of upland rice under different moisture and fertilizer levels.

2. Materials and Methods

2.1 Site description

2.1.1 Location

The study was carried out in Kenya Agricultural and Livestock Research Organization (KALRO), Industrial Crops Research Centre (ICRC) Mwea. ICRC- Mwea, located in Mwea Division, Kirinyaga South District, Kirinyaga County, Mwea East Sub-County, Kenya. The Centre is 21 km South West of Embu town and about 112 km North East of Nairobi. It lies on Latitude 0 37’ S and Longitude 37 20’ E at an elevation of 1159 m above sea level (ASL).

2.1.2 Climate

The average rainfall in this region is about 850 mm with a range of 500 - 1250 mm distributed into long rains (March – June with an average of 450 mm) and short rains (Mid-October to December with an average of 350 mm). The rainfall is characterized by irregular distribution in total quantities, time and space. The temperature ranges from 15.6º C to 28.6º C with a mean of about 22ºC. (Jaetzoid et al., 2005).

2.1.3 Soils

The soil type used in the experiment was carried from Kirogo farm. The soil analyses was done and are categorized as red sandy loam that is low in Nitrogen and Zinc contents and relatively high Phosphorus levels and moderate Potassium levels.

2.2 Treatment and Treatment Combination

The experiment consisted of four levels of P; 0 kg P_2O_5 ha^{-1} (P_1), 20 kg P_2O_5 ha^{-1} $^{(}P_2$), 40 kg P_2O_5 ha^{-1} (P_3) and 60 P_2O_5 kg ha^{-1} (P_4) coupled with four levels of K; 0 kg K_2O ha^{-1} (K_1), 10 kg K_2O ha^{-1} (K_2), 20 kg K_2O ha^{-1} (K_3) and 30 kg K_2O ha^{-1} (K_4). Equal amount of N levels at rate of 60 kg ha^{-1} were added to all units through Ammonium Sulphate ($(NH_4)2SO_4$) Two water regimes were used 3.5mmday^{-1}-W_1 and 7mmday^{-1}-W_2. Water regimes and fertilizer levels were tailored in split- plot arrangements in Randomized Complete Block Design (RCBD) with three replicates. Moisture regimes were in main plot, while fertilizer levels combinations in sub plots.

2.3 Experimental Procedure

The experiment was done using 20 liter plastic pots placed in a greenhouse environment. The pots were packed well with 20 kg of soil taken from the top soil (0-30 cm deep from the soil surface) of an upland field in Kirogo farm and mixed with well decomposed farmyard manure at rate of 5 t ha^{-1}. NERICA I seeds were sown on 9th March 2017 in the first season and on 5th July 2017 in the second season by dibbling at the rate of four seeds per hill and 4 hills per pot with a spacing of 15 x 25 cm and planting depth of 2 cm and later thinned to one plant per hill. Micronutrients 3 kg Zn ha^{-1} was applied to the soil after leveling and just before the planting in all pots. Fertilizers were applied in three splits: (1) basal – ¼ N, all P, ½ K, all S, and all Zn; (2) at maximum tillering – ½ N and ½ K; (3) at panicle initiation (PI) – ¼ N. The pots were kept saturated for three days before planting and watered daily to field capacity until they were three weeks old after which subsequent water regimes application continued for 16 weeks. The actual watering was done on Mondays and Thursdays at rate of 4:3.Weeding and plant protection measures were done as and when necessary.

Growth and yield parameters were recorded every two weeks, plant height, number of tillers, number of leaves, spikelet fertility, number of panicles, weight of panicles, weight of 100 seeds (g) and grain yield as per Standard Evaluation System of Rice (IRRI, 2014).

2.4 Data Analysis

The data was keyed in Microsoft excel and the parameters recorded subjected to analysis of variance (ANOVA) to find out if there were significance difference due to treatments using SPSS software version 23.Mean separation was carried out by using least significance difference and Dancan multiple range test at 5% level of significance.

3 Results and Discussion

3.1 Effect of Water Levels

3.1.1 Effect of Moisture Levels on Growth

Plant height , tiller numbers and number of leaves under different water levels were measured at different growth stages and result subjected to F-test to check for significant differences and a post-hoc analysis done to compare the treatments means, as summarized in Table 1.

Table 1: *Means for plant height, number of tillers and number of leaves in response water levels*

Season 1 (Feb-June 2017									
Water Levels	Mean Plant Height(cm)			Mean Number of Tillers			Mean Number of Leaves		
	32 DAS	52 DAS	72 DAS	32 DAS	52 DAS	72 DAS	32 DAS	52 DAS	72 DAS
W$_1$ 3.5m mday^{-1}	42.4 a	92.2 a	106.2 a	3.5a	4.6 a	4.7 a	11.9 a	19.6 a	17.0 a
W$_2$ 7.0m mday^{-1}	47.8 b	91.7 b	111.8 b	3.4b	4.1 b	4.4 b	12.2 a	20.2 a	18.7 a
P value	**.009***	**.009***	**.009***	**.047***	**.047***	**.047***	**.081**	**.081**	**.081**

Means in the same column with the same letter are not significantly different ($p > 0.05$)

Results in Table 1 shows that plant height and number of tillers were significantly affected by water levels with water level of 7.00mmday^{-1} having higher values at different growth stages. No significance difference was noted on number of leaves. MA Mannan et al. (2012) noted that plant height, tiller number and dry matter of rice varieties varied significantly at different growth stages due to variation in water stress.

3 1.2 Effect of Water Levels on Yields

The effect of water levels on yields was analyzed using yield components as observed at harvest and as summarized in Table 2 after ANOVA and Post-hoc analysis.

Table 2*: Post-hoc analysis results for the effect of water levels on yield indicators*

S1							S2
Water levels	Panicle Weight(g)	Spikelet Fertility%	Grain Length (mm)	Grain Width (mm)	100grains Weight in (grams	Yield kgHa^{-1}	Yield Kg Ha^{-1}
3.5mm day^{-1}	3.2a	59.4a	8.95a	3.04a	2.44a	3135.9a	2312.5a
7.0mm day^{-1}	3.9b	57.5a	8.90a	3.10a	2.64b	4535.6b	2705.1b
P value	0.001*	0.607	0.695	0.566	0.003*	0.000*	0.032*

Means in the same column with the same letter are not significantly different ($p > 0.05$)
**There is a significant difference at 0.05*

Results in Table 2 shows that water level had significant effect on panicle height, 100 grains weight and yields. Water level 7.00mmday^{-1} had higher values than 3.5mmday^{-1}. This was in line with studies by Sikuku, et al.(2010) who noted, more yield (kg ha^{-1}), higher filled grain ratio percentage and higher yields resulted from well watered plants of NERICA varieties, compared to those exposed to water deficit.

3.1.3 Effect of Water Levels on Water Use Efficiency

The effect of water level on water use efficiency was determined and results summarized in Table 3.

Table 3: *Effect of water levels on Water Use Efficiency*

Water levels	Season-1	Season-2
	Water use Efficiency (Kg ha^{-1} mm^{-1}	Water use Efficiency (Kg ha^{-1} mm^{-1})
3.5mm day^{-1}	7.529 (.17359)a	5.552 (.28234)a
7.0mm day^{-1}	5.445 (.15622)b	3.2475 (.16420)b
P value	0.000*	0.000*

The difference is significant since the p value is less than 0.05

Means in the same column with the same letter are not significantly different ($p > 0.05$)

The results in Table 3 reveal that water levels significantly affected WUE in the both season 1 and 2 with water level 3.5mmday^{-1} giving higher WUE. De Vries et al. (2010) showed that in a Sahelian environment, it is likely to realize major savings of irrigation water with little yield penalties.

3.2 Effect of Fertilizer Rates

3.2.1 Effect of Fertilizer Rate on Growth

Means of growth parameters namely, plant height, tiller numbers and number of leaves under different fertilizer rates was measured at different DAS and results as showed in Table 4.

***Table 4:** Effect of Fertilizer Rates On Growth Parameters*

Season 1 (Feb-June 2017)			
DAS	Plant Height (cm)	Tiller number	Number of leaves
32DAS	45.094 (1.151)	3.448 (.117)	12.052 (.406)
52DAS	91.917 (1.151)	4.354 (.117)	19.896 (.406)
72DAS	108.990 (1.151)	4.521 (.117)	17.813 (.406)
P values	**0.000***	**0.000***	**0.000***
Season two(July-November 2017)			
DAS	Plant Height (cm)	Tiller number	Number of leaves
Seedling-30 DAS	71.2609 (.770)	3.365 (.150)	13.708 (.564)
Tillering-45 DAS	77.458 (.770)	4.229 (.150)	18.812 (.564)
Booting- 60 DAS	88.500 (.770)	4.927 (.150)	18.062 (.564)
Mature grain-90 -100 DAS	110.729 (.770)	4.365 (.150)	17.281 (.564)
P values	0.000*	0.000*	0.000*

SE-indicated in the brackets
**Significantly difference at $p<0.05$*

Table 4 shows that there was significant difference in plant height, tiller numbers and number of leaves as affected by fertilizer rates across all the stages as of growth per DAS. Phosphorus and Potassium after Nitrogen are significant in growth of upland rice.

3.3.2. Effect of P and K on Growth

To observe the effect of additional P_2O_5 and K_2O in the fertilizer combination on growth traits, a separate data was summarized as indicated in Table 5.

***Table 5:** Summary of Effect of P& K on Growth of NERICA 1*

Rate of P Kg ha^{-1}	**Season 1(Feb-June 2017)**			**Season Two(July-Nov 2017)**		
	Plant Height (cm)	Tiller Number	Number of leaves	Plant Ht (cm)	Tiller Number.	Number of Leaves
P_1K_1-0Kg P_2O_5	79.17ab	3.94b	15.44b	87.17ab	3.88cd	15.58bcd
P_2K_1-20kg P_2O_5	86.89a	4.28ab	17.78ab	88.29ab	4.67abc	19.36ab
P_3K_1-40kg P_2O_5	83.78ab	4.39ab	17.61ab	83.75b	4.08cd	16.42bcd
P_4K_1-60kg P_2O_5	78.28ab	4.06ab	17.39ab	92.00a	5.29a	22.08a
Rate of K - Kg ha^{-1}						
P_1K_1-0Kg K_2O	79.17ab	3.94b	15.44b	87.17ab	3.88cd	15.58bcd
P_1K_2-10kg K K_2O	82.33ab	4.11ab	15.89ab	87.00ab	4.04cd	16.13bcd
P_1K_3-20 kg K_2O	86.94a	4.11ab	17.72ab	86.58b	4.42abcd	18.25bc
P_1K_4-30kg K_2O	79.78ab	3.89b	15.17b	87.00ab	4.29bcd	17.21bc

Means within same column followed by the same letter do not differ significantly at the 0.05

Table 5 shows that there is a general increase in plant height, tiller and leaves numbers with increase of P_2O_5 to 20 kg ha^{-1} in both seasons and a decrease in all parameters at P_2O_5=60 kg ha^{-1} in season one and increase in season two. Increase of K_2O up to20 kg ha^{-1}, increases plant height, tiller and leave numbers in the two seasons but decreases at K=30 kg ha^{-1}. 20 kg ha^{-1} K_2O fertilizer treatment rate had highest number of tallest plant, tiller and leaves number in both seasons while 0 kg ha^{-1} K_2O fertilizer rate had the lowest. Almost similar results were reported by Dakshina Murthy et al. (2015) that by increasing amount by 25% over the recommended dose of phosphorus and Potassium a significant increase in tillers as well as dry matter production were observed. Soil tests at the site revealed adequate Potassium and high Phosphorus.

3.3.3 Effect of Fertilizer Rates on Yields

The results of fertilizer rates on yields components are indicated in Table 6.

***Table 6:** Summary of Effect of P & K on Yields and Yield Components of NERICA 1*

Rate of P& K Kg ha^{-}	Season 1(February-June 2017)				Season 2(July-November 2017)	
	Panicle wt(gm)	Spikelet Fertility %	100Grain Weight(gm)	Yield in kg Ha^{-1}	100Grain Weight(gm)	Yield in kg Ha^{-1}
P_1K_1	2.97ba	53.96ab	2.68abc	3284.48ab	2.49a	1913.15edf
P_2K_1	3.812ba	60.17ab	2.64acb	3938.69ab	2.45a	1845.21ef
P_3K_1	3.50ba	54.83ab	2.89a	4334.21ab	2.56a	3076.84abc
P_4K_1	3.46ba	51.00ab	2.73ab	3880.88ab	2.45a	2671.74bcd
P_1K_1	2.97ba	53.96ab	2.68abc	3284.48ab	2.49a	1913.15edf
P_1K_2	3.05ba	62.00ab	2.46abcd	3586.01ab	2.44a	3476.84a
P_1K_3	3.48ba	60.50ab	2.47abcd	3725.32ab	2.57a	1263.473f
P_1K_4	4.15ba	69.67a	2.63abc	3377.45ab	2.62a	1997.54ef

Means within same column followed by the same letter do not differ significantly at the 0.05

Increasing Phosphorus to 20 kg ha^{-1} resulted in increase in panicle weight and % spikelet fertility in season one, while increasing to 40 kg ha^{-1} increased both 100 grain weight and yields in both seasons. Further increase of Phosphorus to 60 kg ha^{-1} decreases panicle weight, spikelet fertility, 100 grain weight and yield in both seasons. Increase in Potassium increases panicle weight and spikelet fertility while 100 grain weight and yield increases with Potassium levels up to 40 kg ha^{-1} in the two seasons. The results are in line with report from Dakshina Murthy, (2015) who observed that increase in P & K amounts from 100 to 125% enhanced rice grain yield significantly but no significant yield improvement on additional incremental doses of P & K beyond 125%.

3.3.4 Effect of Fertilizer Rates on Water Use Efficiency

The water use efficiency (WUE) for the two seasons was calculated and how it was affected by fertilizer rates is summarized in Table 7.

Table 7*: Effects of fertilizer rates on WUE in season 1 and 2*

Fertilizer Combination	Season 1	Season 2
	WUE(kgha^{-1}m$^{-3)}$	WUE(kgha^{-1}m^{-3})
P_1K_1-0 kg ha^{-1}P_2O_5+ 0 kg ha^{-1}K_2O	.5929cba	.3335cde
P_2K_1-20 kg ha^{-1} P_2O_5+0 kg ha^{-1}K_2O	.661cba	.3366cde
P_3K_1-40 kg ha^{-1}P_2O_5+0 kg ha^{-1}K_2O	.7330ba	.5837ab
P_4K_1-60 kg ha^{-1}P_2O_5+ 0 kg ha^{-1}K_2O	.6356cba	.4476abcd
P_1K_2-0 kg ha^{-1} P_2O_5+10 kg ha^{-1}K_2O	.6164cba	.6614a
P_2K_2-20 kg ha^{-1}P_2O_5+ 10 kg ha^{-1}K_2O	.6721cba	.5181abc
P_3K_2-40 kg ha^{-1}P_2O_5+10 kg ha^{-1}K_2O	.7106cba	.5680ab
P_4K_2-60 kg ha^{-1}P_2O_5+10 kg ha^{-1}K_2O	.6060cba	.4077bcde
P_1K_3-0 kg ha^{-1}P_2O_5 +20 kg ha^{-1}K_2O	.6595cba	.2292ed
P_2K_3-20 kg ha^{-1}P_2O_5+20 kg ha^{-1}K_2O	.7330ba	.5647ab
P_3K_3-40 kg ha^{-1}P_2O_5+20 kg ha^{-1} K_2O	.7920a	.5840ab
P_4K_3-60 kg ha^{-1}P_2O_5+ 20 kg ha^{-1}K_2O	.6236cba	.4062bcde
P_1K_4-0 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.5524cb	.3299cde
P_2K_4-20 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.5979bca	.4396bcd
P_3K_4-40 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.6592cba	.4228bcde
P_4K_4-60 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.5226c	.2067e
P value	.212	.000*

Means in the same column with the same letter are not significantly different ($p > 0.05$)
**There is a significant difference at 0.05*

Table 7 shows that there was significant difference in WUE due to fertilizer rates in season two (p=0.000). The highest value of WUE was achieved in P_1K_2- 0 kg ha^{-1} P_2O_5+ 10 kg ha$_{-1}$ K_2O- (0.6614) in season two . P_4K_4-60 kg ha^{-1} P_2O_5+ 30 kg ha^{-1} K_2O- had the lowest value of WUE in the seasons one and two with .5226 and .2067 respectively. P_3K_3 (40 kg ha^{-1}P_2O_5+20 Kg ha^{-1}K_2O) gave the highest WUE of .688kgha^{-1}m^{-3} while P_4K_4 (60 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O) gave lowest .3646 kg ha^{-1}m^{-3}, average for the two seasons. Bationo et al. (1998) showed that fertilizer use increased seasonal crop-water use slightly (i.e. 5.4- 14.4 kg mm^{-1} ha^{-1}) due to significant increase of crop growth and yield, in an experiment with pearl millet (Pennisetum glaucum).

3.4. Effect of Water- Fertilizer Interaction

3.4.1 Effect of Water Fertilizer Interaction on Growth

The growth parameters plant height, tiller and leaves numbers was subjected to analysis of variance to determine if there was any interaction effect between water levels and fertilizer rates. The number of leaves and plant height showed significant interaction effect has shown in figures 1.

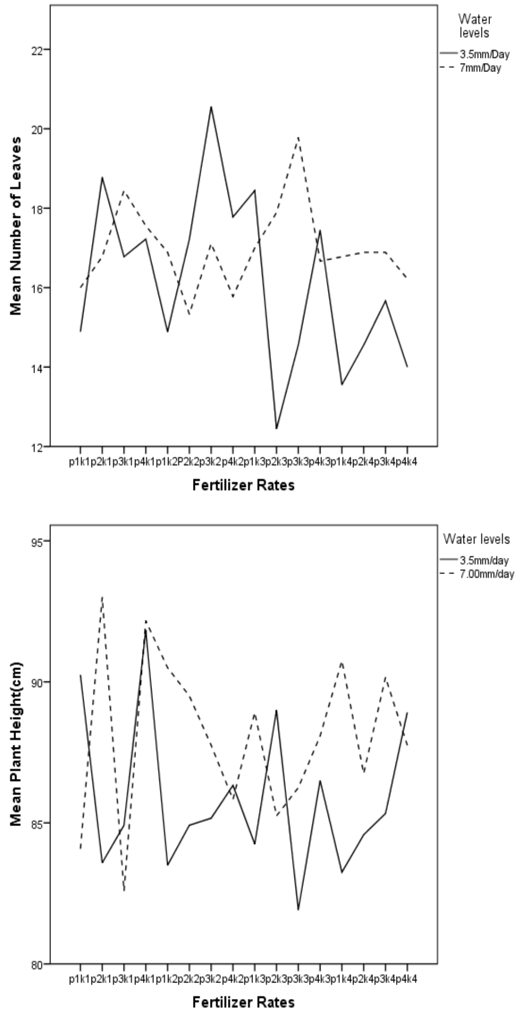

Figure 1: *Interaction effect between fertilizer rates and water levels on number of leaves and plant Height*

3.4.2 Interaction Effects Between Fertilizer Rates and Water Levels on Yield

There were no significant interaction effect on yield parameters noted in the two season, however interaction effect on yield was highly significant (p=0.000) and was due to both fertilizer rates and water levels as shown in Figure 2. The highest yield attained due to interaction was 4,218.9 kg ha^{-1} by P_3K_2+W_2 (40 kg ha^{-1} P_2O_5+10 kg ha^{-1}K_2O-7.00 mm day^{-1}) while the lowest yield was 1,050.7 kg ha^{-1}a by P_4K_4+W_1 (60 kg ha^{-1} P_2O_5+30 kg ha^{-1} K_2O+3.5 mm day^{-1}). Pooled yields for the two seasons showed that P_3K_3+W_2 (40 kg ha^{-1}P_2O_5+20 kg ha^{-1} K_2O -7.00 mm day^{-1} had highest yields of 4,414.173kg ha^{-1} while $P_4K_4W_1$ ((60 kg ha^{-1}P_2O_5+30 kg ha^{-1} K_2O -3.5 mm day^{-1})gave the lowest yield of 1,882.4 kg ha^{-1}. Generally fertilizer rates with water level of 7.00 mm day^{-1} resulted to higher yields than those from water level of 3.5 mm day^{-1}. This is in line with studies by Sokei et al. (2010) who reported that fertilizer application is more effective in high-rainfall environments, whereas in drought-prone systems fertilizer use is less beneficial.

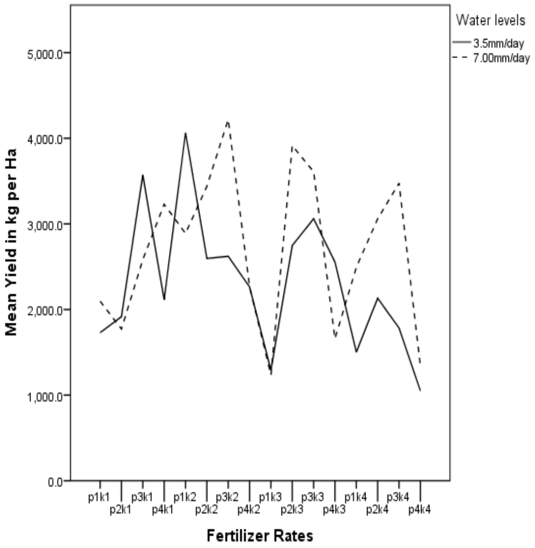

Figure 2: *Interaction effect of fertilizer rates and water on yields*

3.4.3 Interaction Effects Between Fertilizer Rates and Water Levels on Water Use Efficiency

To evaluate interaction effect of fertilizer rates and water on water use efficiency, F-test was used and the p-values were less than 0.05 for the two seasons. The response was further investigated by comparing the group means using Duncan multiple range test (DMRT). Pooled data for the two seasons indicated that the highest WUE of .86 $kgha^{-1}m^{-3}$ was attained in the interaction $P_1K_2W_1$ (0 kg $ha^{-1}P_2O_5$+10 kg $ha^{-1}K_2O$, 3.5$mmday^{-1}$) while the lowest (.2985 $kgha^{-1}m^{-3}$) was attained by $P_4K_4W_2$ (60 $kgha^{-1}$ P_2O_5 +30 kg ha^{-1} K_2O+ 7.00mm/day). When both water and fertilizers were at the highest (P_4K_4 W_2), WUE appeared to decline. This is in line with findings by Dong et al.2011 on Chinese White Polar (populous tomentosa carr.). Overwatering coupled with over fertilization results in luxury use and reduction in water and fertilizer use efficiency which deceases plant growth and production. Sylvester-Bradley and Kindred (2009) also noted that markedly high levels of water and fertilizer higher than levels essential for optimum production often result in reduction of water and fertilizer use efficiency. WUE was more sensitive to irrigation than to fertilization. Similar results were reported by Xiukang and Yingying, (2016) on Tomatoes. The graphical representation of the interaction between fertilizer rates and water levels on WUE is shown on Figure 3.

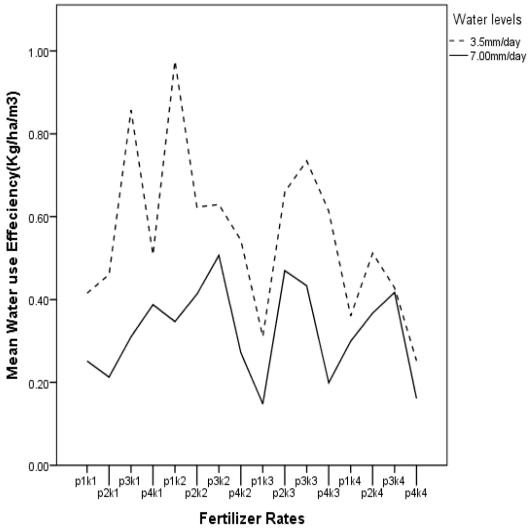

Figure 3: *Interaction effect between fertilizer rates and water levels on WUE*

4. Conclusions and Recommendations

4.1 Conclusions

Results from this study suggests;(i) Water levels significantly affected growth, yields and water use efficiency of NERICA 1, (ii) 77.8% of highest yield attained due to water-fertilizer interaction $P_3K_3W_2$ (40 kg $ha^{-1}P_2O_5$+20 kg ha^{-1} K_2O -7.00 mm day^{-1}) 4,603.6 $kgha^{-1}$ was attained by water-fertilizer interaction $P_1K_2W_1$ – (0 kg $ha^{-1}P_2O_5$+10 kg $ha^{-1}K_2O$-3.5$mmday^{-1}$)-3,581.1 $kgha^{-1}$ giving higher water use efficiency.(iii) Higher rates of fertilizer (P_4K_{4-} 60 $kgha^{-1}$ P_2O_5 +30 kg ha^{-1} K_2O) did not results to increase in growth or yields irrespective of water levels.

4.2 Recommendations

The following recommendations are made based on results of this study for consideration for increase production of NERICA 1 under varying moisture and soil nutrients levels. (i) in seasons of low moisture levels (3.5mm/day) use of P_1K_2 (0 kg $ha^{-1}P_2O_5$+10 kg $ha^{-1}K_2O$) and sustained nitrogen levels will be beneficial for sand loamy soils (ii) Higher rates of Phosphorus and Potassium with sustained amount of Nitrogen are uneconomical irrespective of amount of moisture.(iii) Further study on effect of water-fertilizer interaction should be extended in other upland areas with soils deficient of phosphorus.

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