EFFECTS OF WATERING REGIMES, FERTILIZER LEVELS ON NUTRIENTS UPTAKE, GROWTH AND YIELD OF UPLAND RICE IN MWEA, KENYA

BY

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DECLARATION AND RECOMMENDATION

Declaration;

I declare that this research thesis is my original work and has not been presented in any other University.

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Recommendations

This research thesis has been submitted for examination with our approval as university supervisors.

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DEDICATION

To my beloved family, Bernard Kairiba my husband, Betty Nkatha, Oscar Kinoti and Grace Karwitha, for their steadfast support in the success of my life.

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ABSTRACT

Upland rice contributes substantially to food and nutritional security in many African countries. Introduction of NERICA cultivars was meant to boost the production and hence area under upland rice. Factors such as poor soils and inadequate rainfall limit both the quality and achievement of yield targets. The research aimed to establish the impact of water levels, fertilizer rates on nutrients uptake and performance of NERICA 1 rice variety. It was carried out in a greenhouse setting in 2017 for two seasons and a field experiment at Kirogo farm at KALRO-Mwea. The treatments were; two water rates; 3.5 mm day^{-1} and 7.0 mm day^{-1}; four rates of Phosphorus from Triple superphosphate applied at a ratio of 0, 20, 40, 60 kg ha^{-1} P_2O_5 and 4 rates of Potassium (K_2O) at 0, 10, 20, 30 kg ha^{-1} applied as murate of potash. 60 kg ha^{-1} of N was applied in all treatments. Experimental set up was arranged in split plot layout replicated three times, whereby water levels were assigned in the main plot while fertilizer rate in sub-plot. Plant height, number of tillers and leaves, were growth parameters measured while yield components included weight of panicle, percentage of filled grains, weight of 100 dry grains, grain width/length ratio and overall grain yield ha^{-1}. Details of nutrients uptake (NPK) in straw and crude protein in grain, and soil analysis were recorded. The data was subjected to F-Test at 5% significance level using SPSS version 23 and means separation done using LSD, DMRT and T-test. Water levels had significant effect at p= 0.05 on growth parameters, yield of crop and WUE. Maximum grain yield of 4,535.6 kg ha^{-1} and 2,705.1 kg ha^{-1}was achieved with 7.0 mm day^{-1} in season one and two respectively while top most crop yield of 3,745.4 kg ha^{-1} was attained by P_1K_2 (0 kg ha^{-1} P_2O_5+0 kg ha^{-1} K_2O) fertilizer level, being average of two seasons. In second season, fertilizer levels had significant effect (p= 0.05) on WUE with P_1K_2 (0 kg ha^{-1} P_2O_5+0 kg ha^{-1} K_2O) giving highest value of 0.66.00 kg ha^{-1}m^{-3},whereas P_4K_4 (60 kg ha^{-1}P_2O_5+30 kg ha^{-1} K_2O) gave lowest yield of 0.36 kg ha^{-1}m^{-3}, as an average for the two seasons. P_3K_3+W_2 (40 kg ha^{-1} P_2O_5+20 kg ha^{-1} K_2O -7.0 mm day^{-1} water fertilizer interaction had highest yields of 4,603.6 kg ha^{-1} whereas $P_4K_4W_1$ had the least crop yield of 1,832.4 kg ha^{-1}. Significant interaction effect (p= 0.05) was observed in water regimes and fertilizer rates on WUE in both seasons. Greatest WUE of 0.86 kg ha^{-1}m^{-3} was achieved in the $P_1K_2W_1$ (0 kg ha^{-1} P_2O_5+10 kg ha^{-1} K_2O) interaction while the lowest (0.30 kg ha^{-1}m^{-3}) was attained by $P_4K_4W_2$ (60 kg ha^{-1} P_2O_5 +30 kg ha^{-1} K_2O+ 7.0 mmday^{-1}). Percentage NPK uptake in straw and crude protein in grain increased with increase of P_2O_5 and K_2O levels up to 20 kg ha^{-1} above which it dropped. For profit, efficient water use, and good performance of NERICA 1, use of P_1K_2 (0 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O) with 3.5 mm day^{-1} while for quality parameters, P_2K_2 (P_2O_5, 20 kg ha^{-1} and K_2O -10 kg ha^{-1}) plus 7.0 mm day^{-1} seems to be the sustainable choice for production of the variety in Kirogo –Mwea soils.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	:	Analysis of Variance
ASL	:	Above Sea Level
AWD	:	Alternate Wetting and Drying
BNF	:	Biological Nitrogen Fixation
DMRT	:	Duncan Multiple Range Test
DNA	:	Deoxyribonucleic Acid
EC	:	Electrical Conductivity
ET	:	Evapotranspiration
FAO	:	Food and Agriculture Organization of the United Nations
FSA/UDSA	:	Farm Service Agency of United State Department of Agriculture
GCRPS	:	Ground Cover Rice Production System
ICRI	:	Industrial Crops Research Institute
IRRI	:	International Rice Research Institute
KALRO	:	Kenya Agricultural and Livestock Research Organization
K_2O	:	Potassium Oxide
LSD	:	Least Square Difference
MBCR	:	Marginal Benefit Cost Ratio
NERICA	:	New Rice for Africa
NPK	:	Nitrogen, Phosphorus and Potassium
NRDS	:	National Rice Development Strategy
P_2O_5	:	Phosphorus Pentoxide
SRI	:	System of Rice Intensification
SSA	:	Sub Saharan Africa
WARDA	:	West African Rice Development Authority

USDA	:	United State Department of Agriculture
US$	:	United States Dollar
WUE	:	Water Use Efficiency

CHAPTER ONE

INTRODUCTION

1.1 Background Information

According to Fageria and Baligar (2003), fifty percent of the global population depends on Rice (*Oryza sativa*) as the main food and supplies 20% of the calories consumed globally. It has become a major food source in sub-Saharan Africa (SSA), over the past decade (Sohl, 2005). Population increase, improved income earnings as well as change in consumer preferences towards rice, specifically in non-rural setup, has led to increase rice demand in Africa compared to other regions in the world (Balasubramanian et al., 2007). In Kenya, the crop is ranked third most essential staple grain from maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.). Data from Kenya National Bureau of Statistics (KNBS, 2019) and NRDS-2 (2019-2030) indicates 750,000 tonnes are estimated to be consumed annually. The increase in consumption is the highest at an average rate of twelve percent compared to four percent for wheat and one percent for maize annually. This consumption growth rate is partly attributed to NERICA rice introduced in upland regions and improvement in milling services in non-traditional areas (MOA, 2009).

The global upland rice contribution in the world is approximately 13%, and according to report from International Rice Research Institute (IRRI, 2006) it plays a significant role in several regions of the tropics; in Africa about 32.4% and in Latin America 46.7%. Strides made in Africa to increase rice production as reported by (West Africa Rice Development Association [WARDA], 1999) and (Futakuchi et al., 2003) includes initiation of New Rice for Africa (NERICA), cultivars established by crossbreeding African rice cultivar *Oryza glaberrima* Steud, with Asian rice variety - *Oryza sativa* L. The Asian rice is recognized due to ability to endure dry spell coupled with high water use efficiency, an attribute linked to spatial configuration of a plant's root system (Lilley & Ludlow, 2006). NERICA varieties are high yielding, with agronomic qualities of adaptability to severe weather found in Africa. NERICA varieties have drought tolerance, greater weed competitiveness, and pest or disease resistance hence have yield benefits compared to *O. glaberrima* and *O. sativa*. NERICA adjust well to the rainfall system in SSA in which small-scale farmers have insufficient resources to irrigate or use chemical fertilizers or pesticides as required (WARDA, 2008).

Water for agriculture is constantly becoming scarce. By 2025, Tuong and Bouman (2003) estimates that fifteen to twenty million hectares of rice under irrigation will be exposed to certain level of water shortage. Rice ecologies comprise of 79 million hectares for irrigated lowland rice, 54 million hectares under rain fed low - land rice upland rice 14 million hectares and flood-prone rice 11 million ha, (Maclean et al., 2002).

The approaches that have been used to decrease rice water requirements include; raised beds (Singh & Bouman, 2002) aerobic rice (Bouman et al., 2002) alternate wetting and drying, as cited by (Li, 2001; Tabbal et al., 2002), system of rice intensification (SRI) as reported by Stoop et al. (2002), ground cover systems (Lin Shan, & Sattelmacher, 2002), and Saturated soil culture (Kima et al., 2014).

Apart from moisture requirement, crop nutrition is vital. Potassium, Phosphorus, and Nitrogen are key elements taken by the rice crop in remarkably large amounts hence are therefore mostly significant in producing a high yield. Many soils are getting exhausted due to constant mining problems of Sulphur, Phosphorus and Potassium deficiencies and increased Nitrogen due to growing of high yielding rice varieties and imprudent fertilizer management. This has led to soil health deterioration (Bindraban et al,. 2015; Talpur et al., 2013).

The role of fertilizer in crop production is recognized globally. Crop production connects intensely and positively with fertilizer ingestion (Idachaba, 2006). A yield target is achieved when the right quantity of nutrients are availed at the correct stage to meet the nutrients requirement of the crop throughout its growth period. Well organized and nutrient management approaches should aim at maximizing uptake of nutrients by crop supplied by soil native sources and fertilizers. It is important also to utilize completely nutrients availed in different forms such as residues form crops, farm and animal manures. In addition, use of mineral fertilizers as required in addressing particular nutrient limitations (Bindraban et al., 2015).

Upland rice (NERICA) has been documented to grow and attain maturity with rainfall of 476 mm. It was for this reason that the work was designed to find out the most appropriate and economical level of moisture for NERICA 1 rice variety in Mwea. Studies indicate that use of diverse fertilizer rates, with varying amount of rainfall can lead to great difference in crop yields. The main objective of this study was to assess the impact of fertilizer and water levels on uptake of nutrients and performance of upland rice as a foundation for designing improved management practices for upland rice production in Kenya.

1.2 Statement of the Problem

Introduction of NERICA upland rice in sub-Saharan Africa where approximately fifty percent of land space planted to rice is upland was anticipated to catalyze a rice green revolution (Balasubramanian et al., 2007). The anticipation remains not achieved owing partly to susceptibility during cultivation of upland rice to drought according to Kimani et al. (2011), plus additional yield limiting factors like soil salinity and acidity, low soil fertility and insufficient water control. Yield decline due to uninterrupted cropping can develop from interconnected causes, comprising of development of soil-borne micro-organisms, reduction of mineral nutrients, and buildup of lethal elements which can occur simultaneously in a rain-fed system. Research indicates that among the abiotic constraints, low soil fertility is the utmost vital soil linked constraint, whereas flooding and lack of rainfall remain the utmost key weather-linked constraints (Drechsel et al., 2001).

Of total rice produced in Kenya, only 20% is produced under rain-fed environment despite the great potential for upland rice production in the country. The average yields in upland ecosystem is around 1 tonne ha^{-1} (Kijima et al., 2006) mainly due to factors such as drought, low organic matter and nutrient depletion. To meet the rising demand as a result of growing consumption rate of 12% per year, increase in production is a must and this can be achieved through improved yields and expanding areas under production.

Improved agronomic practices coupled with use of upland cultivars adapted to water and nutrient supply limitations can lead to improved yields in rice. This can be achieved by application of moisture and fertilizers to well adapted upland rice cultivars, when least susceptible to losses and use of right quantities established by plant requirements at stage of growth. Documentation of proper agronomic practices for adapted upland cultivars and later availed to farmers can aid in enhancing production and possibly reverse the rice supply shortfall to one of abundance. Research work in Sub-Saharan Africa on the NERICA varieties as affected by moisture variations and different fertilizer rates has been on increase. Limited studies exists on interaction of fertilizer and water variations on nutrients uptake, water use efficiency (WUE) and performance of upland rice in enhancing its production in Africa. It is against this background that this research was proposed.

1.3 Broad Objective

The study's broad objective was to document appropriate moisture, P and K application rates to enhance NERICA production.

1.4 Specific Objectives

The Specific Objectives were to:

i) Establish the performance of NERICA1 when subjected to different moisture regimes

ii) Determine the effects of different levels of P and K on growth and yield of NERICA1

iii) Examine the interaction of moisture regimes, P and K rates on development and yield of NERICA1.
iv) Analyze the influence of moisture regimes, P and K rates on nutrients uptake.
v) Evaluate the water use efficiency of NERICA1 rice under fertilizer levels and varied moisture regimes.
vi) Assess the economic viability of P and K rates in production of NERICA1.

1.5 Research Hypothesis

i) Variation of moisture regimes has a significant effect on performance of NERICA1
ii) Significant effect exists on yield of NERICA1 due to different levels of P & K.
iii) Interactions of moisture regimes, P and K rates have significant effect on development and yield of NERICA1.
iv) Variation of P and K rates, moisture levels, has significant effect on nutrients uptake.
v) Water use efficiency is significantly affected by variation of moisture levels and P & K rates.
vi) Varying P and K rates has significant effect on economic viability in production of NERICA1.

1.6 Justification

Large quantities of rice are still being imported to meet the demand in several countries of the world as rice demand exceeds production according to the Foreign Agricultural Service of the U.S. Department of Agriculture (FAS/USDA, 2016). From 2000 to 2012 rice utilization growth rate in SSA was estimated at five percent per year (USDA, 2013). According to report by Seck et al. (2012), total rice consumed is estimated to rise from twenty four million tonnes (Mt) in 2012 to thirty six million tonnes (Mt) in 2020. The percentage of rice self-sufficiency in sub-Saharan Africa in 2010–2011 was around sixty percent with importation nearly ten million tonnes (Mt) annually, constituting a third of what is offered in global market, costing approximately US$ five billion annually (Wopereis et al., 2013).

Kenya Bureau of Statistics (2016) report indicate that out of 25,000 hectares of land, current rice production in Kenya to be 156,000 metric tons, compare to annual consumption of 750,000 metric tons (NRDS-2 2019-2030, 2020). While rice consumption is expected to increase due to population increase and variations in eating habits, the production meets only approximately 20% of the entire demand (Atera et al., 2011). Ministry of Agriculture (2010) project that by 2030, the market requirement for rice will rise to 1,301,000 mt.

Report by Oikeh et al. (2008) indicates that roughly 3 billion individuals rely on rice as their essential food and source of livelihood. Introduction of ‘New Rice for Africa’, offers a unique and new chance for sustainable agricultural growth for Africa’s rice farmers in the rain fed environments where most can earn a living. The research findings therefore, will help in maximizing the yields and reduce differences between farms caused by varied use of fertilizers under different moisture levels. The tendency of rice cultivation in various ecologies is going towards production approaches where water use efficiency and conservation is emphasized, increased rice production will rise smallholder farmers’ revenue, advance food and nutritional security, provide employment creation in rural regions, and decrease the rice import bill, hence the importance of this study.

1.7 Limitations, Delimitations and Assumptions of the Study

The primary limitation of this study is the generalization of greenhouse results to field condition. However, according to Harmeto et al. (2005), crop evapotranspiration in the greenhouse correspond to 75-80% crop evapotranspiration observed in open environment. Secondly a field experiment was done to compare the results although water regimes could not be controlled in field experiment and was subject to rainfall variability.

The study confined itself to accessing effect of Potassium and Phosphorus as key nutrients supplied by the fertilizers under different water regimes and how their interactions affected rice yield, quality, and water use efficiency.

In this study it was assumed that the rainfall for field experiment would be adequate reliable and well distributed throughout the crop cycle.

CHAPTER TWO

LITERATURE REVIEW

2.1 Production of Rice: Global Perspective

Above 50% of the global population consume rice (*Oryza sativa*) which remains the key staple food commodity. This is due to shift in food inclination in the rural and urban regions, aggravated by increased urbanization (Khalil et al., 2009). Seck et al. (2012) projected that global rice consumption will increase by 2020 to 496 million tons and additional rise by 2035 to 555 million tonnes. In terms of production, rice takes position three worldwide, following wheat and maize. Of the entire cultivated rice, 85% is consumed by human when compared to 72% for wheat and 19% for maize and supplies 15% per capita protein and 21% of entire human per capita energy (IRRI, 2002). Globally, 161 million hectares is the approximate area under rice cultivation with production ranging to about 679 million metric tons yearly (Statista, 2019).

Except for Antarctica, rice is produced in all continents, with more than one hundred and twenty-two countries as current producers. Rice crop can thrive in china, in latitudes of 53 degrees North of the equator, in tropical regions, thirty five to forty degrees and to elevation of 2400 meters above sea level (Kenmore, 2003). Being a very versatile crop, rice can grow under a varied range of temperatures and water systems, which include low and high altitudes and latitudes as well as in dry and wetland conditions (Seck et al., 2012*)*. Figure 2.1 shows different rice ecologies.

Figure 2.1

Rice Production Ecosystems

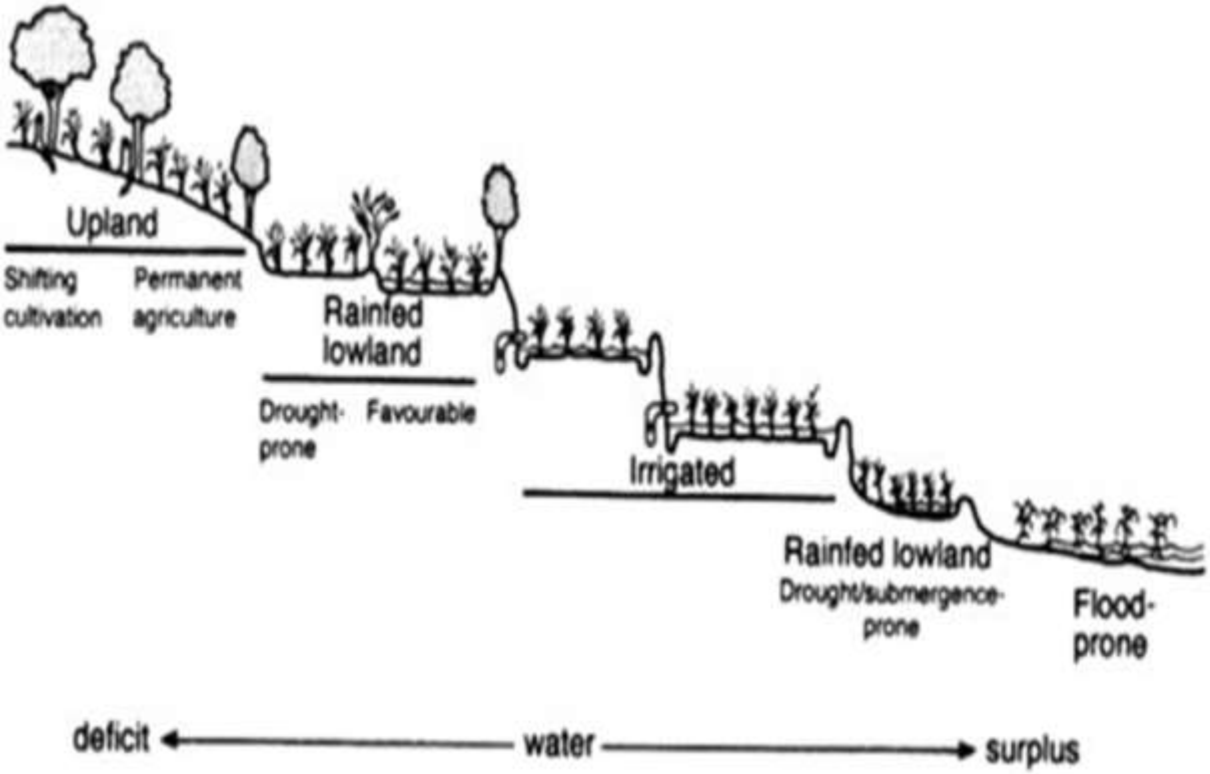


Figure 2.1 shows schematic distribution of different rice ecosystems in the landscape. Copyright 1993 by International Rice Research Institute.

2.2 Review of Rice in Africa

Rice is a fast growing food commodity for African countries that lies in South of the Sahara, primarily driven by urbanization. Rice utilization in Africa is projected to grow significantly as the proportion of Africans dwelling in non-rural regions is estimated by 2030 to go up from the present 38% to 48% (Africa Rice, 2011b). The comparative requirement for rice in SSA countries is rising at quicker rate compared to other region globally, owing to population growth, increase in earnings coupled with change in consumer inclinations in favor for rice, particularly in non – rural regions (Balasubramanian et al., 2007).

Due to ease in storage and cooking, rice is becoming more and more popular food in Africa and its taste allows use of a wide range of meals. The crop is grown in over seventy five percent of countries in African, with an estimated populace of 800 million people. In ten African countries, the crop is regarded as the major staple diet and the average consumption per person is increasing expeditiously and may double in the coming years (WARDA, 2004).

According to USDA (2013), there was a notable increase in amount of rice produced in sub-Saharan Africa by 8.4 percent annually from 2007 to 2012 as displayed in Table 2.1. As stated by Africa Rice Center, out of the global rice production, Africa harvests merely three percent, four million metric tonnes of milled rice. In Africa, rice yields are low averaging to about 2.15 tons ha^{-1} as recorded by USDA (2013) in comparison with other continents, which to great extent is associated with poor cultural practices (Diagne at al., 2013), as represented in Table 2.1, 2.2 and Figure 2.2.

Table 2.1

Rice Production and Consumption Trends for Sub Saharan Africa

Region	Attribute	2006 /2007	2007 /2008	2008 /2009	2000 /2010	2010 /2011	2011 /2012	2012 /2013	2013 /2014
SSA	Production	9,701	9,090	10,925	11,424	13,598	12,997	13,376	14,006
SSA	Consumption	17,588	17,808	18,136	19,767	21,698	23,811	24,777	26,628

Source: Foreign Agricultural Service, Official USDA Estimates (2013).

Figure 2.2.

Global Rice Production, 2016

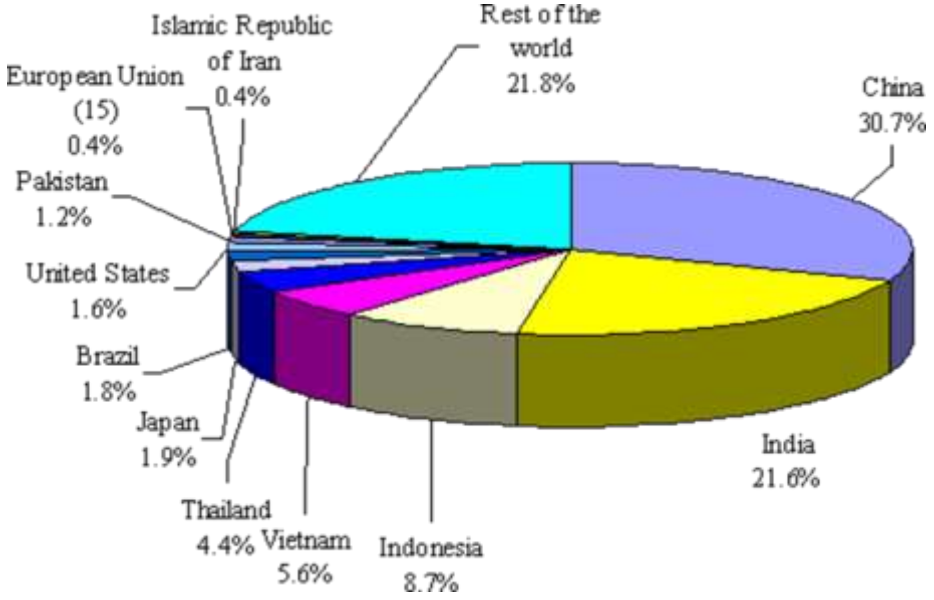


Figure 2.2 shows the distribution of World paddy rice production in Average of the 1999-2003 (UNCTAD, 2005)

Table 2.2

Rice Yields (Million Metric Tonnes) in Major Regions

Region	2007/2008	2008/2009	2009/2010	2010/2011	2011/2012	2012/2013
South Asia	196,402.59	205,092.27	191,645.07	197,978.90	213,365.27	209,816.89
Southeast Asia	155,201.09	157,050.92	156,185.55	157,269.98	160,448.39	162,752.73
East Asia	177,470.41	182,766.92	184,899.33	184,958.76	188,863.79	191,316.99
Sub Saharan Africa	17,003.41	19,523.88	19,924.59	23,430.75	23,335.51	23,194.88
South America	20,710.59	21,574.84	20,687.14	22,286.67	19,889.71	20,516.69

Source: Official USDA Estimates (USDA 2013). Foreign Agricultural Service,
Note about dates: Trade period is January-December of the next year of the split.
For instance, 2010/2011 alludes to 2011 calendar year.

This indicates that consumption exceeds production hence the introduction of improved cultivars such as NERICA is expected to help bridge this gap. Through increased adoption of new and improved varieties and area expansion, many SSA countries have made major steps towards increasing rice production (WARDA, 2008).

In Kenya, around 750,000 metric tons of rice is consumed annually (Kenya Bureau of Statistics, 2016; NRDS-2 2019-2030, 2020). Report by Kenya National Rice Development Strategy [NRDS] (2009) indicates that, whereas wheat yearly consumption is at 4% and maize 1%, annual rice consumption is growing at the rate of 12%. This high rate is attributed to change in eating lifestyles of the people. In future, the demand for rice is hence likely to continue growing. The growth or development of rice and its utilization in Kenya will help in eliminating dependency on maize as a basic foodstuff, hence improve food security and earnings for rural and urban households.

2.3 Factors Affecting Rice Production

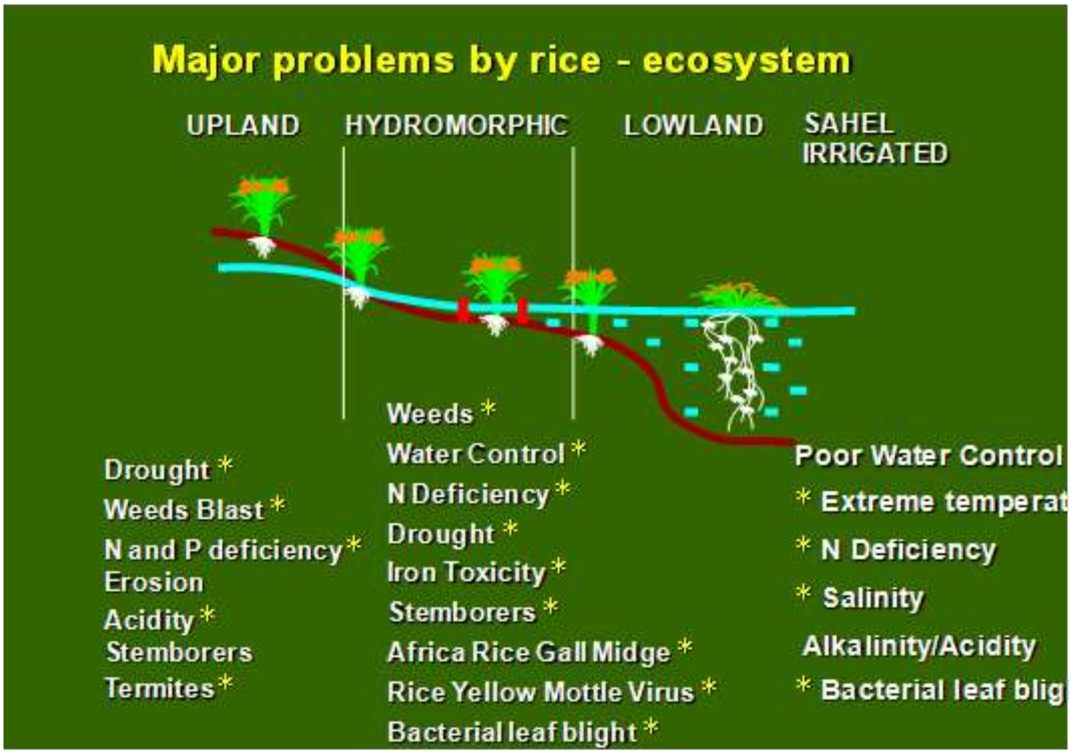
Globally, rice production mainly depends on the lowland irrigated production system. It's continuity is endangered by fresh water shortage, competition for water use and water pollution. The causes for the shortage are varied and location-specific. In sub-Saharan Africa, production is highly on low-input and rainfed agriculture plus biophysical limitations, thus leading to numerous abiotic strains on rice crops (Defoer et al., 2002). A lot of these constraints are linked to water accessibility, either by lack of rain or excessive water, extreme heat or cold temperatures and soil problems (toxicities, nutrient deficiencies and salinity).

Rice productivity is constrained by unplanned water supply, pests' invasions, poor soil fertility and poverty (Wade et al., 1999). Soil Nutrient removal increases due to lack of application of mineral or supplied in inadequate quantities with use of newly developed and high yielding rice cultivars with enhanced soil nutrient mining. Preceding research as revealed by Ahmed et al. (2005); Oikeh et al. (2008) indicates that appropriate fertilizer use can raise the quality of rice significantly and improve the yield.

Three macronutrients Nitrogen, Phosphorus, and Potassium are consumed by the rice plant and are essential in enhancing high yields. The most limiting crucial nutrient in majority of soils in the tropics is Nitrogen, seconded by Potassium, the reason why NPK fertilizers are crucial in achieving excellent yield (Abe et al., 2009). Other interlinking factors that lead to yield decline is continuous cropping include; accruing of microorganisms transmitted in the soil, mining of mineral nutrients, and buildup of lethal matter (allelopathy). Decrease in crop yield is linked strongly to nutrient depletion dues to soil degradation (Roy et al., 2003). Both inadequate fertilizer usage and uneven fertilization could lead to nutrient depletion (Tan et al., 2005). Continuous soil fertility and rice farming will be determined in future by soil nutrient balance. Pest infestation, weeds and their interactions with nutrient stress and drought are other yield reducing factors and can take place concurrently in rain fed systems (Wade et al., 1999) as shown in Figure 2.3.

Figure 2.3

Constraints of Rice Production Transverse Ecosystems



Major problems by rice - ecosystem

UPLAND

Drought *
Weeds Blast *
N and P deficiency *
Erosion
Acidity *
Stemborers
Termites *

HYDROMORPHIC

Weeds *
Water Control *
N Deficiency *
Drought *
Iron Toxicity *
Stemborers *
Africa Rice Gall Midge *
Rice Yellow Mottle Virus *
Bacterial leaf blight *

LOWLAND

SAHEL
IRRIGATED

Poor Water Control
* Extreme temperat
* N Deficiency
* Salinity
Alkalinity/Acidity
* Bacterial leaf blig

Figure 2.3 demonstrates various constraints of rice production across ecosystems

Copyright 2011 by Africa Rice Center (WARDA)

2.4 Sustainable Rice Production Enhancement Practices in SSA

Rice yields in sub Saharan Africa are curtailed by both biotic and abiotic factors resulting to huge gaps between achievable and actual yields, in input-intensive systems as well. Competition for water due to growing demand of urbanization, agriculture, livestock, climate change and rising salinity and alkalinity levels are among other challenges affecting the yields in rice farming. Diagne et al. (2013) indicates that poor soil fertility is the main soil linked constraint among the abiotic factors, whereas flooding and dry spell are considered as main climate-related constraints. Reports from farm-household surveys carried out by the AfricaRice Center in 12 sub-Saharan African countries revealed that drought and flooding causes yield reduction of about thirty three percent (Africa Rice, 2011a).

Yield reductions through soil-linked constraints are more in the lowlands compared to those of the uplands. Soil fertility, a combination of soil biological, physical and chemical determinants that influences the potential of the land is naturally poor in sub-Saharan Africa, as sands cover around 90% of the land surface and nutrient-impoverished granites and basement sediments exists (Smaling, 2005).

NPK are among the depleted soil nutrients that limit rice production. Rice producers are conscious of the significance of inorganic fertilizers in contributing to steady gain in Agricultural production. Minimal use of fertilizer in subsistence farming coupled with costly practices to manage soil deficiencies contribute to farmers inability to use fertilizers to compensate nutrients extracted from soils by crops harvested. Amounts added are less than nutrient requirements by upland rice (Manyong et al., 2001). Yield of up to 2 t $ha^{-1}$and above can be attained for upland rice under favorable situations of good soil fertility, favorable hydrological settings, subsequent extended fallows or suitable choice of crops in rotation systems (Miyamoto et al., 2012; Kijima et al., 2011). According to Miyamoto et al. (2012), Becker and Johnson (2001), in intensive rice systems and extended cultivation, decreased rice yield in Uganda as against rotation systems since many upland soils are P fixing and have low N availability. Fertilizer use in high-rainfall environments is more effective, while in drought-prone localities, fertilizer application is less helpful and so in such conditions, different fertilizer application approaches are necessary (Sokei, et al., 2010).

2.5 NERICA Rice Development

NERICA refers to “New Rice for Africa” and has wide range of cultivars extending to over 3000 segregates. The NERICA varieties were a success of crossing the two propagated species namely *Oryza glaberrima* Steud and *Oryza sativa* L. Upland rice or the traditional rainfed - (Japonica) and lowland rice or the traditional irrigated - (indica) are the two strains of Asian rice *O. sativa*. In the development of upland NERICA, Japonica varieties were utilized during cross-breeding, whereas indica varieties were used for development of the lowland NERICA (Africa Rice, 2010). The Asian rice varieties are perceived to lack resistance or unable to endure numerous environmental production stresses characteristic of Africa, but the traditional rice varieties from Africa have low yield potential although well adapted to these stresses (WARDA, 2008). The African Rice Centre in 1999 undertake to merge the beneficial qualities of the two propagated strains so as to increase the production and usage of upland rice in African Agricultural systems.

In 2000, African Rice Centre named and released seven (1 to 7) NERICA cultivars. Eleven additional varieties of NERICA were specified and then categorized according to their outstanding functionality and acceptance amongst the growers (WARDA, 2002). Introduction of NERICA rice cultivars to Sub-Saharan Africa was attributed to their appropriateness for cultivation to the tropical upland ecology. The NERICA cultivars are likely to substitute certain lowland cultivars as well as give farmers numerous benefits

(Kaneda, 2007). It is a modern and exceptional chance for majority of Africa's rice farmers in rainfed conditions to make good returns and sustainable agricultural development.

The NERICAs are said to be high yielding, outcompete weeds, tolerant to pests and diseases like; termites, rice stem borers and devastating blast. They have short cycle, grow in poor soils and mature in 30-50 days before the traditional varieties (Kaneda, 2007). Some of the varieties are more robust in the vegetative growth stage which is a beneficial feature for weed control. Compared to the majority of imported rice varieties, NERICAs have greater protein content and amino acid balance and respond very well to the use of inputs like fertilizers. By 2005, WARDA had named 18 upland NERICAs after their selection by farmers (Diagne et al., 2010). With sufficient rainfall, high yield ranging from 2.7 t ha^{-1} to 3.3 t ha^{-1} has been reported in farmers' fields which depict the high yield potential of NERICA's (Miyamoto et al., 2012).

NERICA offers hope to numerous small scale rice farmers who endeavor to make ends meet in urban set up utilizing most of their little earnings on rice. Studies by Lodin (2012); Kijima et al. (2006) indicated that proceeds of rural households were enhanced by development of NERICA rice varieties in Uganda and was perceived as starting point for reducing poverty. Benefits of NERICA include; improved diets, enhanced incomes for resource-constrained farmers, food security, and less pressure on the environment. Given that several NERICA varieties appear to survive better with little moisture in drought inclined settings, slash and-burn agriculture system.

2.6 Performance of NERICA Varieties in Kenya

In 2004, the NERICA varieties were launched in Kenya by Africa Rice Centre (ARC) for adaptability tests. Four of the New Rice for Africa cultivars that is, (NERICA 10, NERICA 11, NERICA 1 and NERICA 4) were found to be appropriate amongst the eighteen NERICA cultivars evaluated and later launched for farmers use in 2008. The NERICAs’ yields were found to vary from 3.5 to 5 tons per hectare as shown in Table 2.3.

The key rice ecologies found in Kenya are irrigated, rain-fed lowland and upland. Around eighty percent of the rice produced in the country comes from schemes that are under irrigation founded by Kenyan Government whereas the twenty percent remaining is produced under rain-fed environment. Rice is a significant diet for greater number of urban dwellers and also consumed in small amounts by a good number of Kenyans living in the rural areas. Yearly consumption is growing at a rate of twelve percent against four percent and one percent for wheat and maize respectively, making it the major predominate food commodity due to continuous change in eating habits. Approximately 750,000 metric tons are consumed annually against yearly production of one hundred and fifty six thousand metric tons as reported by Kenya Bureau of Statistics (2016). Cultivation of rice is inclined towards upland rice production whereby water use efficiency and conservation is underscored. The MOA (NRDS-2008-2018) projected an increase in both area under production and yield of upland rice from 2150 to 4100 ha and 5851 to 14,800 tons from 2008-2018 respectively.

Table 2.3

Characteristics of Four NERICA Cultivars Grown in Kenya

Variety	Potential Yield	Characterization
NERICA 1	Twelve point five to twenty five bags in an acre. One to two tons per acre Two point five to five tons in a hectare	Grain and stem has purple pigment, aromatic, protein level high - 25%, ability to smother weeds, tolerant to blast, Rice yellow mottle virus and bacterial leaf blight, matures faster, has good cooking characteristics, short awn. May be cultivated in upland ecosystems in N. Eastern, Rift Valley, Coast, Western, Central, Eastern, and Nyanza.
NERICA 4	Fifteen to thirty bags in an acre One point two to two point four ton per acre Three point two to six ton in a hectare	Protein level is high, has long grain, ability to smother weeds, tillering ability high, average threshability, can persist bacterial leaf blight, rice yellow mottle virus and blast, average maturity with acceptable cooking attributes. Can be planted in upland eco-systems in Coast, Eastern , Central Rift Valley, Western, N. Eastern and Nyanza,
NERICA 10	Eighteen to thirty bags in an acre One point four to two point four ton per acre Three point five to six tons per hectare	Grains are long, high protein accumulation, awned, mature early and good cooking attributes, purple pigmented grains, tolerant to blast, Rice yellow mottle virus and Bacterial leaf blight. Does well in upland ecologies in Central, Nyanza, Eastern, N. Eastern, Rift Valley, Coast and Western
NERICA 11	Fifteen to twenty five bags per acre One point two to two tons in an acre Three to five ton in a hectare	Resistance to drought, poor exertion, tolerates pests & diseases, high protein accumulation and can withstand blast, bacterial leaf blight plus rice yellow mottle virus, high ability to sprout, medium maturation and excellent cooking attributes. May be cultivated in upland environments in Rift Valley, Coast, N. Eastern , Nyanza, Eastern, Western, and Central

***Note.* Written and Corrected by J. Kimani, W. Kore, J. Okora, G. Onyango and T. Okiyo**

http://www.kalro.org/ricebank/index.php/home/rice-regions/41-rice-regions/varieties

Studies by Atera et al. (2018) revealed that a significant number of farmers in rice growing areas possess below and up to 5 acres or so with those cultivating upland rice having only

1 acre. This signifies that upland rice production is still at subsistence stages in many upland growing regions.

Studies by Kijima et al. (2006) and Africa Rice Center (2008) indicate that rice output in upland ecologies is around 1 ton in a hectare in Kenya. In upland environments, poor rice yield is caused by various challenges like decline in nutrients contents, prolonged dry spell and inadequate organic matter. Cultivation of rice is as well adversely influenced by pests and disease prevalence like, blast, destruction by bird, leaf blight, parasitic weed striga and rice midge (Bruce, 2010). Future rice production increase will be achieved through enhanced yields brought about by increased land under cultivation and better management practices.

Performance of the four new rice for Africa varieties in specific localities in Kenya has been ascertained. Four distinct soil categories, i.e., black cotton, sandy clay, black cotton, red clay soils and volcanic ash represent regions with upland rice cultivation potential and also upland rice-growing areas in Kenya. Research done by Atera et al. (2011) showed that amongst the NERICAs evaluated, NERICA 1 though early maturing, had the highest potential to withstand the severe climatic conditions and therefore would be appropriate for growers in Western Kenya. However, NERICA 4 was the most favored variety in western Kenya and its preference could be due to its noted greater yield amongst other attributes as reported by (Kanga & Ariga, 2018).

Further studies by M’Ringera (2014) showed that incorporation of NERICA varieties in the cropping system would hence bring major improvement in the potential yield of rice in Kenya and revolutionize the rice industry generally. NERICA-4 and NERICA-1 are reported to be more tolerant to weed pressure and better yielding than NERICA-10 and NERICA-11. The study further confirmed that the common NERICA cultivars namely NERICA 11, NERICA 10, NERICA 4, and NERICA 1 plus the standard check Dourado precoce are not likely to encroach, therefore would not exhibit any major environmental or agricultural threat in central Kenya. Rahab et al., (2019) reported that among the upland cultivars, NERICA 4, NERICA 1, can appropriately be cultivated throughout in rain-fed upland environment in Kenya in main rice-growing regions. To achieve and maximum productivity in any given area, temperature and type of soil should be put into consideration when choosing varieties.

Reports on the milled NERICA cultivars revealed that their protein values are higher and have well balance amino-acids constituents in relation compared to the imported rice as per the international rice standard (Onyango, 2014). Numerous NERICA cultivars also portray better micronutrient (iron and zinc) contents (Nassirou & He, 2011). Several communities in Kenya are currently recognizing the significance of rice as a staple food for household use and in addition being considered as a cash crop for generation of income (MoA, 2009). It calls therefore for more research on factors that limit enhanced NERICA yields in upland regions where potential still remains unexploited.

2.7 Protein Content of NERICA Varieties Grown in Kenya

Protein content has been recognized as an attribute of rice grain quality and contributes to its consumption, acceptability, adoption and marketing (Sanni et al., 2005). Rice nutritional value changes with different cultivars, fertility of soil, fertilizer used and environmental settings upon which they grow. Nutrients concentration in rice grains is also affected by the method of milling (Oko et al., 2012). In comparison with milled white rice, the un-milled rice comprises of greater quantity of roughage and has more nutrients. Numerous NERICA cultivars have good milling features that result to high-quality grains (Watanabe et al., 2006).

Compared to other food crops, protein from rice is of very high quality and forms the second plentiful constituent in rice grain. According to Mahender et al., (2016), the protein content in the grain ranges from seven percent in rice that has been milled to eight percent in brown rice even though this can vary due to varietal and environmental factors. Rice protein has remarkably good and balanced amino acid with Lysine content ranging from 3.8 to 4.0% of the protein. The amount of amino acid constituents and its edibility determines the protein quality (Frei & Becker, 2003). According to FAO/IRRI (2006), the rice amino acid outline displays high levels of aspartic and glutamic acid whereas lysine amino acid is in limiting amounts.

When milled NERICA varieties are compared to the imported varieties and the international rice standard, their protein level appear to be higher, at the same time the amino acids well balanced (WARDA, 2008).

Well balanced vital amino acids coupled with the high protein levels in NERICA cultivars may take an important part in dealing with undernourishment issues, as rice is staple food in several sub-Saharan African countries. Table 2.4 shows the Protein and certain amino acid values (%) of NERICA varieties grown in Kenya. Zhang et al. (2012) reported that Phosphorous has positive impact on rice grain quality, for instance, fluffiness, glossiness, fragrance, whiteness and softness are qualities linked to Phosphorus accumulation in rice grain and not amount present in plant.

Table 2.4

Some Protein and Selected Amino Acid Values (%) of polished and parboiled NERICA Rice

Cultivar	**Component of seed**	**Polished**	**Parboiled**
NERICA 1	Protein	10.04	11.02
	Lysine	0.4	0.42
	Methionine	0.31	0.33
	Tryptophan	0.13	0.13
NERICA 2	Protein	10.48	11.81
	Lysine	0.3	0.44
	Methionine	0.27	0.37
	Tryptophan	0.11	0.13
NERICA 4	Protein	8.87	9.17
	Lysine	0.37	0.35
	Methionine	0.1	0.17
	Tryptophan	0.23	0.2

The table shows the % protein and some selected amino acid values. Copyright 2008 by Africa Rice Center (WARDA)

2.8 Root Architecture of Rice Plant

For good performance of rice (NERICA), root architecture has been found to be a critical factor. The root system improves productivity of the crop due to its crucial roles throughout plant development. They include access to moisture and mineral elements, anchoring plant to the soil, reaction to both biological and non-biological pressures plus association with symbiotic microorganisms (Gewin, 2010; Herder et al., 2010; kimani et al., 2020). Root growth comprises of regulatory links with the shoot part of the plant plus constitutive and adaptive techniques which is a complex process (Puig et al., 2012). The majority of rice cultivars extend to depth of one meter or deeper utmost in upland soils which are not hard. Nevertheless, rice roots rarely exceed a depth of forty centimeters in flooded soils and it is mainly as a result of inadequate oxygen dispersion through the aerenchyma, the air channels that allows gaseous exchange in the roots to furnish the developing tips of the root.

At around flowering stage, root development with regards to number, weight, and entire morphology reaches upper limit. Branching goes on to generate fresh vigorous parts of the root system up to full growth. As the sequence of branching enlarges, root diameter is successfully reduced (ranging from 1000 to 40 µm). Rice root hairs are 5-10 µm in diameter and 50-200 µm long. Structure of root hairs is influenced by root surroundings. Aerobic environments in dry land soils favors root hair formation, reductive condition in flooded soils damage it. The root diameter and hairs symbolizes the ability of root system to absorb nutrients. Compared to thicker roots with fewer fine hairs, thinner and fine root hairs absorbs more water and nutrients (Fageria, 2009). It is necessary therefore to investigate the interaction of water and fertilizer levels and see how it affects the root system of upland rice.

2.9 Key Features of the Rice Root System

Rice plant has a robust-characteristic fibrous root structure typical of monocots which displays lateral, seminal and nodal roots. Root structure consists of postembryonic shoot borne-roots named crown roots and a seminal root (Rebouillat et al., 2009; Coudert et al., 2010). The duo categories of root system are able to divide to create lengthy or non-prolonged lateral roots. In the stem starting at radial ground meristem that has general features with the root pericycle is where crown roots evolve from (Itoh et al., 2005; Coudert et al., 2013b). Lateral roots change from the root pericycle and partly from the endoderm (Orman-Ligeza et al., 2013; Rebouillat et al., 2009). Additionally, Rostamza, Richards and Watt (2013) stated that coarse seminal roots and nodes emerging from bottom quotas of the stem offer further chances for crop searching for late-season rainfall with diverse reaction to soil moisture besides the main root system. The mass of length and the total area the surface of such root systems constitutes the lateral roots in both woody and herbaceous crops which play active role in the root system in regards to water uptake (Rewald et al., 2011).

The rice roots radial structure (Figure 2.4) contains the subsequent tissues, from the middle to the borderline: the stele, as well as xylem and phloem vascular tissues plus the pericycle; the endoderm; the cortex- which has cells that can go through necrobiosis to create the aerenchyma; the sclerenchyma; the exodermis; and the epidermis (Rebouillat et al., 2009). The stellate formation demonstrates the ability of rice plant roots to develop in aerobic conditions along with anaerobic environment. Remarkably, the soft plant tissue containing air spaces (aerenchyma) allows exchange of gases with the shoot while the crop is developing in surroundings where free oxygen is absent. Under drought situation, initiation of root aerenchyma increases performance of the crop and enhances carbon economy in maize (Zhu et al., 2010). In water-stressed rice, aerenchyma hinders radial mobility of moisture via the root cortex and reduces uptake of water (Yang et al., 2012).

Figure 2.4

The Radial Structure of the Rice Roots

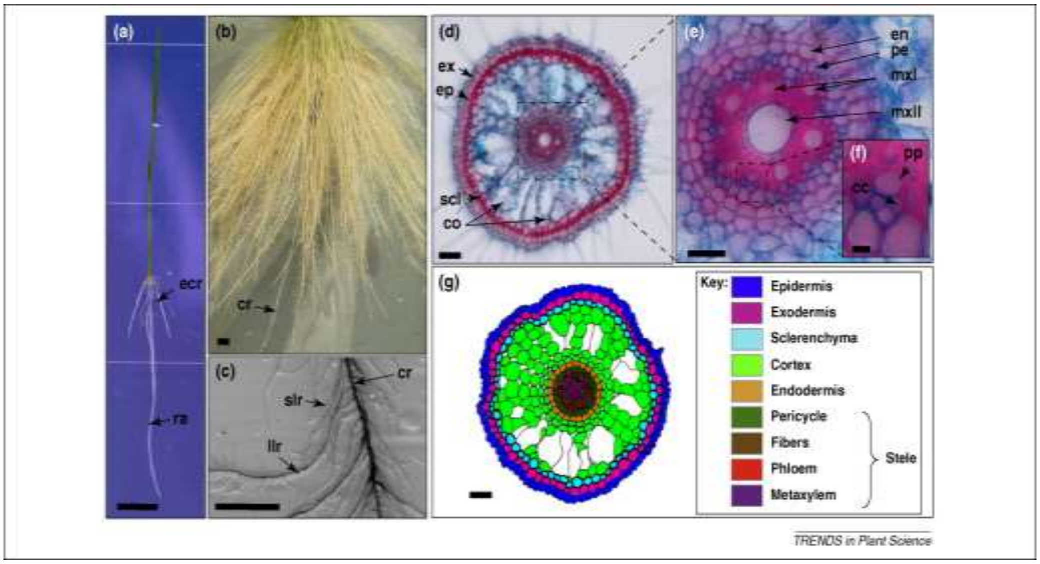


Figure 2.4 shows the molecular genetics of rice root development, (a) Morphology of the embryonic root system (Rice root system morphology, 40 days after germination (c) Crown root details (d) Transverse section of a radicle (e)enlargement of root stele (f) Detail of phloem vessels (g) a schematic representation of radical transverse organization. Copyright 2009 by Rebouillat, et al. https://link.springer.com/

2.10 Effect of Water on Upland Rice

USDA (2013) estimates rice yield in Africa to be 2.15 t ha^{-1}, which is low compared with other regions and is attributed to great extent by rice cropping system in sub-Saharan Africa (SSA) being rain fed. Rice cultivation in marginal regions comprising of low soil fertility and susceptible to harsh abiotic pressure (which includes duration of dry spell in the growing season) have a major impact on production of rice (Heinemann et al., 2007 and Pinheiro et al., 2006).

In rain fed rice regions, dry spell conditions are a severe restrictive aspect to productivity and yield reliability. The effect of dry spell differs based on variety, extent and length of pressure and its conformity with diverse development phases (Kato et al., 2004). Rice plant is incapable of controlling water loss through transpiration as efficiently as other grains, hence it's more prone to drought than other cereals (Alberto et al., 2011).

Matsumoto et al. (2014) showed that for upland varieties, an additional of 1 mm of water increases yield of rice by eleven to twelve kilogram per hectare. In regards to percentage of contribution, the grain filling rate was the highest, seconded by panicle number per m^{-2}, sum total grains in a panicle plus the weight of 1000-grains. Atera et al. (2011); Kato et al. (2008) showed rice plant is extremely reactive to moisture stress particularly during the reproductive phases. However, the production of effective tillers, leading to grain yield decrease is influenced by moisture stress during the vegetative stage of the NERICAs. Stress through the reproductive stage has tendency to hamper pollination, fertilization and filling of grains thus decreasing grain yield. Saito et al. (2005) discovered that there was an enhancement in yields of upland rice improved varieties when water stress does not occur during the growth phase.

2.11 Effect of P and K on Upland Rice Production

Phosphorus and Potassium are important macronutrients required by rice plant for various physiological processes. Modern rice varieties need sufficient amount of vital nutrients to produce high yields. Heffer (2013) reported that in 2010–2011, 14.3% which is 24.7 Mt of the total 172.2 Mt fertilizer ($N+P_2O_5+K_2O$) used worldwide, was spent on rice with Nitrogen (N) accounting for 15.4%, Phosphorus (P) 12.8% and Potassium (K) 12.6% .

Of the three major macronutrients, N, P, K, the most abundant cation in plant is Potassium (K). Potassium deficiency in upland rice growing areas is not as pronounced as for N and P, but according to Bijay-Singh et al. (2004), production of high yields coupled with use of high producing cultivars of rice plus additional crops for several years have mined soils of K reducing its reserves. This therefore calls for consistent usage of K fertilizer to attain optimal yields of rice. Fairhurst et al. (2007) recommended use of 25 kg K ha^{-1} in the plots getting no fertilizer K, for every tonne of target grain yield increase over the yield of rice in managing K as general guideline for rice in soils with small supply of K. Likewise, Oikeh et al. (2008) recommend for soils with low P and K levels based on soil tests, use of 30-60 kg ha^{-1} P_2O_5 and 30 kg ha^{-1} K_2O respectively. For medium P & K soil fertility class; 15-30 P_2O_5 kg ha^{-1} and 15-30 K_2O kg ha^{-1} respectively, while for high soil fertility class, 0-15 P_2O_5 kg ha^{-1} and 0-15 K_2O kg ha^{-1} is recommended.

For sustenance of plant growth and development, Potassium is required in almost all processes. It enhances growth of roots plus plant vigor, improves crop resistance to diseases and pests and aids in lodging prevention through lignification of vascular bundles (Mengel et al., 2001). As stated by Wegner (2013) K is a key osmoticum in the vacuole which drives the generation of turgor pressure facilitating expansion of cell. Gajdanowicz et al (2011) emphasis that Potassium is essential in generation of root pressure in the vascular tissues, while in the phloem it is central in transporting photo-assimilates from the source to the sink. Qiangsheng et al. (2004) stated that uptake of K by rice plants is highest between elongation stage to heading stage of plant growth. Studies by Sarker et al. (2001) indicated that use of Potassium in rice production significantly raised number of tillers hill^{-1}, increased the spikelets number per panicle, filled grains percentage and 1000-grain weight. Increased number of filled grains panicle^{-1} with application of K fertilizer was also recorded by (Krishnappa et al., 2006; Esfehani et al., 2005). Basal application of K showed positive effect on the percentage of filled grains which resulted in higher number of desirable seeds increasing the number of grains panicle^{-1}, while its deficiency initiated pollen sterility with low percentage of the filled grains panicle^{-1}. Esfehani et al. (2005) reported reduced spikelet sterility in rice with incremental amounts of Potassium, while Islam et al. (2008) noted a progressive decrease in spikelet sterility with incremental doses of K up to additional dose of 50 %. In rice plant, Potassium nutrition enhances pollen germination in the floret which leads to high spikelet fertility.

Uddin (2013) noted that increase in grain yield with application of K was largely caused by yield components improvement, such as, number of effective tillers, panicle length and grains panicle^{-1}. He reported highest grain yield of 2.88 t ha^{-1} of NERICA 1 in studies carried out on silt loam and well drained soils low in organic matter content of 1.19% with potassium applied at rate of at 40 kg K_2O ha^{-1}. Substantial results of grain yield of rice to potassium application have been reported by numerous researchers (Quampah et al., 2011; Bahmanyar and Mashaee, 2010).

Phosphorus is a crucial elements necessary for plants growth as earlier stated. It is part of high energy compounds such as adenosine triphosphate (ATP) and genetic materials necessary for production of seed. Similarly it is used in the production of compounds such as glycophosphates, nucleotides and phospholipids and its shortage can intensely decrease development and plants yield (Mengel et al., 2001). At tillering and when accumulation dry matter commences in rice plant, deficiency of P start showing which can retards cell elongation and expansion of leaf.

According to Nishigaki et al. (2019), soils such as Oxisols and Ultisols which are greatly weathered in many regions of the world, Phosphorus deficiency has been identified as a main cause limiting upland rice production. In addition to the naturally low P in such soils, high P-fixation capacity makes phosphorus inaccessible to plants. Numerous soil properties, particularly Al, Fe, and clay levels are associated closely to the P-sorption capacity of such soils and therefore use of appropriate amount of P is an essential consideration for upland rice production in such soils. Phosphorus deficiency in soils under intensive rice cultivation may develop and problem can be intensified with use of improved cultivars. P deficiency can delay maturity of rice crop by 10-12 days, while according to Fageria and Gheyi (1999), applying P on P-deficient soils increased number of panicles, rice root growth, and grain weight of rice.

Studies by Islam et al. (2008) revealed that grain yield together with yield components were significantly affected by rates of P application. Increasing dose by 25% over the optional amount for Phosphorus and Potassium had significant increase in tillers and production of dry matter. Fifty percent increase in P amount had significant increase on panicle production and filled grains per panicle but increasing P & K amounts above 125% did not give any significant yield increase. Their studies indicate that soil P deficiency may account for P deficiency in grain and it may be the reason for P deficiency in the human diet. Increased grain yield linked with additional fertilizer rates might be explained by accumulative effect of enhanced translocation of photosynthates to sink leading to increase in yield components (Rao et al., 2004).

2.12 Nutrients Uptake by Rice

The usage of fertilizer and high yielding varieties are amongst the essential ingredients in attaining high rice yield. Globally, the role of fertilizer is well-known as crop production relates strongly and positively with fertilizer use (Idachaba, 2006).

Research done in West African soil classification of rice ecosystems by AfricaRice Center revealed that in the crop production system in the uplands, Nitrogen shortage extent is more in semi-arid region as compared to the humid forest, while Phosphorus (P) shortage due to leaching is greater in the humid forest but minimal in the semi-arid (WARDA, 2008). N, P and Potassium (K) three main macronutrients are scarce on soils developed from sandstones hence application of chemical fertilizers to optimize NERICA production in these soils is required.

Uninterrupted growing of high yielding varieties (HYV) and unwise fertilizer management is causing poor soil quality with shortage in key mineral elements; mainly N, P, K, and S. The first three are taken up by the rice crop in remarkably large amounts and are hence principally significant in producing high yield. For diverse agricultural systems in Africa, the nutrient balances comprise of main nutrient inflows received through precipitation, organic manure, symbiotic, inorganic fertilizers, Nitrogen-fixation and sedimentation, while nutrient outflows are from harvested crops and what is lost through leaching and soil erosion. Drechsel et al. (2001) concluded that soil nutrient reduction is rather rigorous in Africa estimating net loss in the order 10 kilogram Nitrogen ha^{-1}, 4 kilogram P_2O_5 ha^{-1} and 19 kilogram K_2O ha^{-1}.

Abe et al. (2009) indicated that in many tropical soils, Nitrogen is the most lacking element followed by Potassium, therefore NPK fertilizer in required to obtain good yields. For the initiation of leaves and florets, provision of sufficient Nitrogen to the crop in their initial development phase is very vital (Mandana et al., 2014). Phosphorus insufficiency is expected to take place in various soils with rigorous rice production coupled with usage of improved varieties in rice production. The reaction of rice plant to Phosphorus fertilizer is slightly noticeable compared to N under favorable soil environments. Even though Phosphorus extraction from soil remains owing to the intense farming, Phosphorus fertilizers are rarely used for rice. Islam et al. (2008) indicated that shortage of P in the soil may account for Phosphorus shortage in grain and might be the reason for Phosphorus deficiency in the human nutrition. Some of the causes for poor rice yields might be shortage of P in rice soils witnessed in several regions over the years.

Qiangsheng et al. (2004) stated that Potassium intake by rice plants is amplified in the development period of stem extension to heading phase. In rice, application of Potassium considerably increases tiller number for every hill Sarkar et al. (2001). Adesmoye and Kloepper (2009) observed that in the previous decades, the amount of NPK fertilizer usage has improved extremely in crop production. Studies reveal that appropriate application of fertilizer can raise the yield and increase the rice quality greatly (Ahmed et al., 2005; Oikeh et al., 2008). Blending of inorganic and organic fertilizer complimentarily meets nutrients requirements of rice plants and similarly increases soil organic matter. Studies by NaingOo et al. (2010) showed that combined use of Nitrogen and Potassium at rate of 80 kilogram N per hectare plus 40 kilograms K_2O per hectare gave the highest grain yield of 3.49 t ha^{-1} of NERICA 1. Generally, rice growers do not use right quantities of N, P, Potassium (K), and other fertilizers.

Mineral fertilizer usage is rare in traditional upland rice cultivation and not very widespread in rain fed lowlands (Sakurai, 2010; Kamara et al., 2011). This is influenced by fertilizer accessibility, which is greater in irrigated lowlands, less in rain fed uplands with production risks being less in irrigated lowlands and more in rain fed uplands (Oikeh et al., 2008; Mghase et al., 2010).

2.13 Forms of Nutrients Absorption in Rice Plant

Nutrients absorption is considered as either ion absorption or ion intake since nutrients are taken up by roots in ionic form, either as cations or anions. The organic ions are manufactured inside plant tissue whereas ions derived from inorganic compounds are assimilated from the culture medium. The univalent positively charged ions and anions are taken up more quickly than the divalent or polyvalent cations or anions.

Soil texture, organic matter content and rooting depth influences nutrient storage capacity and accessibility, though the accessibility is altered by soil pH and moisture (Keller, 2005). These variables can influence numerous chemical and biochemical activities taking place in the soil, hence controls the movement and availability of mineral elements in the plant as displayed in Table 2.5 (He et al., 2005). Uptake of nutrients available for the plant which are dissolved in the soil solution is influenced by specific crop, botanical structure of particular tissue, type of soil and mineral element in addition to the water uptake through the soil-root-shoot pathway and is taken up as ions (Keller, 2005; Raţić et al., 2005). Different nutrients are frequently obtained in diverse locations, for instance, nitrate (NO_3^-) percolate below the topsoil faster than potassium (K^+), one that spread out quickly as compared to phosphate ($H_2PO_4^-$). This can result in superficial roots taking up soil-immobile nutrients like Potassium and Phosphorus, whereas roots extending far down get soil-mobile nutrients, for instance NO_3^- (Keller, 2005). Tester and Leigh (2001) indicated that, cations and anions can be taken up into the root system through two processes; passive process through which cations and ions move to the root endodermis from the soil solution and non-passive process which occurs against a concentration gradient by utilizing metabolic energy - adenosine-5'-triphosphate (ATP). When availability of certain ions (e.g. NO_3^- and K^+) in soil medium is high, usually in the mM range, for example when fertilizer is applied, they are taken up passively across ion channels and actively preferentially through conveyors, when accessibility is low -

generally in the μM range. A close link exists between the metabolic processes of the root and the shoot with the xylem being the dominant way for upward passage of ions and water from the roots to the leaves (Sattelmacher, 2001). Almost all of the crucial macronutrients are conveyed as inorganic ions in the xylem vessels. The elements uptake is dependent on specific elements' interconnections. Antagonism occurs when a particular element decreases the intake of the other, whereas the interaction where the uptake is increased by each other is regarded as synergism. Synergistic and antagonistic interactions may take place amongst macro- and micro-nutrients where various micro-elements might influence the uptake of macro-elements and the other way round.

To meet the requirement of optimal growth, vigorously growing crops display higher percentage of nutrient uptake (Marin et al., 2011). Internal nutritional state can as well control absorption level through production of indictor molecules conveyed from shoot to the roots. Nature and structure of soil, yield volumes, season and variety strongly affects nutrients uptake and demand by rice. By early panicle initiation stage, around fifty percent of Nitrogen, fifty five percent of Potassium and sixty five percent of Phosphorus are taken up out of entire uptake. Eight percent of N, sixty percent of Potassium and ninety five percent of Phosphorus ingested is over by the time panicle is fully visible- heading phase (Dobermann & Fraihurst, 2000). The relative degree of uptake of cations by the rice crop seems to follow the order;

$NH_4^+ > K^+ > Mg^{2+} > Ca^{2+}$

Among anions it appears to be;

$NO_3^- > H_2P0_4^- > Cl^- > SO_4^{2-}$

In rice plants, determination of critical concentration of both macro and micro elements, below which deficiency signs appears and beyond which toxicity manifestations might arise is essential (Sahrawat, 2000). Toxic effects of manganese, aluminum and iron along with others, produce nutritional disorders in rice plants.

Table 2.5

Soil pH Values for the Absorption, Absorption Forms and Mobility of Some Essential Nutrients

Nutrient	**Nutrients Absorption form**	**Ideal soil pH for the absorption**	**Mobility in Plant (phloem)**
Nitrogen	NH_4^+, NO_3^-	6.0 – 8.0	High
Phosphorus	HPO_4^{2-}, $H_2PO_4^-$	6.5 – 7.5	High
Potassium	K^+	6.0 – 8.0	High
Magnesium	Mg^{2+}	6.0 – 8.5	High
Zinc	Zn^{2+}	3.5 – 7.0	medium
Calcium	Ca^{2+}	7.0 – 9.0	Low
Iron	Fe^{2+}, (Fe^{3+})	3.0 – 6.5	medium

The table demonstrates various nutrients absorption forms and ideal pH for their absorption by Bavaresco et al., (2010)

2.14 Application of Excess Potassium and Phosphorus in Cultivation of Rice

Among the key considerations for continuous increase in production of rice meant to meet the demand for projected global population from the time of green revolution is fertilizer usage. Farmers in a number of developing countries apply inorganic fertilizers in their farmland exceedingly and haphazardly whereas others apply effectively adopting fertilizer management caused by lack of training in continual innovations.

In efforts to secure good yields, farmers apply a lot of fertilizer of which much goes to waste. Ineffective fertilization can elevate costs of production by about thirty three percent and greenhouse gases by sixty percent and approximately fifteen to eighteen percent decrease in yields (The International Fertilizer Development Center [IFDC], 2013). To achieve profitable yields, efficient application of the right types and amounts of fertilizers to provide required nutrients is important. For optimum crop production, use of soil tests can assist to decide the status of plant available nutrients to come up with fertilizer recommendations. Variation in fertilizer recommendations is caused by poor soil sampling technique. To provide adequate and balanced nutrient supply, these analytical results are utilized to justify fertilizer recommendations. If the results are inaccurate, the suggested quantities of fertilizer to be applied will be faulty. Major inorganic fertilizers applied in rice production are muriate of potash (MoP), triple superphosphate (TSP), and Urea with around 75% of nutrient use constituted by Nitrogen (Sultana et al., 2014). Although the pattern of reaction with respect to genetic disparity of varieties differs, rice plant normally reacts positively to use of these key nutrients to enhance yield parameters and grain yield (Mahato et al., 2007).

Soils like Oxisols and Ultisols are highly weathered and have naturally low level of Phosphorus with high capacity of P-fixation which causes Phosphorus inaccessible to plants. The soils P-sorption capacities are linked closely to numerous soil characteristics, particularly clay, Fe, and Al contents (Fageria & Gheyi, 1999). Uptake of Phosphorus differs amongst rice cultivars and the difference is determined by fertility of soil and rice cultivar (Choudhury et al., 2007). Application of sufficient amount of P on these soils is a vital factor for upland rice production. However, high Phosphorus levels in the soil may have negative effect to other nutrients. At elevated P level, Fe is rendered inactive due to precipitation as insoluble phosphate in the vein as noted by Drechsel et al. (2015) rendering it unavailable for assimilation. Research by Panda et al. (2012) revealed that concentration of Iron in grains of all the varieties improved with additional amount of Phosphorus applied in the soil up to forty kilograms per hectare and decreased at eighty kilogram per hectare. In upland rice growing areas, Potassium deficiency is not as predominant as N and P. Nevertheless, soil reserves of K cannot be adequate to sustain high productivity for prolonged period, if high productivity cultivars are used. When Potassium is obtained by Mehlich-1 extracting solution is greater than 50 mg kg^{-1}, no reaction of upland rice to K used is observed (Fageria, 2009). Li et al. (2001) reported restraint of Fe absorption by an excess of K in rice. Restriction of iron buildup at higher amounts of Potassium is apparent due to the fact that potassium in higher quantities rises the oxidizing power of rice roots, that leads to oxidation of Ferrous ion (Fe^{2+}) to Ferric ion (Fe^{3+}) and barring the ferric ion from being absorbed.

2.15 Aluminum and Iron Toxicity in Rice

The earth crust is composed of many elements of which Aluminum is among those found in abundance, and with the concentration of more than 2–3 part per million with a soil pH < 5.5, it becomes toxic to numerous plants (Balsberg-Pahlsson, 1990). Aluminum dissolves and the quantity of Aluminum in the soil solution rises when soil pH drops. To the roots of sensitive plant species, soil aluminum concentration of 2–5 parts per million (ppm) is poisonous while beyond 5 ppm is lethal to tolerant species. As reported by Barceló and Porchenrieder (2002) toxicity caused by Aluminum is a main reason of poor performance of plants in the acidic soils that prevails in tropical weather conditions.

Division of root cell and the capacity of the root to extend is affected soil solution with lethal levels of Aluminum. Root tips are distorted, fragile while growth and branching of roots is decreased. Inadequate water and nutrition results to poor crop and pasture development, reduced crop yield and grain size. Aluminum toxicity effects are highly evident in seasons with a dry spell. Subsurface soils which are acidic forms a barrier that hampers effective roots development to access subsoil water stored for grain filling. Aluminum restricts division of cells in lateral roots and root tips, escalates cell wall stiffness by cross linking pectins, and lessens DNA replication by enhancing the DNA double helix rigidness. In addition, Phosphorous is fixed in less accessible forms by aluminum in soils and on surfaces of root, reduces root respiration, affects activity of enzymes controlling sugar phosphorylation and the discharging of cell wall polysaccharides, and the uptake, transport, as well as usage of numerous vital nutrients such as Ca, Mg, K, P and Fe (Gessa et al., 2005).

Aluminum toxicity in rice reduces the entire root length but water uptake frequency per unit length is not affected. However, under drought conditions, Aluminum toxicity increases plant water stress as maximum rooting depth is reduced (Tamás et al., 2006).

Excess Al encourages signs of iron (Fe) deficiency in wheat, rice and sorghum (Macêdo et al., 2008). In irrigated rice systems, Al toxicity is comparatively uncommon. It rarely happens in lowland rice apart from in certain soils where there is very moderate soil reduction after flooding.

Historically, upland rice plants have been believed to bear soil acidity and Al^{3+} toxicity (Famoso et al., 2010). According to Freitas et al. (2017), Al^{3+} has a high negative impact on mineral nutrition of upland rice plants, particularly in their roots. They reported that owing to interaction between Al and Ca, reduction in Ca contents and accumulation, are among greatest effects triggered by Al^{3+} on mineral nutrition of upland rice plants. Additionally Al causes reductions in Zn absorption by the plant; a negative effect related to Al^{3+}.

A higher reduction in the amount and accumulation of Fe and Mn was reported also, with greater doses of Al (Freitas et al., 2017). Greater consideration hence should be taken with regards to these micronutrients where upland rice crops are grown in soil with high Al^{3+} concentration. Fageria (2009) revealed that these micronutrients accrue in larger amount in such soil culture. Soils which experience Al toxicity are:

i. Ultisols, Oxisols -Acid upland soils which have huge exchangeable Al content, Aluminum toxicity frequently happens jointly with Manganese (Mn) toxicity.
ii. Soils with Acid sulfate, in cases where rice plant is planted as upland crop a week earlier ahead of flooding.
iii. Soils that are flooded and with a pH of less than four, before iron toxicity signs develops (IRRI, 2007).

In rice, Zinc deficiency is frequently associated to iron toxicity. Iron signs begin when the quantity of ferrous iron (Fe^{2+}) dissolved around the root region is high. The Ferrous ions act as an active absorbent of zinc rendering it inaccessible by the crop. Generally, in reduced environments of wetland rice, ferrous iron induces physiological stress in rice plant as well. The dissolved iron is absorbed up into the roots and piled up in plant leaves causing brown spots and reduced development (Hägnesten, 2006).

Although there is presently no practical treatment option for aluminum toxicity, it is possible to manage it by undertaking the following precautions:

1. Use of lime to raise the soil pH by first determining via lime requirement test, the particular amount needed per ha, to range from 1−3 t lime ha^{-1}.
2. Undertake laboratory tests and measures. Ameliorate subsoil acidity to increase the development of root beneath the plow level which causes Calcium to be leached into the subsoil when calcium oxide solution is administered to the surface of the soil. Add NO_3^- or SO_4^{2-} anions to go along with Calcium ion (Ca^{2+}) which is incorporated into the layer of soil under the topsoil by using green manure crop, gypsum, or urea with extra quicklime to counteract the amount of acid produced in nitrification.
3. For acid upland soils, fix soil erosion traps and integrate one ton per hectare of reactive rock phosphate to lessen Phosphorus shortage.

Iron plays essential roles in plant which includes; electron transport chain of photosynthesis, plant respiration, division of cell and amalgamation of chlorophyll (Müller et al., 2015). Enormous area of land suitable for agriculture in Asia, Africa and South America, remain unfarmed owing to the iron toxicity. In the soil, Iron ferric ion ($Fe^{3+)}$ is predominant which is insoluble therefore basically inaccessible for absorption.

The soil lower pH results in the reduction of Fe^{3+} to Fe $^{2+}$ which is soluble and can be absorbed by the rice plant (Becker & Asch, 2005). High level of iron in soil is toxic to plants and is a major concern in rice cultivation. Excessive uptake of Fe^{2+} by crops may alter the oxidants and antioxidants equilibrium to a pro-oxidant state, leading to variations in the physiological, biochemical and morphological features of the plant (Sahrawat, 2004) whereby in extreme situations, can cause death of plant. Research done by Dufey et al., (2012) revealed that in extreme instances of toxicity by iron, rice crops portrayed water content decrease, chlorophyll content index and a raised stomata resistance, shoot iron uptake and shoot /roots iron concentration. As indicated by Goicoechea et al. (2001) rice crop stomata closes to restrict the transpiration rate, which can influence the exchange rate of carbon dioxide and associated photosynthetic activities, signifying reduction in plant growth. As recorded by Apel and Hirt (2004) rice plants develop orange brown spots on the leaves due to Fe toxicity and the indication is usually called leaf bronzing and occurs as an effect of oxidative stress. Additionally, impaired root systems and strong growth depression can be noticed on rice crops planted in excessive iron environment. The accessibility and absorption of potassium may lessen the reactions of ferrous toxicity (Jahan et al., 2015). Management of Fe toxicity is crucial as it can have an impact on rice crop during the course of its development.

Management of Fe toxicity is attainable by balancing the application of NPK+ lime or NPK fertilizers, usage of adequate Potassium (K) fertilizer, administering quicklime on soils that are acidic and limiting quantities of organic matter. This include straw and manure on soils with huge quantities of iron and organic matter and use of urea in areas with poor drainage (less acidifying) in place of ammonium sulfate which to greater extent is acidifying (Dobermann & Fairhurst, 2000).

2.16 Interaction of Water and Fertilizer in Crop Production

The task of guaranteeing future universal food and nutrition security entails increase in the agricultural output. This can be attained through (i) intensifying crop production on land presently under cultivation at the same time conserving ecosystem services to averting more land degradation, (ii) prudently increasing area planted .

Fast growth of fertilizer consumption, use of irrigation, acceptance of better-quality seeds and good management practices has been observed. This has caused substantial yields increase of key crops whereas growth of between 2.5 to 3 times in agricultural production has been observed since the beginning of the 1960s (FAO, 2011). Based on 2010 statistics, fifteen percent of fertilizer Nitrogen (N) is utilized and thirteen percent of fertilizer P and Potassium (K) used globally for rice production (Heffer, 2013). Several farmers are less furnished with information to improve nutrient and water use which is crucial, since the two inputs are related closely. Although present crop yields have not reached their maximum, enhancements in nutrient and soil management can produce main benefits in water use efficiency (Molden, 2007).

The procedures of nutrient build up or extraction are frequently linked to water mobility processes. For soil fertility management, the interrelation of water and nutrients is directed by these factors:

i. Soil moisture stress usually inhibits soil mineral usage at the crop level.
ii. Soil-supplied elements uptake by crop only occurs if adequate soil solution permits bulk movement and nutrients diffusion to the roots.
iii. Amount of moisture in the soil is one of most significant element governing the frequency of various biological and chemical activities that affect availability of nutrients (Drechsel et al., 2015).

Low soil fertility restricts the capacity of crops to effectively utilize moisture (Bossio et al., 2008). In dry regions of Africa, for example, simply ten to fifteen percent of the rainwater is utilized for crop development and the rest is lost through evaporation, drainage and run-off. The low water usage is partially due to crops not able to access it, owing to deficiency of nutrients for vigorous root development (Wang, et al., 2011).

Long-term research shows that uninterrupted farming of two and three rice crops annually can be maintained by integration of adequate irrigation to sustain soil submergence, use of newly launched rice cultivars which can resist pests and diseases and balanced fertilizer inputs (Dobermann & Fairhurst, 2000; Pampolino et al., 2008). Soil submergence system supports continuous supply of plant-available Nitrogen to the plant. This is achieved through biological fixation of atmospheric N_2 (BNF) by micro-organisms existing in soils that are thoroughly soaked in flood water (Buresh et al., 2008). The provision of indigenous Nitrogen for rice supports the continuous cultivation of rice crop at minimal outputs in farms short of organic materials and additional Nitrogen fertilizer. Soil submergence similarly improves the accessibility of Phosphorus in the soil by changing of insoluble phosphate compounds to better forms that are soluble and improving movement of phosphate ions.

Rainfed upland rice systems occupies approximately 10% of the worldwide rice production area, contributes merely four percent of rice produced globally due to low yields (Global Rice Science Partnership [GRiSP], 2013). The soils are not flooded or saturated apart from for short-term duration after strong or extended rainfall. The noticeable decrease in flooding tends to escalate Nitrogen, Phosphorus, and Potassium fertilizers demand for a particular targeted output. Greater requirement for Nitrogen fertilizer may emerge from poorer biological Nitrogen fixation BNF and likely less net Nitrogen mineralization in soils that are aerobic compared to submerged soil. Greater demand for Phosphorus fertilizer can likewise emerge due to decrease in availability of soil P in aerobic conditions. Uses of Nitrogen in addition to water are complementary inputs for cultivation of rice (Dobermann & Fairhurst, 2000).

2.17 Water use Efficiency for Increased Rice Productivity

Water use efficiency (WUE), calculated as the biomass generated for each unit of transpiration, explains the connection linking usage of water and crop production. WUE describes the relationship between the volume of water utilized and grain yield (Borrel, et al., 1997). This indicates that, higher WUE can be achieved by either increasing grain yield without decreasing water supply, by decreasing the amount of water used by the crop at the same time maintaining yield, or combinations of the two (Tabbal et al., 2002). WUE can be written as follows:

$$\text{WUE (kgm}^{-3}\text{)} = \frac{\text{Yield}}{\text{Water consumed}}$$

Crop WUE is particularly a significant concern in situations of inadequate or diminishing available water resources. The world’s 80% of locatable water resource is currently used up by irrigated agriculture. 69% of all freshwater resources is consumed by irrigated agriculture and approximately forty percent of all food produced (FAO, 2000). Between

2000 and 2025, the requirement for cereals, rice and wheat included is estimated to rise by 1.27% yearly due to global population growth (Rosegrant & Cai, 2000).

Water scarcity can be imposed by abiotic stresses like salinity and drought, which are amongst the most vital factors constraining plant performance and yield globally (Araus et al., 2002). Enhancing water use productivity or improving water productivity in Agriculture is a vital reaction to increasing water shortage. This includes a call to allow adequate water in lakes and in the rivers to maintain biome and address the increasing quests in industries and in the cities. With increase in population, more coherent production from small-scale water resource irrigation will be required. This will as well compel considerably greater water-use efficiency from rainfed agriculture that continues to be the leading method of food production in many countries for the majority farmers.

One of the vital considerations in rice production is water availability and its supply in sufficient amount. The majority of studies from experiment stations to farm on limitations to higher rice yield show that water is the major cause of gaps in yield and variance (Papademetriou, 2001). It is crucial to raise the water-use productivity of irrigated as well as rain fed crop production (Hamdy & Scarascia-Mugnozza, 2003). System of Rice Intensification (SRI), alternate wetting and drying (AWD), Aerobic rice culture, raised beds and ground-cover rice production system (GCRPS) are water-saving rice production systems which have proved to reduce unproductive water discharge and enhance WUE. These technologies can occasionally cause several reductions in yields especially when the existing lowland cultivars are utilized, (Farooq et al., and 2009).

The adjustment from transplanting to direct seeding decreases the irrigation water entry necessary throughout soil preparation giving a chance to rise water use efficiency (WUE) in rice cultivation (Cabangon & Abdullah, 2002). Studies by Fujii and Cho (1996) showed in the wet direct-seeded rice, there was a decrease from 1836 to 1331mm in water use by reducing irrigation duration. De Vries et al. (2010) similarly resolved it is likely to realize water savings used in irrigation with slight yield decline in Sahel surroundings in research done in Africa.

It would be important to produce high amount of biomass that contributes to crop yield, with little or inadequate volume of water in water-limiting environments. Studies have shown that water-saving space and productivity of upland rice cultivation is high when compared to that of conventional flooding irrigation (Bouman & Toung, 2001; Cheng et al., 2006). Production technologies in upland rice such as ground cover and aerobic rice production system are considered to be vital. When rainfall is inadequate in these production systems, rice is cultivated under upland environments with additional irrigation according to the rice water demand characteristics and sufficient inputs (Bouman et al., 2002; Tao et al., 2006). The technologies similarly disclose higher yield and saves on water in rice by the plant. By capitalizing on one main factor of production, which is water, increasing cropping intensity and increasing area under irrigation, rice production can be increased reliably.

Studies by Akinbile (2010) on upland rice indicated that at the mid-season or reproductive phase, the maximum quantity of soil water extraction occurs because this is when metabolic activities are on increase and therefore more water use. Water application is a leading cause influencing development and grain yield of rice and therefore it is necessary to appropriately schedule it for enhanced production as well as to evade waste.

Several approaches are essential in increasing water use productivity in irrigated agriculture and rain-fed systems (Wang et al., 2002). One such approach is to breed crop cultivars that are additionally effective in water usage. Improved management of the water supply and variations in managing crop are additional strategies. The approaches would achieve greatest gains through complementary methods connecting each of them. Studies indicate that water productivity can be increased in two ways, that is, use of large Nitrogen fertilization and great yield varieties (Zhang et al., 2012).

Further reasons to increase agricultural water productivity include (i) meeting the growing food quests and shifting diet patterns of an increasing, richer and progressively urban population, (ii) contributing economic development of poor farmers and poverty reduction (iii) reacting to burdens to move water from agriculture to industries plus cities and make sure it is accessible for climate change adaptation and environmental uses (Molden et al., 2010).

2.18 Economic use of Fertilizer

Among the key objectives of modern agriculture is balanced fertilizer usage and reduced cost of production (Yousaf et al., 2017). According to Rijpma and Jahiruddin (2004), for sustainable crop production system with high yield target, nutrient inputs to soil should balance nutrient removed by crops. Yadav et al. (2000) emphasized the need for chemical fertilizer application to improve crop yields and sustenance of soil fertility. The fertilization has substantial residual benefit to subsequent crops and increases yields of the first crop in rotation. Abegaz (2005) confirms that the effect of fertilizer use of on crop production is huge.

Tilman et al. (2011) stated that, too much or wrong application of fertilizer does not warrant continually yield increase but instead can lower efficiency in nutrient use, and also causes economic and environmental problems in agro-ecosystems. Over-fertilization by farmers is a common practice compelled by desire for increased yields although the desired results are not achieved always. Abegaz (2005) noted that agricultural cost-effectiveness and enhanced nutrient use efficiency can be attained through improved management of plant nutrient that comprises of application of optimum fertilizer. Additional amount of fertilizer is profitable to farmers if it improves either yield or quality of the crop (Kiros, 2010).

For Economic analysis, partial budget analysis tool used includes calculation of gross margin and marginal benefit-cost ratio (MBCR). Marginal benefit-cost ratio is the ratio of marginal or added benefits and marginal or added costs. Studies done by Rahman et al. (2011) revealed that farmers in various regions use high amounts of inorganic fertilizers without taking into account the economic benefit. Maximum profits are not always attained at maximum yield since additional fertilizer required to give slightly higher yield may be costly compared to worth of yield increase. It requires therefore rational and economically profitable use of fertilizers as imprudent fertilizer application affects soil fertility, farmers economy and future crop productivity negatively (Lichtfouse, 2011).

Studies done by Rahman et al. (2011) on economic of fertilizer use, showed that higher amount of fertilizer application had inverse relationship with marginal benefit cost ratio (MBCR). Increase in rates of fertilizer application resulted in increased gross margins, since increased fertilizer application leads to the higher variable cost.

Alem et al. (2018) demonstrated that high grain yield do not basically give highest MRR (Marginal rate of gain) MRR. Treatment that was using 138 kg N ha^{-1} plus 46 kg P_2O_5 ha^{-1}, with highest grain yield presented no marginal rate of return. In that study, use of 69 kg N ha^{-1} with 23 kg P_2O_5 ha^{-1} fertilizer combination with MRR of 284% was found to be most economically feasible.

CHAPTER THREE

RESEARCH METHODOLOGY

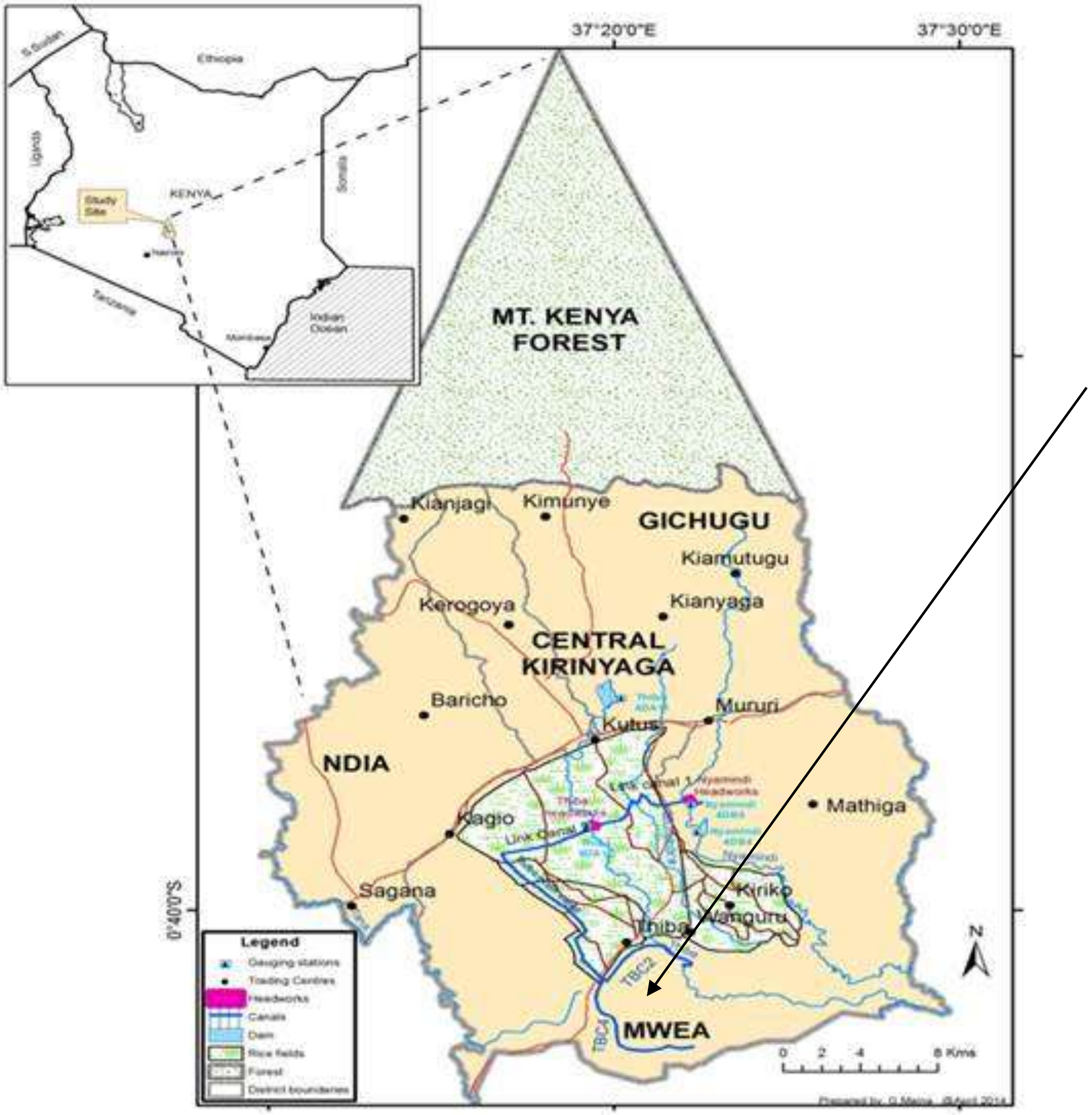
3.1 Description of Study Area

3.1.1 Site

This research study took place in Kenyan Agricultural and Livestock Research Organization (KALRO), Industrial Crops Research Centre (ICRC), Mwea. ICRC- Mwea, found in Mwea Division, Mwea East Sub County in Kirinyaga County as shown in Figure 3.1. From Nairobi, it is approximately 112 km North East and 21 km South West of Embu Municipality. The Centre is located in an elevation of 1159 meters above sea level (ASL) and stretches on Longitude 37 20’ E and Latitude 0 37’ S. ICRC-Mwea has mandate for rice research and rice production in Kenya and has 16.8 hectares under research with efficient irrigation facilities.

Figure 3.1

Map of Kenya Displaying the Experimental Site Location



The Map of Kenya showing Mwea irrigation scheme the study site.

http://article.sciencepublishinggroup.com/html/10.11648.j.hyd.20150306.11.html

3.1.2 Climatology

The rainfall average in this area is around 850 mm per year ranging from 500 - 1250 mm and distributed into short and long rains. The long rains take place from the month of March, up to June recording a rainfall mean of 450 mm while from Middle of October to December, the short rains are evident with a mean of 350 mm. The rainfall is considered to have unequal distribution in overall quantities, time and space. Site temperatures vary between 15.6º C and 28.6º C with an average of around 22ºC (Jaetzoid et al., 2005). The quantity of rainfall and temperatures recorded throughout the experimental period as shown in Table 3.1 and displayed in Figure 3.2 and 3.3.

Table 3.1

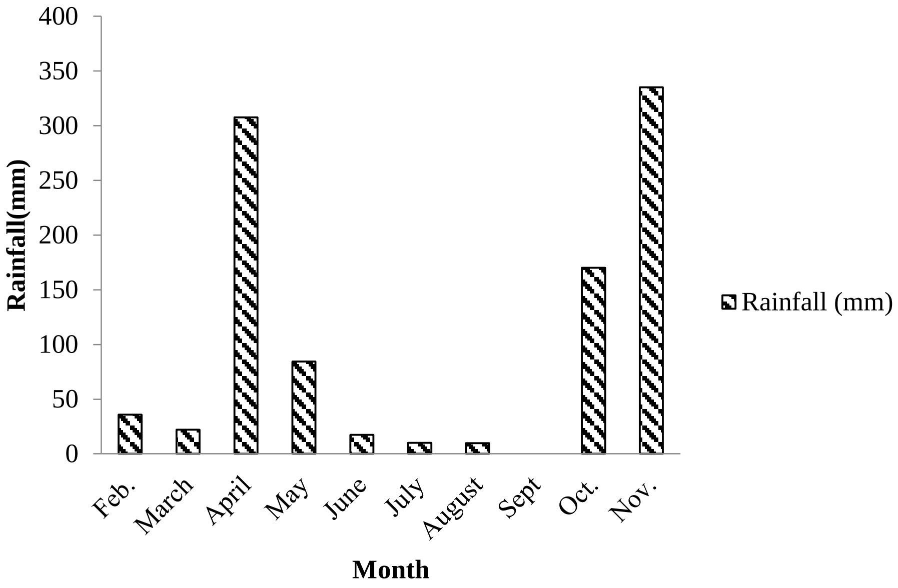
Average Temperatures and Rainfall Records at KALRO Mwea

Month (2017)	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sep**	**Oct.**	**Nov.**
Mean Temperatures °C	24.2	24.6	23.4	22.6	22.4	20.9	22	21.9	24	22.5
Rainfall (mm)	35.9	22	307.6	84.4	17.4	10.2	9.8	0	170.2	335.3

The Table shows the Average Temperatures (^{0}C) and Rainfall (mm) recorded in two growing season at Mwea, year 2017

Figure 3.2

Rainfall Distribution Pattern at KALRO-Mwea -2017



The figure shows monthly rainfall distribution from in Mwea during the study cropping seasons of 2017.

Figure 3.3

Maximum and Minimum Monthly Temperatures for KARLO –Mwea-2017

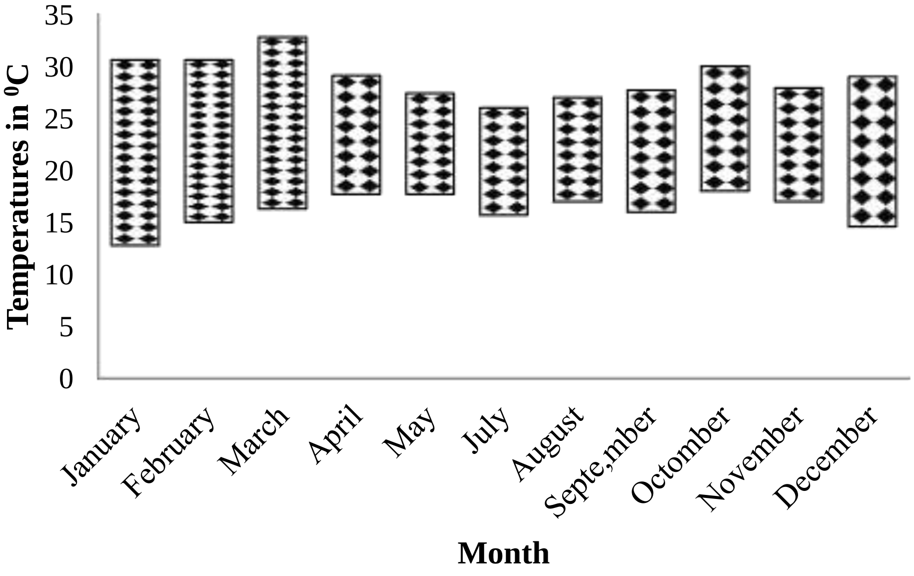


Figure 3.3 shows maximum and minimum monthly Temperatures in KARLO-Mwea during the cropping seasons of 2017.

Of the key factor affecting growth and yield of rice is temperature. There are variations in temperature requirements from one stage of growth to the other. In early growth stages of the crop, low temperatures retards seedling development and production of dry matter. In vegetative phase, low temperature causes slow development, retards the number of seedlings and their vigor which lead to increase mortality and prolong plant growth (Shimon et al., 2002). High temperatures during vegetative and reproductive stages affects photosynthesis, reduces period for grain filling as well as vegetative time and increases respiration. This is due to interruption in movement of water, ion and organic solute through plant membranes (Halford, 2009). The temperatures in the study area and environment were within the optimal temperatures necessary for rice production.

3.1.3 Soils analysis

The soil used in the study was from Kirogo farm, of KALRO-Mwea. The soils are classified as red sandy loam, low in Zinc and Nitrogen content but with fairly high levels of Phosphorus and moderate Potassium. However, the slight medium acidic soils limit the amount of Phosphorus available to plant. Additional of P despite the soil test indicating high was advice by the fact that retrieval of Phosphorus applied is very low by crop plants in a growing season. More than 80% of the P becomes unattainable and immobile for plant uptake owing to precipitation, adsorption, or conversion to the organic form, (Vance et al., 2003). It is also true that when compound NPK fertilizers are used, high amounts of Phosphorus & Potassium fertilizers are applied unnecessarily by many growers.

3.2 Greenhouse Experiment

The greenhouse was set up at KALRO-Mwea, to investigate the impact of two irrigation rates, P and K rates on growth and yield of NERICA 1.

3.2.1 Experimental design

Fertilizer rates and water regimes were arranged in split- plot design with Complete Randomized Design (CRD) and replicated three times. Water regimes assigned in the main plot, whereas combinations of P & K rates were assigned in sub plots as shown in Figure 3.4 and Table 3.3.

3.2.2 Treatments and treatment combinations

The experiment tested the following treatments;

Two water levels, (i) 3.5 mm day^{-1} of moisture level applied over period of 16 weeks of crop growth, (ii) 7.0 mm day^{-1} moisture level.

Four different rates of Phosphorus and Potassium as indicated in Table 3.2.

P LEVELS (kg ha^{-1})	**K LEVELS (kg ha^{-1})**
0-P_1	0-K_1
20-P_2	10-K_2
40-P_3	20-K_3
60-P_4	30-K_4

Where P-Phosphorus and K Potassium

New Rice for Africa (NERICA 1) variety was identified due to its good agronomic characteristics which includes early maturing, high yield potential, grain quality and good ability to resist insects and lodging.

Table 3.2

Treatment Combinations for Fertilizer Levels

Kg ha^{-1}	**P_1-0**	**P_2-20**	**P_3-40**	**P_4-60**
K_1-0	K_1P_1	K_1P_2	K_1P_3	K_1P_4
K_2-10	K_2P_1	K_2P_2	K_2P_3	K_2P_4
K_3-20	K_3P_1	K_3P_2	K_3P_3	K_3P_4
K_4-30	K_4P_1	K_4P_2	K_4P_3	K_4P_4

Table 3.3

Treatment Combinations

		⟸ **Fertilizer Combination** ⟹															
		P_1K_1	**P_2K_1**	**P_3K_1**	**P_4K_1**	**P_1K_2**	**P_2K_2**	**P_3K_2**	**P_4K_2**	**P_1K_3**	**P_2K_3**	**P_3K_3**	**P_4K_3**	**P_1K_4**	**P_2K_4**	**P_3K_4**	**P_4K_4**
Water Level ⟹	**3.5mm/ Day- W_1**	P_1K_1 W_1	P_2K_1 W_1	P_3K_1 W_1	P_4K_1 W_1	P_1K_2 W_1	P_2K_2 W_1	P_3K_2 W_1	P_4K_2 W_1	P_1 K_3 W_1	P_2K_3 W_1	P_3K_3 W_1	P_4K_3 W_1	P_1K_4 W_1	P_2K_4 W_1	P_3K_4 W_1	P_4K_4 W_1
	7.0mm/ Day- W_2	P_1K_1 W_2	P_2K_1 W_2	P_3K_1 W_2	P_4K_1 W_2	P_1K_2 W_2	P_2K_2 W_2	P_3K_2 W_2	P_4K_2 W_2	P_1 K_3 W_2	P_2K_3 W_2	P_3K_3 W_2	P_4K_3 W_2	P_1K_4 W_2	P_2K_4 W_2	P_3K_4 W_2	P_4K_4 W_2

Key

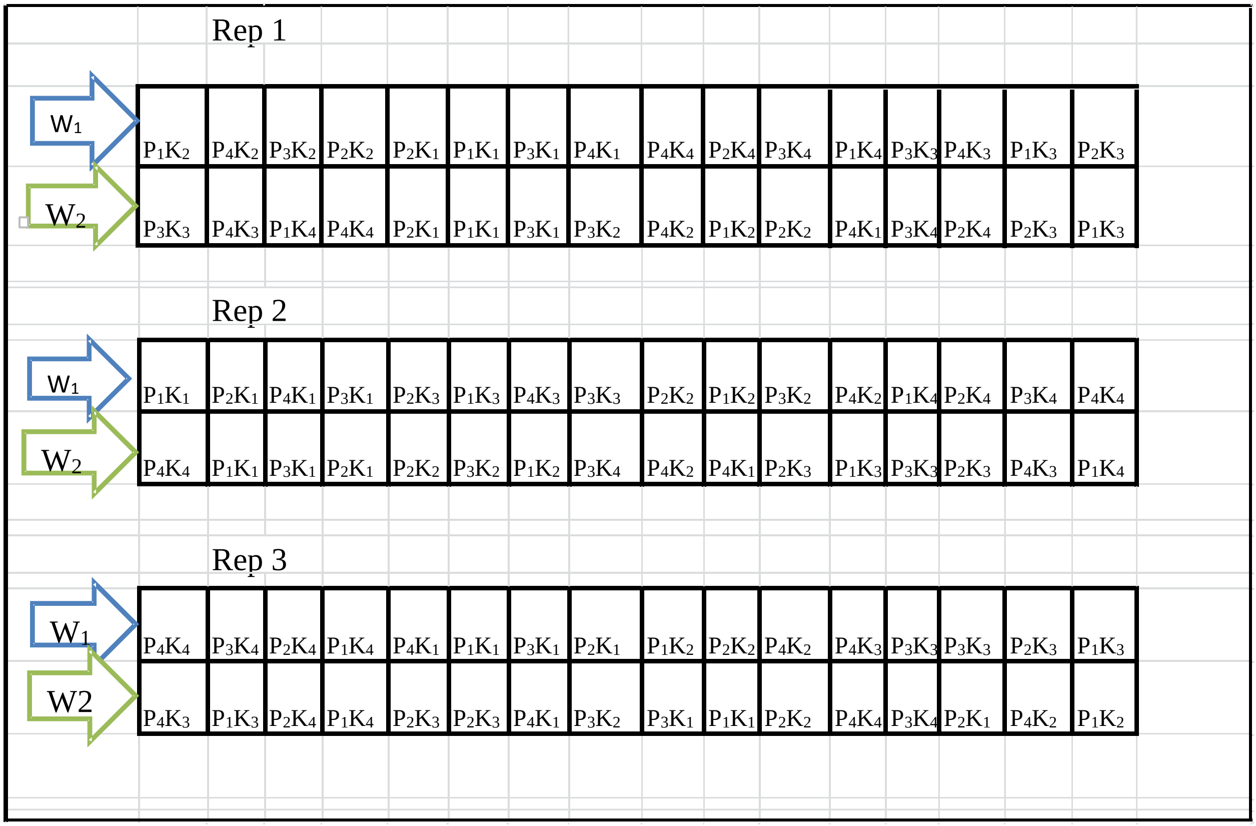
P1K1- 0kg ha^{-1} P_2O_5+0 kg $ha^{-1}K_2O$
P2K1-20kg $ha^{-1}P_2O_5$ + 0kg $ha^{-1}K_2O$
P3K1-40 kg ha^{-1} P_2O_5+ 0kg ha^{-1} K_2O
P4K1-60kg $ha^{-1}P_2O_5$+ 0kg $ha^{-1}K_2O$
P1K2-0kg $ha^{-1}P_2O_5$+ 10kg $ha^{-1}K_2O$
P2K2-20kg ha^{-1} P_2O_5 + 10kg $ha^{-1}K^2O$
P3K2-40kg $ha^{-1}P_2O_5$+ 1 0kg ha^{-1} K_2O
P4K2-60kg $ha^{-1}P_2O_5$ +10 kg $ha^{-1}K_2O$
P1K3-0kg $ha^{-1}P_2O_5$+20 kg $ha^{-1}K_2O$
P2K3-20 kg $ha^{-1}P_2O_5$ +20 kg $ha^{-1}K_2O$
P3K3-40 kg $ha^{-1}P_2O_5$+ 20 kg $ha^{-1}K_2O$
P4K3-60 kg ha^{-1} P_2O_5+ 20 kg ha^{-1} K_2O
P1K4-0 kg $ha^{-1}P_2O_5$+30 kg $ha^{-1}K_2O$
P2K4-20 kg $ha^{-1}P_2O_5$+30 kg $ha^{-1}K_2O$
P3K4-40 kg ha^{-1} P_2O_5+ 30kg $ha^{-1}K_2O$
P4K4-60 kg $ha^{-1}P_2O_5$+30 kg $ha^{-1}K_2O$
W1-3.5$mmday^{-1}$
W2-7.0 $mmday^{-1}$

3.2.3 Plot Layout

The plot layout in the greenhouse consisted of two rows of sixteen (20 litre) pots each under two water levels replicated three times and with four NERICA 1 plants per pot. Figure 3. 4 show the randomization of the treatments.

Figure 3.4

Experimental Layout



Rep 1

W_1	P_1K_2	P_4K_2	P_3K_2	P_2K_2	P_2K_1	P_1K_1	P_3K_1	P_4K_1	P_4K_4	P_2K_4	P_3K_4	P_1K_4	P_3K_3	P_4K_3	P_1K_3	P_2K_3
W_2	P_3K_3	P_4K_3	P_1K_4	P_4K_4	P_2K_1	P_1K_1	P_3K_1	P_3K_2	P_4K_2	P_1K_2	P_2K_2	P_4K_1	P_3K_4	P_2K_4	P_2K_3	P_1K_3

Rep 2

W_1	P_1K_1	P_2K_1	P_4K_1	P_3K_1	P_2K_3	P_1K_3	P_4K_3	P_3K_3	P_2K_2	P_1K_2	P_3K_2	P_4K_2	P_1K_4	P_2K_4	P_3K_4	P_4K_4
W_2	P_4K_4	P_1K_1	P_3K_1	P_2K_1	P_2K_2	P_3K_2	P_1K_2	P_3K_4	P_4K_2	P_4K_1	P_2K_3	P_1K_3	P_3K_3	P_2K_3	P_4K_3	P_1K_4

Rep 3

W_1	P_4K_4	P_3K_4	P_2K_4	P_1K_4	P_4K_1	P_1K_1	P_3K_1	P_2K_1	P_1K_2	P_2K_2	P_4K_2	P_4K_3	P_3K_3	P_3K_3	P_2K_3	P_1K_3
W2	P_4K_3	P_1K_3	P_2K_4	P_1K_4	P_2K_3	P_2K_3	P_4K_1	P_3K_2	P_3K_1	P_1K_1	P_2K_2	P_4K_4	P_3K_4	P_2K_1	P_4K_2	P_1K_2

Key

P_1K_1-0 kg of P & 0 kg of K
P_2K_1-20 kg of P &0 kg of K
P_3K_1-40 kg of P & 0 kg of K
P_4K_1-60 kg of P & 0 kg of K
P_1K_2-0 kg of P & 10 kg of K
P_2K_2=20 kg of P & 10 kg of K
P_3K_2-40 kg of P & 10 kg of K
P_4K_2-60 kg of P & 10 kg of K
P_1K_3-0 kg of P &20 kg of K
P_2K_3-20 kg of P & 20 kg of K
P_3K_3-40 kg of P & 20 kg of K
P_4K_3-60 kg of P & 20 kg of K
P_1K_4- 0 kg of P & 30 kg of K
P_2K_4-20 kg of P & 30 kg of K
P_3K_4-40 kg of P & 30 kg of K
P_4K_4-60 kg of P & 30 kg of K
W_1-Water level 3.5mm day^{-1}
W_2-Water level 7.0mm day^{-1}

3.2.4 Experimental procedure

The layout in greenhouse comprised of 20 liter plastic pots adequate to support four plants per pot. The containers were filled with 20 kg of soil from an upland field in Kirogo farm, scooped from the upper 0-30 cm deep from surface of soil and mixed with farmyard compost manure that had decayed well at a rate of 5 t ha^{-1}. The research comprised of four levels of P viz 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 kg P_2O_5 ha^{-1}(P_4) coupled with four levels of K viz 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 quantity of Nitrogen at rate of 60 kg ha^{-1} was used in all containers from Ammonium Sulphate $(NH_4)_2SO_4$). Quarter of Nitrogen was applied at pre-planting and balance added in two portions as top dressing, half N at maximum tillering phase and quarter at panicle commencement phase and Potassium levels added as treatments requirements through Triple super phosphate (TSP) and Potassium Chloride (MOP). Full amount of Phosphorus and half K was added at planting and the balance amount, half K at maximum tillering stage.

Two water regimes were used; 3.5 mm day^{-1}-W_1 and 7.0 mm day^{-1}-W_2. The treatment with least water application is lower than the level specified as the least rainfall for NERICA cultivation of 4 mm per day, (National Crops Resources Research Institute [NaCRRI], 2010). Real water application was done on Mondays and Thursdays at ratio of 4:3 for 16 weeks after the seedlings were three weeks old. The influence of watering regimes on growth and yield parameters was compared with those of rain fed crop in the field environment. (NERICA 1) variety, the trial variety was acquired from KALRO ICRC-Mwea, from the category of foundation/ pre-basic seed. Weeding and other plant protection procedures were done as required.

3.2.5 Determination of *f*ertilizer application ates

The rates of fertilizer application are showed in Table 3.4.

Table 3.4

Rates of Fertilizer Application in (Kg Ha^{-1}) Per Fertilization Method

	Type of fertilizer used kg ha^{-1}		
Fertilizer Levels used (P &K) N (Constant-60 kg/ha	**Ammonium Sulphate**	**Triple superphosphate**	**Murate of potash (MOP)**
	(21:0:0) N% 24%S	**(0:45:0)-$P_2 0_5$ %**	**(0:0:50) $K_2 0$ %**
P_1-0	285.7	0	60
P_2-20	285.7	44.4	60
P_3-40	285.7	88.9	60
P_4-60	285.7	133.3	60
K_1-0	285.7	66.7	0
K_2 -10	285.7	66.7	20
K_3- 20	285.7	66.7	40
K_4- 30	285.7	66.7	60

The Table indicates the calculated amounts of Phosphorus and Potassium supplied by three types of fertilizers used.

3.2.6 Fertilizer calculation

The calculation of Potassium and Phosphorus quantities which was applied per pot in the greenhouse experiment was done to ascertain the exact amount supplied by the fertilizer type used. Fertilizer used per pot was based on weight of the soil – Hectare furrow slice (HFS). A hectare furrow slice of soil is a soil sample that is one hectare in area and 15 cm thick. One hectare furrow slice of soil weighs 2,000,000 kg. Each pot had 20 kg soil.

3.2.6.1 Nitrogen.

Application rate of Nitrogen was 60 kg ha^{-1} supplied by Ammonium Sulphate and applied in three splits.

1st split ¼ of nitrogen at planting =0.714 grams

2nd split half of Nitrogen at maximum tillering stage=1.429 grams

3rd split ¼ Nitrogen at panicle initiation stage=0.714 grams

3.2.6.2 Phosphorus.

It was supplied by Triple super phosphate and all was applied at once during planting.

P_1-0 kg ha^{-1} -equivalent per pot=0 grams

P_2-20 kg ha^{-1}- equivalent per pot= 0.444 grams

P_3-40 kg ha^{-1}-Equivalent per pot=0.889 grams

P_4-60 kg ha^{-1}-equivalent per pot=1.33 grams

3.2.6.3 Potassium.

Fertilizer used was murate of potash, where the amount of Potassium was divided into two equal portions and one half was used at planting and the rest of K at maximum tillering stage.

K_1 0 kg ha^{-1} –amount per pot used=0 grams

K_2-10 kg ha^{-1}-amount used per pot=0.1 gram

K_3-20 kg ha^{-1} –amount per pot- 0.2 grams

K_4-30 kg ha^{-1}- amount per pot-0.3 grams.

The first season crop in the green house was established on 9th March 2017 and harvested on 28th June 2017 while planting in the second season was done 28th June 2017 but later replanted on 5/7/2017 due to poor germination and harvesting done on 29/10/2017.

3.2.7 Planting

The sowing of seeds was done on 9th March 2017 for the first season and on 5th July 2017 for the season two by planting four seeds per hill with 4 hills in a 20 liter container and spaced at 15 x 25 cm and 2cm planting depth which was later thinned to one seedling per hill. Micronutrients Zinc was added at a rate of 3 kg ha^{-1} to the soil just before planting to every pot. The three fertilizers N, P, K were added in three splits: (i) before planting – a quarter N, all P, half K, full amount of S and Zn; (ii) at maximum tillering – half N and half K; (ii) at panicle initiation phase (PI) – a quarter N. The plastic pots were kept soaked with water for three days before planting was done and water put daily to field capacity for three weeks and thereafter assigned water regimes ratios were applied for 16 weeks. Plate 3.1 shows the condition of crop at seedling stage and plate 3.2 at tillering stage in greenhouse setup. Watering of pots was done on Mondays and Thursdays apportioned at rate of 4:3. This means that, the total amount of water per week was calculated for each level (W_1 &W_2) and applied at rate of 4:3 on Mondays and Thursday respectively. The water was divided into equal amounts and watering was done in the morning and evening in the specified days. The layout of the crop in the greenhouse at initial stage of development to harvest is showed in Appendix 5.

Plate 3.1

Seedling Stage in Greenhouse

Plate 3.1 shows the view of greenhouse layout when the crop was at seedling stage-32 days after planting. The rows with green pots were subjected to 3.5mmday^{-1} water level and the adjacent row pots in each replicate to 7.0mmday^{-1}.

Plate 3.2:

Crop at Tillering Stage

Plate 3.2 shows the view of greenhouse layout when the crop was at tillering stage-52 days after planting. The rows with green pots were subjected to 3.5mmday^{-1} water level and the adjacent row pots in each replicate to 7.0mmday^{-1}.

3.3 Field Experiment

The experiment in the field was carried out at KALRO- Kirogo farm to monitor the impact of rainfall on performance of NERICA 1 in relations to growth and yield outputs. The results were compared with those in greenhouse for the effect of irrigation rates on growth and yield of NERICA 1. No fertilizer variations were applied in this case since measure of Phosphorus and Potassium uptake required control of other factors as it was done in the greenhouse setup.

3.3.1 Land preparation and planting

Preparation of land was first done at Kirogo farm after which three sections were identified. Three Plots of size 5 m x2.5 m were leveled at each site in blocks. NERICA seeds acquired from KALRO ICRC-Mwea were planted after onset of rains on 26th October 2017 at seed rate of three seeds in a hole and afterwards thinned to two plants per hill spaced at 15 x 25 cm with seeds planting 2 cm deep. The plots were separated from each other by one meter path in each site. Micronutrient at a ratio of three kg of Zn ha^{-1} was added to the soil on leveling and before planting was done.

Additionally, well decomposed farmyard compost manure at rate of five tons ha^{-1} was incorporated in the soil prior to planting. The initial soil Potassium and Phosphorus content acted as basis for the two nutrients supply to the crop. Equal quantity of N levels at ratio of 60 kg ha^{-1} were applied to entire units as Ammonium Sulphate $(NH_4)_2SO_4$). Quarter of N was added at pre-planting and balance added in two portions as top dressing, half N at maximum tillering stage and quarter at panicle commencement phase. Agronomic practices which included weeding and control of diseases and pests were carried out as and when required.

3.3.2 Field experiment sampling procedure

In every plot plants identified for data collection were chosen and labeled at random. The plot consisted of twelve rows of 25 hills, the border rows and plants were not considered. The remaining clusters of plants in every plot were sampled for details required. Systematic random sampling technique was applied in which second plant from each row was identified and earmarked for detailed collection of data and subsequently each of the tenth plant in alternate rows was picked. The identified plants were labeled with a red ribbon in each plot for subsequent data collection from which growth and yield parameters were measured. The following growth parameters data were taken; plant height, panicle length, tiller number and culm length while yield parameters included; filled grain per hill, filled grain weight per hill, empty grain per hill, weight of empty grain, weight of straw per hill and grain yield at 14% moisture level.

3.4 Data Collection

The following data was collected; (i) meteorological data (ii) crop growth parameters (iii) yield and yield components (iv) amount of water used (v) plant sampling results.

3.4.1 Daily weather, soil and plant profile data

Meteorological data which included rainfall, relative humidity, temperature, sunshine hours and wind speed was collected from Meteorological Station in KALRO. The station had automatic weather recording equipment, a configuration of various weather sensors with optional transmission components for automated remote weather monitoring. The station had the following apparatus; Rain gauge for measuring rainfall, thermometer for determining temperature, Ceilometers for measuring cloud height, Anemometer for measuring wind speed, Barometer for measuring pressure, Hygrometer for measuring humidity, current weather sensor or visibility sensor.

Canal water used for irrigation was analyzed to determine the pH, nutrients content and amounts used for every plot was measured using calibrated containers. Tensiometer inserted at depth of 15 and 30 cm were used to gauge the soil moisture tension, to regulate watering after the first three weeks. Farm yard manure used was analyzed at National Agricultural Research Laboratories (NARL), to verify the pH, percentages of total Nitrogen, organic matter, Potassium and Phosphorus. Following agronomic traits were recorded; seedlings vigor-through measuring plant height, tillering ability - Tiller number, number of leaves, grain yield at 14% moisture spikelet fertility, recorded as per standard evaluation system of rice (IRRI, 2014). Yield data; panicles number and weight, 100 seed weight in grams plus grain yield in tonnes per hectare were determined. Weights were determined by use of a precision weighing balance. Morphological characters such as, ligule length, leaf length, culm length, culm number, leaf width, length of grain, panicle length and grain width were documented as per standard evolution system of rice (IRRI, 2014).

3.4.2 Growth parameters considered and recorded in greenhouse setup

Growth parameters measured included the agronomic traits: plant height, number of leaves and number of leaves, while the morphological characters measures were, ligule length, leaf length, culm length, culm number and leaf width.

3.4.2.1 Plants height

Plant height recording commenced two weeks after water scheduling was affected. Each pot per treatment had four rice plants and the average of the four was taken. The height of the plant was taken using a ruler in centimeter (cm), starting from culm base to the top of longest leaf as per standard evaluation system of rice (IRRI, 2014). Measurements were done fortnightly from seedling stage to maturity stage. All measurements were taken in the morning before watering the plants to ensure the base of plant was upright and recorded in designed data sheets.

3.4.2.2 Number of tillers and leaves.

The numbers of tillers for each of the four hills in the pot were counted and average recorded in data sheet. Counting was done weekly from stage three (Tillering-immediately after appearance of first tiller) to stage five (booting) as guided by SSE (IRRI, 2014). Data recording was done early in the morning of each specified date up to maximum tillering phase, when it was not possible to identify the central culm as all tillers had almost same length and width and the number of counts remained constant. The number of leaves were counted after a week and recorded appropriately for each treatment.

3.4.3 Yield factors

The yield parameters considered in the first season included; weight of panicle (grams), percentage spikelet fertility, grain length and width, 100 grain weight in grams and yields at 14% moisture level. In the second season, grain length and width in centimeter by use of meter rule, 100 grain weight in grams and yield data were recorded. At maturity stage, filled spikelet per panicle were evaluated by counting the spikelet with grains per panicle and those which were not filled or were empty. Some treatment had some unfilled spikelet as displayed in Plate 3.3. A sickle knife was used to harvest the crop at maturity and threshed by gently hitting the panicles with dry pieces of wood. At maturity stage, (plate 3.4) the crop was harvested, threshed and winnowed to clear off any impurities, they were put in separate bags as per treatment. 100 grains were picked from each package and weight taken and thereafter total yield at moisture level of 14%.

Plate 3.3:

Unfilled spikelet

Plate 3.3 shows unfilled spikelet grain caused by difference in water levels in the greenhouse. Percentage spikelet fertility was calculated by counting the unfilled grain in the spikelet over the total number of grains per spikelet in relation to filled grains per spikelet.

Plate 3.4:

Harvested crop of NERICA 1

Harvested crop as per treatment left to dry before threshing. This was done to ensure proper moisture content was achieved.

3.4.4 Plant sampling and nutrients uptake

Plant samples (straw) of selected treatments were collected at maturity, afterward drying of grain and shoot was done at 70°C in an oven to attain constant weight. Samples from plant were crushed and ground for tissue analysis. A proportion of plant sample weighing, 0.20 grams was ingested by H_2SO_4 to determine Nitrogen content by distilling through micro-Kjeldahl distillation apparatus (Yoshida et al., 1976). Colorimetric method was used to determine Phosphorus and the Potassium determined by atomic absorption spectrophotometer. Crude protein percentage in rice grains was estimated by multiplying value of Nitrogen obtained through micro-Kjeldahl method by 6.25.

3.4.4.1 Nitrogen, Phosphorus and Potassium determination in plant samples and grain

Measurement of NERICA 1 crude protein in selected samples was established by use of Micro Kjeldahl method, which involved three key processes mainly; digestion of protein followed by distillation and later titration.

3.4.4.1.1 First step involved digestion of protein.

Approximately two grams of the refined rice grain or straw specimen was placed in a Kjeldahl flask after weighing. One gram of Potassium Sulphate, Copper Sulphate catalyst plus a fragment of fine Selenium were introduced after which twenty five milliliters of concentrated Sulphuric acid was added. Distilled water together with Sodium Hydroxide - an alkali was used to dilute the digest to counteract effect of Sulphuric acid. That combination in the fume cupboard was exposed to intense heating for around 30 to 60 minutes depending on sample and temperature of up to 420^0C raising the heat and infrequent shaking until green color was attained in the solution. Distilled water was used to wash down the dark specks appearing at the top part of the flask after the solution cooled. The mixture was heated again softly in the beginning till the green color vanished and let to cool down. The product was moved to a volumetric flask of 250 ml capacity through numerous cleaning and distilled water used to make it up to the mark and later, distillation done by use of Markham distillation equipment.

3.4.4.1.3 Second step was protein distillation

For 15 minutes, the Markham distillation equipment was steamed through and later a 100 ml conical container having 5 ml boric acid/ indicator was positioned under a condenser ensuring the tip of condenser was beneath the liquid. By use of a pipette, 5.0 ml of the digest was transferred into the apparatus through a tinny funnel opening. Distilled water was used to wash down the digest accompanied by additional of 50 ml of 60% NaOH solution. For approximately 5 minutes, the mixture was exposed to steam in the condensing flask and later adequate ammonium sulphate gathered. The flask receiving the distillate was put away and the condenser's tip cleaned with water into the container and condensed water taken out afterwards. 0.01M hydrochloric acid was used to treat the mixture in the receiving flask, after which a blank was similarly run alongside with the sample from the plant.

3.4.4.1.4 Nitrogen percentage computation.

The percentage of Nitrogen in the sample was computed after titration by use of this formula:

Percentage Nitrogen = $VS – VB \times M\ acid \times 0.01401 \times 100W$

Whereby: VS= Volume in milliliters of required acid to quantify the sample;

VB= the Volume in milliliters needed to titrate the blank;

M acid represents Molarity of the acid;

W = Weight of the Sample in grams

From the rice sample- Total percentage of crude protein was computed from the percentage of Nitrogen using the formula;

Percentage crude protein = Percentage Nitrogen × F, Whereby: F is the conversion figure equal to 6.25.

3.4.4.1.5 Potassium.

The digestion of the sample was carried out in a silica crucible after weighing 2 grams of grounded sample in a silica dish and later incinerated for around 12 hours at temperatures of 550^0C in a muffle furnace. The ash was then cooled and 20 ml of 20% dilute hydrochloric acid put into it and sediments removed through whatmann filter paper and filtrate collected in 100 ml volumetric flask which was topped to mark with di-ionised water. Two milliliters of the mixture was pipetted to a 50 ml container and topped to mark using di-ionized water. Standards were prepared from higher grade potassium chloride/ sodium chloride, 0,2,4,6,8,10 ppm after which standards were run in the flame photometer and light emitted determined. The samples were run and concentration established from the standard working curve. The calculation was based on the formula;

$$\%K = \frac{\text{Graph reading x } 100 \text{x} 50/2}{\text{Sample weight x } 1000 \text{x} 1000} \text{ x } 100$$

3.4.4.1.6 Phosphorus.

From the sample stock solution, 2 ml was pipetted together with 15 ml vanadate-molybdate reagent which formed a colored yellow complex after around 10 minutes.

Phosphorus was quantified by measuring the absorbance of the solution at 400 nm and compared with standard calibration curve.

3.4.5 Post-harvest soil analysis

Four Selected soil samples of; P_1K_1, P_2K_2, P_3K_3 and P_4K_4 pots under each water level and replication were analyzed for nutrients depletion after harvest. Soil properties that included

Nitrogen, Phosphorus, and Potassium contents together with EC (Electrical conductivity) were recorded.

3. 5 Methods of Data Analysis

Data collected was entered into Microsoft excel and parameters documented put through analysis of variance (ANOVA) to establish if there existed significance difference owing to treatments using version 24 of SPSS software. The difference among treatment means were compared by LSD (least significant different) and Duncan multiple range test (DMRT) at 5% significant level. Correlation analysis was done evaluate the strength of relationship between yields and yields components for the field crop.

P value was used to make a conclusion on if to reject or fail to reject the null hypothesis (H_0). Where the Null hypothesis was rejected a post hoc test was done to decide which means were significantly different from each other.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Findings of Chemical Properties of Soil, Manure and Irrigation Water Used

Table 4.1 and Table 4.2 represent the findings of chemical characteristics of soil, manure and irrigation water used in the study after the laboratory analysis. The average pH of the soil was found to be 5.65 which was considered to be medium acidic. The FAO (2000) stated that pH range of 6.5 up to 7 for majority of the crops, rice included, and good productive soils are considered to be appropriate. Consequently, the pH of the soils used in the study from Kirogo farm was within the scope of soils that are productive. The total organic carbon and total nitrogen content in the experimental site was 2.0% and 0.9%, respectively. The nitrogen content and quantity of soil organic carbon of the soil type used in the experiment were low and moderate, respectively. The Phosphorus content of 225 ppm was high while amount of potassium at 0.76 me% was adequate. The soil had low Zinc content of 3.1 ppm, however, this was supplemented by adequate amounts provided by the manure. The fertility values of manure used in the study indicated that all elements supplied were suitable for rice production. The manure came from a farmer's cattle shed and was left out to cure after which it was ready for use. Table 4.2 displays the qualities of irrigation water derived from a canal that was used in the study. The amount of magnesium me/litre of 0.11 was low while no carbonates me/litre was detected. All other elements were within the normal range and therefore the water was appropriate for production of rice.

Table 4.1

Soil and Manure Chemical Attributes

	Soil Fertility Results	Average Value for two sites	Class
1.	Soil pH	5.65	Medium Acidic
2.	Total Nitrogen %	0.9	Low
3.	Total organic Carbon %	2	Moderate
4.	Phosphorus ppm	225	High
5.	Potassium me%	0.76	Adequate
6.	Calcium me%	8.8	Adequate
7.	Magnesium me%	2.17	Adequate
8.	Manganese me%	0.42	Adequate
9.	Copper me%	1.57	Adequate
10.	Iron ppm	73	Adequate
11.	Zinc ppm	3.1	Low
12.	Sodium me%	0.5	Adequate

	Farm Manure fertility	Values	Class
1.	Nitrogen %	1.86	Suitable
2.	Phosphorus %	0.63	Suitable
3.	Potassium %	3.3	Suitable
4.	Calcium %	OAO	Suitable
5.	Magnesium %	0.06	Suitable
6.	Iron mg/kg	2770	Suitable
7.	Copper mQ/kQ	23.2	Suitable
8.	Manganese mg/kg	1137	Suitable
9.	Zinc mg/kg	118	Suitable

Table 4.2

Quality of Irrigation Water

	Irrigation Water Qualities	**Value**	Class
1	pH	7.04	within normal range
2	Conductivity, mS/cm	0.07	within normal range
3	Sodium, me/litre	0.06	within normal range
4	Potassium, me/litre	0.01	within normal range
5	Calcium, me/litre	0.08	within normal range
6	Magnesium, me/litre	0.11	Low
7	Carbonates, me/litre	ND*	within normal range
8	Bicarbonates, me/litre	0.23	within normal range
9	Chlorides, me/litre	1.1	within normal range
10	Sulphates, me/litre	0.41	within normal range
11	Sodium Adsorption Ratio	0.19	within normal range

*ND Not Detected

Table 4.2 shows the quality of water used in the study with major elements were within the normal range suitable for production of rice.

Higher sodium content or lower calcium levels in water affects the infiltration rate, limiting crop water supply. Certain ions like sodium, chloride or boron, if in high amounts can accumulate in the crop causing crop damage at high concentrations which reduces yields.

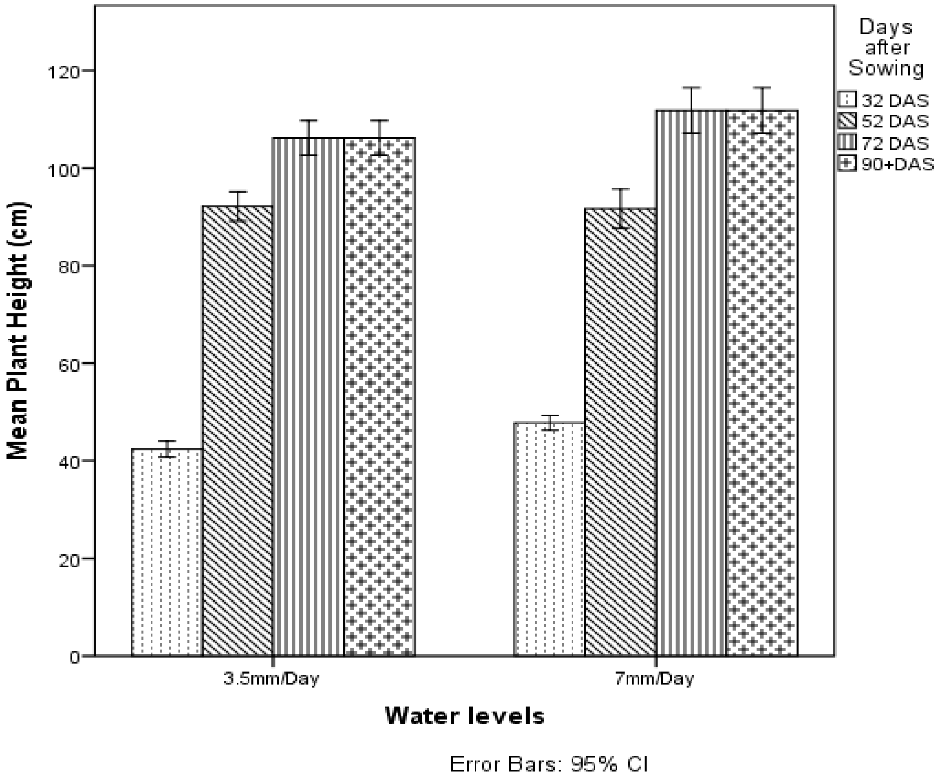
4.2 Performance of NERICA 1 Under Varying Moisture Levels

4.2.1 On growth parameters

Three key growth parameters were monitored throughout the plant growth stages for the two seasons; number of tillers, height of the plant and number of leaves. They were evaluated commencing 30 days after sowing as per different stages of rice development, IRRI, 2014 and the data obtained is presented in Figure 4.1, Figure 4.2 and Figure 4.3 for plant height, number of tillers and number of leaves, respectively.

Figure 4.1

Plant Height as Affected by Water Levels

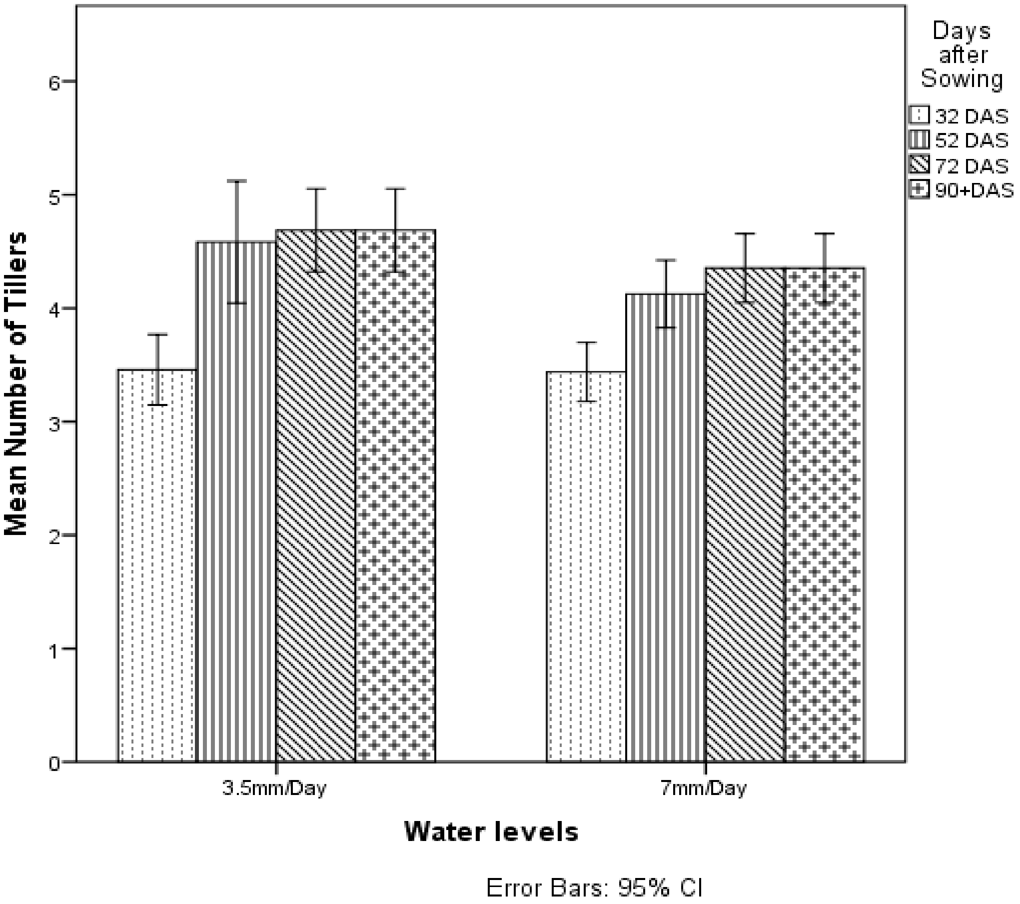


The bar graph shows the increasing plant height in (cm) under the two watering regimes in the cropping season February -June 2017

Water level of 7.0mm/day had higher plant heights across days after sawing (DAS) compared with water level 3.5mm/day in both seasons (Figure 4.1). Adequate moisture facilitates physiological processes essential for plant growth. To determine if the difference was significant t-test was done.

Figure 4.2

Water Levels Effect on Tiller Number

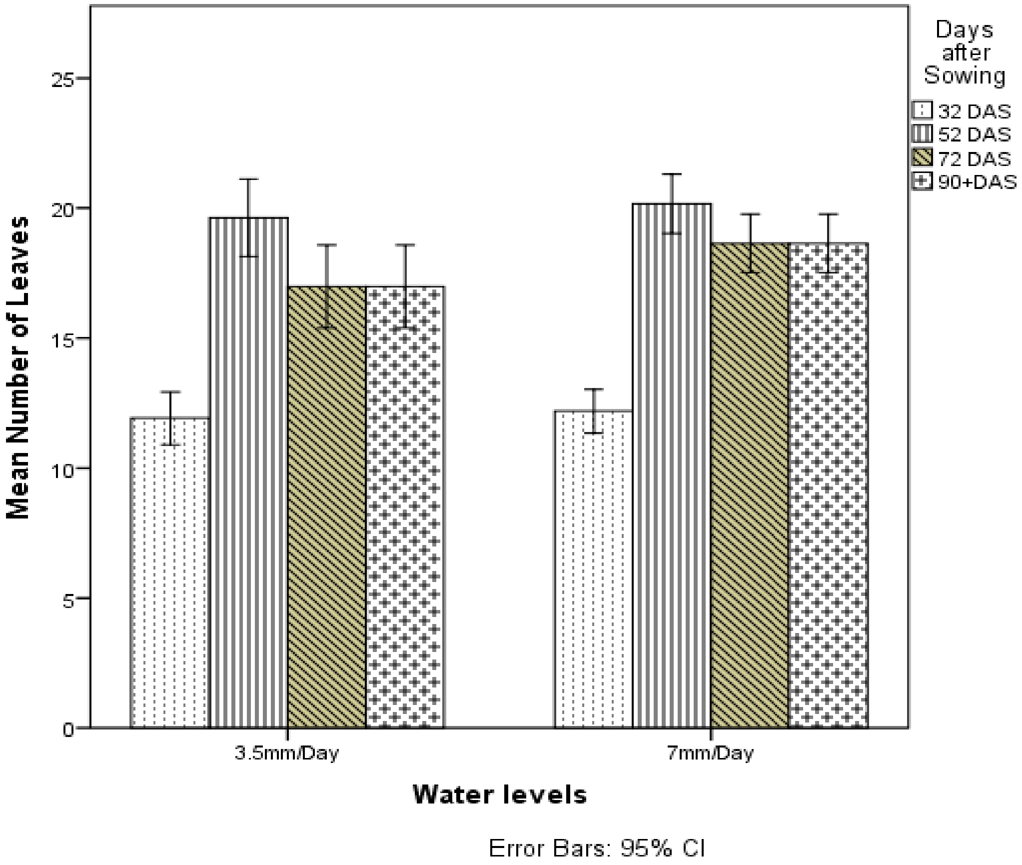


The bar graph shows the number of tillers under the two watering regimes in the cropping season February -June 2017

Tiller number in a plant defines the number of panicle which is a vital factor of grain yield. Mean number of tillers was higher in water level 3.5mm/day as compared to that of 7.0mm/day across the days after planting (Figure 4.2). However moisture content aids in mobilizing assimilates and nutrients among the tillers, hence 7.0 mm/day moisture content resulted in stronger and productive tillers. To ascertain if the difference was significant, means separation was done.

Figure 4.3

Effect of Water Regimes on Number of Leaves



The bar graph shows the mean number of leaves under the two watering regimes in the cropping season February -June 2017.

There was an increase in height of plant, number of tiller and leaves across the growth stages and in the two water levels evidence of crop development. At maturity stage, the increase in tiller number, height of the crop and leaves number remained constant. To check if there was any significance difference due to water application rates, t-test was conducted and the results are presented in Table 4.3 for the two cropping seasons.

Results for both seasons indicates that with p values of 0.000, difference in plant height, tiller number and number of leaves across the growth stages was significant. Significant differences in plant height in both seasons I & II, (p values 0.001 and 0.005 respectively), plus number of tillers, number of leaves; (p value 0.012, 0.014) due to different water levels was also observed in first season. No significant differences were noted in leaves numbers and number of tillers in the second season due to water levels.

Table 4.3

Means for Plant Height, Tiller Numbers and Number of Leaves in Response to Water Levels

Season I(Feb-June 2017

Water Levels	Mean –height of plant (cm) DAS				Mean- tiller number DAS				Mean -number of leaves DAS			
	32	52	72	90	32	52	72	90	32	52	72	90
W_1	42.4a	92.2a	106.2a	106.2a	3.5a	4.6a	4.7a	4.7a	11.9a	19.6a	17.0a	17.0a
W_2	47.8b	91.7b	111.8b	111.8b	3.4b	4.1b	4.4b	4.4b	12.2b	20.2b	18.7b	18.7b
P value	.001*	.001*	.001*	.001*	.012*	.012*	.012*	.012*	.014*	.014*	.014*	.014*

Season II (July-November 2017

Water Levels	Mean – height of plant (cm) DAS				Mean - tiller number DAS				Mean number of leaves DAS			
	30	45	60	90+	30	45	60	90+	30	45	60	90+
W_1	71.0a	77.3a	87.5a	107.8a	3.4a	4.2a	5.1a	4.3a	14.3a	19.3a	18.5 a	16.9a
W_2	71.6 b	77.6b	89.5b	113.7b	3.3a	4.3a	4.8a	4.4a	13.1a	18.4a	17.6 a	17.7a
P value	0.005*	0.005*	0.005*	0.005*	.662	.662	.662	.662	.352	.352	.352	.352

No significant difference noted when means appearing in same column are represented with the similar letter ($p > 0.05$)

Key

W_1: 3.5mmday^{-1}
W_2:7.0 mmday^{-1}

For both seasons, difference in plant height was significant across the growth stages as per days after sawing (DAS) due to water levels as indicated in Table 4.4. 7.0 mm day^{-1} generally produced higher plants height than 3.5 mm day^{-1} across the growth stages. This is consistent with studies by Akinbile (2010) in which stable and coherent increase in the plant's height across the growth stages was credited to the amount of irrigation water supplied signifying that moisture has great effect on growth for the rice plant. Mannan et al. (2012) noted that owing to variation of moisture stress, dry matter, tiller number and plant height of rice cultivars differed considerably at various growth phases. Additional water at vegetative and reproductive phases resulted with higher plant height.

In seasons II, no significant differences due to water levels were observed in number of leaves and number of tillers (p=0. 352 and 0.662) across the growth stages. In season I water level of 7.0 mm day^{-1} produced relatively more leaves than that of water level 1 (3.5 mm day^{-1}). However, in the second season water level 1 produced more leaves across the growth stages than water level 2 (7.0 mm day^{-1}). Number of tillers produced in season 1, differed significantly (p=0.012) with W_1 (3.5 mm day^{-1}) producing relatively more than those of W_2 (7.0 mm day^{-1}). However in season II no significant difference was noted on tiller number due to water levels across the difference growth stages.

According to studies by Hidayati et al. (2016), rice plants under SRI management produced more tillers, leaves and their root systems were more extensive compared to those in conventional methods. Maintaining the soil in moist but not flooded conditions provides good aeration for the plant and hence allows complete more phyllochrons of growth, producing more tillers and roots, before the flowering phase.

4.2.2 Effect of water levels on other morphological traits of NERICA 1

Six morphological features namely; leaf width, leaf length, panicle length, culm number, culm length and ligule length were monitored. Figure 4.4 and 4.5 displays the impact of water application rates on panicle and culm length which was significant.

Figure 4.4

Effect of Water Application Rates on Panicle Length

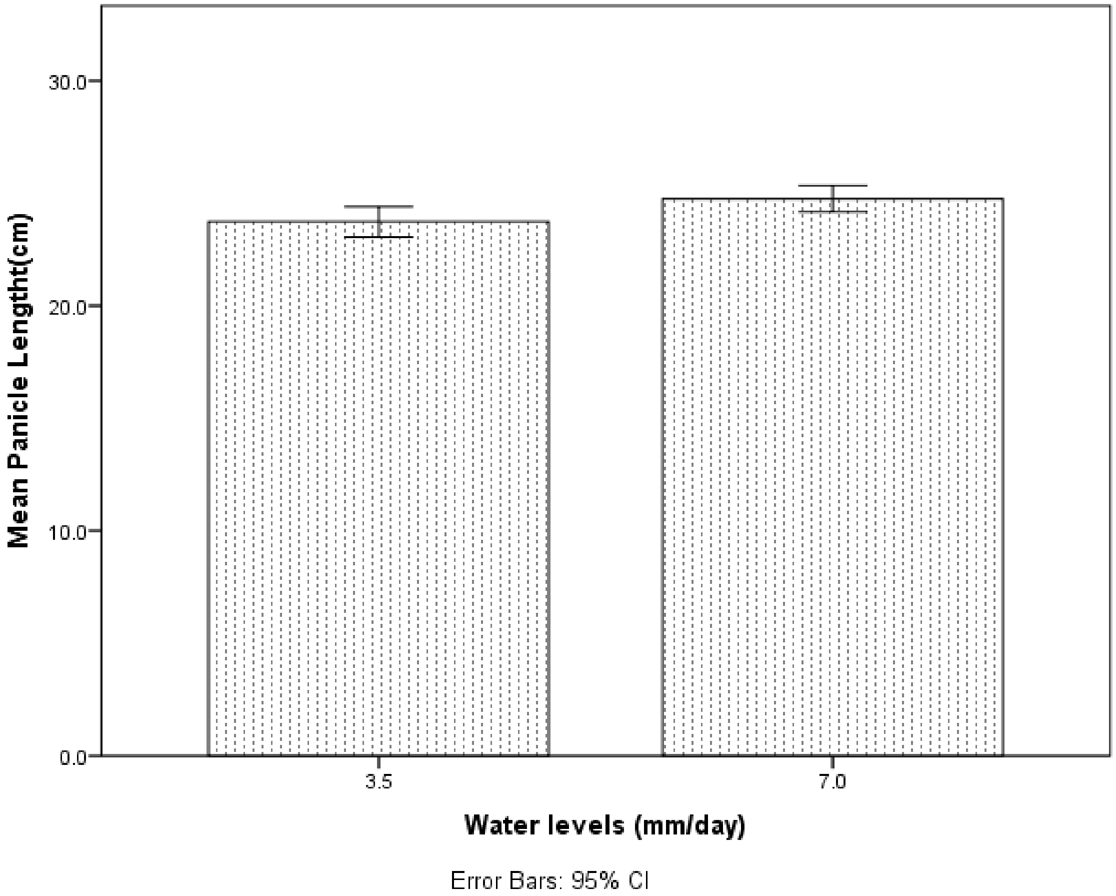


Figure 4.4 shows the mean panicle length (cm) as affected by the two water levels. This is an indication that higher water level as an effect on growth.

Figure 4.5

Effect of Water Application Rates on Culm Length

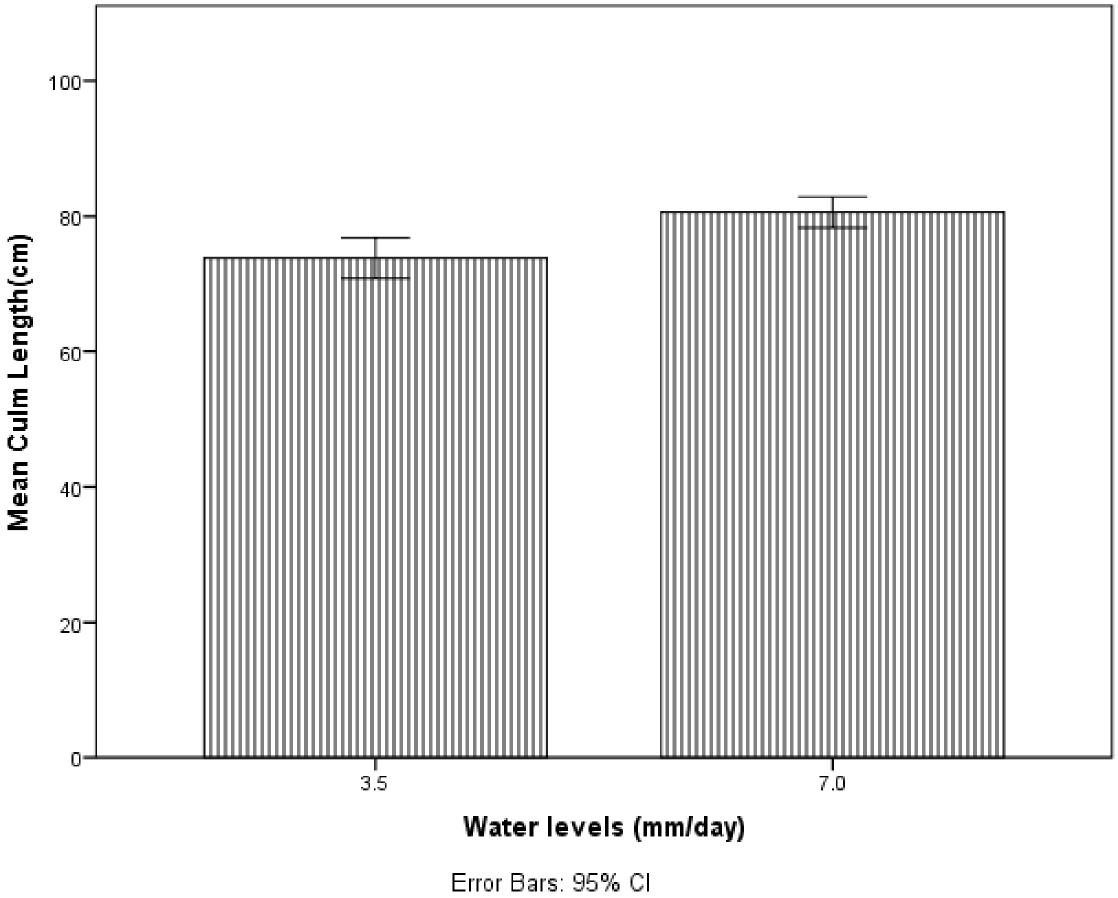


Figure 4.5 indicates the mean culm length (cm) as affected by the two water levels. The parameters were subjected to LSD for comparison of means and the summary is showed in Table 4.4

Table 4.4

Means Comparison for Effect of Water Levels on Morphological Parameters at Maturity

Water levels	Panicle Length (cm)	Leaf Length (cm)	Leaf Width (cm)	Ligule length (mm)	Culm Number	Culm Length (cm)
3.5 mm day^{-1}	23.729a	34.875a	1.733a	1.204a	4.313a	73.813a
7.0 mm day^{-1}	24.750b	37.271b	1.863b	1.215a	4.396a	80.583b
P value	0.024*	0.044*	0.006*	0.845	0.780	0.000*

No significant difference for means appearing in the same column and having similar letter at $p = 0.05$
*There is a significant difference at $p = 0.05$

The results shows that water application rates did not significantly affect ligule length and culm numbers with p= 0.845 and 0.780, respectively. Water level of 7.0 mm day^{-1} produced higher means of all the six parameters compared to water level of 3.5 mm day^{-1}, of which the difference in panicle length, culm length, leaf length and leaf width was significant. Akinbile, (2010) also observed related responses of entire agronomic parameters due to variations in application of water, showing the central impact of moisture on growth and development of the rice crop. This can be explained by the fact that, large amount of living protoplasm in the plant cells comprises of water, which aids in maintaining cell turgidity for structure and growth. Water generally exerts an intracellular pressure on the protoplasm and cell wall consequently maintaining the rigidity of leaves, roots and other plant organs. Reduced water levels as the plant grows deter length of cells and cell division resulting in decreased plant height, panicle length, leaf length and other growth parameters (Anjum et al., 2017). This deterrent in plant development influences numerous physiological and biochemical processes such as photosynthesis, ion uptake, growth promoters, respiration, nutrient metabolism, carbohydrate, and source–sink relationship (Fahad et al., 2017).

4.2.3 Influence of water levels on yield and yields parameters

Panicle weight, grain length, spikelet fertility, grain width, 100 grains weight and total grain yield at maturity were the yields indicators considered in the study. The findings for both seasons are outlined in Table 4.5.

Table 4.5

Means Comparison of Yield and Yield Components Due To Effect of Water Levels for Both Seasons

Season I							**Season II**			
Water levels	Panicle Weight (g)	Spikelet Fertility %	Grain Length (mm)	Grain Width (mm)	100 Grains Wt.(g)	Yield kg/ha	Grain Length (mm)	Grain Width (mm)	100 Grain Wt (g)	Yield kg/ha
3.5 mm Day^{-1}	3.20a	59.40a	8.96a	3.04a	2.44a	3135.86a	8.73a	2.96a	2.41a	2312.48a
7.0 mm Day^{-1}	3.90b	57.54a	8.90a	3.10a	2.64b	4535.58b	8.69a	2.92a	2.65b	2705.14b
P value	0.001*	0.607	0.695	0.566	0.003*	0.000*	0.736	0.407	0.000*	0.032*

No significant difference for means appearing in one column and having similar letter
*Significance difference observed at 0.05

The two water regimes of 3.5 mm day^{-1} and 7.0 mm day^{-1} that is equivalent to 392 mm and 782 mm of rainfall respectively were used to assess the influence on yield attributes in the study. The yield attributes considered in season I were weight of the panicle, fertility of the spikelet's, the total grain length and width, weight of 100 grains and total yield taken at fourteen percent moisture content. For the second season crop, the attributes measured were the grain width and length, weight of 100 grains and the grain yield calculated and adjusted at 14 percent level of moisture. Similar observations on grain yield and weight of 100 grains were evident in the two cropping seasons. Generally, first season crop did better in terms of yields when compared to the second cropping season. The difference could be attributed to the seedlings used in the second season which were transferred after the initial seeds planted in the pots failed to germinate as expected. The findings in Table 4.5 show no significant difference in spikelet fertility, grain length and grain width for two seasons due to water levels. However, there were significant difference in treatment means due to water levels in panicle weight, 100 grains weight and total grain yields. Water levels of 7.0 mm day^{-1} produced higher panicle weight of 3,890 g, 100 grains weight of 2,643 g in season one and 2,654 g in season two. Higher grains yields of 4,535.8 kg per hectare observed in season I and 2,705.1 kg ha^{-1} in season II was attained with 7.00 mm day-1 moisture level. This agrees with findings by Sikuku et al. (2010) who stated, additional yield (kg ha^{-1}), higher percentage in ratio of filled grain and increased yields at fourteen percent moisture level was achieved from well watered plants of NERICA cultivars, as compared to those under water deficit conditions. Sarvestani et al. (2008) also noted that water shortage lowered yield in Oryza sativa. Similar results were observed by Bouman and Toung (2001) and they resolved that rice plants in numerous countries are prone to dry spell that leads to huge yield loss.

The results portray the crucial part played by water in growth and development of rice. Adequate moisture levels which are applied in sufficient amounts are critical to sustain processes during growth of rice plant. According to Papademetriou (2001), water is the key cause for experienced gaps and inconsistency in yields at farm level.

Reduced moisture can decrease grain yield by distracting properties of gaseous exchange in leaf, particularly stomatal conductance and rate of CO_2 assimilation. This limits the sizes of source and sinks tissues, weakening loading in phloem and assimilates translocation, and decreases the activities of starch synthesis and sucrose (Farooq et al., 2009; Anjum et al., 2011). If water limits during or before panicle initiation, it decreases potential spike number and reduces translocation of assimilates to the grains, which leads to decrease in grain weight and surges number of empty grains. Figure 4.6 displays the influence of water levels on grain yields achieved in the first cropping season whereby 7.0 mm day^{-1} moisture level produced yields of 4,535.6 kg ha^{-1} compared to 3.5 mm day^{-1} that resulted in yield of 3,135.9 kg ha^{-1}.

Figure 4.6

Water Levels Effect on Yields

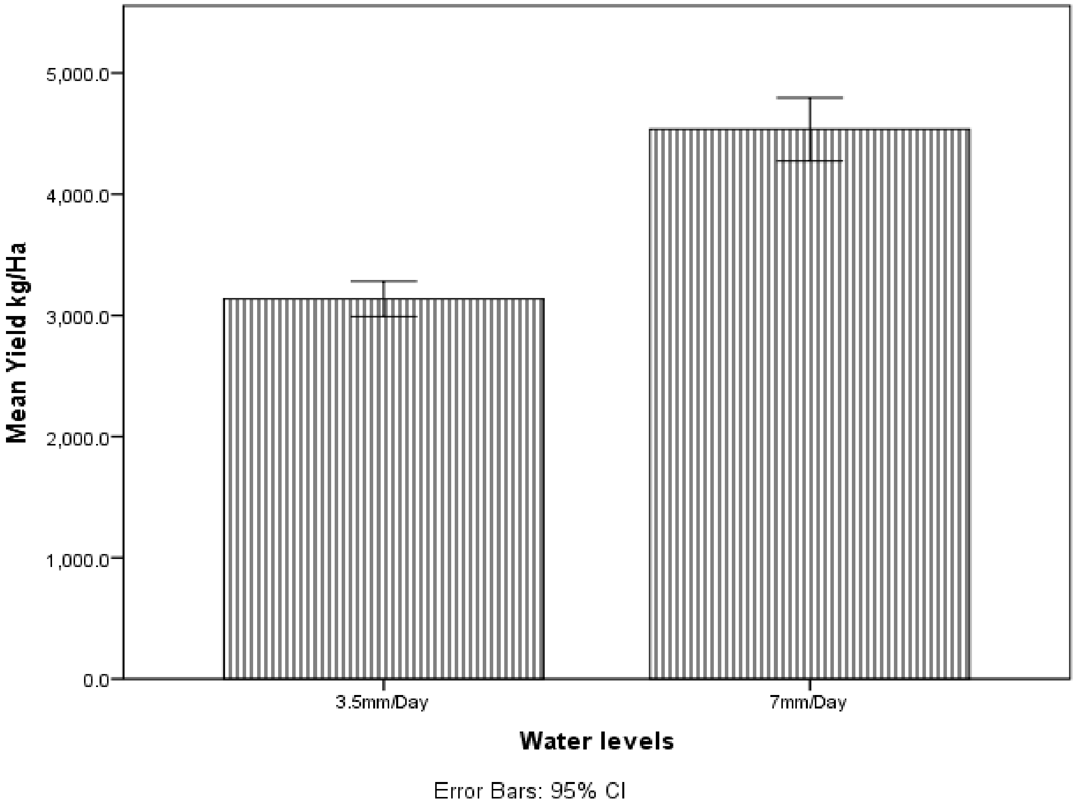


Figure 4.6 shows the mean yields (kgha^{-1}) of NERICA 1 under two watering regimes in first cropping season February-June 2017. Higher yields were achieved with 7.0mmday^{-1} as compared to 3.5mmday^{-1}indicating that moisture had positive impact on yields of NERICA 1.

According to Blum (2009) and Chaves et al. (2009), photosynthetic activity in plant is reduced by moisture stress, due to both stomatal and non-stomatal restrictions. Water stress induces closure of stomata which reduces CO_2 uptake and transpiration rate (de Souza et al., 2013). Water content of guard cell influences the opening and closing of stomata, whereby, little amount of water causes them to close and opens if they hold large amount of water. In chemical reactions of photosynthesis, water is the source of hydrogen to reduce carbon dioxide to glucose. Low yields resulting from low water application rates during different growth stages can be explained by reduced translocation of assimilates to the grain which results to reduced grain weight and high number of empty grains. Rahman et al. (2002) reported that reduced crop growth caused by limited moisture at flowering stage, can lead to reduced total grain number per panicle and 1000 grain weight hence affecting the yields. According to Fukai et al. (1999), maintaining leaf water potential before flowering is linked with higher panicle water potential, low spikelet sterility and reduced delay in flowering time which gives rise to higher yield.

4.2.4 Effect of watering regimes on growth and yield parameters in relation to rain fed crop.

Effect of the two watering regimes on tiller numbers, culm length (cm), panicle length in centimeters, spikelet fertility (%) and yield (Tonne ha^{-1}) were compared against those from rain fed crop in field environment as displayed in Table 4.6.

Table 4.6

Comparison of Means on Effect of Rainfall and Two Water Regimes on Growth and & Yield Parameters

	Growth and Yield Parameters				
Watering Regime	**Tiller Numbers**	**Panicle Length (cm)**	**Culm Length (cm)**	**Spikelet fertility %**	**Yield Tons ha^{-1}**
W$_1$-3.5mm day^{-1}-(392mm)	4.50a	23.70a	79.33a	58.00a	2.72b
W$_2$-7.0mm day^{-1}-(784mm)	4.40a	24.73a	80.50a	52.67a	3.62a
Rainfall (543. mm)	8.10b	25.33a	79.06a	67.40a	3.67a
P Value	**.000***	**.186**	**.086**	**.411**	**.000***

No significant difference for means appearing in the one column and having similar letter at p = 0.05.

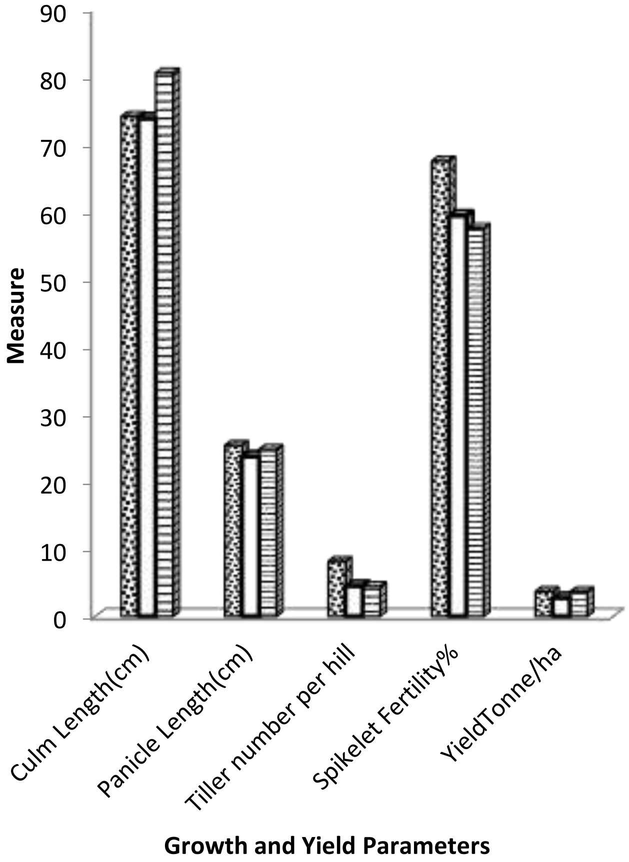
*There is a significant difference at $p \leq 0.05$

Comparison of means of some growth and yield parameters under two water regimes administered under greenhouse environment and that from rain environment indicated no significant difference in panicle length, culm length, and spikelet fertility. However, rain fed crop gave relatively higher spikelet fertility %, panicle length, tiller number and yield than those of both water regimes in the greenhouse. Higher tiller numbers under rain fed environment contributed to higher yields. Soil compaction in potted plants may have limited roots penetration restricting growth and exploitation of soil nutrients and moisture.

Percentage Spikelet fertility did not differ significantly for greenhouse and field crop despite the difference in water levels (Figure 4.7). This could be attributed by the fact that the average temperatures in both green house and in the field did not differ greatly as spikelet fertility is mainly affected by high temperatures. Culm length and panicle length in green house and field crop did not differ significantly indicating that both environment were conducive for plant growth and that the moisture levels supplied were sufficient to sustain the crop physiological processes.

Figure 4.7

Effect of Rainfall and Two Water Regimes on Some Growth & Yield Parameters



4.2.5 Correlation analysis

Correlation analysis was done to ascertain if there was association in the variables, number of tillers, culm length, filled grain per hill, weight of filled grain per hill, straw weight per hill and grain yield ton ha^{-1}. Table 4.7

Table 4.7

Correlation between Yields and growth/ yield components of NERICA1 as affected by rainfall

	Culm Length in cm	Number of tillers/hill	Filled Grain/hill	Straw weight(g)/hill	Filled grain Weight (g)/hill	Grain yield Ton/ha
Culm Length in cm	1	0.298	0.112	0.386	0.068	0.113
Number of tillers/hill	0.298	1	0.54	0.007	0.61	0.539
Filled Grain /hill	0.112	0.54	1	-.718*	.945**	1.000**
Straw weight(g)/hill	0.386	0.007	-.718*	1	-0.66	-.718*
Filled grain Weight(g)/hill	0.068	0.61	.945**	-0.663	1	.945**
Grain yield Tonne/ha	0.113	0.539	1.000**	-.718*	.945**	1

* Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

It was observed that;

1. A very strong positive correlation was observed between filled grain per hill and grain yield ton ha^{-1} which was statistically significance. (r = 1.00**, n = 9, $p \leq 0.01$)

2. A positive correlation though not significant between number of tillers and yield tonne ha^{-1} existed; (r=.539, n=9)

3. Inverse correlation between straw weight per hill and grain yield tonne ha^{-1} which was statistically significant existed ;(r =-0.718*, n = 9, p = 0.05)

4. A very strong positive correlation, statistically significant existed between filled grain weight per hill and grain yield tonne ha^{-1}.

The results were in agreement with studies by Zhao et al. (2020) who stated that grain yields were significantly and positively linked to grain weight, plant height, filled grain number per panicle, filled grain percentage and grain number m^{-2}. Grain number and filled grain number per panicle are critical considerations in determination of grain yield.

4.2.6 Influence of water rates used on water use efficiency.

Water use efficiency (WUE), measures the extent of a cropping system's ability to transform water into grain or plant biomass. Crop water use efficiency is calculated as;

Crop WUE (kg $ha^{-1}mm^{-1}$) = Grain yield (kg ha^{-1}) ÷ **Crop water supply (mm) -**

Soil evaporation

Crop Water use efficiency was calculated for the two water levels for the two season and results summarized in Table 4.8 and figure 4.8.

Table 4.8

Effects of Water Levels on WUE for the Two Seasons

	S1	S2
Water levels	Water use Efficiency (kg ha^{-1} mm^{-1}	Water use Efficiency (kg ha^{-1} mm^{-1})
3.5 mm day^{-1}	7.53(.17359)a	5.55 (.28234)a
7.00 mm day^{-1}	5.45(.15622)b	3.25(.16420)b
P value	0.000*	0.000*

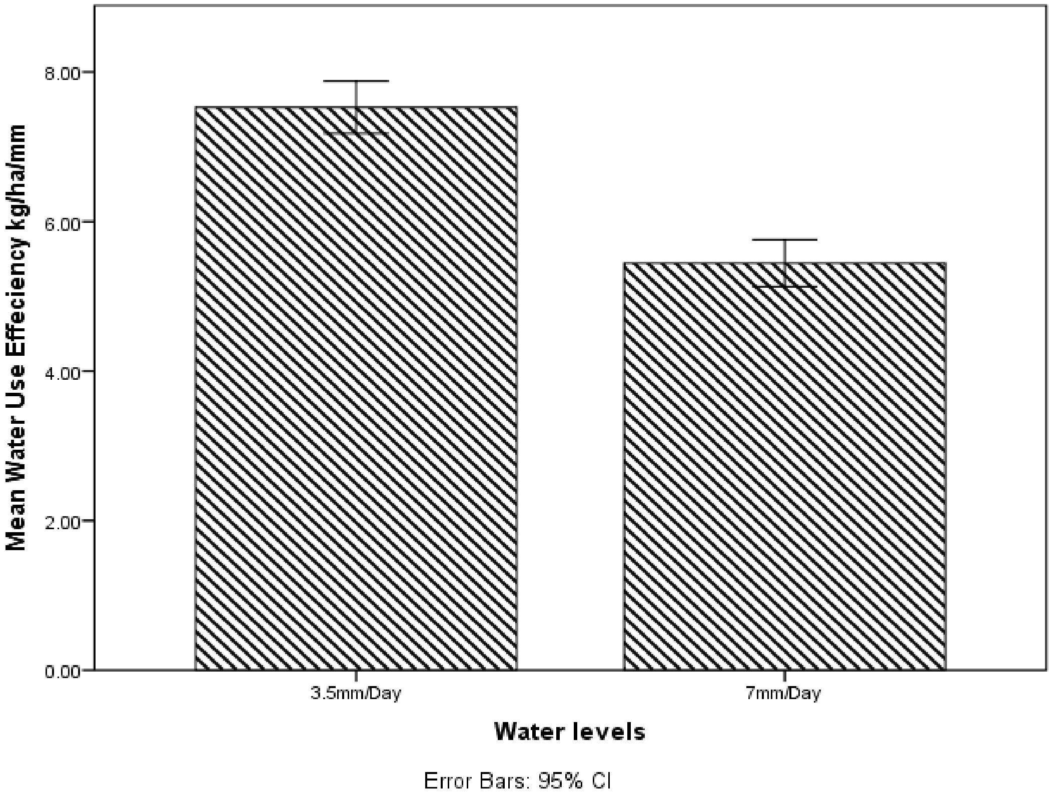
*The difference is significant since the p value is less than 0.05
No significant difference for means appearing in the one column and having similar letter at p = 0.05

The result shows that in both season one and two, irrigation regime significantly affected water use efficiency with higher values attained in 3.5 mm day^{-1} giving 7.5 kg ha^{-1} mm^{-1} and 5.6 kg ha^{-1} mm^{-1} respectively. The results agree with De Vries et al. (2010) studies conducted in Africa where irrigation water ranging between 480 to 1060 mm was utilized in the water-saving treatments giving rice yields of 2.3 to 11.8 t ha^{-1} while 3.7 to 11.7 t ha^{-}

^{1} was achieved from 800-1490 mm in the treatments where rice plot were flooded. He concluded that in Sahelian surroundings, it is possible to achieve main irrigation water savings with slight yield reduction. Mostafazadeh-Fard et al. (2010) also noted that the reducing depth of flooding in paddy fields produced 36.5% improvement in water use efficiency. Arora (2006) indicated in continuous submergence system the average yield and ET (Evapotranspiration) were similar for depths of 50 and 75 mm irrigation, giving equal values of ET-based water productivity.

Figure 4.8

Water Levels Effect on WUE



4.3 Performance of NERICA 1 Under Varying Fertilizer Rates

This section outlines the effect of different P & K combination rates on NERICA 1 growth and yield.

4.3.1 Effect of fertilizer combination on growth indicators

The influence of fertilizer combinations of three growth indicators namely tiller number, height of plant and number of leaves were monitored throughout the plant growth stages for the two seasons. Measurement on plant height, number of tillers and number of leaves were taken thirty days after sowing and throughout all different phases of rice development as described in standard evaluation of rice (IRRI, 2014). The data obtained was subjected to analysis of variance (Appendix 7(A) and summarized in Table 4.9 after subjecting the means to DMRT to ascertain if the means were significantly different.

In season 1, fertilizer combinations had no significance difference in plant height, number of tillers and number of leaves. However, in the second season the fertilizer rates significantly affected the number of leaves and tillers. The differences could be attributed to some extraneous variable like soil nutrient contents used in two seasons which can vary over section of land. However, the consistent data on plant height over the two season indicate validity of the measurement.

Table 4.9

Effect of P and K Rates on Plant Height, Tiller Number and Number of Leaves for the Two Seasons

Fertilizer Combination	Season I(Feb-June 2017) Plant Ht (cm)	Tiller Number	Number of leaves	Season II (July-Nov 2017) Plant Ht (cm)	Tiller Number.	Number of Leaves
P_1K_1-0Kg of P & 0 kg of K	79.167a	3.944a	15.444a	87.167a	3.875cd	15.583bcd
P_2K_1-20kg of P &0 kg of K	86.889a	4.278a	17.778a	88.292a	4.667abc	19.375ab
P_3K_1-40kg of P & 0 kg of K	83.778a	4.389a	17.611a	83.750a	4.083cd	16.417bcd
P_4K_1-60kg of P & 0 kg of K	78.278a	4.056a	17.389a	92.000a	5.292a	22.083a
P_1K_2-0 kg of P & 10kg of K	82.333a	4.111a	15.889a	87.000a	4.042cd	16.125bcd
P_2K_2-20kg of P & 10kgof K	77.833	4.278a	16.278a	87.208a	4.250bcd	16.958bcd
P_3K_2-40kg of P & 10kg of K	86.611a	4.889a	18.833a	86.458a	5.083ab	18.667bc
P_4K_2-60kg of P & 10kg of K	83.778a	4.222a	16.778a	86.083a	4.083cd	16.542bcd
P_1K_3-0 kg of P &20 kg of K	86.944a	4.111a	17.722a	86.583a	4.417abcd	18.250bc
P_2K_3-20kg of P & 20kg of K	79.778a	3.667a	15.167a	87.125a	3.875cd	15.042cd
P_3K_3-40kg of P & 20kg of K	83.833a	4.222a	17.167a	84.083a	4.083cd	16.083bcd
P_4K_3-60kg of P & 20 kg of K	79.167a	4.278a	17.056a	87.292a	3.917cd	16.250bcd
P_1K_4- 0kg of P & 30kg of K	79.778a	3.889a	15.167a	87.000a	4.292bcd	17.208bc
P_2K_4-20kg of P & 30 kg of K	78.722a	4.000a	15.722a	85.667a	4.125cd	17.417bc
P_3K_4-40kg of P & 30 kg of K	84.333a	3.833a	16.278a	87.750a	3.458d	13.458d
P_4K_4-60kg of P & 30kg of K	80.778a	3.556a	15.111a	88.333a	4.000cd	16.000bcd
P value	0.122	0.183	0.128	0.125	0.003*	0.000*

No significant difference for means appearing in the one column and having similar letter (p = 0.05)
*The difference is significant at p value = 0.05

The findings in Table 4.9 indicates that highest values in plant height were attained in P_1K_3 (0 kg ha^{-1} P_2O_5 +10 kg ha^{-1} K_2O)-86.94 and P_4K_1 (60 kg $ha^{-1}$$P_2O_5$+0 kg $ha^{-1}$$K_2O$)-92.00 in season 1 and 2 respectively. P_3K_2 (40 kg $ha^{-1}$$P_2O_5$+10 kg $ha^{-1}$$K_2O$) with 4.89 and P_4K_1 with 5.29 seasons 1 and 2 respectively were values of highest tiller numbers. High number of leaves was attained in P_3K_2-18.83 and P_4K_1 - 22.08 for season one and two respectively. Likewise, lowest plant height was attained in P_2K_2 (20 kg $ha^{-1}$$P_2O_5$+10 kg ha^{-1} K_2O)-77.88 in season 1 and P_3K_1 (40 kg ha^{-1} P_2O_5 + 0 kg ha^{-1} K_2O)-83.75 in season two, while P_4K_4 (60 kg ha^{-1} P_2O_5+30 kg ha^{-1} K_2O) and P_3K_4 (40 kg ha^{-1} P_2O_5+30 kg ha^{-1} K_2O) showed the lowest number of tillers and leaves in season one and two respectively. No significant difference was observed due to fertilizer rates on plant height (in the two seasons), tiller numbers and number of leaves in first season. Significant difference in number of tillers ($p = 0.003$) and number of leaves ($p = 0.000$) in the second season was observed.

Average mean values of plant height, tiller number and number of leaves as influenced by fertilizer combination throughout the growth phases is outlined in Table 4.10.

Table 4.10

Effect of P & K Rates on Plant Height, Tiller Numbers and Number of Leaves Across DAS for the Two Seasons

Season I(February to June 2017)			
DAS	Height of plant (cm)	Tiller number	Number of leaves
32	45.09(1.15)	3.45(.12)	12.05(.406)
52	91.92(1.15)	4.35(.12)	19.90(.41)
72	108.99(1.15)	4.52(.12)	17.81(.41)
P values	**0.000***	**0.000***	**0.000***
Season II (July to November 2017)			
DAS	Height of Plant (cm)	Tiller number	Number of leaves
Seedling-30	71.26(.77)	3.37(.15)	13.71(.56)
Tillering-45	77.46(.77)	4.23(.15)	18.81(.56)
Booting- 60	88.50(.77)	4.93(.15)	18.06(.56)
Mature grain-90 -100	110.73(.77)	4.37(.15)	17.28(.56)
P values	0.000*	0.000*	0.000*

SE-indicated in the brackets
*Indicates values which are statistically difference at p = 0.05

Table 4.10 indicate the difference due to plant height, tiller numbers and number of leaves as influenced by fertilizer levels throughout the development stages which was statistically significance. Phosphorus and Potassium after Nitrogen are important in development of upland rice.

Qiangsheng et al. (2004) stated that during development period of elongation phase to heading stage, uptake of K by rice population is maximized. Within the rice crop, Phosphorus is a crucial nutrient necessary for transfer and storage of energy. Studies by Ryan et al. (2008b) showed that, in the farms where soil test measure for Phosphorus are low, crop responses to Phosphorus was detected and in regions where P accumulation was observed owing to regular fertilization, slight or no reaction to P applied was observed. Reactions to Phosphorus are likely to be greater in dry environments owing to activating influence on growth of the root (Fageria, 2007). Studies by Hasan et al. (2016) indicate that direct P fertilization can raise yields of rice on soils that have inadequate P availability caused by high soil pH ($pH > 6.5$) and have naturally low soil test P levels. To observe the effect of additional P_2O_5 and K_2O as per allocated fertilizer combination on growth parameters, data was extracted separately and summarized in Table 4.11. Phosphorus rates were kept constant and amount of Potassium varied from 0; 10; 20; 30 kg ha^{-1} and the effect growth attributes noted namely height of the plant, number of tillers per hill and leaves per plant. The quantities of Phosphorus were then varied with amount of Potassium remaining constant and same variables were evaluated as re-ordered in table 4.11. The Nitrogen supplied in all treatments remained constant at rate of 60 kg ha^{-1} and equivalent amounts computed for each 20 litre pot.

Table 4.11

Summary of Effect of P & K on Growth of NERICA 1

	Season 1(February to June 2017)			Season Two(July to November 2017)		
Rate of P kg ha^{-1}	Plant Height (cm)	Tiller Number.	Number of leaves	Plant Height (cm)	Tiller Number.	Number of Leaves
P_1K_1-0 kg P_2O_5	79.17a	3.94a	15.44a	87.17a	3.88cd	15.58bcd
P_2K_1-20 kg P_2O_5	86.89a	4.28a	17.78a	88.29a	4.67abc	19.38ab
P_3K_1-40 kg P_2O_5	83.78a	4.39a	17.61a	83.75a	4.08cd	16.42bcd
P_4K_1-60 kg P_2O_5	78.28a	4.06a	17.39a	92.00a	5.29a	22.08a
Rate of K -kg ha^{-1}						
P_1K_1-0 kg K_2O	79.17a	3.94a	15.44a	87.17a	3.88cd	15.58bcd
P_1K_2-10 kg K K_2O	82.33a	4.11a	15.89a	87.00a	4.04cd	16.13bcd
P_1K_3-20 kg K_2O	86.94a	4.11a	17.72a	86.583a	4.42abcd	18.25bc
P_1K_4-30 kg K_2O	79.78a	3.89a	15.17a	87.000a	4.29bcd	17.21bc

Means with similar letter within same column do not differ significantly at $p = 0.05$

The results showed in table 4.11 indicates increase in plant height, tiller and leaves numbers as P_2O_5 increased up to 20 kg ha^{-1} for the two seasons and a decrease in all measures at $P_2O_5 = 60$ kg ha^{-1} in first season but a rise in second season.

Fertilizer treatment rate of 20 kg ha^{-1} of P_2O_5 showed the highest plant height and number of tillers whereas 0 kg ha^{-1} P_2O_5 had the lowest in season one. In the second season, fertilizer treatment rate of 60 kg ha^{-1} P had highest plant height, tiller and number of leaves, whereas 0 kg ha^{-1} P_2O_5 rate had the least.

Increase of K_2O to rate of 20 kg ha-^{1}, resulted to an increase in plant height, tiller and number of leaves in both seasons but dropped at K=30 kg ha^{-1}. Fertilizer treatment rate of 20 kg ha^{-1} K_2O gave the highest number of tallest plant, tiller and leaves number in seasons one and two whereas fertilizer rate of 0 kg ha^1 K_2O gave the least. Potassium and Phosphorus fertilization enables appropriate growth of root and other nutrients uptake, which eventually enhances growth and development of the crop. Increased rate of potassium aids in producing large quantities of starch owing to K-mediated carbohydrate metabolism. It also assists in effective translocation of photo-assimilates to the developing sinks which permits the plants to use entirely applied N and P fertilizers (Wang et al., 2013). According to White and Karley, (2010), Potassium contributes significantly to cell turgor, particularly in cells that are expanding fast, and acts as a counter cation for anion collection and electrogenic transport processes. P has been observed to increase root growth and has an effect on early maturity, straw strength, crop quality and disease resistance (Grant et al., 2001). More or less similar observation were stated by Dakshina Murthy et al. (2015) that increasing the rates by 25% above the stated dosage of Potassium and Phosphorus, resulted in significant increase in tillers and dry matter production. Soil tests indicated sufficient Potassium and high Phosphorus for the soils used in the study.

4.3.2 Effect of fertilizer levels on yield and its components

Panicle weight, grain width, spikelet fertility, grain length, 100 grains weight and total grain weight were the yield components monitored in the research study. The fertilizer treatment rates effect on means of yield components (Appendix 7 (B) after subjecting the means to DMRT to ascertain if there were any significant differences for both seasons are outlined in Table 4.12.

Table 4.12

Effect of Fertilizer Rates on Yield and Yield Components for the Two Seasons

	Season 1(February-June 2017)						**Season 2(July-November 2017)**			
Fertilizer Combination	Panicle wt (g)	Spikelet Fertility %	Grain Length (mm)	Grain Width (mm)	100Grain Weight (g)	Yield in kg per ha	Grain Length (mm)	Grain Width (mm)	100 Grain Weight(g)	Yield in kg per ha
P_1K_1	2.97a	53.96a	9.00a	3.42a	2.68abc	3284.48a	8.67a	3.00a	2.49a	1913.15edf
P_2K_1	3.81a	60.17a	9.00a	2.83a	2.64acb	3938.69a	8.50a	3.00a	2.45a	1845.21ef
P_3K_1	3.50a	54.83a	9.00a	3.00a	2.89a	4334.21a	8.83a	2.83a	2.56a	3076.84abc
P_4K_1	3.46a	51.00a	9.00a	3.00a	2.73ab	3880.88a	8.83a	3.00a	2.45a	2671.74bcd
P_1K_2	3.05a	62.00a	9.33a	3.00a	2.46abcd	3586.01a	8.50a	3.00a	2.44a	3476.84a
P_2K_2	4.37a	59.50a	9.33a	3.17a	2.37bcd	3878.67a	8.83a	3.00a	2.60a	3017.82abc
P_3K_2	3.33a	49.50a	8.00a	2.83a	2.14d	4111.84a	9.17a	2.83a	2.78a	3420.26ab
P_4K_2	3.07a	59.50a	8.67a	3.17a	2.27cd	3618.32a	8.67a	3.00a	2.60a	2264.21ed
P_1K_3	3.48a	60.50a	9.00a	3.17a	2.47abcd	3725.32a	8.67a	3.00a	2.56a	1263.47f
P_2K_3	3.14a	56.00a	8.50a	2.83a	2.70abc	4236.17a	8.83a	2.67a	2.53a	3330.55abc
P_3K_3	3.34a	57.67a	9.00a	3.33a	2.66abc	4698.41a	8.33a	2.83a	2.46a	3334.59abc
P_4K_3	3.89a	62.46a	8.86a	3.27a	2.62abc	4054.47a	8.50a	3.00a	2.53a	2106.46ef
P_1K_4	4.15a	69.67a	9.00a	3.00a	2.63abc	3377.45a	9.00a	3.00a	2.62a	1997.54ef
P_2K_4	3.76a	66.67a	9.00a	3.17a	2.49abcd	3614.34a	8.33a	2.83a	2.47a	2596.05cd
P_3K_4	4.34a	66.00a	9.17a	2.83a	2.42bcd	3857.84a	9.00a	3.00a	2.46a	2629.60cd
P_4K_4	2.89a	44.67a	9.00a	3.17a	2.48abcd	3046.05a	8.67a	3.00a	2.50a	1196.70f
P value	0.19	0.646	0.423	0.789	.022*	0.429	0.519	0.386	0.881	0.000*

Treatments within each column with the similar letter are not significantly different. (P= 0.05) DMRT

*The difference is significant at p value = 0.05

Table 4.12 shows no significant differences in yield parameters namely, weight of panicle, fertility of spikelets, grain length, grain width and 100 grain weight due to fertilizer combinations in the two seasons. This can be explained by two facts; first, is that the Nitrogen content remained constant at 60 kg ha^{-1} with varying amounts of Potassium and Phosphorus. Wilkinson and Sumner (2000) noted that adding N levels raises the need for other nutrients, particularly K & P, while the reaction to one nutrient is determined by the adequacy amount of other nutrients. The second reason is that the soils at the site had significance values of Phosphorus and Potassium and therefore response to the increase in either was subject to increase in Nitrogen. With P = 0.000, grain yield in second season was significant.

Fertilizer combination of P_2K_2 (20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O) produced highest values of panicle weight of 4.37 g and grain length of 9.33 mm, while P_1K_4 (0 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O) gave highest spikelet fertility of 69.67 as P_3K_1 and P_3K_3 gave highest 100 grain weight (4.33 g) and yield (4,698.4) respectively in season one P_3K_2 (40 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O) had the highest grain length 9.17, 100 grains weight of 2.78 and grain yield in kg ha^{-1} of 3,420.26 in season two. The lowest values in panicle weight 2.89 spikelet fertility of 44.66 and yield 3,046.05 were attained with P_4K_4 (60 kg $ha^{-1}$$P_2O_5$ + 30 kg ha^{-1} K_2O) fertilizer combination in season one. The lowest value for grain length, grain width and 100 grain weight (2.44) in season two, was attained with P_2K_2 (20 kg ha^{-1} P_2O_5 + 20 kg ha^{-1} K_2O). The least values in grain yield of 3,046.05 kg ha^{-1} and 1,196.70 kg ha^{-1} was achieved with P_4K_4 (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O) in season one and two respectively. Pooled data for the two seasons indicted that grain yield of 3,745.41 kg ha^{-1} which was the highest was achieved by P_1K_2 (0 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} of K_2O) while the least yields of 2507.70 kg ha^{-1} was attained by P_4K_4 (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O).

Potassium plays a vital role in starch synthesis and grain development hence its sufficient supply results in positive effect in producing heavier rice grain. Increase of K fertilizer increased the photosynthetic capacity and translocation of photo-assimilate availability of NPK (Wang et al., 2013). It also expedites carbon reallocation and translocation throughout the grain filling phase (Yang et al., 2004). Increased yield with higher K dose is due to its contribution in positively influencing all the yield contributing characters of rice plants. Phosphorus is a constituent of other compounds essential for transfer of genetic material (DNA, RNA) and synthesis of protein. It is also a key constituent in ATP, the molecule that delivers energy to the plant for processes like protein synthesis, nutrient uptake, photosynthesis, nutrient translocation, and respiration (Grant et al., 2001). High amounts of Phosphorus and Potassium generally inhibits the uptake of other elements like Zinc, Iron and Manganese.

The results are almost consistent with those reported by Fageria and Oliveira (2014) that fertilization of Potassium, Nitrogen and Phosphorus has strong positive interaction in upland production. According to Wilkinson et al. (2000), reductions in yield were observed where high rates of particular nutrient were applied with lower rates of other nutrients. In our case, Nitrogen levels remained constant affecting the responses of additional Phosphorus and Potassium. To improve the yield depressing impact of extreme macronutrient amount requires eliminating the constraint of a lower amount of additional nutrients. Table 4.13 tabulate effect of additional P & K on yield and yield components.

Table 4.13

Effect of P & K Levels on Panicle Weight, Grain Width, Spikelet Fertility, Grain Length, 100 Grain Weight and Yields

	Season I (February-June 2017)						Season 11(July-November 2017)			
Rate of P&K kg ha^{-1}	Panicle wt (gm)	Spikelet Fertility %	Grain Length (mm)	Grain Width (mm)	100 Grain Weight (gm)	Yield in kg per ha	Grain Length (mm)	Grain Width (mm)	100 Grain Weigh t(gm)	Yield in kg per ha
P_1K_1	2.97ba	53.96a	9.00a	3.42a	2.68abc	3284.48a	8.67a	3.00a	2.49a	1913.15edf
P_2K_1	3.81ba	60.17a	9.00a	2.83a	2.64acb	3938.69a	8.50a	3.00a	2.45a	1845.21ef
P_3K_1	3.50ba	54.83a	9.00a	3.00a	2.89a	4334.21a	8.83a	2.83a	2.56a	3076.84abc
P_4K_1	3.46ba	51.00a	9.00a	3.00a	2.73ab	3880.88a	8.83a	3.00a	2.45a	2671.74bcd
P_1K_1	2.97ba	53.96a	9.00a	3.42a	2.68abc	3284.48a	8.67a	3.00a	2.49a	1913.15edf
P_1K_2	3.05ba	62.00a	9.33a	3.00a	2.46abcd	3586.01a	8.50a	3.00a	2.44a	3476.849a
P_1K_3	3.48ba	60.50a	9.00a	3.17a	2.47abcd	3725.32a	8.67a	3.00a	2.576a	1263.47f
P_1K_4	4.15ba	69.67a	9.17a	3.00a	2.63abc	3377.45a	9.00a	3.00a	2.62a	1997.54ef

Means in the same column followed by similar letter do not differ significantly at p = 0.05

Increase in Phosphorus to 20 kg ha^{-1} caused a rise in panicle weight and percentage spikelet fertility in the first season, whereas an increase to 40 kg ha^{-1} resulted to increase in 100 grain weight and yields in seasons one and two. In both seasons additional increase of Phosphorus to 60 kg ha^{-1} decreased spikelet fertility, 100 grain weigh, panicle weight, and yields. Additional Potassium increased spikelet fertility and panicle weight although yield and 100 grain weight increased with Potassium rates up to 40 kg ha^{-1} in both seasons. Observations are related to those conveyed by Dakshina Murthy et al (2015) who stated that addition of P & K levels from 100 to 125% improved significantly grain yield of rice but additional incremental amounts of P & K beyond 125% showed no significant yield improvement. Almost similar findings were likewise noted by Uddin et al. (2013) with NERICA 1 rice grain yield increasing with the additional Potassium rate to K_2 (40 kg K_2O ha^{-1}) in soils with Exchangeable Potassium of 0.13 and thereafter decreasing. Grain yield increase with K application was largely caused by yield components improvement, such as number of effective tillers and panicle length and weight. No significant difference was noted in grain width and grain length by increasing both Phosphorus and Potassium in both seasons.

Adequate supply of K in roots of plant produces osmotic pressure gradient that draws water to the roots. In short supply of water, plants lacking in K are subjected to water stress more as they are less able to absorb water. Potassium is involved in transportation of water and nutrients in the xylem and inactivation of many enzymes involved in growth. Energy in the form of ATP is used by the plant's transport system, and therefore, less ATP is availed if there is shortage leading to breaks down of transport system. According to Thomas and Thomas, (2009), sufficient K supply is necessary for efficient functioning of these systems. Shortage of K affects the rate of photosynthesis and reduced the ATP production rate, which slows down all procedures that are reliant on ATP. Soil K levels are supposed to adequately enough to supply sufficient Potassium at any time throughout the crop growth. Short periods of shortage, particularly in critical developmental phases may lead to severe losses. This explains effect of low rates of K in growth parameters and yield in the research findings.

On the other hand Phosphorus is essential for a range of cellular processes which includes development of high–energy molecules, production of bimolecules and membrane structure maintenance. According to Assuero et al. (2004), Phosphorus aids in cell division plus enlargement, activation or inactivation of enzyme and metabolism of carbohydrate. Low levels therefore affect growth parameters such as, leaf area, plant height, number of leaves and dry biomass of shoot. The main substrates for photosynthesis to take place are Pi, CO_2, water, light energy in presence of chlorophyll, therefore the process is highly dependent on Phosphorus availability. Optimum Phosphorus amounts in initial phase assist to improve other nutrients availability, in so doing increases the crop yield. However it is also good to note that, excess of Phosphorus generally interferes with uptake of elements, like Iron, Manganese and Zinc, whereas that of Potassium can induce deficiencies of nutrients like Nitrogen, Calcium and Magnesium. This can affect crop development and yield which therefore explains the decrease of yields at high levels of both K and P (Binay et al., 2012).

4.3.3 Effect of fertilizer combination on water use efficiency

Calculation of WUE for both seasons and how it was influenced by fertilizer levels is tabulated in Table 4.14. The ratio of grain yield per hectare over the total amount of water used in the entire period of growth in cubic meter was used to get the values of water productivity. For the sixteen fertilizer treatments used as per the rate of Phosphorus and Potassium used in each case, the WUE was computed and the values analyzed for statistical difference using DMRT after analysis of variance was done (Appendix 7 C).

Table 4.14

Effects of Fertilizer Rates on WUE in Season I and II

	Season I	**Season II**
Fertilizer Combination	WUE (kg ha^{-1} m$^{-3)}$	WUE (kg ha^{-1} m^{-3})
P_1K_1-0 kg ha^{-1}P_2O_5+ 0 kg ha^{-1}K_2O	.593a	.334cde
P_2K_1-20 kg ha^{-1} P_2O_5+0 kg ha^{-1}K_2O	.661a	.337cde
P_3K_1-40 kg ha^{-1}P_2O_5+0 kg ha^{-1}K_2O	.733a	.584ab
P_4K_1-60 kg ha^{-1}P_2O_5+ 0 kg ha^{-1}K_2O	.636a	.448abcd
P_1K_2-0 kg ha^{-1} P_2O_5+10 kg ha^{-1}K_2O	.616a	.661a
P_2K_2-20 kg ha^{-1}P_2O_5+ 10 kg ha^{-1}K_2O	.672a	.518abc
P_3K_2-40 kg ha^{-1}P_2O_5+10 kg ha^{-1}K_2O	.711a	.568ab
P_4K_2-60 kg ha^{-1}P_2O_5+10 kg ha^{-1}K_2O	.606a	.408bcde
P_1K_3-0 kg ha^{-1}P_2O_5 +20 kg ha^{-1}K_2O	.660a	.230ed
P_2K_3-20 kg ha^{-1}P_2O_5+20 kg ha^{-1}K_2O	.733a	.565ab
P_3K_3-40 kg ha^{-1}P_2O_5+20 kg ha^{-1} K_2O	.792a	.584ab
P_4K_3-60 kg ha^{-1}P_2O_5+ 20 kg ha^{-1}K_2O	.624a	.406bcde
P_1K_4-0 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.552a	.330cde
P_2K_4-20 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.598ba	.440bcd
P_3K_4-40 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.659a	.423bcde
P_4K_4-60 kg ha^{-1}P_2O_5+30 kg ha^{-1}K_2O	.523a	.207e
P value	.212	.000*

Means appearing in one column and with letters that are similar do not differ significantly at the ($P< 0.05$) DMRT

Table 4.14 indicates that with p = 0.212, no significant difference was noted in WUE due to fertilizer levels in first season but was observed in second season (p = 0.000). The highest value of WUE was realized in P_3K_3 - 40 kg ha^{-1} P_2O_5 + 20 kg ha^{-1} K_2O (0.792) followed by P_3K_1-40 kg ha^{-1} P_2O_5+0 kg ha^{-1} K_2O and P_2K_3 20 kg ha^{-1} P_2O_5 + 20 kg ha^{-1} K_2O) (- (0.733) in season I and P_1K_2 - 0 kg ha^{-1} P_2O_5+ 10 kg ha^{-1} K_2O- (0.661) in season II followed by P_3K_2 - 40 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O (0.568). P_4K_4 - 60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O had the least value of WUE in the first and second seasons of 0.52 and 0.21, respectively. Higher rates of both Phosphorus and Potassium resulted in low WUE as revealed in the study results. Excess application of some macro-elements may antagonize availability of other microelements as reported by Panda et al. (2012). P_3K_3 (40 kg ha^{-1} P_2O_5 + 20 Kg ha^{-1} K_2O) gave the highest WUE of 0.688 kg ha^{-1} m^{-3} while P_4K_4 (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O) attained the lowest value of 0.365 kg ha^{-1} m^{-3}, average of both seasons. Figure 4.9 displays the influence of fertilizer rates on WUE for the first season. Bationo et al. (1998) indicated that use of fertilizer slightly raises seasonal crop-water usage (that is 5.4 to14.4 kg mm^{-1} ha^{-1}) owing to significant rise in plant growth and yield, in a study with pearl millet.

Figure 4.9

Effect of Water Fertilizer Rates on WUE in Season One

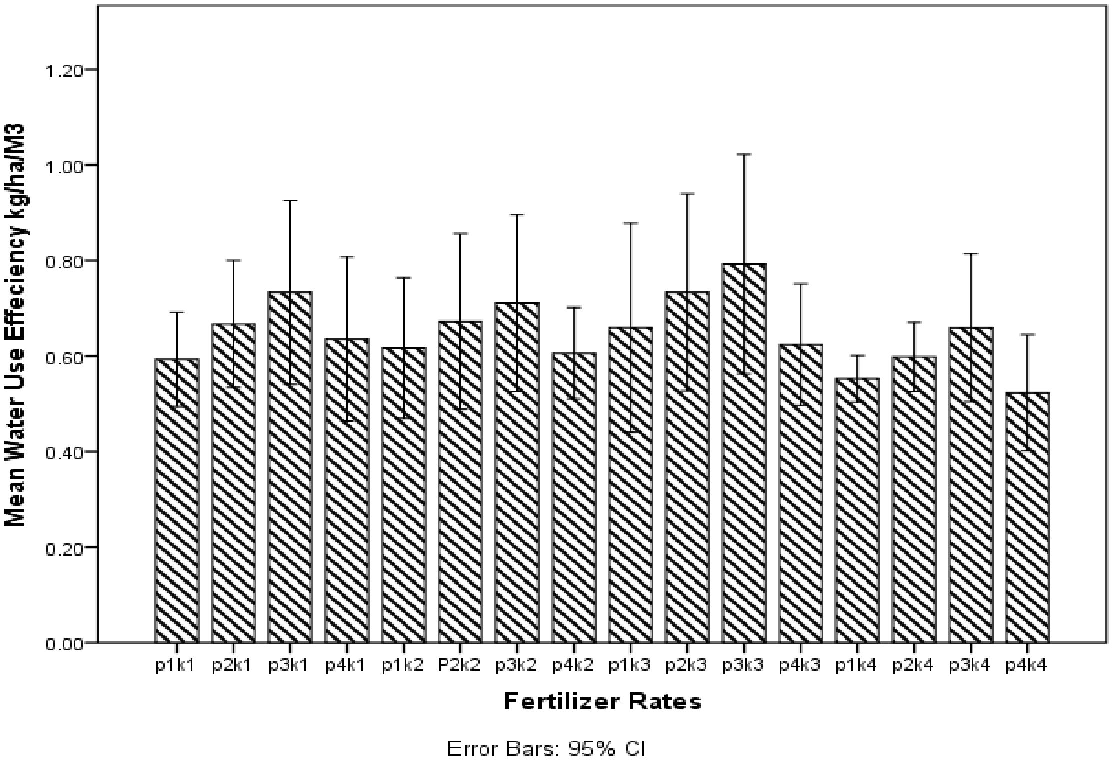


Figure 4.9 shows the effect of different P & K combination on WUE (kgha^{-1}m^{-3} in the first season February to-June 2017. Increasing P & K resulted in an increase in WUE due to increase in plant growth and yield. However very high amounts of P & K as in P4K4 (P- 60kgha^{-1}, K-30kgha^{-1}) resulted in lower WUE due to low water and fertilizer use efficiency.

4.4 Performance of NERICA 1 as Affected by Interaction Between Irrigation Rates and Fertilizer Levels

The section outlines the interaction between water levels and fertilizer rates on growth and yields of NERICA 1.

4.4.1 Growth parameters.

The data taken on the three growth components studied for the two seasons namely, number of leaves, tiller numbers and plant height were subjected to analysis of variance to access interaction effect between fertilizer levels and water regimes. Summary of ANOVA components are presented in Table 4.15 and 4.16.

Table 4.15

Mean Squares for Interaction between Water Levels and P & K Rates in Season 1 on Growth Traits

Source Of variation	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Block	Plant Height (cm)	514.583	2	257.292	2.055	.130
	Number of Tillers	55.111	2	27.556	21.852	.000
	Number of Leaves	555.111	2	277.556	18.786	.000
DAS	Plant Height (cm)	210129.521	2	105064.760	839.041	.000
	Number of Tillers	64.007	2	32.003	25.380	.000
	Number of Leaves	3169.507	2	1584.753	107.263	.000
Water_L * FC	Plant Height (cm)	1643.208	15	109.547	.875	.593
	Number of Tillers	31.108	15	2.074	1.645	.063
	Number of Leaves	461.219	15	30.748	2.081	.011*
FC	Plant Height (cm)	2776.222	15	185.081	1.478	.113
	Number of Tillers	26.385	15	1.759	1.395	.150
	Number of Leaves	341.663	15	22.778	1.542	.091
Water_L	Plant Height (cm)	889.014	1	889.014	7.100	.008
	Number of Tillers	5.281	1	5.281	4.188	.042
	Number of Leaves	49.170	1	49.170	3.328	.069
Error	Plant Height (cm)	31555.451	252	125.220		
	Number of Tillers	317.771	252	1.261		
	Number of Leaves	3723.160	252	14.774		
Corrected Total	Plant Height (cm)	247508.000	287			
	Number of Tillers	499.663	287			
	Number of Leaves	8299.830	287			

(*)The interaction effect is significant since its p value is less than 0.05

Table 4.16

ANOVA Summary for Interaction between Water Levels and Fertilizer Rates on Growth Parameters in Season II

Source of Variation	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Water_L	Plant Height (cm)	461.565	1	461.565	8.623	.004
	Number of Tillers	.440	1	.440	.201	.654
	Number of Leaves	28.711	1	28.711	.936	.334
BLOCK	Plant Height(cm)	18.130	2	9.065	.169	.844
	Number of Tillers	12.380	2	6.190	2.830	.060
	Number of Leaves	186.349	2	93.174	3.037	.049
DAS	Plant Height (cm)	86793.654	3	28931.218	540.514	.000
	Number of Tillers	120.258	3	40.086	18.328	.000
	Number of Leaves	1471.070	3	490.357	15.984	.000
FR	Plant Height (cm)	1231.977	15	82.132	1.534	.091
	Number of Tillers	76.643	15	5.110	2.336	.003
	Number of Leaves	1395.018	15	93.001	3.031	.000
Water_L * FR	Plant Height (cm)	1650.310	15	110.021	2.055	.012*
	Number of Tillers	29.518	15	1.968	.900	.565
	Number of Leaves	401.914	15	26.794	.873	.595
Error	Plant Height (cm)	18573.299	347	53.525		
	Number of Tillers	758.945	347	2.187		
	Number of Leaves	10645.497	347	30.679		
Corrected Total	Plant Height (cm)	108728.935	383			
	Number of Tillers	998.185	383			
	Number of Leaves	14128.560	383			

(*)The interaction effect is significant since its p value is less than 0.05

The means square in Table 4.15 and 4.16 displays that interaction between fertilizer rates and water levels had significant effect on number of leaves (p = 0.011) and plant height (p = 0.012) in season I and II respectively. No significant interaction effect on tiller numbers in season I & II, plant height and number of leaves in season I and II respectively. After subjecting the combinations to Duncan multiple range tests the findings are displayed in Table 4.17.

Table 4.17

Mean Values for Interaction of P & K Rates, Water Levels on Growth Parameters For Both Seasons

Interaction Fertilizer+ Water	First Season			Second Season		
	Plant Height (cm)	Number of Tillers	Number of leaves	Plant Height (cm)	Number of Tillers	Number of leaves
P_1K_1+W	79.17a	3.94a	15.44b	87.17b	3.88a	15.58a
P_2K_1+W	86.89a	4.28a	17.78ab	88.29ab	4.67a	19.37a
P_3K_1-+W	83.78a	4.39a	17.61ab	83.75b	4.08a	16.42a
P_4K_1+W	78.28a	4.06a	17.39ab	92.00a	5.29a	22.08a
P_1K_2+W	82.33a	4.11a	15.89ab	87.00b	4.04a	16.13a
P_2K_2+W	77.83a	4.28a	16.28ab	87.21b	4.25a	16.96a
P_3K_2+W	86.61a	4.89a	18.83a	86.46b	5.08a	18.67a
P_4K_2+W	83.78a	4.22a	16.78ab	86.08b	4.08a	16.54a
P_1K_3+W	86.94a	4.11a	17.72ab	86.58b	4.42a	18.25a
P_2K_3+W	79.78a	3.67a	15.17b	87.12b	3.88a	15.04a
P_3K_3+W	83.83a	4.22a	17.17ab	84.08b	4.08a	16.08a
P_4K_3+W	79.17a	4.28a	17.06ab	87.29b	3.46a	16.25a
P_1K_4+W	79.78a	3.89a	15.17b	87.00b	4.29a	17.21a
P_2K_4+W	78.72a	4.00a	15.72b	85.67b	4.13a	17.42a
P_3K_4+W	84.33a	3.83a	16.28ab	87.75ab	3.46a	13.46a
P_4K_4+W	80.78a	3.56a	15.11b	88.33ab	4.00a	16.00a
P value	.593	.063	.011*	.012*	.565	.595

Means appearing in one column with the letters that are similar do not significantly differ at (p = 0.05)
* Indicates significant difference at p=0.05

Key
P_1K_1-0kg ha^{-1} of P_2O_5& 0 kg ha^{-1} of K_2O
P_2K_1-20kg ha-1 of P_2O_5&0 kg $ha^{-1}$of K_2O
P_3K_1-40kg $ha^{-1}$of P_2O_5& 0 kg $ha^{-1}$of K_2O
P_4K_1-60kg $ha^{-1}$of P_2O_5& 0 kg $ha^{-1}$of K_2O
P_1K_2-0 kg $ha^{-1}$of P_2O_5& 10kg $ha^{-1}$of K_2O
P_2K_2=20kg $ha^{-1}$of P_2O_5& 10kg ha^{-1} of K_2O
P_3K_2-40kg $ha^{-1}$of P_2O_5& 10kg $ha^{-1}$of K_2O
P_4K_2-60kg $ha^{-1}$of P_2O_5& 10kg $ha^{-1}$of K_2O
P_1K_3-0 kg $ha^{-1}$of P_2O_5&20 kg $ha^{-1}$of K_2O
P_2K_3-20kg $ha^{-1}$of P_2O_5& 20kg $ha^{-1}$of K_2O
P_3K_3-40kg $ha^{-1}$of P_2O_5& 20kg $ha^{-1}$of K_2O

P_4K_3-60kg ha^{-1} of P_2O_5& 20 kg $ha^{-1}$of K_2O
P_1K_4- 0kg $ha^{-1}$of P_2O_5& 30kg $ha^{-1}$of K_2O
P_2K_4-20kg $ha^{-1}$of P_2O_5& 30 $kgha^{-1}$ of K_2O
P_3K_4-40kg ha^{-1} of P_2O_5& 30 kg $ha^{-1}$of K_2O
P_4K_4-60kg $ha^{-1}$of P_2O_5& 30kg $ha^{-1}$of K_2O
W-Water level (mean of 3.5mm day^{-1}
&7.0 mm day^{-1}

The highest number of leaves attained in the interaction (fertilizer rate + water) P_3K_2+W, was 18.83 and lowest in P_4K_4+W - 15.11. F-tests results on impact of moisture and fertilizer rates on number of tillers gave p values of p = 0.063 and 0.565 in season one and two respectively, indicating no significant differences in the interaction. A significant difference due to fertilizer levels and due to water rates on the number of leaves was observed as earlier indicated, hence two factors contributed to the interaction effect.

F- Tests results on effect of water levels and effect of fertilizer rates on plant height in second season gave p = 0.004 and 0.091 respectively. This signifies that the significant difference in the interaction is more due to water levels than from fertilizer rates.

Figures 4.10 and 4.11 shows graphical presentation on interaction effects of fertilizer levels, water rates on plant height and number of leaves in first and second season respectively.

Figure 4.10

Interaction Effect between Fertilizer Levels and Watering Regimes on Number of Leaves

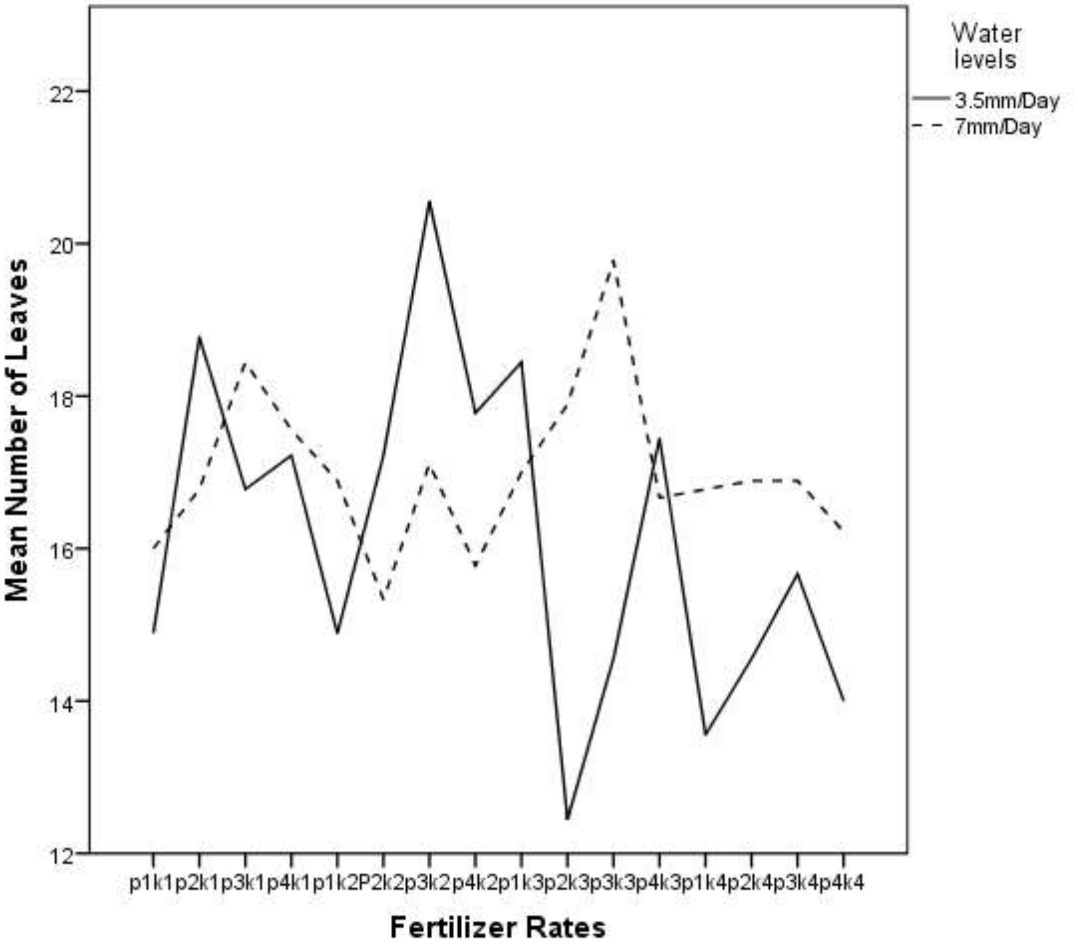
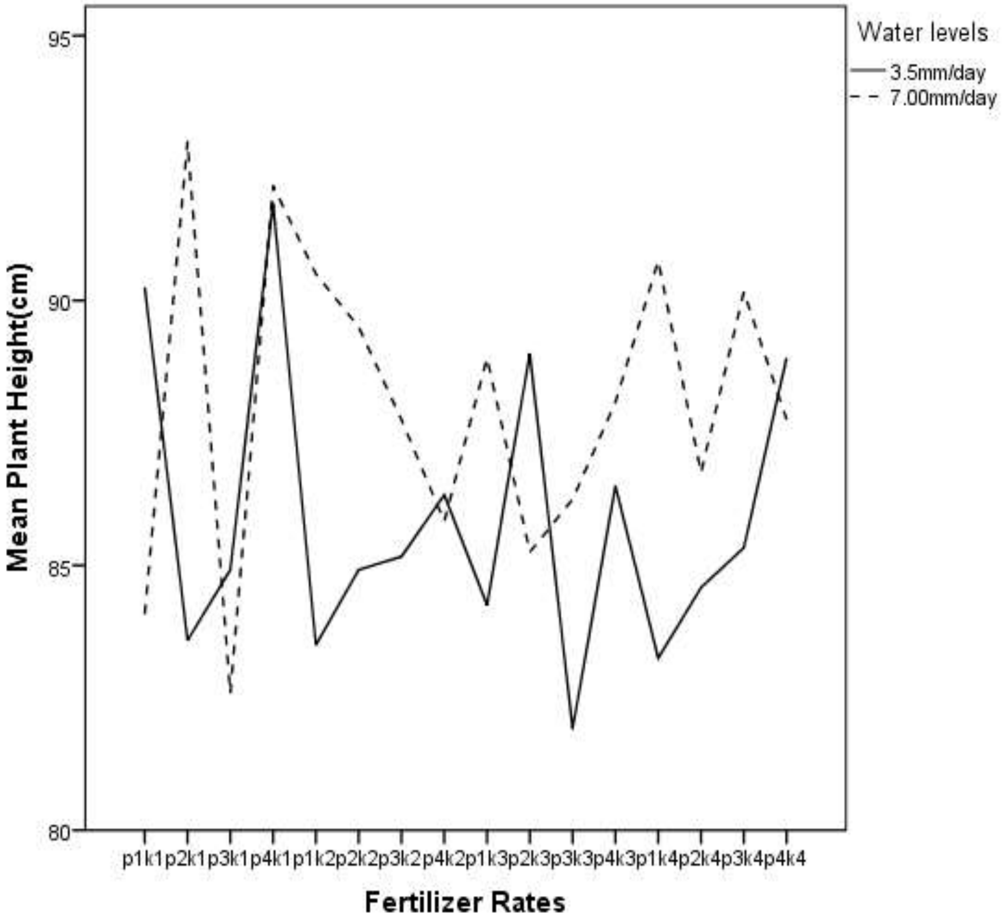


Figure 4.10 shows the interaction of two water level and P –K fertilizer combinations on mean number of leaves in first season of 2017. At lower P & K rates, higher water level resulted in more number of leaves to aid in photosynthesis but at higher fertilizer rates there was a decreased the number of leaves in both water rates. High moisture content aids in absorption of the nutrients supplied by the fertilizer.

Figure 4.11

Interaction Effects of Fertilizer Levels and Watering Regimes on Plant Height



The figure shows the interaction between P-K combinations and watering regimes on mean plant height (cm) during the cropping season-July to November 2017.

When water is limiting, the growth of plant is suppressed as a result of numerous physiological reactions which includes decrease of tissue water potential and water channel activity of membrane aquaporins triggered by lack of moisture at the cellular level (Dichio et al., 2006). Fertilization is expected to alleviate the adverse effects of water insufficiency by enhancing, root growth, foliar nutrient concentration, leaf area plant height, water use efficiency and photosynthesis.

(Alsafar & Al-Hassan 2009).This explains the increase in plant height and number of leaves with increase of P and K, while increase in water also intensifies the absorption of NPK which increases the growth parameters. Too much fertilizer and water, much higher than amounts essential for optimal production, frequently end up in decrease in water and fertilizer use efficiency, higher risk of phosphate and nitrate loss by wind, and thereafter decrease in plant yield and quality (Sylvester-Bradley & Kindred 2009). However, high water levels still gives higher growth and yield parameters than lower water level although in declining rate.

4.4.2 Yield and yield components

F-Test was used at 5% significance level to access interaction effect between fertilizer rates and water level. The results for the season one and two are summarized in Table 4.18 and 4.19, respectively.

Table 4.18

Mean Squares for Interaction between P & K Rates, Water Levels on Yield and Yield Components–Season I

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Water_ L * FR	Panicle Weight (g)	16.106	15	1.074	1.239	.267
	Spikelet Fertility%	6807.323	15	453.822	1.620	.093
	Grain Width (mm)	6.073	15	.405	1.495	.134
	Grain Length (mm)	11.073	15	.738	1.312	.221
	Yield kg/ha	7265021.046	15	484334.736	1.120	.357
	100grain Weight in (g)	.833	15	.056	.550	.901
FR	Panicle Weight (g)	19.659	15	1.311	1.513	.127
	Spikelet Fertility%	3862.073	15	257.472	.919	.548
	Grain Width (mm)	2.990	15	.199	.736	.739
	Grain Length (mm)	9.323	15	.622	1.105	.370
	Yield kg/ha	15064498.650	15	1004299.910	2.323	.010
	100grain Weight in (g)	3.379	15	.225	2.232	.014
Water_ L	Panicle Weight (g)	11.480	1	11.480	13.251	.001*
	Spikelet Fertility%	82.510	1	82.510	.294	.589
	Grain Width (mm)	.094	1	.094	.346	.558
	Grain Length (mm)	.094	1	.094	.167	.684
	Yield kg/ha	47021298.334	1	47021298.334	108.762	.000*
	100grain Weight in (g)	1.030	1	1.030	10.202	.002*
Error	Panicle Weight(g)	55.448	64	.866		
	Spikelet Fertility%	17934.000	64	280.219		
	Grain Width (mm)	17.333	64	.271		
	Grain Length (mm)	36.000	64	.562		
	Yield kg/ha	27669238.482	64	432331.851		
	100grain Weight in (g)	6.460	64	.101		
Corrected Total	Panicle Weight (g)	102.694	95			
	Spikelet Fertility %	28685.906	95			
	Grain Width (mm)	26.490	95			
	Grain Length (mm)	56.490	95			
	Yield kg/ha	97020056.511	95			
	100grain Weight in (g)	11.702	95			

*****Values significant at p=0.05

Table 4.19

ANOVA Summary for Interaction between P & K Rates, Water Levels on Grain Length, Grain Width, 100 Grain Weight and Yield –Season II

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Water_L	Grain Length (mm)	.042	1	.042	.111	.740
	Grain width (mm)	.042	1	.042	.667	.417
	Yield in kg /ha	3700367.246	1	3700367.246	40.521	.000
	100Grain Weight (g)	1.415	1	1.415	23.349	.000
FR	Grain Length (mm)	5.167	15	.344	.919	.548
	Grain width (mm)	.958	15	.064	1.022	.445
	Yield in kg /ha	49837568.653	15	3322504.577	36.383	.000
	100Grain Weight (g)	.709	15	.047	.780	.694
Water_L * FR	Grain Length (mm)	4.625	15	.308	.822	.650
	Grain width (mm)	.625	15	.042	.667	.807
	Yield in kg /ha	17720407.027	15	1181360.468	12.937	.000*
	100Grain Weight (g)	1.227	15	.082	1.350	.200
Error	Grain Length (mm)	24.000	64	.375		
	Grain width (mm)	4.000	64	.062		
	Yield in kg /ha	5844431.491	64	91319.242		
	100Grain Weight (g)	3.880	64	.061		
Corrected Total	Grain Length (mm)	33.833	95			
	Grain width (mm)	5.625	95			
	Yield in kg /ha	77102774.418	95			
	100Grain Weight (g)	7.232	95			

(*)The interaction effect is significant since its p value is less than 0.05

Tables 4.18 and 4.19 shows that only yield kg ha^{-1} had significant affect due to the interaction between fertilizer treatment and water levels with p value of 0.000 in season II. Table 4.20 shows the summary of means of yield after being subjected to DRMT at 5% level of significance to ascertain which means were significantly different.

Table 4.20

Mean Comparison for Interaction Between P & K Levels and Watering Regimes on Yield of NERICA 1

	Season 1	**Season 2**	**Pooled Yield**
Treatment	**Yield kg ha^{-1}**	**Yield kg ha^{-1}**	**Yield kg ha^{-1}**
$P_1K_1+W_1$	2,675.49b	1,729.93f	2,202.71
$P_1K_1+W_2$	4,197.21a	2,096.38e	3,146.79
$P_2K_1+W_1$	3,236.66b	1,917.19e	2,576.93
$P_2K_1+W_2$	4,640.73a	1,773.23f	3,207.00
$P_3K_1+W_1$	3,544.17b	3,570.26b	3,557.21
$P_3K_1+W_2$	5,124.26a	2,583.42c	3,853.84
$P_4K_1+W_1$	2,827.41b	2,114.21d	2,470.81
P_4K1+W_2	4,934.34a	3,229.28c	4,081.81
$P_1K_2+W_1$	3,097.06b	4,065.16a	3,581.11
P_1K_2+W2	4,074.96a	2,888.52b	3,481.74
$P_2K_2+W_1$	3,440.51b	2,596.16c	3,018.34
$P_2K_2+W_2$	4,316.83a	3,439.47b	3,878.15
$P_3K_2+W_1$	3,614.21b	2,621.64b	3,117.92
$P_3K_2+W_2$	4,609.47a	4,218.87a	4,414.17
$P_4K_2+W_1$	2,859.20b	2,263.26e	2,561.23
$P_4K_2+W_2$	4,377.43a	2,265.16d	3,321.30
$P_1K_3+W_1$	3,536.78b	1,291.71f	2,414.24
P_1K3+W_2	3,913.86a	1,235.24g	2,574.55
$P_2K_3+W_1$	3,739.29b	2,747.33c	3,243.31
$P_2K_3+W_2$	4,733.06a	3,913.78ab	4,323.42
$P_3K_3+W_1$	3,798.43b	3,060.28c	3,429.35
$P_3K_3+W_2$	5,598.39a	3,608.90ab	4,603.64
$P_4K_3+W_1$	2,742.02b	2,554.75de	2,648.39
$P_4K_3+W_2$	5,039.18a	1,658.16f	3,348.67
$P_1K_4+W_1$	2,448.51b	1,501.26f	1,974.88
$P_1K_4W_2$	4,306.39a	2,493.83de	3,400.12
$P_2K_4+W_1$	2,732.87b	2,132.04d	2,432.45
$P_2K_4+W_2$	4,495.80a	3,060.07c	3,777.93
$P_3K_4+W_1$	3,267.02b	1,783.85d	2,525.44
$P_3K_4+W_2$	4,448.66a	3,475.35c	3,962.00
$P_4K_4+W_1$	2,614.06b	1,050.74g	1,832.40
$P_4K_4+W_2$	3,478.04a	1,342.66f	2,410.35
P value	0.43	0.00	

No significant difference for means in the same column and with similar letter ($p = 0.05$)

Key
P_1K_1-0kg ha^{-1} of P_2O_5& 0 kg ha^{-1} of K_2O
P_2K_1-20kg ha-1 of P_2O_5&0 kg ha^{-1}of K_2O
P_3K_1-40kg ha^{-1}of P_2O_5& 0 kg ha^{-1}of K_2O
P_4K_1-60kg ha^{-1}of P_2O_5& 0 kg ha^{-1}of K_2O
P_1K_2-0 kg ha^{-1}of P_2O_5& 10kg ha^{-1}of K_2O
P_2K_2=20kg ha^{-1}of P_2O_5& 10kg ha^{-1} of K_2O
P_3K_2-40kg ha^{-1}of P_2O_5& 10kg ha^{-1}of K_2O
P_4K_2-60kg ha^{-1}of P_2O_5& 10kg ha^{-1}of K_2O
P_1K_3-0 kg ha^{-1}of P_2O_5&20 kg ha^{-1}of K_2O
P_2K_3-20kg ha^{-1}of P_2O_5& 20kg ha^{-1}of K_2O
P_3K_3-40kg ha^{-1}of P_2O_5& 20kg ha^{-1}of K_2
P_4K_3-60kg ha^{-1} of P_2O_5& 20 kg ha^{-1}of K_2O
P_1K_4- 0kg ha^{-1}of P_2O_5& 30kg ha^{-1}of K_2O
P_2K_4-20kg ha^{-1}of P_2O_5& 30 kg ha^{-1} of K_2O
P_3K_4-40kg ha^{-1} of P_2O_5& 30 kg ha^{-1}of K_2O
P_4K_4-60kg ha^{-1}of P_2O_5& 30kg ha^{-1}of K_2O
W-Water level (mean of 3.5mm day^{-1} &7.0 mm day^{-1})

Although no significant interaction effect ($p = 0.43$) on yield was observed in season one, there were significance differences in yield due to water levels at all fertilizer rates. The highest yield attained was 5,598.39 kg ha^{-1} in $P_3K_3 + W_2$ (40 kg ha^{-1} P_2O_5 + 20 kg ha^{-1} K_2O + 7.0 mm day^{-1}) followed by 5,124.26 kg ha^{-1} in $P_3K_1 + W_2$ (40 kg ha^{-1} P_2O_5 + 0 kg ha^{-1} K_2O+7.0 mm day^{-1}). The lowest yield in season one due to interaction effect was 2,448.51 kg ha^{-1} in $P_1K_4W_1$ (0 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O-3.5 mm day^{-1}). In season two, yield showed high interaction effect ($p = 0.001$) caused by both fertilizer levels and water rates as indicated in Table 4.21. $P_3K_2 + W_2$ (40 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O-7.0 mm day^{-1}) gave the highest yield of 4,218.87 kg ha^{-1} due to interaction whereas the least grain yield was 1,050.74 kg ha^{-1} from $P_4K_4 + W_1$ (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O+3.5 mm day^{-1}). Yields pooled for the two seasons revealed that $P_3K_3 + W_2$ (40 kg ha^{-1}P_2O_5 + 20 kg ha^{-1} K_2O -7.0 mm day^{-1} had highest yields of 4,603.64 kg ha^{-1} however, $P_4K_4W_1$ attained the least yield of 1,832.40 kg ha^{-1}. In general, fertilizer levels together with watering regime of 7.0 mm day^{-1} produced higher yields compared with those of 3.5 mm day^{-1}water level. The results agrees with those reported from studies by Sokei et al. (2010) which indicated that in high-rainfall environments, application of fertilizer is more effective, while its usage is less useful in drought-prone systems.

As reported by Hua et al. (2008) lower soil water content has an effect on availability of nutrient and are closely related as they have direct impact on water pressure and crop development. Nitrogen and Phosphorus- tissue concentrations of growth-limiting nutrients frequently lessens in the course of water stress, although it is anticipated that those macronutrients concentration increase as influenced by water, directly restricts development more intensely as compared to impact on uptake of nutrient.

Figure 4.12

Interaction between P & K Rates and Water Levels on Yields of NERICA1

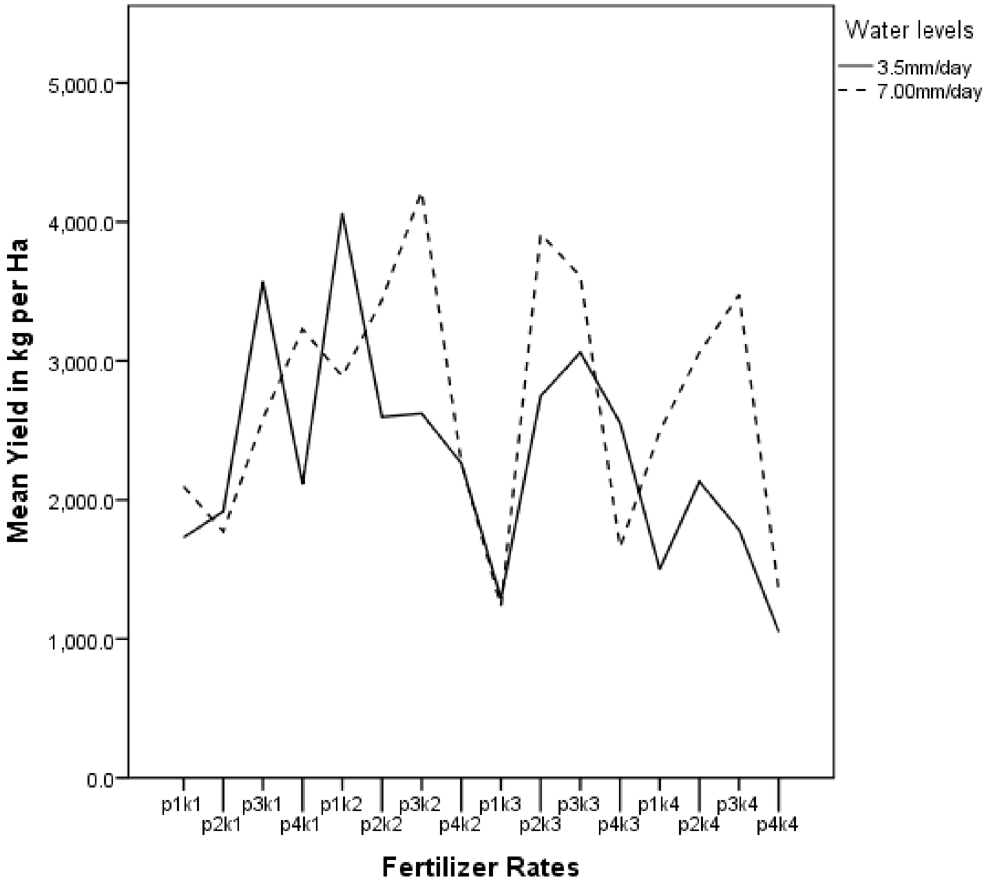


Figure 4.12 shows the interaction effect of P-K combinations rates and water levels on mean yield of NERICA1 (kgha^{-1}) in second cropping season-July-November 2017. Increase of P & K required higher water level of 7.0mmday^{-1} for yield increase and a general increase in yield was witnessed with increase of water level.

Generally, water defines soil nutrients accessibility and transport to the roots (Hu et al. 2009) therefore soil moisture increase will improves plant yield response to fertilization, particularly if a higher levels are applied, as nutrients uptake are strongly influenced by water supply. Alsafar and Al-Hassan (2009) stated that enhanced fertilization can additionally improve water use efficiency which can increase development of plant under water shortage. Dong et al. (2011) reported that overwatering coupled with high level of Nitrogen resulted in luxury consumption reducing water and fertilizer use efficiency, which subsequently led to decline in plant growth and production.

4.4.3 Interaction effect on water use efficiency

To investigate if there were significant effect on interaction between P & K rates and water levels on water use efficiency (WUE), F-tests were done and findings are indicated in Table 4.21.

Table 4.21

Comparison of Means of Interaction Between P & K Rates and Water Levels on WUE

		Season I		Season II		Pooled (S I&S II)
Fertilizer Rates	Water levels	WUE (kgha^{-1}m^{-3}	WUE (kgha^{-1}m^{-3}	WUE (kgha^{-1}m^{-3}	WUE (kgha^{-1}m^{-3}	WUE (kgha^{-1}m^{-3}
P$_1$K$_1$	3.5mmday^{-1}	.642a	.593cde	.415a	.334e	0.529
	7mm day^{-1}	.505b		.252b		0.379
P$_2$K$_1$	3.5mmday^{-1}	.777a	.667bcd	.460a	.337e	0.619
	7mmday^{-1}	.557b		.213b		0.385
P$_3$K$_1$	3.5mmday^{-1}	.851a	.733ab	.857a	.584b	0.854
	7mmday^{-1}	.615b		.310b		0.463
P$_4$K$_1$	3.5mmday^{-1}	.679a	.636bcde	.508a	.448d	0.594
	7mmday^{-1}	.592b		.388b		0.49
P$_1$K$_2$	3.5mmday^{-1}	.744a	.616bcde	.976a	.661a	0.86
	7mmday^{-1}	.489b		.347b		0.418
P$_2$K$_2$	3.5mmday^{-1}	.826a	.672bcd	.623a	.518c	0.725
	7mmday^{-1}	.518b		.413b		0.466
P$_3$K$_2$	3.5mmday^{-1}	.868a	.711abc	.629a	.568bc	0.749
	7mmday^{-1}	.553b		.506b		0.530
P$_4$K$_2$	3.5mmday^{-1}	.686a	.606cde	.543a	.408d	0.615
	7mmday^{-1}	.526b		.272b		0.400
P$_1$K$_3$	3.5mmday^{-1}	.849a	.660bcd	.310a	.229f	0.580
	7mmday^{-1}	.470b		.148b		0.309
P$_2$K$_3$	3.5mmday^{-1}	.898a	.733ab	.660a	.565bc	0.779
	7mmday-^{1}	.568b		.470b		0.519
P$_3$K$_3$	3.5mmday^{-1}	.912a	.792a	.735a	.584b	0.824
	7mmday^{-1}	.672b		.433b		0.553
P$_4$K$_3$	3.5mmday^{-1}	.658a	.624bcde	.613a	.406d	0.636
	7mmday^{-1}	.605b		.199b		0.402
P$_1$K$_4$	3.5mmday-^{1}	.588a	.552de	.360a	.330e	0.474
	7mmday^{-1}	.517b		.299b		0.408
P$_2$K$_4$	3.5mmday^{-1}	.656a	.598cde	.512a	.440d	0.584
	7mmday^{-1}	.540b		.367b		0.454
P$_3$K$_4$	3.5mmday^{-1}	.784a	.659bcd	.428a	.423d	0.606
	7mmday^{-1}	.534b		.417b		0.476
P$_4$K$_4$	3.5mmday^{-1}	.628a	.523e	.252a	.207f	0.44
	7mmday^{-1}	.418b		.161b		0.290
	P value	0.000*	.042*	0.000*	0.000*	

Means in the same column and with similar letter do not differ significantly at p = 0.05

Table 4.21 shows significant interaction effect by P, K rates and water levels on WUE in both season one and two ($p = 0.042$ and 0.000) respectively. The interaction difference was due to both water levels and fertilizer rates in both seasons with water level one (3.5 mm day^{-1}) giving the highest values of WUE. P_3K_3 W_1 (40 kg ha^{-1} P_2O_5+20 kg ha^{-1} K_2O+3.5 mm day^{-1}) produced the highest value of WUE of 0.912 kg ha^{-1}m^{-3} in the interaction in season one and $P_1K_2W_1$ (0 kg ha^{-1} P_2O_5+10 kg ha^{-1} K_2O+3.5 mm day^{-1}) in season two. The lowest WUE value was attained in $P_1K_3W_2$ (0 kg ha^{-1}P_2O_5 + 20 kg ha^{-1} K_2O+7.0 mm day^{-1}) interaction with 0.148 kg ha^{-1}m^{-3} in season two and $P_4K_4W_2$ (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O + 7.0 mm day^{-1}) with 0.418 kg ha^{-1}m^{-3} in season one. Data pooled for both seasons revealed that the greatest WUE of 0.86 kg ha^{-1}m^{-3} was achieved by water- fertilizer interaction of $P_1K_2W_1$ (0 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O) while the lowest (.2985 kg ha^{-1} m^{-3}) was attained by $P_4K_4W_2$ (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O + 7.0 mm day^{-1}). When both water and fertilizers were at the highest ($P_4K_4W_2$), WUE seemed to decline. The results agrees with those observed by Dong, et al. (2011) on Chinese White Polar (*populous tomentosa* carr.). Excessive watering together with superfluous fertilization, leads to luxury use and decrease in both fertilizer and water use efficiency that decreases growth and production of the plant. Sylvester-Bradley and Kindred (2009) similarly observed that significant high amounts of fertilizer and water greater than ratios needed for optimal production frequently ends in lowering fertilizer and water use efficiency. WUE responds greatly to irrigation as compared to fertilization. Xiukang and Yingying, (2016) reported similar findings though studies done on Tomatoes.

Figure 4.13

Interaction Between P & K Rates and Water Levels on WUE

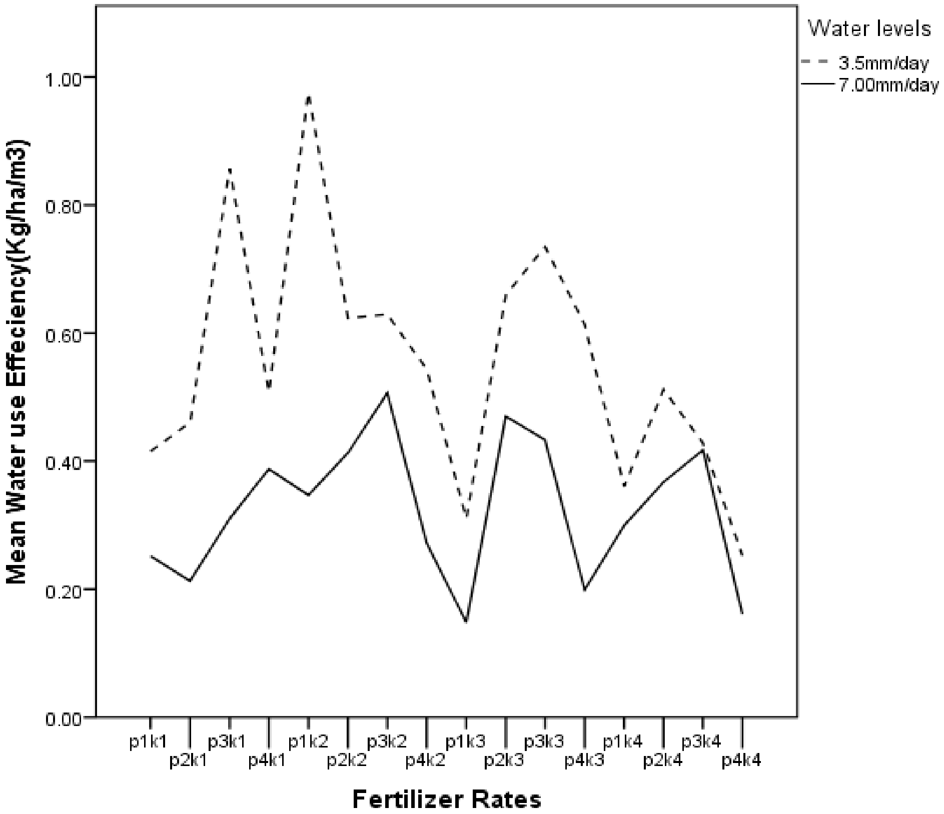


Figure 4.13 shows the interaction between P-K fertilizer rates and two watering levels on WUE during the first cropping season-February –June 2017.

3.5mmday^{-1} water level shows higher WUE as compared to that of 7.0 mmday^{-1}and increases with increase of P up to 20 kgha^{-1} & K up to 20 kgha^{-1}rates. At higher rates of P & K the WUE declines.

4.5 Nutrients Uptake in the Straw and Grain

Nutrient uptake as affected as water levels and fertilizer rates was discussed in this section.

4.5.1 Influence of water levels on nutrients uptake

Nitrogen, Phosphorous and Potassium uptake in straws for selected plants stands were analyzed and summarized findings are outlined in Table 4.22 and Figure 4.14. The selection was based on amount of least to highest P and K added during the growing period.

Table 4.22

Influence of Water Level on Nutrient (NPK) Uptake in Straw

Water Level	%Nitrogen	%Potassium	% Phosphorus
3.5 mm day^{-1}	.988a	.886a	.320b
7.00 mm day^{-1}	1.005a	.812a	.530a
P value	.896	.726	.001*

Means appearing in one column with letters that are similar are not significantly different at ($p = 0.05$)

Table 4.22 indicates that effect of water on uptake of Phosphorus in the straw was significant at p value of 0.001 while water level did not affect uptake of Nitrogen and Potassium significantly. 7.0 mm day^{-1} water level increased Phosphorus percentage in the straw significantly and also Nitrogen though not significant. The results agrees with studies by Bhattacherjee et al. (2014) who noted that in three rice cultivers-NERICA-10, NERICA-1 and BRRI dhan48 increase of moisture regime increased nutrient uptake. Flooding the soil raises the quantity of Phosphorus in solution, hence increasing the quantity of Phosphorus accessible by crop for absorption. It is when adequate soil solution permits mass movement and diffusion of nutrients to roots can soil - supplied nutrients be taken up by plants.

Figure 4.14

Nutrient Uptake as Affected by Water Levels

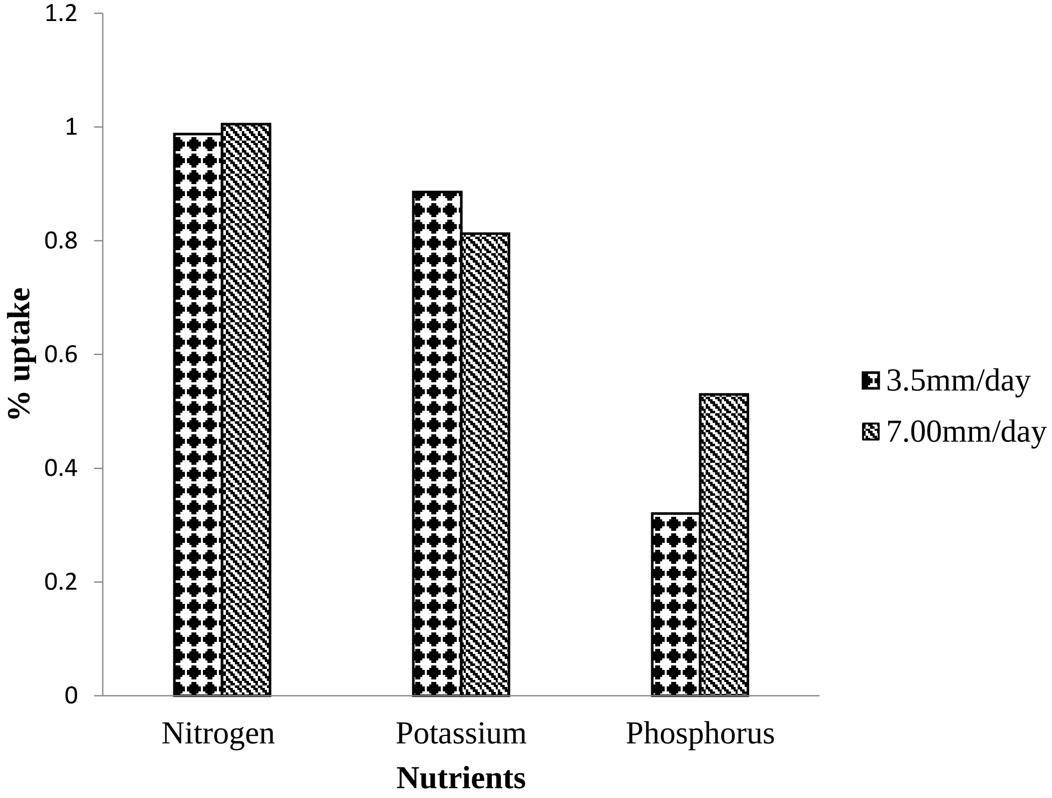


Figure 4.14 shows the % uptake of N, P & K as affected by the two water regimes.

It reveals that the amount of Potassium in the straw is relatively higher than that of Phosphorus. This is consistent with Liza et al. (2014) who observed that K uptake in grain was far less than that taken by straw.

4.5.2 Effect of fertilizer rates on NPK uptake in the straw

The selected plant stands from each NPK uptake in the straw was analyzed for the following fertilizer rates; P_1K_1, P_2K_2, P_3K_3 and P_4K_4. The summary of NPK uptake in the straw as influenced by fertilizer rates is displayed Table 4.23.

Table 4.23

Effect of Fertilizer Rates on NPK Uptake

Fertilizer Rates	**% Nitrogen**	**% Potassium**	**% Phosphorus**
P_1K_1-0 kg ha^{-1} P_2O_5 +0 kg ha^{-1} K_2O	.86a	.88b	.43a
P_2K_2-20 kg ha^{-1} P_2O_5+10 kg ha^{-1} K_2O	.86a	1.61a	.43a
P_3K_3-40 kg ha^{-1} P_2O_5+ 20 kg ha^{-1} K_2O	1.04a	.45b	.48a
P_4K_4- 60 kg ha^{-1} P_2O_5 +30 kg ha^{-1} K_2O	1.22a	.46b	.36a
P value	**.209**	**.003***	**.406**

*The difference is significant as the p value is less than 0.05
Means appearing in one column with the letters that are similar are not significantly different at $p = 0.05$

Table 4.23 shows a general rise in Nitrogen, Phosphorus and Potassium in the straw with an additional fertilizer rates but % uptake decreased for P & K at higher fertilizer rates. This conforms to study findings of Singh and Namdeo, (2004) who noted an increase nutrient absorption by rice with additional fertilizer amounts. Similar results were stated by Kabir et al. (2011) who observed that lower uptake of P & K resulted in lower amounts of fertilizer applied. Plant absorbs the nutrients proportionally to the pool of accessible nutrients increase in soil solution. This might explain increase absorption of N, P and K with additional fertilizer rates. However, Singh, Bhardwaj and Sharma (2005) indicated that increase in N dose by 25% increased the K and P uptake noticeably. This explains the decrease in uptake of P & K at higher fertilizer rates at P_4K_4 (60 kg ha^{-1} P_2O_5+ 30 kg ha^{-1} K_2O) because the Nitrogen rates in all stands remained constant at 60 kg ha^{-1}. Phosphorus levels in the soils under study are characterized as high and Potassium levels as moderate. Potassium uptake was affected significantly (p value = 0.003) by fertilizer rates with highest value of 1.6% attained in fertilizer rate of P_2K_2 (20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O) Figure 4.15. Uptake of Phosphorus in the straw was not affected significantly by increase of P and K and least amount was observed in P_4K_4 (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O).

Figure 4.15

Effect of Fertilizer Rates on Nutrients Uptake

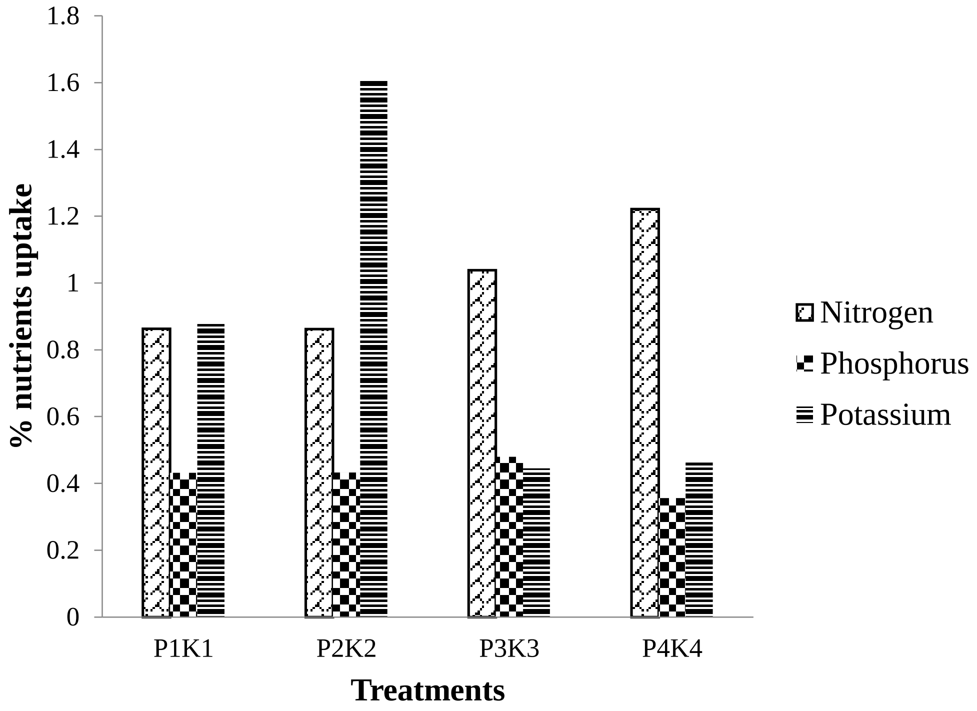


Figure 4.15 shows the % uptake of N, P & K as affected by the fertilizer rates.

Nitrogen % in the straw increased with K and P additional fertilizer amounts though not significantly. According to Dobermann et al. (2004) estimating NPK input-output balance is given by;

$B = M + A + W + N2 – C – PS – G$

Entire constituents taken in kilogram elemental nutrient per hectare

B= Nutrient budget for a rice field

M = Nutrient sources from inorganic and organic applied,

A = Deposition from the atmospheric which included dust and precipitation

W = Sediments, flood water, and irrigation

N2 = Biological Nitrogen Fixation (Only Nitrogen),

C = Net removal by crop through straw and grain (entire intake – nutrients in plant residues reverted to the soil),

PS = percolation and seepage losses, and G = Losses via gases which include; denitrification, NH_3 and volatilization. The assumptions made in this study include;

i. M= N, P and K inputs by fertilization and manure and inputs from the soil (soil analysis results)

ii. A= atmospheric deposition (rainfall and dust) was estimated to be 0 since it was under greenhouse set up

iii. W = Input of N, K and P by irrigation water

iv. N_2 - estimated as 0 since rice is non leguminous crop

v. C = Net amount of NPK removed with grain and straw

vi. PS = percolation and seepage losses was approximated to be 0 since plants were potted.

vii. G = gaseous losses (denitrification, NH_3 volatilization) – was minimal for green house environment and controlled watering.

With the above assumptions nutrients uptake effect was mainly due to fertilization

4.5.3 Interaction effect of P & K rates, water levels on NPK uptake in the straw

To assess the interaction effect of water levels and fertilizer rates, F-test was done and ANOVA is outlined in Table 4.24.

Table 4.24

Mean Squares of Interaction Effect on NPK Uptake in the Straw

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Block	% Nitrogen	.267	2	.134	1.275	.310
	% Potassium	.115	2	.057	.345	.714
	% Phosphorus	.013	2	.006	.490	.622
Water_L	% Nitrogen	.002	1	.002	.018	.897
	% potassium	.032	1	.032	.195	.666
	% Phosphorus	.264	1	.264	20.220	.001
FR	% Nitrogen	.530	3	.177	1.685	.216
	% Potassium	5.358	3	1.786	10.716	.001
	% Phosphorus	.047	3	.016	1.208	.343
Water_L * FR	% Nitrogen	.319	3	.106	1.014	.416
	% Potassium	2.024	3	.675	4.047	.029*
	% Phosphorus	.079	3	.026	2.008	.159
Error	% Nitrogen	1.469	14	.105		
	% Potassium	2.333	14	.167		
	% Phosphorus	.183	14	.013		
Corrected Total	% Nitrogen	2.587	23			
	% Potassium	9.863	23			
	% Phosphorus	.585	23			

*The difference is significant as p value is less than 0.05

Table 4.24 indicates that only Potassium had significant interaction effect due to fertilizer rates and water levels. Table 4.25 summarized the means comparison of NPK uptake in the straw due to interaction.

Table 4.25

Mean Comparison for the Interactions Between P & K Rates, Water Levels on NPK Uptake in the Straw

Fertilizer Rates +Water levels	**% Nitrogen**	**% Potassium**	**% Phosphorus**
P1K1+w1	.68a	.79b	.28a
P1K1+w2	1.05a	.97b	.58a
P2K2+w1	.95a	1.26a	.28a
P2K2+w2	.77a	1.96a	.59a
P3K3+w1	1.14a	.88b	.47a
P3K3+w2	.94a	.01b	.49a
P4K4+w1	1.18a	.62b	.25a
P4K4+w2	1.26a	.31b	.46a
P value	.416	.029*	.159

*The difference is significant as p value is less than 0.05
Means appearing in one column with the letters that are similar do not significantly differ ($p = 0.05$)

Key
P_1K_1-0 kg ha^{-1} P_2O_5 +0 kg ha^{-1}K_2O
P_2K_2-20 kg ha^{-1} P_2O_5+10 kg ha^{-1} K_2O
P_3K_3-40 kg ha^{-1} P_2O_5+ 20 kg ha^{-1} K_2O
P_4K_4- 60 kg ha^{-1} P_2O_5 +30 kg ha^{-1} K_2O
W_1-3.5mm day^{-1}
W_2-7.00 mm day^{-1}

Table 4.25 also confirms that significant difference in Potassium uptake in the straw caused by the interaction effect of fertilizer rates and water levels was noted. The highest % Potassium uptake of 1.96 was attained with $P_2K_2W_2$ (20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O-7.0 mm day^{-1}) followed by 1.26 from $P_2K_2W_1$ (20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O-3.5 mm day^{-1}. The two values were not significantly different meaning the difference in the interaction is not caused by water levels but due to fertilizer rates. According to Dobermann et al. (1996a), at maturity about eighty to ninety percent of the above-ground Potassium content in rice is reserved in stems and leaves. This explains the high values of K in the straw. As mentioned earlier, low uptake of P & K in the straw with higher fertilizer rates consisting of Phosphorus and Potassium can be explained by Nitrogen level which remained constant (60 kg ha^{-1}) in all the stands. The graphical presentation of interaction effect on Potassium uptake is shown by Figure 4.16.

Figure 4.16

Interaction Effect between P & K Rates and Water Levels on Potassium Uptake in the Straw

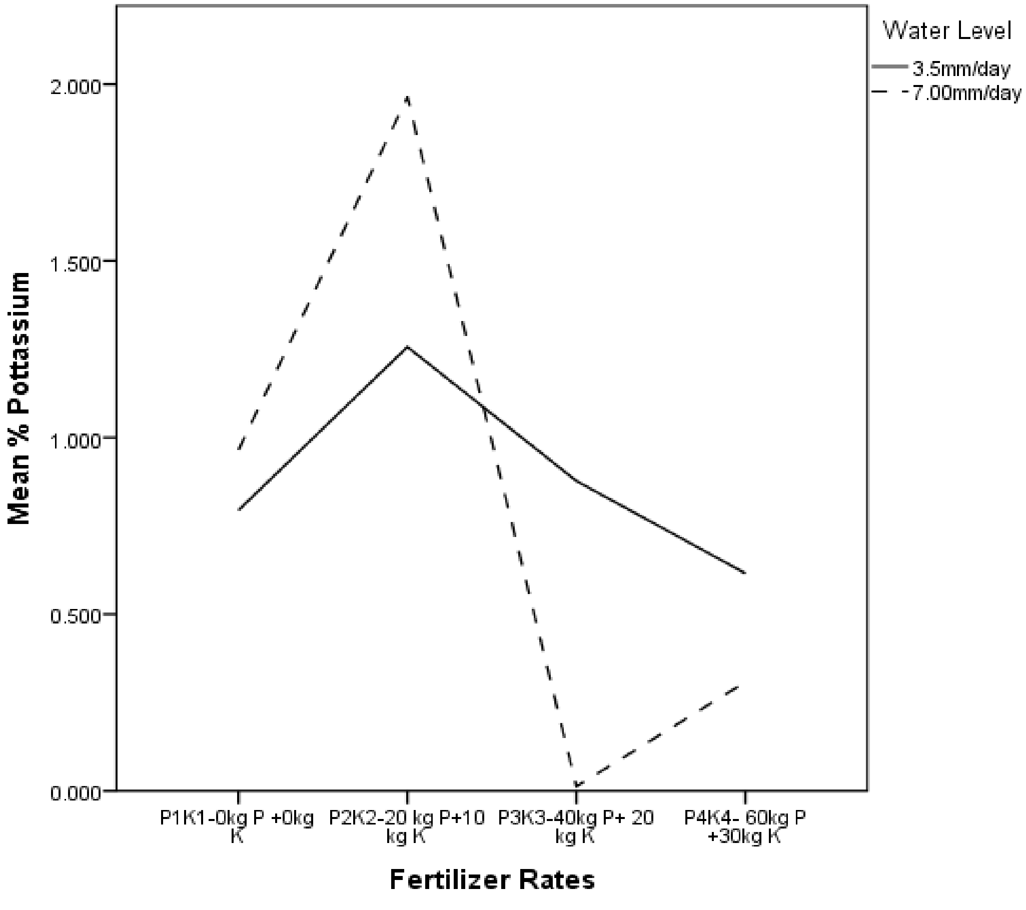


Figure 4.16 shows the percentage Potassium uptake in the straw as affected by different P-K rates. Highest K uptake was achieved at fertilizer rate of P_2K_2 for both water levels although 7.0 $mmday^{-1}$ water level had resulted to more K uptake in the straw.

Rice plants absorb K in larger amounts even than Nitrogen for proper function of various activities. According to Sarkar et al. (2017), modern high-yielding rice cultivars remove much higher amount of K than Phosphorous (P) or even Nitrogen (N). Rice crops remove about 103 kg of Potassium for a yield level of 7.0 t ha^{-1} (FRG, 2012). High water levels increase the absorption of K but declines at extremely higher amounts of K.

4.5.4 Effect of water levels and fertilizer rates on crude protein contents in the grains

Crude protein present in grains of selected stands for two seasons were tested for crude protein content and findings in Table 4.26.

Table 4.26

Influence of Water Levels and Fertilizer Rates on Crude Protein in Grains for the Two Seasons

Water Level	**Mean**
3.5 mm-day^{-1}	12.90a
7.0 mm-day^{-1}	11.35a
P value	**.176**
Fertilizer Rates	
	Mean
P_1K_1-0 kgha^{-1} P + 0 kg ha^{-1} K	11.32a
P_2K_2-20 kg ha^{-1} P +10 kg ha^{-1} K	12.70a
P_3K_3-40 kg ha^{-1} P + 20kg ha^{-1} K	12.83a
P_4K_4-60 kg ha^{-1} P +30 kg ha^{-1} K	11.65a
P value	**.691**

No significance difference in crude protein in grains was observed due to either water levels or fertilizer rates in the two seasons. The means for crude protein in the two seasons were also not significantly different. 3.5 mm day^{-1} water level gave higher crude protein percentage of 12.90 than 7.0 mm day^{-1} with 11.35, though the difference was not significant.

Additional of P & K values in the fertilizer rates increased the crude protein content up to 40 kg ha^{-1} P_2O_5 and 20 kg ha^{-1} K_2O. Dakshina Murthy et al. (2014) reported almost similar results where they recorded that protein content in grain gradually improved with the incremental quantities of N & P but the rise was quantifiable up to 50% extra amount of N and up to 25% increment of P only. The increase can be explained by greater accessibility of Nitrogen & Phosphorus in plant and in grain for greater absorption of Nitrogen and synthesis of protein.

P_4K_4 (60 kg ha^{-1} P_2O_5 + 30 kg ha^{-1} K_2O) fertilizer rate gave the least protein content in the grains and this was attributed again by Nitrogen level in the fertilizer application that remained constant.

4.5.5 Interaction effect between fertilizer rates and water levels and on crude protein content in grains.

The ANOVA summary in Table 4.27 and means comparison Table 4.28 shows interaction between water levels and fertilizer rates on percentage crude protein in grains of NERICA 1 was not significantly different.

Table 4.27

ANOVA Summary of Interaction Between Water Level and Fertilizer Rates on Crude Protein in Grain

Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Water_L	9.626	1	9.626	1.860	.210
FR	6.787	3	2.262	.437	.732
Water_L * FR	8.273	3	2.758	.533	.672
Error	41.389	8	5.174		
Corrected Total	66.074	15			

Table 4.28

Means Comparison on Interaction Between of Water Levels and Fertilizer Rates on Crude Protein Content in Grains

Fertilizer Rates+ Water Level	Mean
P_1K_1+W_1	12.57a
P_1K_1+W_2	10.08a
P_2K_2+W_1	12.45a
P_2K_2+W_2	12.95a
P_3K_3+W_1	14.45a
P_3K_3+W_2	11.21a
P_4K_4+W_1	12.14a
P_4K_4+W_2	11.16a
P value	.681

Means appearing in one column with the letters that are similar do not significantly differ ($p > 0.05$)

Key

P_1K_1-0 kg ha^{-1} P_2O_5 + 0 kg ha^{-1} K_2O
P_2K_2-20 kg ha^{-1} P_2O_5+ 10 kg ha^{-1} K_2O
P_3K_3-40 kg ha^{-1} P_2O_5+ 20 kg ha^{-1} K_2O
P_4K_4-60 kg ha^{-1} P_2O_5+30 kg ha^{-1}K^2O
W_1-3.5mm day^{-1}
W_2--7.0mm day^{-1}

The highest percentage in crude protein of 14.45 was from $P_3K_3W_1$ (40 kg ha^{-1} P_2O_5 + 20 kg ha^{-1} K_2O and 3.5 mm day^{-1}) while the least crude protein % of 10.08 was from P_1K_1 + W_2 (0 kg ha^{-1} P_2O_5 + 0 kg ha^{-1} K_2O and 7.0 mm day-^{1}). Higher fertilizer levels with Phosphorus and Potassium above the available soil nutrient values (which was adequate) increased grain quality by improving the grain protein.

4.6 Post-Harvest Soil Status

4.6.1 Effect of water levels on soil properties

Post-harvest soil analysis for selected treatment in the first season was done and soil properties that included, soil pH, % Nitrogen, Phosphorus (ppm) and Potassium (me $100g^{-1}$) and EC (µs cm^{-1}) recorded. The selected treatments were chosen based on least to highest rates of both Phosphorus and Potassium. Table 4.29 summaries the post-harvest soil status as affected by water levels.

Table 4.29

Means Comparison of Soil Properties as Affected by Water Levels

Water level	PH	% Nitrogen	Phosphorus (ppm)	Potassium (me/100g)	EC (µs/cm)
3.5 mm day^{-1}	6.15a	.15a	159.44a	2.67a	150.78a
7.0 mm day^{-1}	6.08a	.14a	142.22a	1.99b	101.56b
P value	.505	.992	.189	.019*	.029*

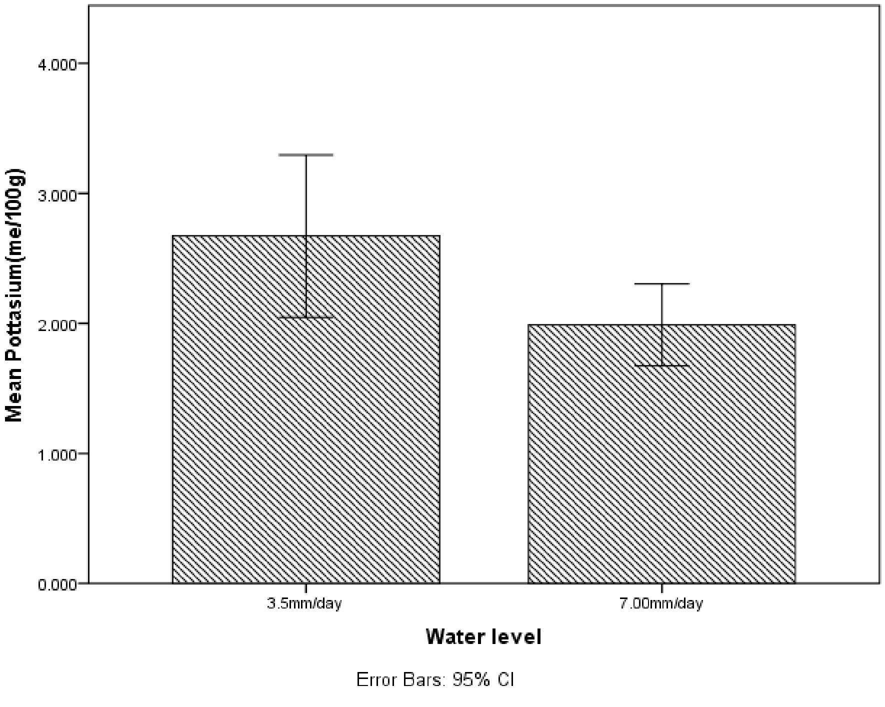
Means appearing in one column and with letters that are similar do not significantly differ at ($p = 0.05$)
* The difference is significant as the p value is less than 0.05

Table 4.29 shows Potassium (me/100g) and EC (us/cm) were significantly influenced by watering regimes. Soils subjected to water values of 3.5 mm day^{-1} had higher levels Nitrogen%, Phosphorus, Potassium and electrical conductivity.

Nutrients supplied in the soil are absorbed by crops only after adequate soil solution permits bulk movement accompanied by nutrients diffusion to the roots. This means that, with 7.0 mm day^{-1} water level, more of nutrients were absorbed by the plant decreasing the values of NPK in the soil. The results agrees with findings by Subhani et al. (2012) who demonstrated that sustaining suitable soil moisture content throughout the growing season is crucial to nutrient use efficiency. Graphical presentation of effect of water on Potassium (me100g-1) and EC (µs cm-1) is displayed in Figure 4.17 and 4.18, respectively.

Figure 4.17

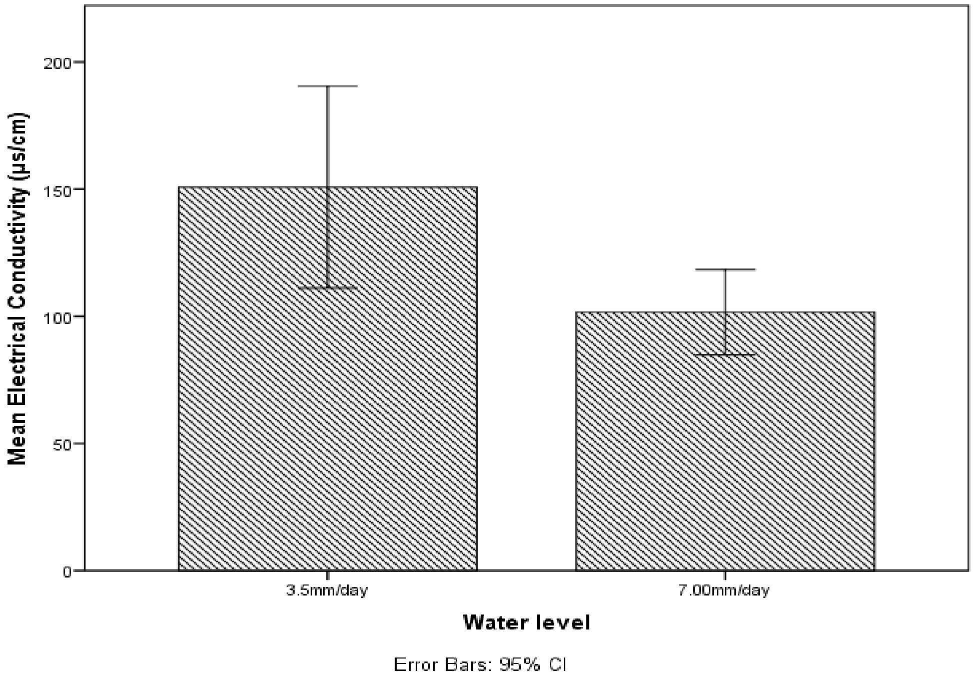
Effect of Irrigation Rates on Potassium after Harvest



Note. The bar graph shows the effect of water levels on potassium (me/100g) in the soil after post-harvest analysis

Figure 4.18

Effect of Water Levels on Electrical Conductivity



Note**.** The figure represents the effect of watering regimes on electrical conductivity of the soil after harvest

4.6.2 Effect of fertilizer levels on soil properties

The summary of soil properties as affected by fertilizer rates is presented in table 4.30.

Table 4.30

Soil Properties as Affected by Fertilizer Rates

Fertilizer Combination	pH	% Nitrogen	Phosphorus (ppm)	Potassium (meq $100g^{-1}$)	EC (µs cm^{-1})
P2K2-20kg P + 10kg K	6.05a	.13a	138.33a	2.52a	145.83a
P3K3-40kg P+ 20 kg k	6.02a	.13a	151.67a	1.81b	121.33a
P4K4-60kg P+ 30kg K	6.28a	.17a	162.50a	2.66a	111.33a
P value	0.111	0.209	0.309	0.038*	0.376

Means appearing in one column and with letters that are similar do not significantly differ at (p = 0.05)
* The difference is significant as the p value is less than 0.05

A general increase in pH, percentage levels of Potassium, Nitrogen and Phosphorus, a decrease on electrical conductivity on increase of fertilizer rates was noted. The findings are in line with those by NaingOo, et al. (2010) who noted an increase in extractable P and exchangeable K in post-harvest soil analysis for soils with inorganic fertilizers as compared with those with none. Only Potassium (meq $100g^{-1}$) showed a significant difference due to fertilizer rates. The results on Potassium agrees with studies by Dakshina Murthy et al. (2014) who reported buildup of available K_2O in soil by increasing K dose by 75% over the recommended rates. There was a general decrease in electrical conductivity with increase in fertilizer rates.

4.6.3 Effect of the interaction amongst water levels and fertilizer rates on soil properties.

Table 4.31 summaries the interaction effect portrayed by water levels and fertilizer rates on soil properties after post-harvest analysis.

Table 4.31

Interaction Between Water Levels and Fertilizer Rates on Post-Harvest Soil Properties

Fertilizer Combination	Water level	pH	% Nitrogen	Phosphorus (ppm)	Potassium (meq/100g)	EC (µs/cm)
P_2K_2-20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O	3.5mm day^{-1}	6.10a	.13a	155.00a	3.07a	183.67a
	7.0 mm day^{-1}	5.99a	.13a	121.67a	1.98a	108.00a
P_3K_3-40 kg ha^{-1} P_2O_5+ 20 kg $ha^{-1}K^2O$	3.5 mm day^{-1}	5.92a	.14a	153.33a	1.75a	162.67a
	7.0 mm day^{-1}	6.12a	.12a	150.00a	1.87a	80.00a
P_4K_4-60 kg ha^{-1} P_2O_5+ 30 kg ha^{-1} K_2O	3.5 mm day^{-1}	6.43a	.17a	170.00a	3.19a	106.00a
	7.0 mm day^{-1}	6.13a	.18a	155.00a	2.12a	116.67a
P Value		.139	.801	.644	.069	.091

Means appearing in one column with identical letters do not significantly differ at (p = 0.05

Table 4.31 shows that no significance difference due to interaction between water levels and fertilizer rates on soil properties. However, a general increase in Nitrogen percentage, Phosphorus and Potassium levels in the soil on increase of fertilizer rates exists with higher values detected in 3.5 mm day^{-1} water level. Higher water levels enhances nutrients uptake and reduces the residual nutrients in the soil (Drechsel et al., 2015).

4.7 Economics of Fertilizer use

The soil results for the site indicated high Phosphorus and moderate Potassium levels. To evaluate the partial economic benefit of additional values of Phosphorus and Potassium, additional costs of fertilizer used in each treatment was computed against the yield and gross return in ksh. Partial MBCR (Marginal Benefit Cost Ratio) was computed;

MBCR (over control (no fertilizer) =Added Benefit (over control-No fertilizer)/Added cost (over control-No fertilizer). Only the cost of additional fertilizer was taken into account in the calculation and this explains the high partial MBCR in this results.

Gross return=Yield x Price ksh.

TFC= Total fertilizer cost (ksh per hectare)

Gross Margin= Gross return –Total Variable costs

The computed figures are tabulated in Table 4.32.

Table 4.32

Economic Analysis of Fertilizer use Under NERICA 1 (Average for Two Seasons)

Treatment	Pooled Yield (kg ha^{-1})	Gross return (ksh ha^{-1})	TFC (ksh ha^{-1})	Gross Margin (ksh ha^{-1})	Marginal Gross margin (ksh ha^{-1})	MBCR
P_1K_1	2856.2	399874.4	0	399874.4		
P_2K_1	2809.9	393390.5	2486	390904.5	-8969.9	-3.61
P_3K_1	3442.3	481923.8	4978	476945.8	77071.4	15.48
P_4K_1	3430.8	480311.3	7465	472846.3	72971.9	9.78
P_1K_2	3745.4	524357.1	1080	523277.1	123402.7	114.26
P_2K_2	3725	521504.1	3566	517938.1	118063.7	33.11
P_3K_2	3697.2	517607	6058	511549	111674.6	18.43
P_4K_2	2870.4	401852.9	8545	393307.9	-6566.5	-0.77
P_1K_3	2570.2	359832.8	2160	357672.8	-42201.6	-19.54
P_2K_3	3466.5	485305.7	4646	480659.7	80785.3	17.39
P_3K_3	3460.9	484519.6	7138	477381.6	77507.2	10.86
P_4K_3	2908.5	407196.8	9625	397571.8	-2302.6	-0.24
P_1K_4	2822.9	395212.4	3240	391972.4	-7902	-2.44
P_2K_4	3205	448700.8	5726	442974.8	43100.4	7.53
P_3K_4	3237.2	453207.9	8218	444989.9	45115.5	5.49
P_4K_4	2507.7	351077.4	10705	340372.4	-59502	-5.56

Key

P_1K_1-0 Kg ha^{-1} of P_2O_5 & 0 kg ha^{-1} of K_2O
P_2K_1-20 kg ha-1 of P_2O_5&0 kg ha^{-1}of K_2O
P_3K_1-40 kg ha^{-1}of P_2O_5& 0 kg ha^{-1}of K_2O
P_4K_1-60 kg ha^{-1}of P_2O_5& 0 kg ha^{-1}of K_2O
P_1K_2-0 kg ha^{-1}of P_2O_5& 10 kg ha^{-1}of K_2O
P_2K_2-20 kg ha^{-1}of P_2O_5& 10 kg ha^{-1} of K_2O
P_3K_2-40 kg ha^{-1}of P_2O_5& 10 kg ha^{-1}of K_2O
P_4K_2-60 kg ha^{-1}of P_2O_5& 10 kg ha^{-1}of K_2O
P_1K_3-0 kg ha^{-1}of P_2O_5&20 kg ha^{-1}of K_2O
P_2K_3-20 kg ha^{-1}of P_2O_5& 20 kg ha^{-1}of K_2O
P_3K_3-40 kg ha^{-1}of P_2O_5& 20 kg ha^{-1}of K_2
P_4K_3-60 kg ha^{-1} of P_2O_5& 20 kg ha^{-1}of K_2O
P_1K_4- 0 kg ha^{-1}of P_2O_5& 30kg ha^{-1}of K_2O
P_2K_4-20 kg ha^{-1}of P_2O_5& 30 kg ha^{-1} of K_2O
P_3K_4-40 kg ha^{-1} of P_2O_5& 30 kg ha^{-1}of K_2O
P_4K_4-60 kg ha^{-1}of P_2O_5& 30 kg ha^{-1}of K_2O
TFC-Total Fertilizer Costs
MBCR-Marginal benefit cost Ratio

Table 4.32 shows that the highest NERICA 1 yield of 3745.4 kg ha^{-1} worth gross return of Ksh 524,357.1 was achieved with treatment P_1K_2 (0 kg P + 10 kg K). The highest MBCR of 114.26 was also from P_1K_2 (0 kg P + 10 kg K) treatment while the least MBCR of -19.54 was recorded from P_1K_3 (0 kg P +20 kg K) treatment followed by -5.54 from P_4K_4

(60 kg P+30 kg K) treatment. A reverse association between higher amount of Phosphorus fertilizer applied and marginal benefit cost ratio was observed when

Potassium levels remain constant at 10 kg ha^{-1}. Nearly similar observations were observed by Rehman et al. (2011). Studies by Sri Adiningsih et al. (1991) in Java, Indonesia, found rice yields in 85% of the entire lowland rice region with soil Phosphorus levels that are high, no longer reacted to P application. Phosphorus levels of 60 kg ha^{-1} (P_4) plus Potassium levels higher than what is supplied by the soil recorded negative MBCR.

4.7.1 Economics of fertilizer use in relation to water regimes.

To evaluate the partial MBCR in use of additional Phosphorus and Potassium over that available in the soils in relation to two water regimes, the partial gross returns was calculated using the yields from the two water regimes. The summary is tabulated in Table 4.33.

Table 4.33

Economic Analysis of Fertilizer Use in Relation to Water Regimes

	Water level 1(3.5 mmday^{-1})			**Water level 2(7.0 mmday$^{-1)}$**		
Fertilizer rates	Gross margin (Ksh ha^{-1})	Marginal gross margin (Ksh ha^{-1})	MBCR	Gross margin (Ksh ha^{-1})	Marginal gross margin (Ksh ha^{-1})	MBCR
P_1K_1	699603.2			899894.5		
P_2K_1	701759.8	2156.54	0.87	866830.1	-33064.4	-13.3
P_3K_1	933780.5	234177.3	47.04	983958.5	84063.96	16.89
P_4K_1	758184.8	58581.54	7.85	1148130	248235.8	33.25
P_1K_2	1041938	342334.4	317	1053330	153435.9	142.07
P2K_2	836324.5	136721.3	38.34	1242560	342665.1	96.09
P_3K_2	890017.3	190414.1	31.43	1168294	268399.8	44.31
P_4K_2	727123.4	27520.12	3.22	863198.2	-36696.3	-4.29
P_1K_3	612808.9	-86794.3	-40.18	822202.4	-77692.1	-35.97
P_2K_3	780810.7	81207.46	17.48	1151120	251225.6	54.07
P_3K_3	796071.1	96467.88	13.51	1127731	227836.5	31.92
P_4K_3	751714.6	52111.36	5.41	857822.4	-42072.1	-4.37
P_1K_4	603276	-96327.3	-29.73	971093.6	71199.12	21.98
P_2K_4	733486.3	58581.54	10.23	1049865	149970.7	26.19
P_3K_4	714065.2	14462	1.76	1082330	182435.7	22.2
P_4K_4	537680.9	-161922	-15.13	845218.9	-54675.6	-5.11

Key
P_1K_1-0 kg ha^{-1} of P_2O_5& 0 kg ha^{-1} of K_2O
P_2K_1-20 kg ha-1 of P_2O_5&0 kg ha^{-1}of K_2O
P_3K_1-40 kg ha^{-1}of P_2O_5& 0 kg ha^{-1}of K_2O
P4K1-60 kg ha^{-1}of P_2O_5& 0 kg ha^{-1}of K_2O
P_1K_2-0 kg ha^{-1}of P_2O_5& 10 kg ha^{-1}of K_2O
P_2K_2=20 kg ha^{-1}of P_2O_5& 10 kg ha^{-1} of K_2O
P_3K_2-40 kg ha^{-1}of P_2O_5& 10 kg ha^{-1}of K_2O
P_4K_2-60 kg ha^{-1}of P_2O_5& 10 kg ha^{-1}of K_2O
P_1K_3-0 kg ha^{-1}of P_2O_5&20 kg ha^{-1}of K_2O
P_2K_3-20 kg ha^{-1}of P_2O_5& 20 kg ha^{-1}of K_2O
P_3K_3-40 kg ha^{-1}of P_2O_5& 20 kg ha^{-1}of K_2
P_4K_3-60 kg ha^{-1} of P_2O_5& 20 kg ha^{-1}of K_2O
P_1K_4- 0 kg ha^{-1}of P_2O_5& 30 kg ha^{-1}of K_2O
P_2K_4-20 kg ha^{-1}of P_2O_5& 30 kg ha^{-1} of K_2O
P_3K_4-40 kg ha^{-1} of P_2O_5& 30 kg ha^{-1}of K_2O
P_4K_4-60 kg ha^{-1}of P_2O_5& 30 kg ha^{-1}of K_2O
MBCR-Marginal benefit cost Ratio

Table 4.33 shows that the highest MBCR of 317 and 142.07 from water regimes 3.5 mm day^{-1} and 7.0 mm day^{-1} respectively, was achieved by P_1K_2 (0 kg ha^{-1} P_2O_5+ 10 kg ha^{-1} K_2O). The highest marginal gross margin of ksh 342,334.4 ha^{-1} with 3.5 mm day^{-1} was achieved with P_1K_2 (0 kg ha^{-1}P_2O_5+10 kg ha^{-1} K_2O), while with 7.0 mm day^{-1} water regime the highest marginal gross margin of ksh 342,665.1 ha^{-1} was attained in P_2K_2 (20 kg ha^{-1} P_2O_5+10 kg ha^{-1} K_2O). In both water levels of 3.5 mm day^{-1} and 7.0 mm day^{-1}**,** P_1K_3 (0 kg ha^{-1} P_2O_5+ 20 kg ha^{-1} K_2O) gave the lowest MBCR of -40.18 and -35.97. Increase in Phosphorus levels with K value constant at 10 kg ha^{-1} decreased the MBCR in both water regimes. The marginal gross margin (ksh ha^{-1}) with P_1K_2 (0 kg P+ 10 kg K) and 3.5 mm day^{-1} was 55.2 % higher than that with 7.0 mm day^{-1}. High values of P and K (P_4K_4-60 kg ha^{-1} P_2O_5+ 30 kg ha^{-1} K_2O) gave negative MBCR in both water regimes. This shows that it is totally uneconomical to use fertilizer rates of (60 kg ha^{-1} P_2O_5+30 kg ha^{-1} K_2O) in the soils described in this study.

4.8 Findings of Statistical Assumptions

Cohen et al. (2011) recommends that, the assumptions of normality, multicollinearity, heteroscedasticity and linearity of data be met as they are required for multiple regressions to give valid results.

4.8.1 Linearity

Ombaka (2014) indicates that Multiple linear regression can simply correctly approxime the relatioship between dependent and independent variables when the relationships are linear in nature. It is essential to have a linear relationship among (1) the dependent variable and every independent variable, (2) the dependent variable and the independent variables jointly**.**

Linearity of the data means that the values of the outcome variable for each increament of prediction variable lie along a straight line. Scatterplots were used to test linearity in this study as presented in Figure 4.19.

Figure 4.19

Scatter Plot of Regression Standardized Residuals Versus the Regression Predicted Values

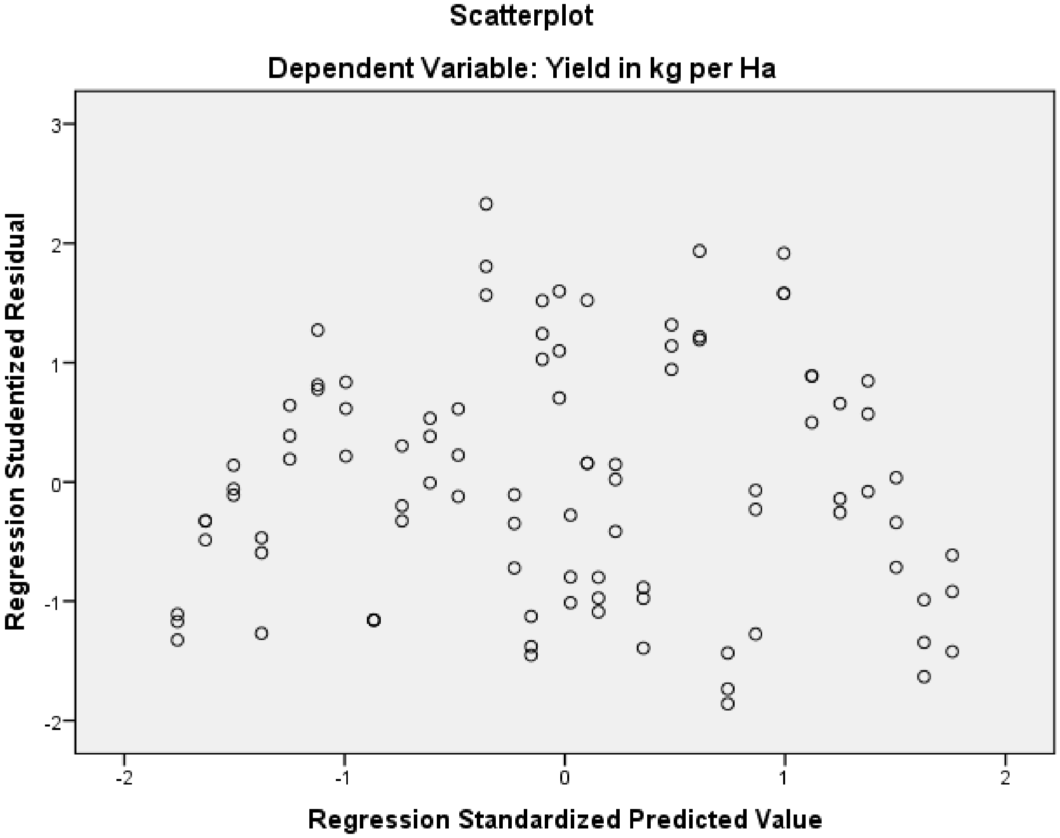


Figure 4.19 shows the relationship between the response variable (yields kgha^{-1}) and predictors, with residuals being randomly scattered around zero

It was revealed that the standardised residuals were randomly spread without any obvious pattern around the standardised predicted value. This is a proof of linearity in the original data of the dependent variable.

4.8.2 Multicollinearity

Multicollinearity happens when there are two or more independent variables that are greatly associated with each other. To identify presences of multicollinearity, an assessment of correlation coefficients and Tolerance/ VIF (Variance Inflation Factor) values were computed as indicate in Table 4.34.

Table 4.34

Collinearity Coefficients

	Collinearity Statistics	
Model	Tolerance	VIF
(Constant)		
Water levels	1.000	1.000
Fertilizer Combination	1.000	1.000

a. Dependent Variable: Yield(kg/ha)

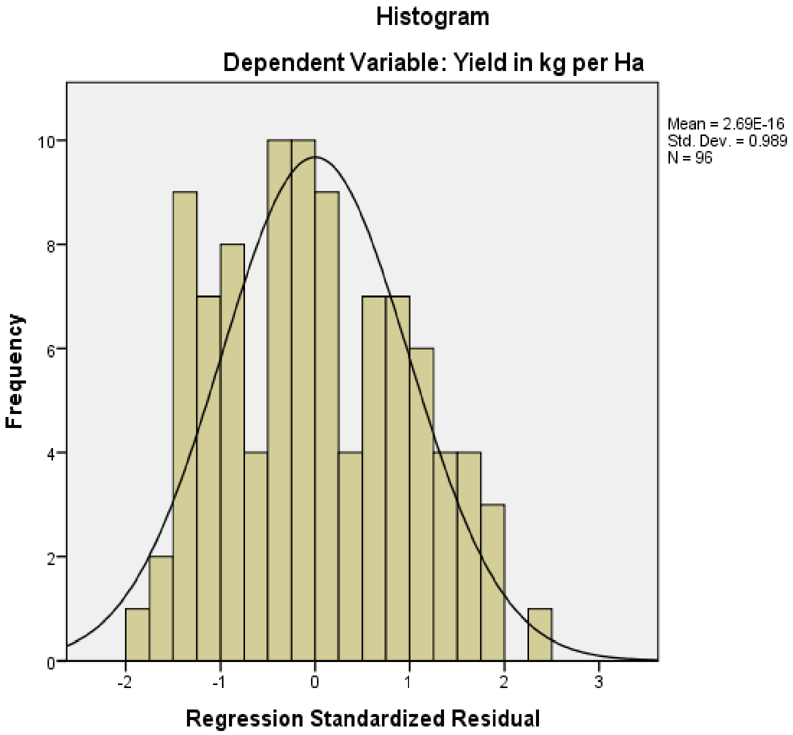
Table 4.34 shows that, the VIF values of variables; water levels and fertilizer combination are less than five. VIF values of less than five shows that the data lacks collinearity (Ombaka, 2014).

4.8.3 Normality

To determine that the residuals (errors) are roughly normally distributed both normality plots and statistical tests were used. For normality plots, a histogram (with a superimposed normal curve) and a normal P-P Plot of the studentized residuals were used. The statistical tests included Kolmogorov-Smirnov and Shapiro-Wilk tests that check the null hypothesis that the data is normally distributed.

Figure 4.20

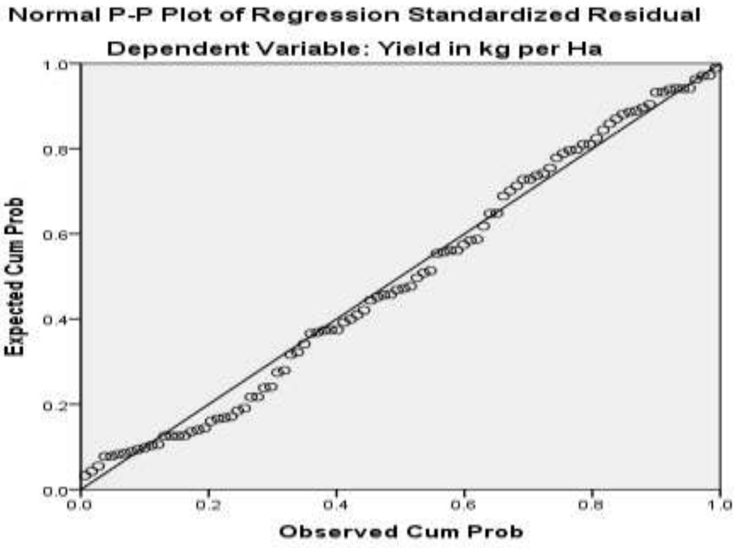
Histogram of Yield in Kg ha^{-1}



The figure shows a symmetric bell-shaped histogram which is evenly distributed around zero indicating normality assumption is true.

Figure 4.21

Normal P-P Plot of Standardized Residuals



The graph compares observed cumulative function (CDF) of the standardized residual to expected CDF of the normal distribution.

The histogram in Figure 4.20 presents symmetrical normal curve with observations distributed almost in central observation with no skewness, kurtosis or outliers. The normal P- P plot in Figure 4.21 indicates that the observed cumulative probability values were spread along the expected normal cumulative probability curve, revealing that the data was normally distributed. Table 4.35 presents Test for normality findings with P values of Shapiro-wilk greater than 0.05, hence null hypothesis was not rejected concluding normality in distribution of the data.

Table 4.35

Test for Normality

Tests of Normality							
		Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Water levels	Statistic	df	Sig.	Statistic	df	Sig.
Yield in kg per Ha	3.5mm/day	.085	48	.200*	.970	48	.253
	7.00mm/day	.102	48	.200*	.957	48	.076
	Fertilizer combination	Statistic	df	Sig.	Statistic	df	Sig.
Yield in kg per Ha	p_1k_1-0 kg p+ 0 kg k	.234	6	.200*	.886	6	.296
	p_2k_1-20 kgp+0 kg k	.188	6	.200*	.967	6	.869
	p_3k_1-40 kg p+0 kg k	.188	6	.200*	.955	6	.784
	p_4k_1-60 kg p+ 0 kg k	.176	6	.200*	.948	6	.728
	p_1k_2-0 kg p+10 kg k	.192	6	.200*	.937	6	.634
	p_2k_2-20 kg p+ 10 kg k	.182	6	.200*	.921	6	.510
	p_3k_2-40 kg p+10 kg k	.284	6	.143	.847	6	.150
	p_4k_2-60 kg p+10 kg k	.238	6	.200*	.907	6	.414
	p_1k_3-0 kg p +20 kg k	.257	6	.200*	.932	6	.593
	p_2k_3-20 kg p+20 kg k	.196	6	.200*	.952	6	.759
	p_3k_3-40 kg p+20 kg k	.204	6	.200*	.917	6	.482
	p_4k_3-60 kg p+ 20 kg k	.200	6	.200*	.945	6	.698
	p_1k_4-0 kg p+30 kg k	.163	6	.200*	.948	6	.724
	p_2k_4-20 kg p+30 kg k	.290	6	.124	.820	6	.087
	p_3k_4-40 kg p+30 kg k	.298	6	.104	.843	6	.139
	p_4k_4-60 kg p+30 kg k	.146	6	.200*	.982	6	.963

a. Lilliefors Significance Correction

4.8.4 Heteroscedasticity

For linear regression, the data requires to display homoscedasticity, whereby the variances along the line of best fit stay alike as you move along the line. This was done by using scatter plot of regression standardized residuals versus the regression predicted values as shown in Figure 4.22.

Figure 4.22

Scatter Plot of Regression Standardized Residuals

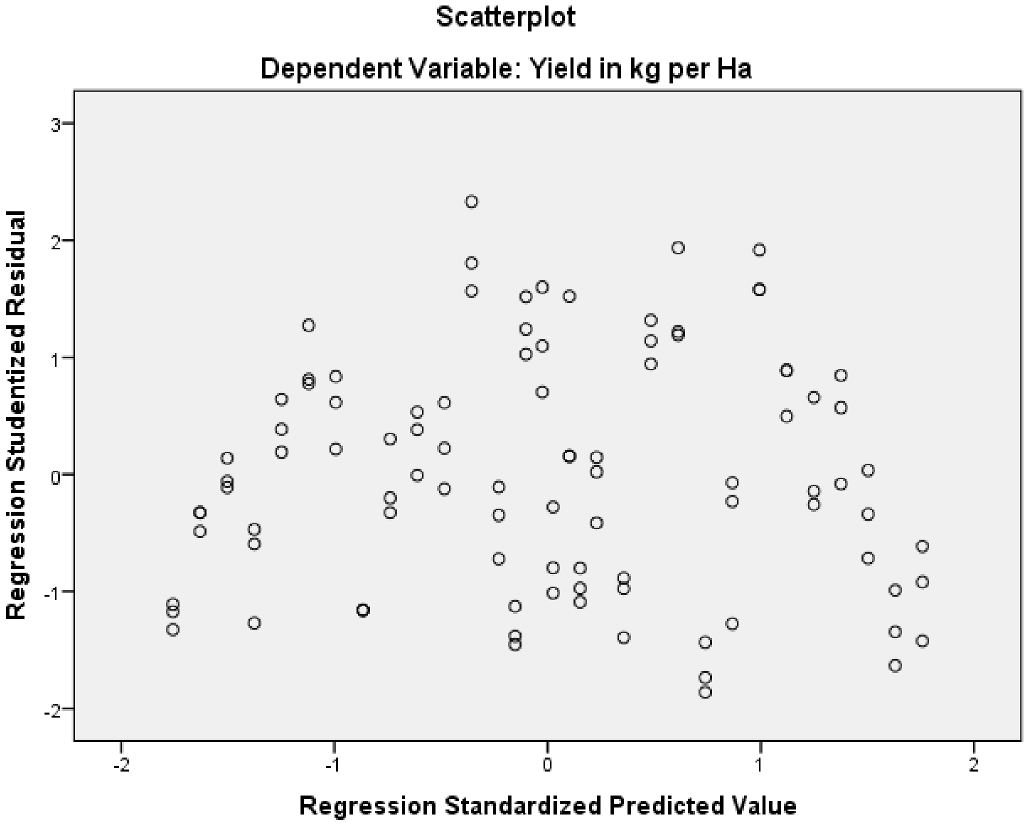


Figure 4.22 display homoscedasticity showing relationship between the response variable (yields kgha-1) and predictors, with residuals being randomly scattered around zero.

Based on scatter plot output in Figure 4.22, the spots are diffused and does not create a clear particular shape, hence it can be resolved that the regression model do not have heteroscedasticity problem.

4.9 Grain Predictor Model and Model Strength

Regression analysis is a generally applied method in research whereby relationships between the considered variables are determined and their impact on crop yield ascertained. Yield of the crop is considered as a dependent variable while other factors are measured as independent variables (Sellam & Poovammal, 2016). Linear regression relationships do not apply indefinitely but are supposed to be limited to the range of data used to generate them. In this study, moisture level and fertilizer rate (specifically Phosphorus and Potassium rates) were considered and their effects on NERICA 1 yield in Mwea.

A grain yield predictor model which can be used to assess the combined effects of the factors (Moisture level and P & K rates) was derived from the experimental pooled data. P and K variates that gave optimum yields under the moisture levels were considered in the regression.

The summary for linear regression model is given in Table 4.36. Given the findings in Table 4.35, the predictor model is:

$$PGY = 2131.717+1519.044WL -39.632P- .763K$$

Where: PGY- Projected Gain Yield of NERICA 1 in (kgha^{-1}); WL water level (mmday^{-1}): P Phosphorus rate (kgha^{-1}) and K potassium rate (kgha^{-1}).

Table 4.36

Anova and Model Summary

ANOVA SUMMARY

Model		**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
1	Regression	11087401.777	3	3695800.592	12.405	.000^b
	Residual	4170841.201	14	297917.229		
	Total	15258242.978	17			

MODEL SUMMARY

Variables entered	R	R^2		**Coefficients**	**Std error of the estimate**
(Constant)			(Constant)	2131.72	545.82
Water Level (mm/day)	.852	.727	Water Level (mm/day)	1519.04	
Potassium (kg/ha)			Potassium (kg/ha)	-39.63	
Phosphorus (kg/ha)			Phosphorus (kg/ha)	-.763	

The model shows coefficient of correlation of 0.852, and a coefficient of determination (R^2) of 0.727 for the predictor model. This means that the percentage of variation between the values of the grain yield predicted by the model that can be explained using the predictor variables (water level, Potassium and Phosphorus rates) is 72.7%. Other variables not used in the model account for 27.3 % of the variability in grain yield of NERICA 1 in this study. From the Anova summary in Table.4.36, the regression model statistical significance value is .000, value less than 0.05, this therefore specifies that the general regression model significantly explains the outcome variable which means that it is a good fit for the data.

The statistical significance of the regression model done for Nitrogen, Potassium and Phosphorus uptake in straw and crude protein in grain indicated that on only Phosphorus significantly predicted the outcome with Sig. value of 0.019 which is less than 0.05.

Table 4.37 outlines the results of model summary.

Table 4.37

Regression Model Summary for NPK Uptake in Straw and Crude Protein in Grain

Dependent Variable	**Predictors:**	**Sig. Value**	R	R Square
% Potassium uptake in straw	Fertilizer Combination, Water Level	.184	.479[a]	.229
% Nitrogen uptake in straw	Fertilizer Combination, Water Level	.400	.362	.132
% Phosphorus uptake in straw	Fertilizer Combination, Water Level	.019	.676[a]	.458
Crude protein % in grain	Fertilizer Combination, Water Level	.349	.387[a]	.149

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMEDATIONS

The chapter gives the summary of the research findings and conclusion after data analysis was done. Recommendations and further research topics to enhance NERICA 1 yields in variety of soils and water regimes are also given in the chapter.

5.1 Summary of Research Finding

The summary of research findings based on objectives were;

5.1.1 Performance of NERICA1 under different moisture regimes

Water levels significantly affected the performance of NERICA1 with W_{2-} (7.0 mmday^{-1}) giving higher yields of 4535.6 kgha^{-1}, compared to W_{1-}(3.5mm day^{-1}) which had yields of 3135.9 kg ha^{-1}. Irrigation amount of 392 mm (3.5 mm day^{-1}) gave 83.7% NERICA1 grain yields attained with 784 mm (7.0 mm day^{-1}) amount. NERICA 1 rice yielded better with rainfall of up to 582 mm as illustrated by the results from the field crop, indicating that as the rainfall increases, the yield also increase. This was as a result of increase in number of tillers in the field crop as compared to greenhouse experiment. A strong positive correlation among number of tillers and the Yield of NERICA 1 was observed in both greenhouse and field experiment.

5.1.2 Effect of different evels of P and K on growth and yield of NERICA1

P & K rates significantly affected the number of tillers, number of leaves, 100 grain weight and yields of NERICA 1. Highest grain yield of 3,745.4 kg ha^{-1}(average of the two seasons) was attained by P_1K_2 (0 kg ha^{-1} P_2O_5- 10 kg ha^{-1} K_2O). The soils used in the study had adequate Phosphorus. The Lowest grain yield of 2507 kg ha^{-1} was achieved by P_4K_4 (60 kgha^{-1} P_2O_5+ 30 kg ha^{-1} K_2O.

5.1.3 Influence of moisture regimes, P and K rates on nutrients uptake.

Water level significantly affected phosphorus uptake in the straw while fertilizer rates significantly affected Potassium uptake in the straw. There was a significant fertilizer water interaction on K uptake in straw with $P_2K_2W_2$ (20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K2O) giving the highest value of 1.92% but no none in the grains. Increase of fertilizer rates up to 20 kg ha^{-1} P_2O_5 and 10 kg ha^{-1} K_2O increased uptake of percentage N, P, K in straw and crude protein in grains after which additional fertilizer caused decrease irrespective of water levels.

5.1.4 Interaction of moisture regimes, P and K rates on development and yield of NERICA1

Fertilizer water interaction had significant effect on plant height, number of leaves, panicle weight, 100 grain weight and yield of NERICA 1. The highest grain yield achieved of 4,603.6 kg ha^{-1} was in the interaction P_3K_3+W_2 (40 kg ha^{-1} P_2O_5+ 20 kg ha^{-1} K_2O+ 7.0mm day^{-1}while $P_4K_4W_1$ (60kg ha^{-1}P_2O_5+30kg ha^{-1}K_2O +3.5 mm day^{-1}) had the least.

5.1.5 Water use efficiency of NERICA1 rice under fertilizer levels and varied moisture regimes.

Water levels significantly affected WUE with water level W_1 (3.5mmday^{-1}) giving the highest value of 7.53 kg ha^{-1}mm^{-1} while 7.0 mm day^{-1} gave 5.45 kg ha^{-1}mm^{-1}. P & K rates had significant effect on WUE in season 1 with P_1K_2 (0 kgha^{-1} P_2O_5+ 10 kgha^{-1} K_2O) giving the highest value of 6.61 kg ha^{-1}mm^{-1}. Fertilizer water interaction had significant effect on WUE with $P_1K_2W_1$ giving the highest value of 8.60 kg ha^{-1}mm^{-1} and the lowest

WUE of 2.9 kg $ha^{-1}mm^{-1}$ was achieved under $P_4K_4W_2$ (60 kg ha^{-1} P_2O_5+30 kg $ha^{-1}K_2O$+7.0 mm day^{-1}) interaction.

5.16 Economic viability of P and K rates, moisture levels in production of NERICA 1

The highest marginal benefit cost ratio (MBCR) of 114.3 was achieved from P_1K_2 (0 kg ha^{-1}+ 10 kg ha^{-1}) and the lowest attained from P_4K_4 (60 kg $ha^{-1}P_2O_5$+ 30 kg ha^{-1} K_2O). In relation to water levels, the highest MBCR of 317.0 and 142.1 was achieved from 3.3mm $day^{-1}$and 7.0mm day^{-1}under P_1K_2 (0 kg$ha^{-1}P_2O_5$ +10 kg $ha^{-1}K_2O$) fertilizer rate.

5.2 Conclusion

The study has made some variable contribution on how to enhance viable upland rice production under minimal rainfall under varying soil properties. This is great benefit to farmers in environments where rainfall is minimal but soils have sufficient Phosphorus and Potassium while adequate Nitrogen levels are sustained. The study has demonstrated that;

Rainfall amount of 392 mm (3.5 mm day^{-1}) can generate up to 83.7% NERICA1 grain yields attained with 784 mm (7.0 mm day^{-1}) amount of rainfall in soils with adequate Potassium and Phosphorus levels together with Nitrogen supply of 60 kg $ha^{-1}$for soils with low Nitrogen. This means that it is possible to increase yields with less water with little yield penalties which is viable in soils with adequate P and additional of 10kgha^{-1} of K and 60kgha^{-1} of N in soils with low Nitrogen.

Water - Fertilizer interaction of $P_1K_2W_1$ gave the highest WUE of 8.60 kg $ha^{-1}mm^{-1}$ levels and MCBR of 317, while $P_3K_3W_2$ produced the highest yields of 4603.6 kg ha^{-1}.

Highest uptake of Nitrogen, phosphorus and Potassium in straw and crude protein in grain was attained by 20 kg ha^{-1} P_2O_5 + 10 kg ha^{-1} K_2O and 7.00 mm day^{-1} water interaction, in soils with sufficient Phosphorus and Potassium plus additional 60 kg ha^{-1} of Nitrogen. Percentage Potassium uptake was significantly affected by water-fertilizer interaction. Higher doses of fertilizer rates results in buildup in the soil although higher rainfall increases the uptake in both straw and grain but up to certain level.

Highest economic returns can be attained by adding 20 kg ha^{-1} P_2O_5 and 10 kg ha^{-1} K_2O with moisture levels of 7.0 mm day^{-1} and 10 kg ha^{-1} K_2O with 3.5 mm day^{-1} in production of NERICA 1, in soils rich in Phosphorus and reasonable Potassium while Nitrogen is maintained at of 60 kg $ha^{-1}$for low N content.

5.3 Recommendations

The stated objectives of this study were; a) Evaluate the performance of NERICA 1under various watering regimes; b) determine the effects of different P & K levels in cultivation of NERICA 1; c) Access the interaction effect of water levels and P& K rates on growth and yield of NERICA 1; d) analyze impact of moisture and fertilizer levels on nutrients uptake; e) Investigate how the water use efficiency NERICA 1 is affected by different water levels and fertilizer rates and (f) access economic viability in production of NERICA with varied rates of P& K and varied water level.

The following recommendations are made based the on research findings, in order to enhance upland rice production under underlying soil properties.

NERICA 1 variety can do well in regions of less rainfall provided moisture of about 392 mm is sustained in all growing stages. This can be achieved through supplemental irrigation which is economically viable and with minimal yield penalties.

NERICA 1 variety will do well in soils with adequate supply of Potassium and Phosphorus which should be ascertained through soil tests but requires a minimum of 60 kg ha^{-1} of nitrogen in soils that have low nitrogen content.

Use of 10 kg ha^{-1} K_2O and rainfall of 3.5 mm day^{-1} (392 mm) results in high water use efficiency and marginal benefit cost ratio in NERICA 1 production under the underlying soil condition in this study

NERICA 1 Variety should be incorporated in the cropping system in all potential upland rice growing regions in the country to assist in alleviating poverty through food security and enhanced income. This is because it does well with both low moisture and fertilizer rates and even better with higher rainfall which increases the quality of grain.

County Governments and other policy makers at national level should endeavor and support soil nutrients management programmes in upland areas and low rainfall regions to avoid nutrients losses through use of straw through burning or as livestock feeds.

Excessive use of Phosphorus and Potassium without increase of Nitrogen in cultivation of NERICA 1 results in decline of the yields and should therefore be avoided irrespective of moisture levels.

With diminishing water sources for irrigation and unpredictable weather conditions, crops with high water use efficiency should be embraced and breeding programmes to take into consideration NERICA varieties as they offer hope to small scale holders in this county.

5.3.1Recommended further research

From the study, the following topics /areas can be recommended for further research;

Impact of additional levels of Nitrogen above 60 kg ha^{-1} on growth and yields of NERICA rice at different soil conditions.

Use different varieties of upland rice to determine water –fertilizer effects and nutrients uptake under same and varied soil conditions.

Analysis of roots development under these moisture, fertilizer rates and soil conditions.

Study of interaction effect of water and fertilizer on growth and yield of NERICA rice in soils deficient of phosphorus and Potassium.

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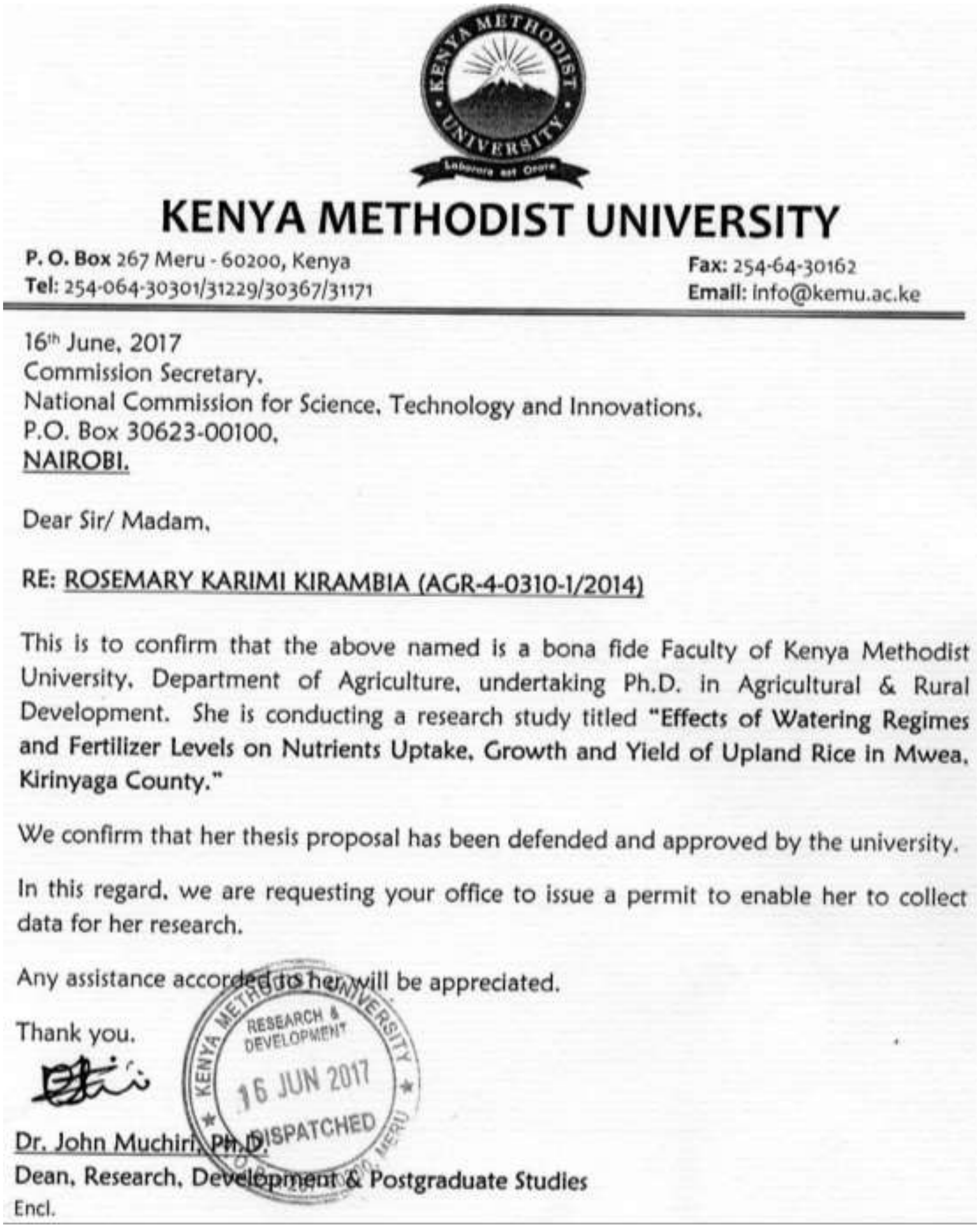
APPENDICES

Appendix 1: Introduction Letter to NACOSTI



KENYA METHODIST UNIVERSITY

P. O. Box 267 Meru - 60200, Kenya
Tel: 254-064-30301/31229/30367/31171
Fax: 254-64-30162
Email: info@kemu.ac.ke

16th June, 2017
Commission Secretary,
National Commission for Science, Technology and Innovations,
P.O. Box 30623-00100,
NAIROBI.

Dear Sir/ Madam,

RE: ROSEMARY KARIMI KIRAMBIA (AGR-4-0310-1/2014)

This is to confirm that the above named is a bona fide Faculty of Kenya Methodist University, Department of Agriculture, undertaking Ph.D. in Agricultural & Rural Development. She is conducting a research study titled **"Effects of Watering Regimes and Fertilizer Levels on Nutrients Uptake, Growth and Yield of Upland Rice in Mwea, Kirinyaga County."**

We confirm that her thesis proposal has been defended and approved by the university.

In this regard, we are requesting your office to issue a permit to enable her to collect data for her research.

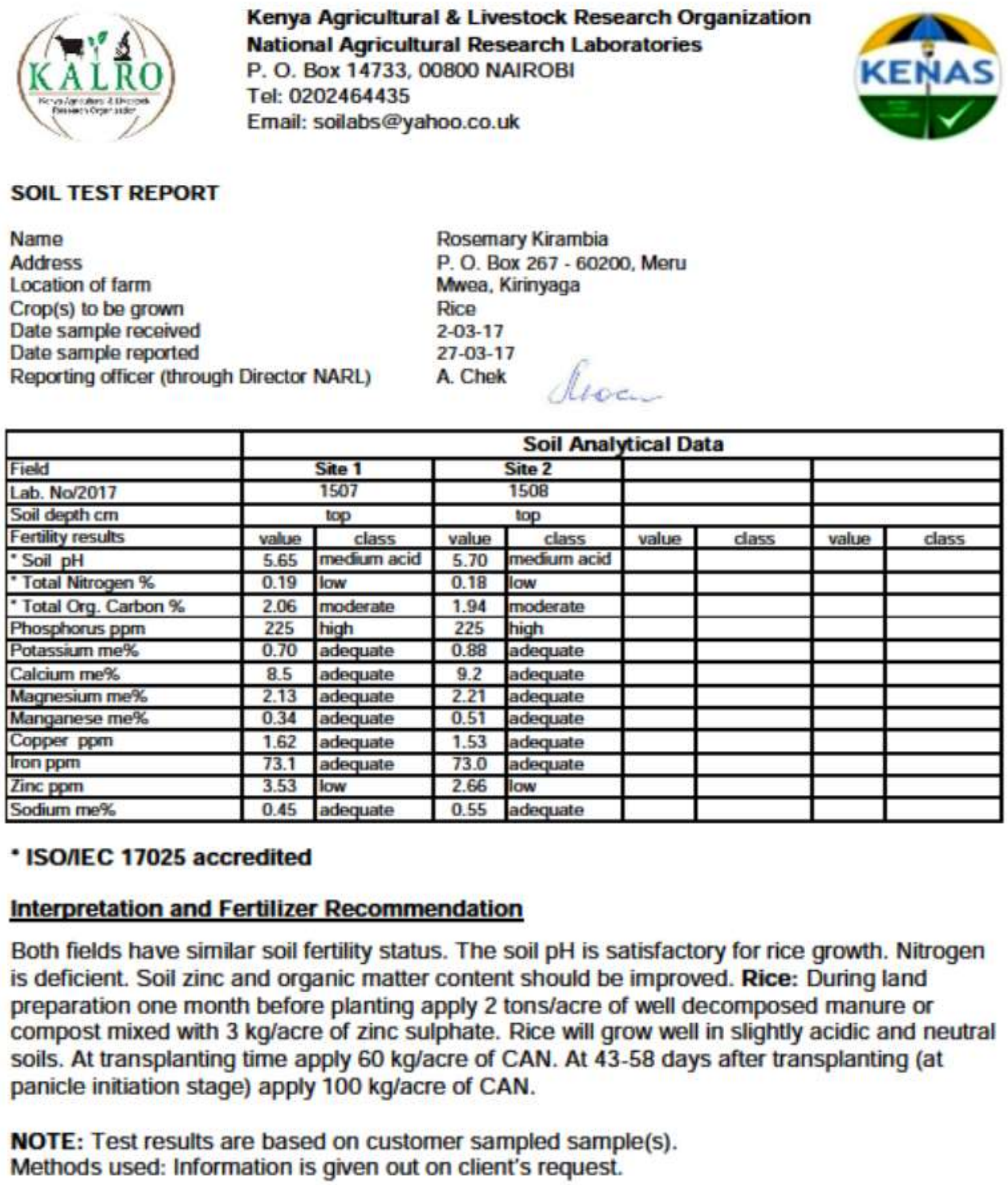
Any assistance accorded to her, will be appreciated.

Thank you.

RESEARCH & DEVELOPMENT
16 JUN 2017
DISPATCHED

Dr. John Muchiri, Ph.D.
Dean, Research, Development & Postgraduate Studies
Encl.

Appendix 2: Soil Test results for Upland soils used in the study



Kenya Agricultural & Livestock Research Organization
National Agricultural Research Laboratories
P. O. Box 14733, 00800 NAIROBI
Tel: 0202464435
Email: soilabs@yahoo.co.uk

SOIL TEST REPORT

Name	Rosemary Kirambia
Address	P. O. Box 267 - 60200, Meru
Location of farm	Mwea, Kirinyaga
Crop(s) to be grown	Rice
Date sample received	2-03-17
Date sample reported	27-03-17
Reporting officer (through Director NARL)	A. Chek

	Soil Analytical Data							
Field	**Site 1**		**Site 2**					
Lab. No/2017	1507		1508					
Soil depth cm	top		top					
Fertility results	value	class	value	class	value	class	value	class
* Soil pH	5.65	medium acid	5.70	medium acid				
* Total Nitrogen %	0.19	low	0.18	low				
* Total Org. Carbon %	2.06	moderate	1.94	moderate				
Phosphorus ppm	225	high	225	high				
Potassium me%	0.70	adequate	0.88	adequate				
Calcium me%	8.5	adequate	9.2	adequate				
Magnesium me%	2.13	adequate	2.21	adequate				
Manganese me%	0.34	adequate	0.51	adequate				
Copper ppm	1.62	adequate	1.53	adequate				
Iron ppm	73.1	adequate	73.0	adequate				
Zinc ppm	3.53	low	2.66	low				
Sodium me%	0.45	adequate	0.55	adequate				

*** ISO/IEC 17025 accredited**

Interpretation and Fertilizer Recommendation

Both fields have similar soil fertility status. The soil pH is satisfactory for rice growth. Nitrogen is deficient. Soil zinc and organic matter content should be improved. **Rice:** During land preparation one month before planting apply 2 tons/acre of well decomposed manure or compost mixed with 3 kg/acre of zinc sulphate. Rice will grow well in slightly acidic and neutral soils. At transplanting time apply 60 kg/acre of CAN. At 43-58 days after transplanting (at panicle initiation stage) apply 100 kg/acre of CAN.

NOTE: Test results are based on customer sampled sample(s).
Methods used: Information is given out on client's request.

Appendix 3: Irrigation Water Used-Test Results

Kenya Agricultural & Livestock Research Organization
National Agricultural Research Laboratories
P.O. Box 14733, 00800 NAIROBI
Tel: 0202464435
Email: soilabs@yahoo.co.uk

WATER ANALYSIS REPORT

Name	Rosemary Karimi
Address	P. O. Box 267 - 60200, Meru
Location of farm	Mwea, Kirinyaga
Date sample received	13-Mar-17
Date sample reported	30-Mar-17
Reporting officer (through Director NARL)	N. Mukiira

Analytical data (Test results)			
Sample Ref.	Borehole	Canal	
Lab. No/2017	1636	1637	
IpH	6.77	7.04	
Conductivity, mS/cm	0.22	0.07	
Sodium, me/litre	0.14	0.06	
Potassium, me/litre	0.01	0.01	
Calcium, me/litre	0.05	0.08	
Magnesium, me/litre	0.55	0.11	
Carbonates, me/litre	ND*	ND*	
Bicarbonates, me/litre	0.50	0.23	
Chlorides, me/litre	1.16	1.10	
Sulphates, me/litre	5.08	0.41	
Sodium Adsorption Ratio	0.26	0.19	

* - Not Detected

Interpretation of analytical data

Borehole and canal water is suitable for irrigation purposes and can be used on all soils with all crops.

NOTE: Interpretation is based on USDA classification of irrigation water.

Appendix 4: Manure Tests Results

Kenya Agricultural &Livestock Research Organization
National Agricultural Research Laboratories
P. O. Box 14733, 00800 **NAIROBI**
Tel: 0202464435
Email: soilabs@yahoo.co.uk

MANURE ANALYSIS REPORT

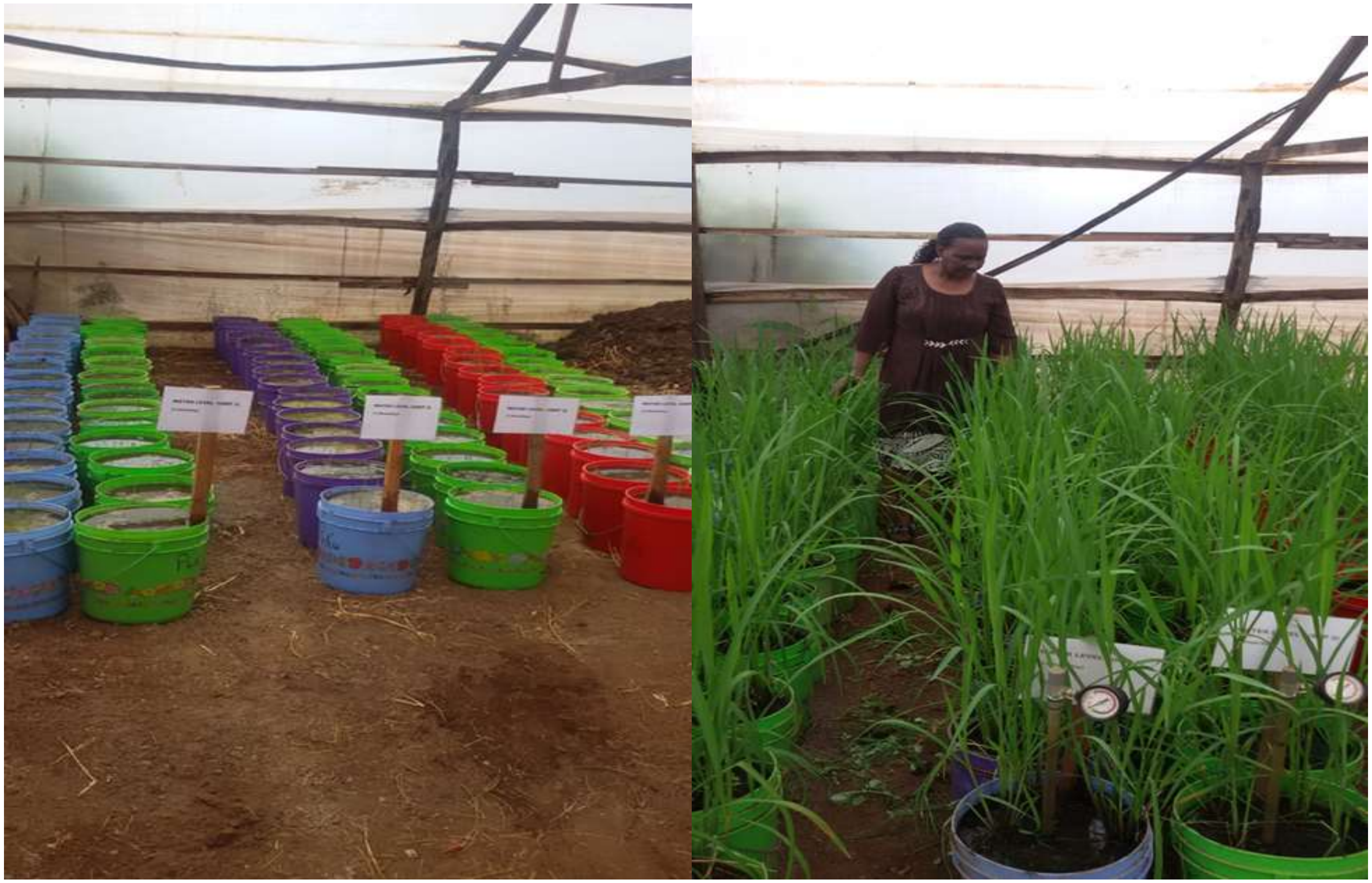
Name	Rosemary Karimi
Address	P. O. Box 267 - 60200, Meru
Location	Mwea, Kirinyaga
Date sample received	13-03-17
Date sample reported	11-04-17
Reporting officer (through Director NARL)	A.Chek

Analytical data (Test results)			
Lab No/2017	1635		
Nitrogen %	1.86		
Phosphorus %	0.63		
Potassium %	3.30		
Calcium %	OAO		
Magnesium %	0.06		
Iron mq/kq	2770		
Copper mQ/kQ	23.2		
Manganese mq/kq	1137		
Zinc mq/kg	118		

Interpretation of analytical data
Farm yard manure sample has low amount of magnesium. Other nutrient elements are within the normal range.

NOTE: Test results are based on customer sampled sample(s).

Appendix 5: Site photos during crop Establishment



Appendix 6: Post-Harvest Soil Analysis results

Mwea Irrigation Agricultural Development (MIAD) Centre

P O Box 210, 10303

WANGURU

Tel: 020 2033987

Email: miadcentre@nib.or.ke

Name: ROSE MARY

Date 09/06/2017

REP 1

Field	W1 p2k2		W2 p2k2		W1 p3k3		W2 p3k3	
Depth	0-30cm		0-30cm		0-30cm		0-30cm	
Fertility class	**value**	**class**	**value**	**class**	**value**	**class**	**Value**	**class**
pH	6.06	ideal	6.07	ideal	5.77	ideal	6.10	ideal
N%	0.119	low	0.102	low	0.077	V.low	0.063	V.low
P(ppm)	150	V. High	115	V. High	145	V.High	90	V. High
K(me/100g)	2.926	V.High	1.866	V.High	2.205	V.High	1.950	V.High
E.C(µs/cm)	156	ideal	116	ideal	202	ideal	92	ideal

Field	W1 p4k4		W2 p4k4	
Depth	0-30cm		0-30cm	
Fertility class	**value**	**class**	**value**	**class**
pH	6.48	ideal	6.18	ideal
N%	0.175	low	0.203	low
P(ppm)	175	V. High	140	V. High
K(me/100g)	2.544	V.High	1.950	V.High
E.C(µs/cm)	71	ideal	116	ideal

REP 2

Field	W1 p2k2		W2 p2k2		W1 p3k3		W2 p3k3	
Depth	0-30cm		0-30cm		0-30cm		0-30cm	
Fertility class	**value**	**class**	**value**	**class**	**value**	**class**	**value**	**class**
pH	6.27	ideal	5.82	ideal	6.02	ideal	6.18	ideal
N%	0.193	low	0.140	low	0.130	low	0.150	low
P(ppm)	170	V.High	130	V.High	140	V. High	150	V. High
K(me/100g)	3.307	V.High	1.611	V.High	1.526	V.High	1.187	V.High
E.C(µs/cm)	180	ideal	93	ideal	112	ideal	68	ideal

Field	W1 p4k4		W2 p4k4	
Depth	0-30cm		0-30cm	
Fertility class	**value**	**class**	**value**	**class**
pH	6.04	ideal	6.04	ideal
N%	0.161	low	0.168	low
P(ppm)	135	V.High	140	V. High
K(me/100g)	3.053	V.High	2.205	V.High
E.C(µs/cm)	167	ideal	139	ideal

REP 3

Field	W1 p2k2		W2 p2k2		W1 p3k3		W2 p3k3	
Depth	0-30cm		0-30cm		0-30cm		0-30cm	
Fertility class	**value**	**class**	**value**	**class**	**value**	**Class**	**value**	**class**
pH	5.97	ideal	6.09	ideal	5.98	Ideal	6.07	ideal
N%	0.175	low	0.158	V.low	0.217	Low	0.147	low
P(ppm)	145	V. High	120	V. High	175	V. High	210	V. High
K(me/100g)	2.968	V.High	2.459	V.High	1.526	V.High	2.459	V.High
E.C(µs/cm)	215	ideal	115	ideal	174	ideal	80	ideal

Field	W1 p4k4		W2 p4k4	
Depth	0-30cm		0-30cm	
Fertility class	**value**	**class**	**value**	**class**
pH	6.77	ideal	6.18	ideal
N%	0.161	low	0.168	V.low
P(ppm)	200	V. High	185	V. High
K(me/100g)	3.986	V.High	2.205	V.High
E.C(µs/cm)	80	ideal	95	Ideal

NB; Phosphorus Test Method-Olsen

Appendix 7: ANOVA OUTPUT.

A) ANOVA Summary-effect of fertilizer rates on growth parameters Season 1 & 11

Season 1

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Block	Plant Height (cm)	514.583	2	257.292	2.023	.134
	Number of Tillers	55.111	2	27.556	20.852	.000
	Number of Leaves	555.111	2	277.556	17.570	.000
DAS	Plant Height (cm)	210129.521	2	105064.760	826.027	.000
	Number of Tillers	64.007	2	32.003	24.218	.000
	Number of Leaves	3169.507	2	1584.753	100.321	.000
FC	Plant Height (cm)	2776.222	15	185.081	1.455	.122
	Number of Tillers	26.385	15	1.759	1.331	.183
	Number of Leaves	341.663	15	22.778	1.442	.128
Error	Plant Height (cm)	34087.674	268	127.193		
	Number of Tillers	354.160	268	1.321		
	Number of Leaves	4233.549	268	15.797		
Corrected Total	Plant Height (cm)	247508.000	287			
	Number of Tillers	499.663	287			
	Number of Leaves	8299.830	287			

Season 11

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	Plant Height(cm)	2905626.065	1	2905626.065	50990.252	.000
	Number of Tillers	6842.815	1	6842.815	3148.600	.000
	Number of Leaves	110534.440	1	110534.440	3622.568	.000
Growth_Stg	Plant Height(cm)	86793.654	3	28931.218	507.708	.000
	Number of Tillers	120.258	3	40.086	18.445	.000
	Number of Leaves	1471.070	3	490.357	16.071	.000
BLOCK	Plant Height(cm)	18.130	2	9.065	.159	.853
	Number of Tillers	12.380	2	6.190	2.848	.059
	Number of Leaves	186.349	2	93.174	3.054	.048
FC	Plant Height(cm)	1231.977	15	82.132	1.441	.125
	Number of Tillers	76.643	15	5.110	2.351	.003
	Number of Leaves	1395.018	15	93.001	3.048	.000
Error	Plant Height(cm)	20685.174	363	56.984		
	Number of Tillers	788.904	363	2.173		
	Number of Leaves	11076.122	363	30.513		
Total	Plant Height(cm)	3014355.000	384			
	Number of Tillers	7841.000	384			
	Number of Leaves	124663.000	384			

B) ANOVA Summary-effect of fertilizer rates on yield & yield components- Season 1

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.
Block	Panicle Weight(g)	3.430	2	1.715	1.694	.191
	Spikelet Fertility%	104.259	2	52.130	.165	.848
	Grain Length(mm)	.774	2	.387	.651	.525
	Grain Width(mm)	.418	2	.209	.707	.496
	Yield kg/ha	5078043.612	2	2539021.806	2.574	.083
	100grain Weight in(g)	.242	2	.121	1.146	.323
FR	Panicle Weight(g)	20.610	15	1.374	1.357	.190
	Spikelet Fertility%	3917.214	15	261.148	.826	.646
	Grain Length(mm)	9.303	15	.620	1.042	.423
	Grain Width(mm)	3.050	15	.203	.688	.789
	Yield kg/ha	15334202.154	15	1022280.144	1.036	.429
	100grain Weight in(g)	3.244	15	.216	2.051	.022
Error	Panicle Weight(g)	78.986	78	1.013		
	Spikelet Fertility%	24649.255	78	316.016		
	Grain Length(mm)	46.416	78	.595		
	Grain Width(mm)	23.044	78	.295		
	Yield kg/Ha	76950683.916	78	986547.230		
	100grain Weight in(g)	8.224	78	.105		
Corrected Total	Panicle Weight(g)	102.694	95			
	Spikelet Fertility%	28685.906	95			
	Grain Width(mm)	26.490	95			

	Grain Length(mm)	56.490	95
	Yield kg/ha	97020056.511	95
	100grain Weight in(g)	11.702	95

C) ANOVA Summary –Effect of Fertilizer rates on WUE Season 1 & 11

Dependent Variable: Water Use Efficiency kg/ha/m^3 S1

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	40.201	1	40.201	1786.895	.000
FR	.445	15	.030	1.318	.212
Block	.075	2	.038	1.670	.195
Error	1.755	78	.022		
Total	42.670	96			

Dependent Variable: Water use Efficiency(kg/ha/m^3) S11

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	18.584	1	18.584	8937.269	.000
Water_L	1.275	1	1.275	613.065	.000
FR	1.584	15	.106	50.778	.000
Block	.036	2	.018	8.603	.001
Water_L * FR	.658	15	.044	21.099	.000
Error	.129	62	.002		
Total	22.266	96			

Appendix 8(I): Raw Data Season 1

S.No.	Block	Water L	DAS	FR	Height	Tiller No	No.Leaves	PanicalL	Leaf L	Leaf w	Legule L	Culm No	Culm L	Grain L	Grain w	Yield	WUE	Wt 100Gr
1	1	1	2	5	39	3	10											
2	1	1	2	8	50	5	20											
3	1	1	2	7	46	5	13											
4	1	1	2	6	48	4	15											
5	1	1	2	2	47	3	11											
6	1	1	2	1	46	3	10											
7	1	1	2	3	53	4	15											
8	1	1	2	4	41	4	14											
9	1	1	2	16	34	2	6											
10	1	1	2	14	41	3	9											
11	1	1	2	15	45	4	13											
12	1	1	2	13	44	3	10											
13	1	1	2	11	39	2	7											
14	1	1	2	12	48	3	10											
15	1	1	2	9	49	3	11											
16	1	1	2	10	51	2	8											
17	1	2	2	11	49	4	14											
18	1	2	2	12	39	4	12											
19	1	2	2	13	50	6	21											
20	1	2	2	16	53	4	16											
21	1	2	2	2	53	5	16											
22	1	2	2	1	46	3	14											
23	1	2	2	3	47	5	19											

24	1	2	2	7	39	3	10											
25	1	2	2	8	43	4	12											
26	1	2	2	5	40	3	11											
27	1	2	2	6	54	4	13											
28	1	2	2	4	44	3	13											
29	1	2	2	15	45	3	11											
30	1	2	2	14	45	3	11											
31	1	2	2	10	52	4	14											
32	1	2	2	9	55	3	9											
33	2	1	2	1	42	2	9											
34	2	1	2	2	43	3	11											
35	2	1	2	4	35	3	9											
36	2	1	2	3	42	3	12											
37	2	1	2	10	27	3	7											
38	2	1	2	9	46	4	13											
39	2	1	2	12	35	3	11											
40	2	1	2	11	46	3	10											
41	2	1	2	6	45	4	12											
42	2	1	2	5	47	3	10											
43	2	1	2	7	52	3	14											
44	2	1	2	8	47	3	10											
45	2	1	2	13	41	2	6											
46	2	1	2	14	45	2	8											
47	2	1	2	15	45	2	7											
48	2	1	2	16	48	2	10											
49	2	2	2	16	38	2	8											
50	2	2	2	1	43	2	10											
51	2	2	2	3	40	2	9											

52	2	2	2	2	51	4	15											
53	2	2	2	6	47	3	13											
54	2	2	2	7	48	4	15											
55	2	2	2	5	47	4	11											
56	2	2	2	15	47	3	10											
57	2	2	2	8	48	3	10											
58	2	2	2	4	42	3	11											
59	2	2	2	10	47	4	14											
60	2	2	2	9	45	4	13											
61	2	2	2	11	48	6	18											
62	2	2	2	14	48	3	10											
63	2	2	2	12	50	3	8											
64	2	2	2	13	48	2	8											
65	3	1	2	16	32	4	13											
66	3	1	2	15	43	5	17											
67	3	1	2	14	37	4	15											
68	3	1	2	13	42	3	10											
69	3	1	2	4	33	4	14											
70	3	1	2	1	36	4	13											
71	3	1	2	3	37	3	10											
72	3	1	2	2	36	4	11											
73	3	1	2	5	38	3	11											
74	3	1	2	7	42	7	21											
75	3	1	2	6	41	4	15											
76	3	1	2	8	43	5	18											
77	3	1	2	12	41	3	14											
78	3	1	2	11	44	5	15											
79	3	1	2	10	39	5	15											

80	3	1	2	9	45	5	19											
81	3	2	2	12	49	4	13											
82	3	2	2	9	50	4	14											
83	3	2	2	14	56	4	12											
84	3	2	2	13	38	3	9											
85	3	2	2	10	42	3	12											
86	3	2	2	11	42	4	15											
87	3	2	2	4	50	3	12											
88	3	2	2	3	51	3	12											
89	3	2	2	7	54	3	13											
90	3	2	2	1	51	3	12											
91	3	2	2	6	48	3	9											
92	3	2	2	16	51	4	15											
93	3	2	2	15	51	3	11											
94	3	2	2	2	58	2	8											
95	3	2	2	8	59	3	10											
96	3	2	2	5	52	3	9											
97	1	1	3	5	86	7	21	44	1.6	10								
98	1	1	3	8	80	7	26	47	1.2	9								
99	1	1	3	7	95	10	30	44	1.4	10								
100	1	1	3	6	82	6	20	45	1.2	10								
101	1	1	3	2	94	7	31	54	1.4	10								
102	1	1	3	1	78	4	13	48	1.2	11								
103	1	1	3	3	104	11	28	44	1.6	11								
104	1	1	3	4	87	7	30	41	1.4	10								
105	1	1	3	16	84	3	16	46	1.3	10								
106	1	1	3	14	93	6	26	53	1	11								
107	1	1	3	15	83	5	21	47	1.1	11								

108	1	1	3	13	75	4	18	41	1.3	10								
109	1	1	3	11	83	4	15	56	1.3	10								
110	1	1	3	12	94	4	20	51	1.3	13								
111	1	1	3	9	90	7	31	41	1.9	10								
112	1	1	3	10	98	3	19	46	1.7	12								
113	1	2	3	11	99	4	23	44	1.6	10								
114	1	2	3	12	85	4	23	47	1.2	9								
115	1	2	3	13	100	7	22	44	1.4	10								
116	1	2	3	16	101	5	27	45	1.2	10								
117	1	2	3	2	107	5	25	54	1.4	10								
118	1	2	3	1	96	4	21	48	1.2	11								
119	1	2	3	3	99	5	27	44	1.6	11								
120	1	2	3	7	94	4	18	41	1.4	10								
121	1	2	3	8	92	4	22	46	1.3	10								
122	1	2	3	5	83	3	15	53	1	11								
123	1	2	3	6	103	4	22	47	1.1	11								
124	1	2	3	4	93	5	24	41	1.3	10								
125	1	2	3	15	100	5	23	56	1.3	10								
126	1	2	3	14	90	4	21	51	1.3	13								
127	1	2	3	10	95	5	25	41	1.9	10								
128	1	2	3	9	96	4	20	46	1.7	12								
129	2	1	3	1	90	5	14	50	1.2	9								
130	2	1	3	2	92	5	21	49	1.3	10								
131	2	1	3	4	79	3	16	45	1.2	11								
132	2	1	3	3	95	3	15	42	1.3	11								
133	2	1	3	10	66	2	9	43	1	10								
134	2	1	3	9	98	4	21	41	1.4	10								
135	2	1	3	12	63	5	19	40	1.1	11								

136	2	1	3	11	103	3	19	42	1.8	10								
137	2	1	3	6	87	5	23	45	1.2	11								
138	2	1	3	5	95	4	18	47	1.4	10								
139	2	1	3	7	110	4	20	45	1.3	10								
140	2	1	3	8	98	3	14	39	1.5	11								
141	2	1	3	13	82	3	16	40	1.6	9								
142	2	1	3	14	88	5	14	54	1.1	10								
143	2	1	3	15	90	2	12	37	1.5	10								
144	2	1	3	16	88	3	15	49	1.2	10								
145	2	2	3	16	77	2	11	40	1	10								
146	2	2	3	1	90	3	14	38	1.4	11								
147	2	2	3	3	85	4	17	43	1.1	10								
148	2	2	3	2	102	4	16	40	1.4	10								
149	2	2	3	6	10	3	16	44	1.6	10								
150	2	2	3	7	99	6	22	45	1.4	10								
151	2	2	3	5	94	7	29	41	1.4	11								
152	2	2	3	15	94	4	21	47	1	11								
153	2	2	3	8	87	4	22	41	1.3	11								
154	2	2	3	4	89	3	17	35	1.6	11								
155	2	2	3	10	79	4	17	45	1.2	9								
156	2	2	3	9	92	5	17	38	1.2	10								
157	2	2	3	11	98	6	29	50	1.4	11								
158	2	2	3	14	99	4	21	37	1.3	11								
159	2	2	3	12	90	4	18	37	1.6	11								
160	2	2	3	13	85	3	18	48	1.2	11								
61	3	1	3	16	94	4	19	51	1.2	10								
162	3	1	3	15	99	4	23	32	1.3	11								
163	3	1	3	14	106	3	15	47	1.6	10								

164	3	1	3	13	99	5	18	38	1.4	10								
165	3	1	3	4	93	5	20	31	1.5	10								
166	3	1	3	1	104	6	26	39	1.5	10								
167	3	1	3	3	96	5	19	43	1.4	11								
168	3	1	3	2	90	5	23	51	1.2	10								
169	3	1	3	5	107	3	15	42	1.4	10								
170	3	1	3	7	92	4	21	33	1.6	10								
171	3	1	3	6	105	3	14	43	1.4	11								
172	3	1	3	8	95	4	23	40	1.5	11								
173	3	1	3	12	105	6	21	47	1.4	11								
174	3	1	3	11	99	3	21	47	1.3	11								
175	3	1	3	10	110	3	16	46	1.5	11								
176	3	1	3	9	99	3	17	44	1.5	11								
177	3	2	3	12	94	5	24	38	1.2	10								
178	3	2	3	9	100	4	20	39	1.3	11								
179	3	2	3	14	99	4	23	39	1.6	11								
180	3	2	3	13	87	3	18	41	1.6	11								
181	3	2	3	10	85	4	19	43	1.1	10								
182	3	2	3	11	91	4	18	37	1.3	10								
183	3	2	3	4	90	5	22	39	1.3	10								
184	3	2	3	3	93	4	22	43	1.2	11								
185	3	2	3	7	100	4	18	44	1.2	11								
186	3	2	3	1	87	4	20	48	1	11								
187	3	2	3	6	83	3	17	38	1	10								
188	3	2	3	16	102	4	20	43	1.2	10								
189	3	2	3	15	101	3	17	46	1.3	10								
190	3	2	3	2	99	3	17	42	1	10								
191	3	2	3	8	94	3	15	40	1.6	11								

192	3	2	3	5	93	3	15	43	1.5	11								
193	1	1	5	5	91	7	23			10	24							
194	1	1	5	8	89	6	20			10	23							
195	1	1	5	7	101	8	33			11	23							
196	1	1	5	6	89	6	24			10	19							
197	1	1	5	2	99	7	24			12	24							
198	1	1	5	1	77	5	10			12	22							
199	1	1	5	3	115	7	27			14	25							
201	1	1	5	4	98	6	23			11	23							
202	1	1	5	16	103	3	13			9	24							
203	1	1	5	14	109	6	18			10	25							
204	1	1	5	15	100	5	23			11	22							
205	1	1	5	13	83	5	17			10	21							
206	1	1	5	11	85	6	17			13	26							
207	1	1	5	12	102	5	17			14	22							
208	1	1	5	9	108	6	31			1	24							
209	1	1	5	10	114	3	16			14	25							
210	1	2	5	11	111	5	17			10	22							
211	1	2	5	12	106	3	13			9	24							
212	1	2	5	13	115	5	21			12	21							
213	1	2	5	16	121	7	22			9	24							
214	1	2	5	2	125	5	21			12	23							
215	1	2	5	1	115	4	18			10	22							
216	1	2	5	3	104	5	24			13	24							
217	1	2	5	7	119	6	19			13	24							
218	1	2	5	8	119	5	17			14	22							
219	1	2	5	5	110	5	17			9	21							
220	1	2	5	6	122	6	17			11	23							

221	1	2	5	4	118	5	23			12	23							
222	1	2	5	15	120	6	25			10	25							
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224	1	2	5	10	118	5	22			10	23							
225	1	2	5	9	122	4	18			11	23							
226	2	1	5	1	93	6	18			12	22							
227	2	1	5	2	113	4	19			9	25							
228	2	1	5	4	95	3	13			8	22							
229	2	1	5	3	112	4	13			14	26							
230	2	1	5	10	79	3	9			7	24							
231	2	1	5	9	118	4	11			12	2							
232	2	1	5	12	87	5	24			12	24							
233	2	1	5	11	119	4	15			10	26							
234	2	1	5	6	115	4	18			10	23							
235	2	1	5	5	116	5	16			14	25							
236	2	1	5	7	121	4	14			15	26							
237	2	1	5	8	117	4	13			13	4							
238	2	1	5	13	107	4	12			10	26							
239	2	1	5	14	100	4	17			10	26							
240	2	1	5	15	110	4	8			12	23							
241	2	1	5	16	111	3	17			14	22							
242	2	2	5	16	101	4	10			12	23							
243	2	2	5	1	104	4	14			11	24							
244	2	2	5	3	103	3	19			10	22							
245	2	2	5	2	119	4	18			11	25							
246	2	2	5	6	114	6	15			12	24							
247	2	2	5	7	122	5	22			10	24							
248	2	2	5	5	119	5	30			10	23							

249	2	2	5	15	118	4	21			11	25							
250	2	2	5	8	115	6	18			10	20							
251	2	2	5	4	104	3	11			12	21							
252	2	2	5	10	106	5	20			9	21							
253	2	2	5	9	119	4	22			10	22							
254	2	2	5	11	124	5	26			11	24							
255	2	2	5	14	111	4	19			9	22							
256	2	2	5	12	115	5	19			10	21							
257	2	2	5	13	108	3	17			0	23							
258	3	1	5	16	97	5	17			11	25							
259	3	1	5	15	108	4	17			10	24							
260	3	1	5	14	116	4	9			12	27							
261	3	1	5	13	116	6	15			10	24							
262	3	1	5	4	103	4	16			11	22							
263	3	1	5	1	113	6	21			13	24							
264	3	1	5	3	112	4	12			10	25							
265	3	1	5	2	119	4	18			12	25							
266	3	1	5	5	119	3	10			10	27							
267	3	1	5	7	106	4	19			10	24							
268	3	1	5	6	113	4	14			12	23							
269	3	1	5	8	120	4	16			11	25							
270	3	1	5	12	122	6	21			11	6							
271	3	1	5	11	119	4	12			14	26							
272	3	1	5	10	123	4	13			9	26							
273	3	1	5	9	114	3	12			12	26							
274	3	2	5	12	100	5	20			9	24							
275	3	2	5	9	119	3	20			10	25							
276	3	2	5	14	14	4	15			12	23							

277	3	2	5	13	116	3	17			12	26							
278	3	2	5	10	105	4	18			9	2							
279	3	2	5	11	110	4	18			10	22							
280	3	2	5	4	115	4	25			10	21							
281	3	2	5	3	120	4	17			11	21							
282	3	2	5	7	119	4	17			10	24							
283	3	2	5	1	114	3	21			13	20							
284	3	2	5	6	95	5	16			12	21							
285	3	2	5	16	119	3	17			11	25							
286	3	2	5	15	119	3	13			12	24							
287	3	2	5	2	117	3	15			13	24							
288	3	2	5	8	112	3	16			2	22							
289	3	2	5	5	106	3	15			14	24							
290	1	1	9	5							20	2.21	61	8	3	2895	6.95	2.74
291	1	1	9	8							19	2.55	47	9	3	3390.1	8.14	2.52
292	1	1	9	7							28	4.12	76	10	3	3681.4	8.84	3.03
293	1	1	9	6							20	3.2	64	8	3	2892.4	6.94	2.93
294	1	1	9	2							30	1.46	42	10	3	3061.4	7.35	2.43
295	1	1	9	1							23	5.3	85	10	3	3490.5	8.38	2.37
296	1	1	9	3							20	2.28	12	9	3	3401.2	8.17	1.27
297	1	1	9	4							15	2.09	48	9	3	2738	6.57	1.52
298	1	1	9	16							24	4.18	54	9	3	3441.3	8.26	2.4
299	1	1	9	14							23	5.3	85	10	3	3729.8	8.96	3.17
300	1	1	9	15							21	3.11	45	10	3	3820.3	9.17	2.74
301	1	1	9	13							23	3.92	63	9	3	2641.6	6.34	1.74
302	1	1	9	11							21	2.59	59	10	3	2614.6	6.28	2.46
303	1	1	9	12							25	4.27	62	10	3	2743.7	6.59	2.75
304	1	1	9	9							24	5.19	76	9	3	3589.1	8.62	2.2

305	1	1	9	10							25	1.82	22	9	3	2622.2	6.3	2.21
306	1	2	9	11							22	4.22	62	10	4	4612.5	5.54	2.88
307	1	2	9	12							26	4.42	47	9	3	5035.8	6.05	2.63
308	1	2	9	13							23	4.31	47	9	4	6376.7	7.66	3.14
309	1	2	9	16							23	3.5	56	9	3	6634	7.96	2.99
310	1	2	9	2							22	3.09	74	9	2	4199	5.04	2.44
311	1	2	9	1							24	4.46	53	9	3	4434.9	5.32	2.44
312	1	2	9	3							23	4.29	70	6	2	4678.1	5.62	1.96
313	1	2	9	7							23	4.83	75	8	3	4415.5	5.3	2.33
314	1	2	9	8							25	4.6	56	9	2	4050.5	4.86	2.87
315	1	2	9	5							21	2.88	38	9	3	5860.1	7.03	3.07
316	1	2	9	6							23	4.06	59	9	4	8247.6	9.9	2.87
317	1	2	9	4							25	4.93	69	9	4	6306.8	7.57	2.49
318	1	2	9	15							24	5.54	60	8	3	4221.9	5.07	2.88
319	1	2	9	14							24	4.22	59	9	3	4372.3	5.25	2.96
320	1	2	9	10							24	4.62	35	9	3	4588.4	5.51	2.44
321	1	2	9	9							21	3.85	60	9	4	3592.5	4.31	2.91
322	2	1	9	1							20	3.41	70	9	3	2614.7	6.28	2.48
323	2	1	9	2							25	4.82	80	10	3	3287.8	7.89	2.38
324	2	1	9	4							21	2.49	65	9	3	4124.9	9.9	2.61
325	2	1	9	3							21	4.53	57	8	3	2129.2	5.11	2.02
326	2	1	9	10							27	3.21	60	9	3	3028.5	7.27	2.31
327	2	1	9	9							23	3.8	71	8	3	3134.6	7.53	2.17
328	2	1	9	12							26	2.65	38	8	3	3566.3	8.56	2.16
329	2	1	9	11							24	2.88	47	9	4	2849.3	6.84	2.42
330	2	1	9	6							21	1.67	51	9	4	3517.8	8.45	2.25
331	2	1	9	5							18	0.9	42	8	2	3608.6	8.66	2.64
332	2	1	9	7							27	3.9	75	9	3	3775.9	9.07	3.02

333	2	1	9	8							23	3.26	39	9	3	2348.8	5.64	2.99
334	2	1	9	13							23	4.14	88	8	2	2390.7	5.74	2.43
335	2	1	9	14							24	2.12	51	9	4	2888.1	6.93	2.36
336	2	1	9	15							24	3.34	84	9	2	3273.4	7.86	2.22
337	2	1	9	16							24	3.6	61	9	3	2640.9	6.34	2.21
338	2	2	9	16							24	2.86	33	9	3	4027.3	4.83	2.56
339	2	2	9	1							25	2.96	38	8	3	4561.6	5.48	2.74
340	2	2	9	3							24	4.32	77	8	2	4579.1	5.5	2.72
341	2	2	9	2							24	3.8	47	10	3	4644.8	5.58	2.71
342	2	2	9	6							24	4.04	64	9	3	4072.1	4.89	2.39
343	2	2	9	7							22	3.89	54	10	3	4145.3	4.98	2.37
344	2	2	9	5							23	3.9	59	9	4	4723.4	5.67	2.37
345	2	2	9	15							20	2.35	40	10	3	4532.8	5.44	2.31
346	2	2	9	8							23	4.3	85	9	3	3743.8	4.49	2.31
347	2	2	9	4							22	3.46	61	8	3	4341.2	5.21	2.43
348	2	2	9	10							24	3.22	51	8	3	4483	5.38	2.46
349	2	2	9	9							23	4.12	71	8	3	6042	7.25	2.46
350	2	2	9	11							22	4.8	53	8	3	4509.2	5.41	2.63
351	2	2	9	14							18	3.97	82	9	3	4650.4	5.58	2.62
352	2	2	9	12							23	4.7	46	9	3	4667.2	5.6	2.27
353	2	2	9	13							27	3.22	50	10	3	3496.1	4.2	3.15
354	3	1	9	16							24	2.13	43	9	4	2516.7	6.04	2.74
355	3	1	9	15							24	4.01	85	10	3	3032.2	7.28	2.96
356	3	1	9	14							25	1.29	0	9	3	2826.3	6.79	2.96
357	3	1	9	13							24	2.2	39	9	3	3460.7	8.31	3.11
358	3	1	9	4							23	2.69	63	9	4	3201.3	7.69	2.36
359	3	1	9	1							23	5.84	73	9	3	3696.4	8.88	2.36
360	3	1	9	3							25	2.77	66	8	2	3875.1	9.3	2.22

361	3	1	9	2							26	3.18	68	7	3	2990.3	7.18	2.31
362	3	1	9	5							26	3.85	70	9	4	3651.2	8.77	2.29
363	3	1	9	7							26	4.73	76	8	3	3879.4	9.31	2.36
364	3	1	9	6							24	1.62	54	9	3	3799.1	9.12	2.31
365	3	1	9	8							23	3.2	85	10	4	3235.7	7.77	2.62
366	3	1	9	12							24	3.12	81	10	3	2340.2	5.62	2.26
367	3	1	9	11							23	3.5	65	8	3	2566.8	6.16	2.16
368	3	1	9	10							22	3.51	78	9	2	2938.5	7.06	2.62
369	3	1	9	9							22	1.56	25	8	3	2579.1	6.19	2.18
370	3	2	9	12							25	4	48	9	3	3910.7	4.69	2.9
371	3	2	9	9							23	4.13	64	8	2	4324.8	5.19	2.61
372	3	2	9	14							25	4.47	64	9	3	4416.9	5.3	2.89
373	3	2	9	13							23	3.51	43	10	3	3524.2	4.23	2.62
374	3	2	9	10							24	3.8	69	10	3	3953.7	4.75	2.85
375	3	2	9	11							25	2.93	21	10	4	4370.3	5.25	2.49
376	3	2	9	4							23	4.1	52	8	3	4426.9	5.31	2.85
377	3	2	9	3							22	3.09	79	9	3	4184	5.02	2.71
378	3	2	9	7							19	2.3	47	9	3	3947.3	4.74	2.71
379	3	2	9	1							18	1.57	34	8	3	3997.9	4.8	2.53
280	3	2	9	6							24	4.1	62	9	4	4064.6	4.88	2.54
381	3	2	9	16							24	3.83	63	8	3	3651.9	4.38	3.14
382	3	2	9	15							24	4.69	77	10	4	4188.2	5.03	3.1
383	3	2	9	2							24	4.47	81	9	3	4464.7	5.36	2.12
384	3	2	9	8							24	4.69	77	10	4	4090.4	4.91	2.76
385	3	2	9	5							25	3.32	50	9	3	3345.5	4.02	2.25

Appendix 8 (II): Raw data Season two

SN	Block	WaterL	FR	DAS	Height	TillerNo	No.Leaves	PanicleL	Leaf L	Leaf W	LeguleL	CulmNo.	CulmL	GrainL	GrainW	Yield	WUE	Wt100Gr
1	1	1	5	2	72	3	12											
2	1	1	8	2	68	3	11											
3	1	1	7	2	71	4	12											
4	1	1	6	2	72	3	17											
5	1	1	2	2	73	6	26											
6	1	1	1	2	68	3	11											
7	1	1	3	2	70	3	13											
8	1	1	4	2	75	5	21											
9	1	1	16	2	74	3	15											
10	1	1	14	2	69	3	17											
11	1	1	15	2	73	4	13											
12	1	1	13	2	72	3	14											
13	1	1	11	2	75	3	18											
14	1	1	12	2	70	4	14											
15	1	1	9	2	68	3	13											
16	1	1	10	2	74	3	12											
17	1	2	11	2	70	3	14											
18	1	2	12	2	81	4	21											
19	1	2	13	2	75	3	13											
20	1	2	16	2	75	3	14											
21	1	2	2	2	79	3	11											
22	1	2	1	2	55	2	9											
23	1	2	3	2	71	2	7											
24	1	2	7	2	71	4	13											
25	1	2	8	2	51	5	20											

26	1	2	5	2	88	4	16											
27	1	2	6	2	75	4	16											
28	1	2	4	2	74	3	18											
29	1	2	15	2	81	4	13											
30	1	2	14	2	77	2	13											
31	1	2	10	2	74	2	8											
32	1	2	9	2	63	3	13											
33	2	1	1	2	74	3	14											
34	2	1	2	2	66	3	12											
35	2	1	4	2	78	6	23											
36	2	1	3	2	73	4	18											
37	2	1	10	2	75	4	13											
38	2	1	9	2	78	3	14											
39	2	1	12	2	76	4	19											
40	2	1	11	2	46	3	11											
41	2	1	6	2	75	4	14											
42	2	1	5	2	68	3	15											
43	2	1	7	2	73	4	16											
44	2	1	8	2	70	3	13											
45	2	1	13	2	72	4	14											
46	2	1	14	2	63	3	13											
47	2	1	15	2	69	4	14											
48	2	1	16	2	75	2	9											
49	2	2	16	2	64	3	12											
50	2	2	1	2	74	4	17											
51	2	2	3	2	59	3	10											
52	2	2	2	2	82	5	22											
53	2	2	6	2	80	4	18											

54	2	2	7	2	63	3	11											
55	2	2	5	2	71	3	12											
56	2	2	15	2	78	3	13											
57	2	2	8	2	64	3	12											
58	2	2	4	2	77	5	21											
59	2	2	10	2	69	3	11											
60	2	2	9	2	80	4	15											
61	2	2	11	2	74	3	13											
62	2	2	14	2	64	2	9											
63	2	2	12	2	72	2	9											
64	2	2	13	2	74	2	9											
65	3	1	16	2	75	4	19											
66	3	1	15	2	74	3	11											
67	3	1	14	2	75	4	19											
68	3	1	13	2	70	3	14											
69	3	1	4	2	68	3	14											
70	3	1	1	2	72	4	16											
71	3	1	3	2	71	3	15											
72	3	1	2	2	72	3	13											
73	3	1	5	2	64	3	11											
74	3	1	7	2	77	4	15											
75	3	1	6	2	70	3	15											
76	3	1	8	2	75	3	15											
77	3	1	12	2	71	3	9											
78	3	1	11	2	63	2	11											
79	3	1	10	2	72	3	11											
80	3	1	9	2	62	2	8											
81	3	2	12	2	69	3	13											

82	3	2	9	2	71	4	16											
83	3	2	14	2	71	4	14											
84	3	2	13	2	70	11	12											
85	3	2	10	2	64	3	11											
86	3	2	11	2	67	4	14											
87	3	2	4	2	89	4	20											
88	3	2	3	2	65	4	14											
89	3	2	7	2	66	3	10											
90	3	2	1	2	60	1	7											
91	3	2	6	2	87	3	11											
92	3	2	16	2	73	4	12											
93	3	2	15	2	54	2	7											
94	3	2	2	2	70	3	13											
95	3	2	8	2	66	2	10											
96	3	2	5	2	88	2	12											
97	1	1	5	3	74	5	18											
98	1	1	8	3	72	5	17											
99	1	1	7	3	70	4	18											
100	1	1	6	3	84	8	24											
101	1	1	2	3	82	6	31											
102	1	1	1	3	75	4	15											
103	1	1	3	3	71	5	19											
104	1	1	4	3	82	7	30											
105	1	1	16	3	76	5	19											
106	1	1	14	3	81	4	18											
107	1	1	15	3	70	4	17											
108	1	1	13	3	71	4	18											
1089	1	1	11	3	79	8	20											

110	1	1	12	3	73	4	16											
111	1	1	9	3	72	4	22											
112	1	1	10	3	73	4	18											
113	1	2	11	3	73	3	15											
114	1	2	12	3	84	6	25											
115	1	2	13	3	76	3	17											
116	1	2	16	3	77	4	20											
117	1	2	2	3	74	3	13											
118	1	2	1	3	63	2	10											
119	1	2	3	3	59	3	10											
120	1	2	7	3	80	5	22											
122	1	2	8	3	93	7	27											
123	1	2	5	3	77	5	25											
124	1	2	6	3	78	4	20											
125	1	2	4	3	71	4	17											
26	1	2	15	3	86	4	19											
127	1	2	14	3	86	5	18											
128	1	2	10	3	78	3	14											
129	1	2	9	3	76	4	16											
130	2	1	1	3	80	4	21											
131	2	1	2	3	75	3	13											
132	2	1	4	3	85	6	31											
133	2	1	3	3	80	4	21											
134	2	1	10	3	83	5	23											
135	2	1	9	3	85	5	23											
136	2	1	12	3	84	4	22											
137	2	1	11	3	50	3	16											
138	2	1	6	3	72	4	18											

139	2	1	5	3	68	3	20											
140	2	1	7	3	83	5	22											
141	2	1	8	3	73	3	16											
142	2	1	13	3	77	5	24											
143	2	1	14	3	82	3	14											
144	2	1	15	3	76	4	17											
145	2	1	16	3	78	3	11											
146	2	2	16	3	63	3	12											
147	2	2	1	3	78	6	27											
148	2	2	3	3	71	3	13											
149	2	2	2	3	86	7	32											
150	2	2	6	3	80	6	26											
151	2	2	7	3	83	9	35											
152	2	2	5	3	80	4	15											
153	2	2	15	3	85	3	13											
154	2	2	8	3	70	3	14											
155	2	2	4	3	83	7	30											
156	2	2	10	3	74	4	16											
157	2	2	9	3	80	7	26											
158	2	2	11	3	73	4	18											
159	2	2	14	3	67	3	14											
160	2	2	12	3	73	3	10											
161	2	2	13	3	82	2	8											
162	3	1	16	3	83	3	15											
163	3	1	15	3	78	3	17											
164	3	1	14	3	81	5	25											
165	3	1	13	3	73	3	16											
166	3	1	4	3	105	4	16											

167	3	1	1	3	82	4	22											
168	3	1	3	3	86	5	28											
169	3	1	2	3	75	4	23											
170	3	1	5	3	85	4	21											
171	3	1	7	3	79	4	18											
172	3	1	6	3	80	4	19											
173	3	1	8	3	78	4	20											
174	3	1	12	3	78	3	13											
175	3	1	11	3	64	3	13											
176	3	1	10	3	74	2	15											
177	3	1	9	3	73	2	12											
178	3	2	12	3	82	6	32											
179	3	2	9	3	79	5	21											
180	3	2	14	3	85	5	23											
181	3	2	13	3	81	7	35											
182	3	2	10	3	75	4	17											
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185	3	2	3	3	76	5	19											
186	3	2	7	3	83	3	11											
187	3	2	1	3	70	2	11											
188	3	2	6	3	79	3	12											
189	3	2	16	3	84	2	10											
190	3	2	15	3	74	2	9											
191	3	2	2	3	84	4	14											
192	3	2	8	3	74	4	16											
193	3	2	5	3	70	2	7											
194	1	1	5	5	74	3	14											

195	1	1	8	5	75	4	15											
196	1	1	7	5	77	4	14											
197	1	1	6	5	94	6	20											
198	1	1	2	5	92	7	29											
199	1	1	1	5	91	5	16											
200	1	1	3	5	89	4	14											
201	1	1	4	5	89	12	46											
202	1	1	16	5	93	6	24											
203	1	1	14	5	80	3	12											
204	1	1	15	5	90	5	19											
205	1	1	13	5	79	4	15											
206	1	1	11	5	87	7	27											
207	1	1	12	5	86	4	15											
208	1	1	9	5	88	5	19											
209	1	1	10	5	94	5	16											
210	1	2	11	5	83	3	13											
211	1	2	12	5	100	7	24											
212	1	2	13	5	88	4	20											
213	1	2	16	5	100	5	17											
214	1	2	2	5	98	3	13											
215	1	2	1	5	85	3	10											
216	1	2	3	5	85	3	13											
217	1	2	7	5	86	4	16											
218	1	2	8	5	98	7	23											
219	1	2	5	5	94	7	22											
220	1	2	6	5	98	5	19											
221	1	2	4	5	98	4	15											
222	1	2	15	5	96	4	16											

223	1	2	14	5	92	5	19											
224	1	2	10	5	87	4	16											
225	1	2	9	5	85	4	16											
226	2	1	1	5	95	4	17											
227	2	1	2	5	75	7	30											
228	2	1	4	5	96	5	22											
229	2	1	3	5	86	5	18											
230	2	1	10	5	94	5	19											
231	2	1	9	5	79	4	16											
232	2	1	12	5	85	5	18											
233	2	1	11	5	98	5	21											
234	2	1	6	5	83	4	14											
235	2	1	5	5	93	9	6											
236	2	1	7	5	94	5	17											
237	2	1	8	5	96	6	21											
238	2	1	13	5	82	4	15											
239	2	1	14	5	98	4	18											
240	2	1	15	5	89	3	10											
241	2	1	16	5	90	3	11											
242	2	2	16	5	86	6	25											
243	2	2	1	5	95	7	22											
244	2	2	3	5	77	7	19											
245	2	2	2	5	89	8	25											
246	2	2	6	5	76	5	16											
247	2	2	7	5	98	10	37											
248	2	2	5	5	93	4	16											
249	2	2	15	5	96	4	16											
250	2	2	8	5	82	5	19											

251	2	2	4	5	96	9	28											
252	2	2	10	5	74	4	14											
253	2	2	9	5	94	8	25											
254	2	2	11	5	91	4	17											
255	2	2	14	5	86	4	15											
256	2	2	12	5	90	3	12											
257	2	2	13	5	100	2	8											
258	3	1	16	5	88	4	17											
259	3	1	15	5	89	3	13											
260	3	1	14	5	91	6	22											
261	3	1	13	5	91	5	15											
262	3	1	4	5	94	7	23											
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266	3	1	5	5	80	4	15											
267	3	1	7	5	82	11	38											
268	3	1	6	5	78	5	20											
269	3	1	8	5	87	4	17											
270	3	1	12	5	90	4	16											
271	3	1	11	5	86	3	12											
272	3	1	10	5	85	5	15											
273	3	1	9	5	81	5	15											
274	3	2	12	5	86	3	12											
275	3	2	9	5	91	6	24											
276	3	2	14	5	92	6	21											
277	3	2	13	5	88	8	28											
278	3	2	10	5	95	4	16											

279	3	2	11	5	87	5	18											
280	3	2	4	5	80	3	11											
281	3	2	3	5	92	4	20											
282	3	2	7	5	85	4	15											
283	3	2	1	5	85	3	11											
284	3	2	6	5	89	3	12											
285	3	2	16	5	88	4	18											
286	3	2	15	5	80	3	11											
287	3	2	2	5	91	4	15											
288	3	2	8	5	88	5	18											
289	3	2	5	5	82	2	9											
290	1	1	5	9	107	4	21	25	38	1.8	0.6	4	33	7	3	3776.4	9.07	2.44
291	1	1	8	9	106	4	16	27	43	2	1.3	4	58	9	3	2153.5	5.17	2.56
292	1	1	7	9	99	4	11	22	29	1.5	1.1	4	72	9	3	2352.9	5.65	2.32
293	1	1	6	9	106	4	14	24	44	2	1	4	65	9	3	2284.1	5.48	2.82
294	1	1	2	9	110	6	20	23	40	2	1.3	6	71	9	3	1645.9	3.95	2.46
295	1	1	1	9	121	5	16	27	46	2	1.3	5	79	9	3	1614.6	3.88	2.37
296	1	1	3	9	99	4	13	21	37	2	1.2	4	57	8	2	3368.1	8.09	2.61
297	1	1	4	9	109	4	19	25	39	1.7	1.4	4	69	8	3	1829.9	4.39	2.81
298	1	1	16	9	112	5	15	23	38	1.8	1.5	5	80	9	3	945.9	2.27	2.37
299	1	1	14	9	90	3	11	23	28	1.6	1.1	3	62	8	3	2260.5	5.43	2.44
300	1	1	15	9	99	4	10	20	37	2	1.4	4	55	9	3	1829.9	4.39	2.96
301	1	1	13	9	95	4	19	20	28	1.6	1.2	4	70	8	3	1659.8	3.99	2.02
302	1	1	11	9	106	4	15	25	37	1.8	1.2	4	71	8	3	2906.4	6.98	2.42
303	1	1	12	9	99	4	12	22	27	1.6	1.1	4	70	9	3	2368.1	5.69	2.36
304	1	1	9	9	111	4	18	24	32	1.9	1.6	4	82	9	3	1291.7	3.1	2.52
305	1	1	10	9	113	5	16	28	46	2	1.2	4	78	9	3	2452.9	5.89	1.96
306	1	2	11	9	94	4	13	23	40	1.4	1.3	4	80	8	3	3614.6	4.34	2.79

307	1	2	12	9	120	4	15	26	38	2	1.4	4	83	8	3	1752.9	2.1	2.68
308	1	2	13	9	117	4	14	27	35	1.9	1.2	4	85	9	3	2207	2.65	2.8
309	1	2	16	9	124	4	13	26	43	2	1.4	4	87	9	3	1507	1.81	2.99
310	1	2	2	9	121	3	9	26	41	2.1	1.4	3	86	9	3	1507	1.81	2.52
311	1	2	1	9	117	3	15	24	41	1.7	1.3	3	81	9	3	2152.9	2.58	2.49
312	1	2	3	9	116	3	9	27	46	2	1.3	3	79	9	3	2260.5	2.71	2.72
313	1	2	7	9	118	3	14	26	35	1.7	1.2	3	88	9	3	4121.6	4.95	3.02
314	1	2	8	9	123	4	16	27	37	1.2	1.2	4	92	9	3	1614.6	1.94	2.86
315	1	2	5	9	110	4	16	26	38	2	1.2	4	78	9	3	2691.1	3.23	2.54
316	1	2	6	9	125	4	15	25	28	1.8	1.1	4	88	9	3	3552.2	4.26	2.67
317	1	2	4	9	119	3	14	24	36	1.3	1	3	93	9	3	3336.9	4.01	2.72
318	1	2	15	9	127	4	17	25	40	1.2	0.9	4	79	9	3	3444.6	4.14	2.49
319	1	2	14	9	114	5	25	24	35	1.8	1.4	5	83	8	3	2668.1	3.2	2.1
320	1	2	10	9	116	4	12	25	20	2	1.2	4	84	9	3	3691.1	4.43	3.02
321	1	2	9	9	120	4	21	24	42	2	1.1	4	83	9	3	1184.1	1.42	3.11
322	2	1	1	9	109	4	12	24	38	1.9	0.9	4	74	9	3	1861.1	4.47	2.36
323	2	1	2	9	109	7	33	24	30	1.8	0.8	7	77	8	3	2275.8	5.46	2.39
324	2	1	4	9	108	4	17	22	33	1.5	1.3	4	68	8	3	2152.9	5.17	2.51
325	2	1	3	9	106	4	18	23	35	1.7	1.2	4	76	10	3	3552.2	8.53	2.1
326	2	1	10	9	118	4	15	27	35	1.5	1.4	4	81	9	3	2798.7	6.72	2.49
327	2	1	9	9	99	3	16	16	25	1.4	0.8	3	67	8	3	1291.7	3.1	2.37
328	2	1	12	9	109	5	20	25	33	1.8	1.7	5	77	8	3	2759.2	6.62	2.74
329	2	1	11	9	111	4	18	25	37	1.3	1.5	4	81	9	3	3336.9	8.01	2.17
330	2	1	6	9	107	4	17	23	41	1.5	1.2	4	86	8	3	2583.4	6.2	2.12
331	2	1	5	9	108	9	44	27	26	1.9	1	9	82	9	3	3982.8	9.56	2.22
332	2	1	7	9	118	4	16	23	33	1.3	1.4	4	77	9	3	2691.1	6.46	2.96
333	2	1	8	9	114	4	21	24	33	1.8	1.9	4	85	9	3	2045.2	4.91	2.63
334	2	1	13	9	108	4	19	25	33	1.4	1.1	4	75	9	3	1767.5	4.24	2.41

335	2	1	14	9	109	4	17	22	38	1.8	1.1	4	72	9	3	2090.4	5.02	2.37
336	2	1	15	9	107	3	10	22	37	1.2	1.3	3	70	9	3	1691.7	4.06	2.42
337	2	1	16	9	113	4	18	27	43	1.8	1.1	4	75	9	3	1076.4	2.58	2.18
338	2	2	16	9	106	7	25	24	32	1.9	1	7	73	8	3	1291.7	1.55	2.49
339	2	2	1	9	113	7	26	24	37	1.7	1.2	7	82	7	3	2414	2.9	2.7
340	2	2	3	9	103	4	20	23	31	1.8	1.1	4	84	8	3	2906.4	3.49	2.7
341	2	2	2	9	113	6	24	24	31	1.6	1.2	6	75	7	3	2059.2	2.47	2.46
342	2	2	6	9	102	5	22	22	30	1.8	1.3	5	76	9	3	3214	3.86	2.56
343	2	2	7	9	121	10	34	23	41	1.9	1.3	10	91	9	3	4413.3	5.3	3.01
344	2	2	5	9	123	4	16	23	33	2	1.3	4	90	9	3	3382.8	4.06	2.72
345	2	2	15	9	117	4	12	22	33	2	1	4	87	9	3	3875.1	4.65	2.31
346	2	2	8	9	112	4	20	21	34	2	0.9	4	73	8	3	2521	3.03	2.31
347	2	2	4	9	117	9	35	25	33	1.8	1.1	9	80	9	3	3575.1	4.29	2.17
348	2	2	10	9	96	4	20	24	30	1.7	0.6	4	70	9	3	4336.3	5.21	3.02
349	2	2	9	9	118	7	28	28	41	1.7	1.4	7	96	9	3	1445.2	1.73	2.72
350	2	2	11	9	124	4	12	25	40	2	1.5	4	91	9	2	3767.5	4.52	2.21
351	2	2	14	9	99	4	15	23	36	1.7	1.3	4	71	9	2	3843.9	4.61	2.63
352	2	2	12	9	117	3	10	23	42	2	1	3	85	9	3	1829.9	2.2	2.69
353	2	2	13	9	129	2	10	27	32	2	1.8	2	82	9	3	2583.4	3.1	3.11
354	3	1	16	9	110	4	13	21	26	1.5	1.7	4	67	9	3	1129.9	2.71	2.31
355	3	1	15	9	110	3	10	25	32	2	1.1	3	77	9	3	1829.9	4.39	2.12
356	3	1	14	9	96	6	21	21	31	1.4	1.1	6	64	8	3	2045.2	4.91	2.46
357	3	1	13	9	109	4	20	25	36	2	1.3	4	77	10	3	1076.4	2.58	2.67
358	3	1	4	9	113	4	17	22	31	1.5	1.4	4	79	10	3	2359.8	5.67	2.33
359	3	1	1	9	122	4	13	23	41	2	1.6	4	85	9	3	1714	4.12	2.27
360	3	1	3	9	99	4	16	21	30	2	1	4	74	9	3	3790.4	9.1	2.12
361	3	1	2	9	89	2	11	21	29	1.6	1	2	65	9	3	1829.9	4.39	2.11
362	3	1	5	9	109	4	14	24	33	1.9	0.9	4	80	8	3	4436.3	10.7	2.01

363	3	1	7	9	99	7	19	24	30	1.7	0.4	7	75	10	3	2821	6.77	2.73
364	3	1	6	9	98	5	19	26	29	1.4	1.6	5	72	9	3	2921	7.01	2.65
365	3	1	8	9	122	4	12	25	33	1.8	1	4	90	9	3	2591.1	6.22	2.51
366	3	1	12	9	117	4	25	25	40	2	1	4	85	8	3	2536.9	6.09	2.37
367	3	1	11	9	118	5	14	26	44	2	1.3	5	96	8	3	2937.6	7.05	2.72
368	3	1	10	9	113	4	13	26	36	1.6	1.2	4	82	8	2	2990.4	7.18	2.24
369	3	1	9	9	115	5	15	26	34	1.9	1	5	80	9	3	1291.7	3.1	2.2
370	3	2	12	9	83	2	8	24	22	1.5	0.7	2	54	9	3	1391.7	1.67	2.31
371	3	2	9	9	110	5	26	28	43	2	1.2	5	76	8	3	1076.4	1.29	2.47
372	3	2	14	9	108	6	25	24	31	2	1.1	6	74	8	3	2668.1	3.2	2.8
373	3	2	13	9	109	8	36	25	38	2	1	8	78	9	3	2691.1	3.23	2.72
374	3	2	10	9	121	5	20	23	46	2.1	1.4	5	76	9	2	3714	4.46	2.44
375	3	2	11	9	120	6	24	24	42	2	1.5	6	91	8	3	3444.6	4.14	2.44
376	3	2	4	9	110	3	14	26	46	2	1.3	3	79	9	3	2775.8	3.33	2.18
377	3	2	3	9	117	5	20	28	44	2	1.4	5	80	9	3	2583.4	3.1	3.12
378	3	2	7	9	99	4	14	26	37	2	1.3	4	70	9	2	4121.6	4.95	2.63
379	3	2	1	9	114	3	12	26	38	2	1	3	81	9	3	1722.3	2.07	2.75
380	3	2	6	9	105	2	9	21	36	2	1.2	2	72	9	3	3552.2	4.26	2.77
381	3	2	16	9	113	5	20	21	38	1.9	1.2	5	85	8	3	1229.3	1.48	2.66
382	3	2	15	9	108	3	16	25	38	2	1	3	75	9	3	3106.4	3.73	2.55
383	3	2	2	9	129	6	21	30	50	2	1.7	6	81	9	3	1753.5	2.11	2.73
384	3	2	8	9	109	2	8	23	42	2	1.6	2	72	8	3	2659.8	3.19	2.74
385	3	2	5	9	110	2	10	28	47	2.2	1.1	2	69	9	3	2591.7	3.11	2.73

Appendix8 (III): Raw data for Field Experiment

Block	Rep	CulmL	PanicleL	TillerN	FilledG	FilledWt	EmptyG	EmptyWt	StrawWt	Total Gf	GrainF	Yield
1	1	79.8	25.5	8.1	341.9	9.8	938.4	4.0	37.3	1280.3	.27	1.5
1	2	81.1	26.4	8.0	821.6	24.0	650.3	4.4	35.6	1471.9	.56	3.7
1	3	73.5	25.3	6.9	399.4	11.8	668.9	3.2	36.5	1068.3	.37	1.8
2	1	71.4	23.2	8.0	998.8	28.7	241.2	1.5	16.7	1240.0	.81	4.5
2	2	81.8	21.7	9.4	1326.9	38.1	214.6	1.3	19.7	1541.5	.86	6.0
2	3	70.7	22.7	5.7	803.4	24.1	101.0	0.7	15.0	904.4	.89	3.6
3	1	77.2	27.0	9.0	947.6	37.5	183.4	1.2	25.1	1131.0	.84	4.3
3	2	74.5	26.3	9.7	1082.8	36.3	324.6	1.7	23.2	1407.4	.77	4.9
3	3	65.9	24.3	8.8	805.1	26.2	358.5	2.2	25.2	1163.6	.69	3.6

Appendix 8 (IV): Raw data for post-harvest soil analysis and Nutrients uptake in straw and grain

S.No.	Block	WaterL	FR	PH	N	P	K	EC
1	1	1	1	6.1	0.012	150	2.926	156
2	1	1	2	5.8	0.077	145	2.205	202
3	1	1	3	6.5	0.175	175	2.544	71
4	1	2	1	6.1	0.102	115	1.866	116
5	1	2	2	6.1	0.063	90	1.95	92
6	1	2	3	6.2	0.203	140	1.95	116
7	2	1	1	6.3	0.193	170	3.307	180
8	2	1	2	6	0.13	140	1.526	112
9	2	1	3	6	0.161	135	3.053	167
10	2	2	1	5.8	0.14	130	1.611	93
11	2	2	2	6.2	0.15	150	1.187	68
12	2	2	3	6	0.168	140	2.205	139
13	3	1	1	6	0.175	145	2.968	215
14	3	1	2	6	0.217	175	1.526	174
15	3	1	3	6.8	0.161	200	3.986	80
16	3	2	1	6.1	0.158	120	2.459	115
17	3	2	2	6.1	0.147	210	2.459	80
18	3	2	3	6.2	0.168	185	2.205	95

S.No.	Block	WaterL	FR	N	K	P
1	1	1	1	0.56	1.487	0.249
2	1	1	2	1.15	0.66	0.233
3	1	1	3	1.2	0.528	0.649
4	1	1	4	0.68	0.661	0.194
5	2	1	1	0.86	0.367	0.312
6	2	1	2	0.75	1.88	0.339

7	2	1	3	1.24	1.254	0.289
8	2	1	4	1.62	0.572	0.312
9	3	1	1	0.62	0.529	0.282
10	3	1	2	0.95	1.23	0.265
11	3	1	3	0.98	0.85	0.464
12	3	1	4	1.24	0.615	0.253
13	1	2	1	0.86	1.235	0.555
14	1	2	2	0.79	1.439	0.504
15	1	2	3	0.99	0.015	0.65
16	1	2	4	0.56	0.345	0.312
17	2	2	1	1.18	0.72	0.602
18	2	2	2	0.43	2.502	0.679
19	2	2	3	0.92	0.011	0.505
20	2	2	4	1.4	0.27	0.61
21	3	2	1	1.1	0.94	0.593
22	3	2	2	1.1	1.95	0.575
23	3	2	3	0.9	0.013	0.32
24	3	2	4	1.83	0.31	0.453

S.No.	Season	WaterL	FR	CP
1	1	1	1	14.12
2	1	1	2	11.63
3	1	1	3	18.37
4	1	1	4	12.78
5	1	2	1	9.67
6	1	2	2	11.96
7	1	2	3	11.91
8	1	2	4	10.71
9	2	1	1	11.01

0	2	1	2	13.26
11	2	1	3	10.53
12	2	1	4	11.5
13	2	2	1	10.49
14	2	2	2	13.94
15	2	2	3	10.51
16	2	2	4	11.6