# EFFECT OF PLANT DENSITIES ON GROWTH AND YIELD POTENTIAL OF NERICA 10 RICE VARIETY (*Oryza sativa* L.) IN TAITA TAVETA COUNTY

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**A thesis submitted in partial fulfillment of the requirements for the Degree of**
**Master of Science in Agronomy of Pwani University**

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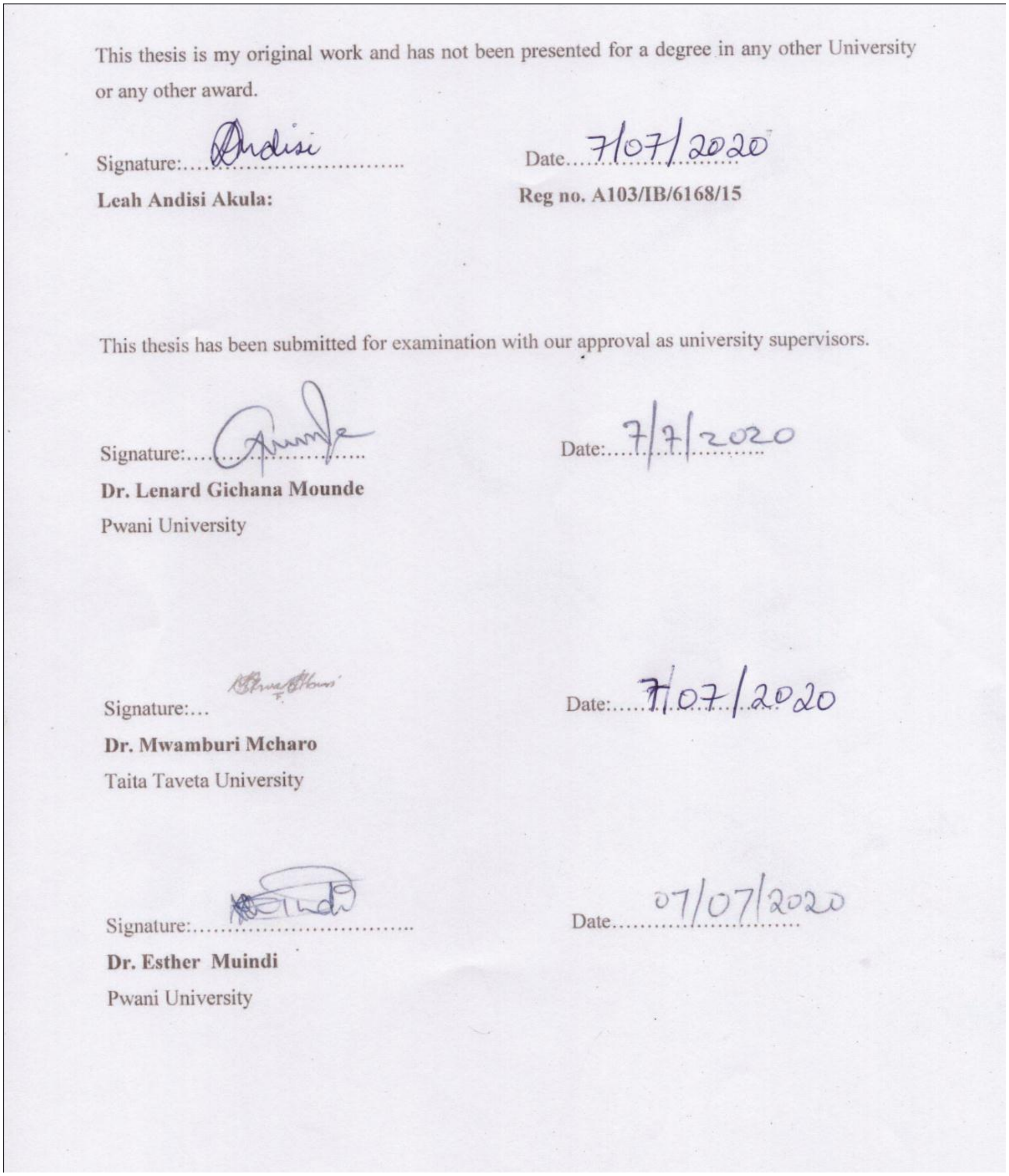
# DECLARATION



This thesis is my original work and has not been presented for a degree in any other University or any other award.

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# DEDICATION

I dedicate this thesis to my late parents, Mr. Joram Akula and Mrs. Efalina Akula.

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## ABBREVIATIONS

| | |
|---|---|
| ARC | Africa Rice Center |
| ANOVA | Analysis of Variance |
| CIDP | County Integrated Development plan |
| CV | Coefficient of variation |
| DAS | Days after seeding |
| FAO | Food for Agriculture Organization |
| g | grams |
| GLM | General Linear Model |
| ha | Hectare |
| IPCC | International Panel for Climate Change |
| IRRI | International Rice Research Institute |
| KALRO | Kenya Agricultural & Livestock Research Organization |
| KNBS | Kenya National Bureau of Statistics |
| Kg | Kilogram |
| MSD | Mean significant difference |
| NARL | National Agricultural Research Laboratories |
| Nerica | New Rice for Africa |
| NIB | National Irrigation Board |
| ns | Non significant |
| MOA | Ministry of Agriculture |
| RCBD | Randomized Complete Block Design |
| SAS | Statistical Analysis Software |

# ABSTRACT

Rice grain annual requirement in Kenya exceeds production, and is expected to increase from the current 0.55 million tonnes to 517.5 million tonnes by 2030 (KBS, 2016). In order to contribute to the rice deficit gap an experiment was carried out in Dembwa and Kipusi, Taita Taveta County in Kenya during the 2019 long rain season. Kipusi is situated at an altitude of 846m above sea level, on $3^o28'45.8''$S latitude and $38^o22'56.4''$E longitude while Dembwa is at an altitude of 1,088m above sea level on $3^o26'50.3''$S latitude and $38^o21'46.4''$E longitude. The purpose of the study was to evaluate the yield potential of the New Rice for Africa (Nerica 10) under selected plant densities within the County. The treatments included plant spacing, seeding rate per hill and their interaction. These treatments were laid out in Randomized Complete Block Design (RCBD) with factorial arrangement and replicated three times. Data collected included: Initial soil chemical characteristics, plant height, number of tillers per hill, days to 50% heading, days to 80% maturity, panicle length, grains per panicle, 1000 grain weight, grain and straw yield. Collected data was subjected to analysis of variance using the procedure for General Linear Model and significant means at F-test were separated using Tukey's test. All significant analysis was performed at $p$=0.05. The results showed that plant spacing of 20 cm x 10 cm at single seedlings per hill significantly ($p \leq 0.05$) improved rice grain yield, dry biomass, straw yield and 1000grain weight by 58%, 33%, 37% and 24% respectively. The 20 cm x 10 cm spacing showed 23% higher harvest Index than farmers practice of 30 cm x 15 cm spacing. Therefore the interaction between 20 cm x 10 cm spacing and single seedling per hill was found to be the most effective for cultivation of Nerica 10 rice in Taita Taveta County.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background information

Rice crop is a grass belonging to genus *Oryzae* in the *Poacea* family. The genus contains twenty three species out of which two are cultivated. The cultivated species are *Oryza sativa* and *Oryza glaberrima* (Fuller, 2011). *Oryza sativa* comprises sub species *indica* and *japonica*, and is grown all over the world while *Oryza glaberrima* is commonly grown in West Africa. *Oryza Sativa* originated from Korea, Japan and India about 130 million years ago and spread as a wild grass in Asia, Australia and Antarctica (Singh *et al*., 2018). On the other hand, the *Oryza glaberrima* originated from the inland Delta of Niger river in Africa and its widespread in the flooded plains of West Africa (Yang *et al*., 2018).

Rice (*Oryza sativa* L.) is one of the most important agricultural food crops consumed by more than half of the global population and whose demand increases with increase in human population (Seck *et al*., 2013). It is second to wheat in terms of area under cultivation and it provides more calories per hectare(ha) than any other crop (Raman, 2014). According to Dipti *et al*. (2012), rice is the main source of calories and micronutrients to large population of people in Africa. Apart from direct use of rice grain, it is processed into snacks, brewed beverages, flour and oil. Rice straws are used as animal feed or they can be ploughed back to the soil as mulch. They can also be used for weaving baskets and hats. The husks can be used as a substrate in mushroom farming or as fuel source (Danbaba *et al*., 2019. The trend of rice production in Kenya from 1961 to 2013 is as shown in Figure 1.1. The total rice produced increased by about 70% from 21,800 tons to 146,900 tons. The overall increase in production is majorly attributed to the increase in total area under rice cultivation (Atera *et al*., 2017).

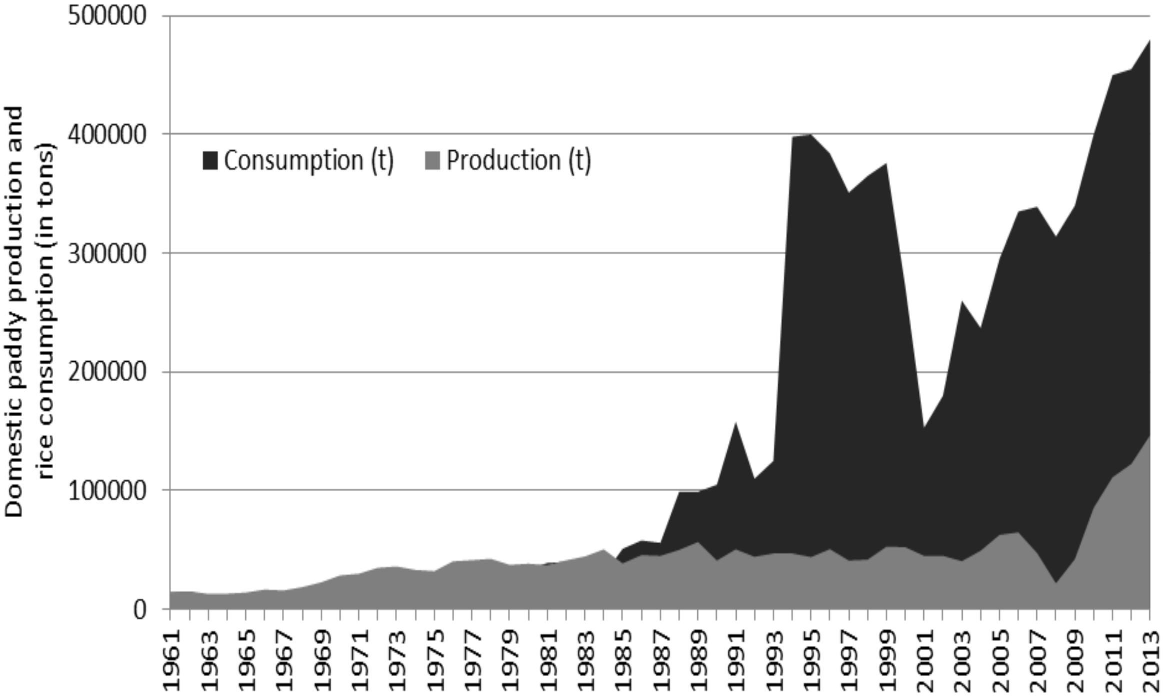

Fig. 1.1: Gaps between domestic paddy rice production and consumption in Kenya (Adopted from Atera *et al*., 2017).

Productivity of rice in Kenya is lower compared to the Africa's average with irrigated lands producing about 5 tons per hectare and rainfed conditions producing one ton per ha (Africa Rice Center, 2008). This is far below the Africas' production potential of about 10 tons per ha and 7 tons per ha for irrigated and rain fed rice, respectively (MOA, 2008). This low productivity can be attributed to poor agronomic practices, inadequate water availability and lack of suitable rice varieties (Kimani *et al*., 2011).

Plant population has a major influence on the rice growth and grain yield, because of its competitive effects, both on the vegetative and reproductive development. According Mohan *et al.* (2019), plant spacing is a key factor to be optimized with an aim of maximizing agronomic yield and economic returns of the farmers. The plant density that results a maximum yield depends on temperature, solar radiation, moisture, soil fertility and crop variety among other factors. According to Bozorgi *et al.* (2011), unsuitable population of rice crop may have limitation in maximum availability of growth resources, thus reduced grain yields. Mohaddesi *et al*. (2011) reported that improper spacing reduced yield of rice up to 20- 30%. Optimum spacing ensures better plant growth through efficient utilization of solar radiation and nutrients. It is therefore necessary to determine the optimum plant spacing and seeding rate that may lead to proper plant population thus maximum grain yield of Nerica 10 rice in Taita Taveta County.

## 1.2 Statement of the Problem

Consumption of rice in Taita Taveta County has been on the increase in the recent past, almost surpassing that of maize, making the county use a lot of money to import rice from other regions. This resulted in introduction and field trials of upland rice varieties, of which Nerica were found to grow well and produce under prevailing available rainfall and climatic conditions. Adaptive trials to familiarize farmers across the County with the rice varieties were however, never carried out despite the findings hence farmers are still not familiar with these rice varieties. Consequently, there are currently no recommended planting patterns that farmers may use in case the varieties are promoted. In short, there is a dearth of information on scientifically proven upland rice production practices suitable for Taita Taveta that farmers may adopt.

## 1.3 Justification of the Study

Rice grain annual requirement in Kenya exceeds production, and is expected to increase from the current 0.55 million tonnes to 517.5 million tonnes by 2030 (KBS, 2016). The consumption deficit gap which accounts for seventy three (73%) is filled through imports from other countries such as Tanzania, Pakistan, Egypt, Thailand and Vietnam and it is valued at US$87.5 million per annum over 5 years range (Atera *et al*., 2011). The reliance on rice imports is costly and unsustainable, and can contribute to increased poverty levels, food insecurity due to use of revenue that would otherwise be used for developmental activities within the Country. According to the MOA (2008), rice production must increase at a rate of 9.3% per annum, in order to meet consumption demand in Kenya by 2030. This can be achieved by increasing rice productivity and rice cultivated area in the high potential areas of Lake Victoria basin and coast region including Taita Taveta County (Onyango, 2014). Kimani *et al*. (2011) reported that in order to satisfy the rice demand, there is need to upscale production per unit area through adoption of new technologies and agronomic practices such as proper plant population per unit area and promotion of rice varieties which are resilient to biotic and abiotic stress.

The increasing preference of rice in Kenya, compared to maize which has been the traditional staple food, compounded by subsequent expenditure on rice imports, prompts a need to find ways of reducing the gap between demand and supply. Therefore, this study sought to evaluate the performance of Nerica 10 under different plant densities at Dembwa and Kipusi in Taita Taveta county. These areas were amongst the previously identified potential upland rice production areas in Taita Taveta County. Farmers in the area cultivate on small holdings of 0.1 - 0.5 acres that require crop intensification. Although planting densities are pre-requisite to higher yields (Raman, 2014), there however, exists limited available information on the morphological and physiological responses of the Nerica 10 rice varieties under these environmental conditions. Successful introduction of Nerica in the county will contribute to saving foreign currency reserves by decreasing dependence on imported rice, improve food security, decrease rural poverty and create employment opportunities.

## 1.4 Objectives of the study

### 1.4.1 Broad objective

To enhance the production of Nerica 10 rice in Taita Taveta County through plant densities.

### 1.4.2 Specific objectives

i. To determine the effect of plant spacing on growth and yield of Nerica 10 rice variety.
ii. To determine the effect of seeding rate on growth and yield of Nerica 10 rice variety.
iii. To determine the interaction effects of plant spacing and seeding rate on yield of Nerica 10 rice variety.

### 1.4.3 Study hypotheses

i. Differences in plant spacing have no statistically significant effect on growth and yield of Nerica 10 rice variety.
ii. Different seeding rates have no statistically significant effect on growth and yield of Nerica 10 rice variety.
iii. Interaction of plant spacing and seedling rates has no statistically significant effect on growth and yield of Nerica 10 rice variety.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Botany and Ecology of Rice

Rice belongs to the grass family and grows as an annual crop but can also be left to ratoon for up to 30 years (Wasimfiroz *et al*., 2018). The crop can grow up to a height of about 1.8 meters tall depending on genotype and nutrition. Rice plant consists of a shallow fibrous rooting system on which stands a hollow stem (Meng *et al*.,2019). The stem is composed of a series of nodes and internodes. A single lanceolate leaf and a bud arises from each node. The primary tillers give rise to secondary tillers, which grow and in turn produce tertiary tillers (Paul, 2018). Tillering ability of a rice plant is a function of the variety because it is genetically controlled, but is also influenced by soil nutrient status, water, sunlight and general health of the plant. The number of tillers has been reported to have a positive association with plant biomass and economic yields in rice (Deng *et al.,* 2015). Tillers may develop an inflorescence on the last internode at the top part of the rice plant, called a panicle. Tillers that do not bear panicles are called ineffective tillers. The panicles carry the spikelets in which grains may or may not form. Grain weight is normally a function of number of effective tillers and spikelets per panicle (Yoshida, 1981). Spikelets which don’t form grain are referred to as sterile or infertile spikelets (Paul, 2018).

According to IRRI (2008), rice is cultivated in a wide range of ecological conditions. Maclean *et al.* (2002) report that rice production ecosystems are irrigated (good water control or flooded throughout growing season), rain fed lowland (relying on rainfall, with fields bunded to retain water), upland (grown without surface water, relying solely on the rainfall) and flood-prone (deepwater rice, grown in river areas) Irrigated and rain fed lowland rice systems account for about 80% of the worldwide harvested rice area and 92% of total rice production (Fuller *et al*. 2011).

Rice crop requires an average rainfall of 800 – 2000 mm per annum and an altitude of 0 - 1700 m above sea level. It requires critical temperature range of 25°C to 31°C at tillering stage, 30°C to 35°C during anthesis and 20°C to 29°C at ripening stage (Deng *et al*., 2015). Extreme temperature is harmful to its growth and development. Exposure to cold temperature affects all phenological stages of rice and lower grain yield. Critical stages for cold damage include germination, booting, heading and grain filling stages. High temperature causes early physiological maturity, shortens growth period and reduces accumulation of assimilates demonstrated by spikelet sterility (Fahad *et al*., 2019).

Table 2.1: Critical Temperatures at different growth stages of the rice plant (Adapted from Yoshida 1978)

| **Growth Stage** | **Critical Temperature (ºC)** | | |
|---|---|---|---|
| | **Low** | **High** | **Optimum** |
| Germination | 16 – 19 | 45 | 18 – 40 |
| Seedling emergence | 12 | 35 | 25 – 30 |
| Rooting | 16 | 35 | 25 – 28 |
| Tillering | 9 – 16 | 33 | 25 – 31 |
| Panicle initiation | 15 | - | - |
| Panicle differentiation | 15 – 20 | 30 | - |
| Anthesis | 22 | 35 - 36 | 30 – 33 |
| Ripening | 12 – 18 | > 30 | 20 – 29 |

Rice crop thrives under a wide range of soils including saline or sodic soils with pH range of 5.5 - 6.5 in upland rice cultivation and pH 7.0 - 7.2 under flooded conditions (Somado *et al*., 2008). The most appropriate soils should be fertile loamy soils with good drainage and good water retention capacity.

## 2.2 Overview of Rice Production

Rice crop is second to wheat in terms of area under production. According to FAO (2015), global paddy rice production was about 741.3 million tons, with India and China accounting for more than half of the production. Africa produced 31.1 million tons, representing 3% of the global production. The leading rice production areas in Africa include Madagascar, Nigeria and Egypt while in East Africa Tanzania is the main producer. North and West African countries produced more than 70% of Africa's production while Tanzania produced the largest quantities (2.5 million tons) in the East African region. Seck *et al*., (2013) reports that local rice production in Sub-Saharan Africa (SSA) is far above consumption and the gap between production and demand continues to increase and is filled by imports from outside the region. According to Saito *et al*. (2015), there is need to increase local production by the development of upland rice cultivation systems. Upland rice is usually produced under aerobic conditions without irrigation or paddling. The crop can be found in a range of environments from low–lying valley bottoms to steep sloping land. Under these conditions, land preparation and sowing as well as direct sowing are done without flooding the soil (Atera *et al.* 2017). Upland rice is also grown either as monocrop or as mixture with other crops.

Rice crop was introduced by Europeans at the Kenyan coast in 1907 (Onyango, 2014). It was previously produced as a cash crop but over the years it has become a major staple food for many communities within the country (Atera *et al.*, 2011). The demand for rice grain is higher than other cereals and continues to increase at a rate of 12% compared to 4% increase in wheat and 1% increase in maize per annum. The deficit has continuously increased over the years accounting for about 73% is filled through imports from other countries (Atera *et al*., 2011). Production of more than 70% of cultivated varieties is carried out in government owned irrigation schemes while the rest are grown by small scale farmers under rain fed conditions (Atera, 2017). The schemes are managed by National Irrigation Board (NIB), which is a government agency and they include: Mwea irrigation scheme in central Kenya which covers an area of 6477.7 ha (Munyithya *et al*., 2017), Ahero and west Kano irrigation schemes that covers 3520 ha, and Bunyala irrigation scheme that covers 516 ha (Onyango, 2014). Small quantities of rice are produced along river valleys especially in smallholder irrigation schemes. They include Kore, Alungo, Nyachoda, Wanjare, Anyiko and Gem-Rae in western Kenya and Kipini, Malindi, Shimoni and Vanga at the coastal region (Atera, 2017). Rice cultivation in Taita Taveta County is majorly done in Taveta Sub county under irrigation.

Kenya has a potential of about 0.54 million ha of irrigable and one million ha of rainfed rice production (MOA, 2008). According to Onyango (2014), potential areas for increasing rice production include Lake Victoria basin, central and coastal region including Taita Taveta County. This potential has however remained untapped for decades. The most common irrigated varieties in Kenya include Basmati 370 and 217, BW 196, IR2793-80-1, ITA310 and Sindano (Atera *et al*., 2017) while rainfed upland varieties include Dourado Precoce, Nam Roo, WAB 181-18, TGR-94 and Nerica (Kimani *et al*. 2011; Atera *et al*. 2017). The Nerica cultivars are improved upland rice varieties suitable for changing environment. According to Atera *et al*. (2017) Nericas were developed in the 1990s by African Rice Center (ARC) purposely to survive harsh environment of Africa. They were initially released in Côte d'Ivoire in 2001 (WARDA, 2008). In Kenya, after evaluation for the best performing cultivars, the Africa Rice Centre (ARC) released four varieties namely Nerica 1, Nerica 4, Nerica 10, and Nerica 11 in 2008 for commercial production. The rice variety is a product of crossbreeding of *Oryza sativa* which is high yielding and with *Oryza glaberrima* which is stress tolerant thus possess positive attributes from their parents such as shorter maturity period, higher yield, more tillers with longer grain-bearing panicles than either parent(Atera *et al*.,2011). Other important characteristics include lodging tolerance, high yield potential, high response to organic and inorganic fertilizers, good water use efficiency, tolerance to Africa's serious pests and diseases such as African rice gall midge, rice yellow mottle virus and blast (Onyango, 2014). The crop also have wide and droopy leaves that help to smother weeds in early growth, strong stems that can support heavy heads of grain, higher protein content and amino acid balance compared to other varieties (WARDA, 2008).

According to Atera *et al.* (2017), the development of Nerica, was an opportunity for reducing hunger in Sub-Saharan Africa (SSA). As of the year 2010, more than 30 countries in SSA had established and adopted Nerica (Diagne *et al*., 2010**)**. Studies done in West Africa by Kijima *et al*. (2006), report Nerica yields of 2.5 tons per ha with low use of inputs, and 5 tons per ha under optimum fertilizer use. A study by Sekiya *et al.* (2013), reported better performance of Nerica varieties, compared to local varieties in areas where local varieties are affected by rainfall inconsistency. A study carried by Atera *et al*. (2011) on field evaluation of selected Nerica rice cultivars in western Kenya revealed that Nerica 10 attained physiological maturity at 97 days after seeding (DAS), followed by Nerica 1 at 102 DAS while Dourado precoce took 116 DAS.

According to Atera *et al.* (2017), there is need to train farmers on the adoption of non-monetary inputs like timely sowing, maintaining optimum plant densities, timely irrigation, efficient use of fertilizers, need based plant protection measures and timely harvesting of the crop. The use of optimal plant densities is amongst low cost agronomic techniques that can increase rice yields.

## 2.3 Factors Affecting Rice Production

Rice production in the Country is constrained by several challenges (Atera *et al*., 2011). Biotic constraints are living organisms that have a negative effect on rice crop growth while abiotic factors are non-living factors affecting growth and development of rice crop leading to yield losses. Biotic factors include diseases, pests and weeds. Major diseases include blight, rice blast and rice yellow mottle virus whereas termites, stalked eye fly, rice root aphid, seed corn maggot, African corn cricket, cutworm, rice water weevil, rice leaf beetle, paddy stripper, rice stem borer, rice bug, rodents and birds are important pests of rice. Weeds are also a major cause of low yields in rice production as they compete for plant growth resources. They have been documented to cause average yield losses of about 56% from Striga and 43% from other weeds (Kanga and Ariga, 2018).

The non biotic factors include: unavailability of certified seed, poor agronomic practices such as plant spacing and fertilization regimes, poor post-harvest handling, lodging, high cost of production, limited value addition, land tenure problems, labour scarcity, poor infrastructure and inadequate use of machinery (Atera *et al*., 2017 ; Onyango, 2014).

## 2.4 Effects of Plant Spacing on Rice Growth and Yield Components

Yield potential of a crop is determined by the genetic constituent which is expressed in the field under provided environmental conditions. Genetic, environmental factors and management conditions regulate phenotypic expression of a cultivar in a given location (Ullah *et al*., 2015). Optimum availability of soil fertility, moisture, solar radiation and temperature is mainly determined by plant density (plant population) among various agronomic practices (Dejen, 2018). Plant density refers to the number of plants within a given unit of land area and is a result of plant spacing and number of seedling per hill. It is a significant agronomic factor that influences crop microenvironment of the field and affects growth, development and yield of crops (Raman, 2014). Maintenance of proper plant population plays a great role in maximizing the grain yield of rice by ensuring proper plant growth above and below ground through proper utilization of growth resources (Reuben *et al*., 2016; Raman, 2014). The plant to plant and row to row distance (spacing) determines the plant density per unit area which has direct effect on yield. Plant spacing is an important attribute that influences plant population, biomass, tillering of rice hills, crop growth rate, root distribution and ultimate yield and profitability per unit area (Rahman and Hossain, 2011). Spacing determines the number of plants per unit area (Yoshida *et al*., 1981). The major reason for maintaining optimal spacing is to obtain maximum number of plants per unit area, without compromising on final yields. According to Bozorgi *et al*. (2011), plant population beyond the optimum density results to unnecessary stress on the plants and affects tiller formation, sun light interception, nutrient uptake, rate of photosynthesis and other physiological phenomena and ultimately affects the growth and development of rice plant. Additionally, intercultural operations are hampered. The increased competition for growth resources results to weaker and thinner plants and consequently, grain yield is reduced (Tilahun, 2019). However Uddin *et al*. (2011) reports that in an area where the environment does not limit yield, higher plant densities resulted in higher yield. Plants grown in wider spacing increases the performance of individual plants because they are able to access wider space around them to extract more nutrients, absorb solar radiation for better photosynthetic process as individual plant resulting to increased yields per individual plant, but reduced yield per unit area due to fewer plants (Baloch *et al*., 2002).

The optimum transplanting/planting spacing has been found to differ with factors such as climatic conditions, soil attributes, crop growth patterns, dictating a need for site specific optimal crop spacing. Research work carried out on the effects of spacing on rice growth and yield all over the world have shown that spacing influences rice growth and yields but the optimal spacing varies from region to region. For instance, in Bangladesh, Yasmin *et al*. (2018) reported that narrow spacing of 20 cm x 15 cm produced maximum values of grain yield (4.78 tons per ha), 1000 grain weight (22.67 g) and number of tillers per hill (8.22) compared to wider spacings of 25 cm x 15 cm and 20 cm x 20 cm. Similary, spacing of 20 cm x 10 cm attained the maximum number of total tillers and fertile tillers per $m^2$, highest number of grains per panicle, maximum plant height and dry matter accumulation per culm than closer and wider spacings (Bhowmik *et al*., 2013). Both studies reported higher grain yield in narrower spacing compared to others. However, Bhowmik *et al*. (2013) obtained maximum values of 1000 grains weight (24.53 g) and plant height (93.16

cm) in 20 cm x 15 cm spacing. The highest number of effective tillers per $m^2$ and the highest number of grains per panicle were mainly responsible for this highest grain yield. Grain yield obtained in 15 cm × 10 cm spacing was however statistically similar to the spacing 20 cm × 10 cm. The lowest grain yield 1.85 tons per ha was obtained from 25 cm × 15 cm spacing mainly because of the lower number of effective tillers per $m^2$ and the grains per panicle. Better yields for narrower spacing may be due to higher population of fertile panicles.

Biswas *et al*. (2015) recorded maximum grain yield of 5.22 tons per ha on narrow spacing of 15 cm x 20 cm compared to yield of 3.9 tons per hectare on a spacing of 20 cm x 20 cm. The lower population increased number of tillers per plant but reduced number of hills per unit area thus resulting lower net grain yield. Contrary to the above findings, Mondal and Puteh (2013) in their research on evaluation of the effect of spacing on assimilate availability of four different modern rice varieties reported maximum grain yield (8.5 tons per ha) for best performing high yielding cultivar due to higher number of productive tillers per $m^2$ (65.8) and more filled grains per panicle (101.0 g) in wider spacing of 20 cm x 20 cm compared to closer spacing 20 cm x 10 cm and 20 cm x 15 cm. Total tillers, effective tillers and grain yield increased with increase in spacing whereas narrower spacing 20 cm x 10 cm produced lowest yield of 6.47 tons per ha. However panicle length, 1000 grain weight and harvest index were not significantly affected by spacing. They argued that a highly populated crop stand had a major effect on morphological and physiological characters of rice crop as well as yields. Closely spaced plants may have suffered due to scarcity of light, soil nutrients and moisture thus less total and effective tillers and ultimately less grain yield compared to wider spacing. In a study to investigate the influence of different plant spacing and seedlings per hill on growth characters, yield attributes and yield of newly released transplanted rice variety Shalimar Rice-1 in India, Raman (2014) reported maximum grain yields in narrower spacing 15 cm x 15 cm spacing due to maximum number of tillers per $m^2$ (383.4 g) than spacings 15 cm x 20 cm and 20 cm x 20 cm. However his findings contradict those of Reuben *et al*. (2016), who reported minimum yields at 15 cm x 15 cm spacing and maximum at plant spacing 25 cm x 25 cm for rice variety TXD 306 Super SARO under same conditions. In a studies by Rasool *et al.* (2012), increased production of tillers per unit area, maximum plant height and dry matter production were observed in closer spacing 15 cm x 10 cm, 15 cm x15 cm and 15 cm x 20 cm than wider spacing 30 cm x10 cm, 20 cm x 20 cm and 15 cm x 25 cm.They attributed the better performance to better development of panicles resulting to more panicle length and weight. However maximum effective tillers per $m^2$ were observed under 15 cm × 15 cm spacing and lowest under 20 cm × 20 cm spacing, possibly due to less number of plants. On the contrary, Bishnu *et al*. (2013) report that wider spacing of 25 cm x 25 cm and 30 cm x 30 cm produced significantly higher number of rice tillers, panicles per $m^2$, longer and weighty panicles, and higher grain yield than closer spacing 15 cm x 15 cm. Highest grain yield 11.4 tons per ha was recorded in widest spacing 20 cm x 25 cm, while lowest 3.0 tons per ha in 30 cm x 10 cm spacing. They revealed that narrow spacing significantly reduced number of tillers per hill and number of panicles per $m^2$.

A study carried out by Jahan *et al*. (2017) on variations of growth parameters in transplanted Aman rice (cv. BRRI dhan39) in response to plant spacing and fertilizer management "reported higher yield and yield contributing factors in spacing 25 cm × 15 cm. Studies by Sultan *et al*. (2018) on effect of age of seedlings at staggered planting and spacing on growth and yield of transplant Aman rice (Cv. Brri Dhan 46) reported superior performance of yield and yield contributing factors in 25 cm x 15 cm spacing compared to other spacings. They found that spacing had no significant effect on number of panicles per hill, 1000 grain weight and harvest Index. On the contrary maximum values of grain yield (4.76 tons per ha), grains per panicle (95.65) and biological yield (11.57 tons per ha), were significantly affected by plant spacing.

Studies by Moro *et al*. (2016) on effect spacing on rainfed lowland rice in Ghana reported maximum yields in wider spacing 20 cm x 25 cm (11.4 tons per ha) than closer spacings. They recorded more tiller production (10.6 and 10.1) in wider spacings 20 cm x 20 cm and 25 cm x 15 cm respectively, than narrower spacing. They also observed more vigorous plant growth in wider spacings (25 cm x 20 cm and 20 cm x 20 cm), than narrower spacings (30 cm x 10 cm and 15 cm x 15 cm).As the distance between plant stand decreases, competition for space, light and soil nutrients increased, resulting in lower tiller production. A similar trend was observed where maximum values of panicles per $m^2$ (605), taller plant height (100.1cm) and heavier panicle weight 5.33g in wider spacings than closer spacings. There were no significant differences in 1000 grain weight. These studies are supported by Shrirame *et al*. (2000), who reported that the total number of tillers per hill was higher in wider plant spacing. An investigation carried out by Oghalo (2011) on upland rice in Nigeria reported superior performance of vegetative and yield traits in spacing 30 cm x 30 cm compared to 40 cm x 30 cm and 30 cm x 20 cm. Oghalo (2011) observed increased tillering , panicle numbers, panicle weight and grain yield in these spacing. Studies by Dejen (2018), reported that various plant spacings significantly affected number of days to 50% heading on transplanted irrigated rice in Ethiopia. Plants in wider spacing 30 cm x 20 cm took longer (95 days) to reach 50% heading whereas plants in narrower spacing 20 cm x 10 cm took 92 days. Similarly, the widely spaced plants took more days (124.3) to attain physiological maturity compared to narrowly spaced plants which took 121.7 days. Panicle were longer (20.44 cm) from wider spacing 20 cm × 20 cm and shortest (21.94 cm) from 20 cm × 10 cm spacing, whereas maximum straw yield (7.29 tons per ha) was obtained from wider spacing 20 cm x 20 cm, while the lowest (4.90 tons per ha) was obtained from

20 cm x 10 cm. Dejen (2018) reported maximum tillers per hill (34) at wider spacing 35 cm x 35 cm and minimum (15) at narrower spacing 15 cm x 15 cm. The trend was that as spacing increased, tiller numbers per hill also increased. A study conducted in Tanzania by Reuben *et al*. (2016), to investigate the optimum rice spacing revealed that wider spacings 35 cm x 35 cm produced maximum tillers per hill (34) than narrower spacings. This was attributed to reduced competition for growth resources thus better plant growth. Similarly this spacing produced the highest number of grains per panicle (205.7). The trend was that number of grains increased with spacing, but trend reversed at higher spacing due to reduced plant population per unit area. Maximum grain yields (7.57 tons per ha was obtained in 25 cm x 25 cm spacing.

In a study carried out to investigate adaptability practices to system of rice intensification in Kenya, Nyang'au *et al*. (2014) reported that different areas in the country used different spacings to attain optimum rice grain yields. They reported that farmers in Mwea used 25 cm x 25 cm under System of Rice Intensification (SRI), West Kano used 35 cm x 35 cm whereas Ahero and Bunyala used 20 cm x 20 cm and 25 cm x 25 cm spacing respectively. In an investigation on effect of spacing and intermitted flooding on yield of lowland rice in Mwea irrigation scheme, Munyithya *et al*. (2017) reported highest grain yield (4.3 tons per ha) on narrower spacing 15 cm x 15 cm compared to wider spacings 20 cm x 15 cm, 25 cm x 15 cm and 30 cm x 15 cm. Maximum number of panicles per plant was recorded in wider spacing 30 cm x 15 cm as the spacing between plants increased, number of panicles per plant also increased.

## 2.5 Effect of Seeding Rate on Rice Growth and Yield Components

The number of plants per hill is an important factor for successful rice production because it affects the number of plants per unit area, tiller formation, solar radiation interception, temperature, nutrient uptake, total sunshine reception, photosynthesis and finally affects the growth, development and yields of rice plant (Raman, 2014). Chowdhury *et al.* (2019) reports that the number of seedling per hill plays a key role to enable the plant to grow properly both above and below the soil by optimum use of radiant energy, nutrient, space and water and also could reduce seedlings cost of farmers. Therefore, optimum number of seedling(s) per hill is an important factor in ensuring proper plant growth through optimum utilization of the available growth resources (Mahamud *et al*., 2013). According to Raman, (2014), optimum seedling per hill is an important factor that affects crop micro environment by influencing the degree of inter and intra plant competition. When number of seedlings per hill is less than optimal, insufficient tiller number formation may result, thus keeping space and nutrients underutilized and at the end, total number of panicles per unit area may be reduced resulting in poor gain yield (Bhowmik *et al*., 2013). According to Sultana *et al*. (2012), when number of seedlings per hill is above optimal, there may be over production of tillers, resulting in shading, lodging and production of straw instead of rice grain.

Different workers have reported conflicting information on the most appropriate seedling(s) per hill for maximum rice grain yields. According to Raman (2014), maximum values of yield attributes were obtained with single seedling per hill, followed by the decreasing trend with the increase in seedling number per hill. Raman (2014) reported that the lowest yields were observed with 5 seedlings per hill. Planting fewer numbers of seedlings per hill enabled the plant to produce healthy tillers which experienced normal physiological growth resulting in more healthy panicles with more filled spikelets, whereas, transplanting 4 to 5 seedlings per hill resulted in production of weak panicles with reduced number of filled spikelets. Studies by Rasool *et al.* (2012), reported that 2 seedlings per hill gave significantly higher number of tillers per hill than 3 seedlings per hill. He found increased incidences of unproductive tillers in densely populated rice crops due to inter-specific plant competitions. The above findings on seedling per hill contradict those of Bhowmik *et al.* (2013) who reported that 5 seedling per hill gave maximum yields of 3.05 tons per ha due to maximum number of effective tillers per hill (144) and higher number of grains per panicle (138.9), compared to 3 seedlings per hill.

According to Bhowmik *et al.* (2013) the yield and yield contributing characters of rice variety *Aus* was significantly increased at 5 seedlings per hill except plant height. Maximum values of total tillers per $m^2$, number of effective tillers per $m^2$, number of grains per panicle, and grain yield were obtained at 5 seedlings per hill, whereas minimum values were in 2 seedlings per hill. Mahamud *et al*. (2013) reported maximum number of tillers per $m^2$ (393.38), and maximum dry matter per $m^2$ (707.4 g) at 3 seedlings per hill, while minimum values were obtained at at one seedling per hill. Biological weight and panicle length were not significantly affected by seeding rate.Maximum harvest index (44.55%) was obtained at single seedlings per hill while minimum (40.46%) was at 3 seedlings per hill. One seedling produced higher grain yield compared to straw Mahamud *et al*. (2013) reported number of seedling(s) per hill had no significant effect on plant height of aman rice variety. However the tallest plant (102.3 cm) was obtained from 3 seedlings per hill and the shortest plant (101.9 cm) was obtained from single seedling per hill. Borzogi *et al.* (2011) reported significant differences in panicle length, biological yield, seedlings per hill and harvest index as affected by variation in number of seedlings per hill . Borzogi *et al*. (2011) obtained highest yield of 3.5 tons per ha at 3 seedlings per hill compared to 1 and 5 seedlings per hill. Investigations done by Biswas *et al.* (2015) and Shrirame *et al*. (2000), revealed that two seedlings per hill gave significantly higher number of tillers per hill than three seedlings per hill. According to Ullah *et al*. (2015), planting 7 seedlings per hill resulted in higher grain yields (3.2 tons per ha) than to 5 seedlings and farmers practice of drilling. However plant height (range 141 – 144 cm) and 1000 grain weight were not significantly influenced by number of seedling per hill. In his study, Islam *et al*. (2013) reported the highest number of tiller per hill from 2 seedlings per hill while the lowest was from 4 seedlings per hill.

Dejen (2018) reported that transplanted irrigated rice took more days to reach 50% heading (93.8 days) at 2 seedlings compared to others. Rice planted at higher densities (4 seedling per hill) took shorter time (92.8 days). Additionally plant height was observed to increase with increase in seedling number per hill whereby taller plants (94.01 cm) at 3 seedlings per hill, whereas shorter plants were found at 2 seedlings per hill. Dejen (2018) also reported maximum tiller per hill (14.49) at single seedling per hill while lowest (12.22) was recorded from 4 seedlings per hill. Studies by Munyithya *et al*. (2017), reported that farmers in Mwea irrigation scheme plant 2 seedlings per hill, and associate these spacing to higher grain yield. Spacing should always be optimized depending on soil characteristics and varietal characteristics such as tillering ability, maturity period and photoperiod sensitivity among other factors (Mishra *et al*., 2010).

## 2.6 The Interaction Between Plant Spacing and Seedling Per Hill on Yield and Yield Components

Plant spacing and seedling per hill make up the plant density per unit area of land. Various research findings have shown that plant spacing and number of seedlings per hill interaction plays a major role in increasing rice grain yield. The improved growth and resultant grain yields is attributable to collective influence of effect of high plant density, thus higher temperature in the canopy, more leaf area index, more of light interception thus increase in photosynthesis (Raman,2014). Research from Banglandesh reported that interaction between 20 cm × 10 cm spacing and 5 seedlings per hill gave maximum values of yield and yield components (Bhowmik *et al.*, 2013). Similarly, Raman (2014) obtained higher grain yield in the interaction of plant spacing of 15 cm × 15 cm with single seedling per hill. Studies by Bozorgi (2011) on effect of plant density on yield found that 20 cm x 20 cm spacing with 3 seedlings per hill gave highest grain yield 3.6 tons per ha compared to others. The highest straw yield, plant height and unfilled grains percentage, was found in spacing 15 cm x 15 cm. Dejen (2018) obtained maximum values of grain yields (5.3 tons per ha), straw yield (7.3tons per ha), biomass yield (14.3 tons per ha) number of grains per panicle (217) in spacing 20 cm x 20 cm at 3 seedlings per hill compared to other spacings. The number of grains per each panicle increased with increase in spacing, however further increases reversed the trend due to lower plant density per unit area. The lowest (7.2 tons per ha) was at 20 cm x 10 cm at 2 seedlings per hill. Maximum grain yields (5.3 tons per ha) were obtained in spacing 20 cm x 20 cm at 3 seedlings per hill, while lowest (3 tons per ha) were found in 20 cm x 15 cm at 2 seedling per hill.

The above analysis on various research studies report conflicting findings for the most appropriate plant spacing and seedling rate per hill. This may be due to the differences in cultivars used, soil properties and varying climatic conditions. Site specific determination of optimal plant density is therefore important in successful cultivation of Nerica 10.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Description of the Study Site

The study was carried out in Dembwa and Kipusi, in Taita Taveta County during the 2019 long rains season. Kipusi is geographically situated at an altitude of 846m above sea level, on 3$^{o}$28'45.8"S latitude and 38$^{o}$22'56.4"E longitude while Dembwa is at an altitude of 1,088m above sea level on 3$^{o}$26'50.3"S latitude and 38$^{o}$21'46.4"E longitude. The regions fall under Upper midland (UM 4) agro ecological zone with temperatures of between 15-33 °C and annual rainfall ranging between 300 – 1200 mm (CIDP, 2018). Soils within the area vary from rhodic ferralsols to ferralic arenosols and ferralo chromic luvisols. They are deep, well drained and dark red in color. The texture ranges from loose coarse sand to friable sandy clay loam (Jaetzold *et al.,* 2012). Soil chemical characteristics were determined before land preparation. At the beginning of the season, soil samples were taken randomly from nine points using soil auger at 0-30 cm soil depth. The samples were thoroughly mixed and a 1.0 kg composite sample taken to Kenya Agricultural and Livestock Research Organization (KALRO) National Agricultural Research Laboratories (Nairobi) for chemical soil analysis. The composite sample was analyzed for $pH_{(water),}$ total nitrogen (N), total organic carbon (OC), exchangeable phosphorus (P), exchangeable potassium (K), exchangeable calcium (Ca), exchangeable Magnesium (Mg), exchangeable Sodium, exchangeable Zinc (Zn), Exchangeable Copper (Cu) and Manganese (Mn) following procedures described by Okalebo *et al*., (2002). Soil test result interpretation indicate that the two experimental sites had similar soil fertility status.The available soil nutrients were adequate for rice growing (Table 3.1).

Table 3.1 Soil chemical properties of experimental site

| Soil property | Dembwa | Kipusi |
|---|---|---|
| Soil PH | 6.72 | 6.81 |
| Total Nitrogen | 0.22 | 0.20 |
| Total organic Carbon % | 2.28 | 1.88 |
| Phosphorus(mehlich)ppm | 95 | 35 |
| Potassium me% | 0.32 | 0.30 |
| Calcium me% | 12.6 | 8.6 |
| Magnesium me% | 4.8 | 4.21 |
| Sodium me% | 0.22 | 0.20 |

### 3.2 Experimental Design, Field Layout and Crop Husbandry

The experiments were laid out in Randomized Complete Block Design (RCBD) with factorial arrangement and replicated three times. The treatment structure was 3 x 4 consisting of three levels of plant spacing and four levels of seeding rate. Nerica 10 rice variety was adopted because of its early maturity trait 90-95 days, and resource use efficiency traits considering the rainfall pattern of Taita Taveta County. Plant spacing evaluated were: 30 cm x 15 cm (control), 20 cm x 15 cm and 20 cm x 10 cm, while seedrate levels were: farmers practice (drilling) which involved random seed placement in small groove/line, one seedling per hill, two seedlings per hill and three seedlings per hill. Planting in both sites was done at the onset of long rains during the first week of April of 2019. Upland rice Nerica 10 was planted by randomly placing seeds in rows according to inter row spacing (intra row spacing was not taken into consideration at this stage).

Each of the two experiment sites had 12 treatment combinations which were replicated three times to make 36 plots. Land was mechanically ploughed using a walking tractor, and hand harrowed. Each individual plot covered an area measuring 25 $m^2$, and the plots were separated by 0.5 m wide pathways. One meter wide pathways separated individual blocks (total 3 blocks) making a total experimental area of 1,114 $m^2$. Treatments were randomly assigned to plots within each block. During planting, basal application of

17:17:17 NPK fertilizer at recommended rate of 100Kg per ha was applied to supply about 35 Kg N, 32 Kg $P_2O_5$ and 28 Kg $K_2O_5$ per ha. Intra row spacing and seedling per hill were attained by thinning the crop at 14 days after seeding (DAS). Weeding was done at 21, 35 and 50 DAS. Minor incidences of birds attack after panicle emergence, were controlled using scarecrows.

### 3.3 Data Collection

The parameters that were considered were: plant height, number of tillers per hill, days to 50% heading, days to maturity, panicle length, number of grains per panicle, 1000-grain weight, weight of dry matter, grain and straw yield. Ten plants which excluded plants from border rows and central 1 $m^2$ area were selected randomly from each unit plot and tagged at 14 DAS (Yasmin *et al*., 2018). Border row plants were exluded from data collection because of high probability of being affected by extrenous factors, while the central area of each plot was reserved for final yield data collection. The 10 plants were used for collecting data on plant height, number of tillers per hill, panicle length, days to 50% heading, days to maturity and number of grains per panicle whereas, dry biomass weight, grain yield and 1000 grain weight were determined from final yield harvested using a 1m $^2$ quadrant in the middle of each plot. Growth and yield parameters data collected from the 10 tagged plants and plants within 1 $m^2$ middle plot area were recorded.

### 3.3.1 Plant Height

Plant height was determined by measuring the height of each of the tagged 10 plants per plot from the base to the tallest leaf or panicle, whichever was taller, using a ruler (Plate 3.1). The measurements were taken at 30, 45, 60 and 75 days after seeding as described by Bhowmik *et al*., (2013)

Plate: 3.1 Plant height measurement in the field

### 3.3.2 Number of Tillers per Hill

Number of tillers per hill was determined by observing, counting and recording all shoots per hill at 30, 45, 60 and 75 days after seeding as described by Mahamud *et al*., (2013).

### 3.3.3 Days to 50% Flowering

Procedures similar to those of Mousa *et al*, (2019) whereby the number of days from planting to days when 50% of the tagged plants had initiated flowering in each plot were counted.

### 3.3.4 Days to Maturity

This was determined by counting the number of days from planting to when over 90% of the spikelets of the tagged plants became golden yellow colour (Yasmin *et al*., 2018).

### 3.3.5 Panicle Length

Panicle length was determined by measuring from the panicle base node to the end of the panicle using a measuring ruler. This parameter was evaluated from the ten tagged plants at plant maturity stage (Mousa *et al*, 2019).

### 3.3.6 Number of Grains per Panicle

Tagged plants per plot were harvested at crop physiological maturity, and grains per panicle per plot established by manually counting the grains. The value obtained was then divided by the number of sampled plants (Khare *et al*., 2014).

### 3.3.7 Biomass and Grain Yield

At physiological maturity, plants occupying the middle 1 $m^2$ area in each plot were harvested at ground level using sickle (Plate 3.2), sun dried to 14% moisture content and then weighed to get the total biomass weight for each plot (Bhowmik *et al*., 2013). The dried plants were threshed to separate the grains from the straw. The grains were then weighed to obtain the grain yield per plot. One thousand (1000) grains was then drawn randomly from the harvested grains and weighed to give 1000 grain weight (Plate 3.3). The difference between biological and grain yield gave the straw yield per plot. Harvest index was finally calculated as the ratio of grain yield and biological yield as described by Haji, (2016).

Plate 3.2: Biomass harvesting

Plate 3.3: Data collection in Taita Taveta university Laboratory

### 3.4 Data Analysis

The univariate procedure of SAS (version 9.4; SAS Institute, USA) was used to check for normality of the data before analysis. Data were subjected to analysis of variance (ANOVA) using the procedure for general linear model (proc GLM). Signifiant means at F-test were separated using Tukey's test. All statistical analysis was performed at $p$ =0.05.

# CHAPTER FOUR

# RESULTS

## 4.1 Effect of Plant Spacing on Growth and Yield of Nerica 10

There was no significant ($p \leq 0.05$) effect of plant spacing on rice growth parameters. Plant height, tillers per hill, days to 50% heading and day to maturity were not influenced by the main effect of spacing (Table 4.1). Numerically maximum values of plant height at 64.29 cm and tiller number per hill at 8.01 were observed in narrow spacing of 20 cm x10 cm, while minimum values were observed in 20 cm x 15 cm spacing.

Table 4.1: Plant height, tillers per hill, days to 50% heading and days to maturity of rice as influenced by the main effects of spacing

| Treatments | Plant Height (cm) | Tillers per hill | Days to 50% heading | Days to maturity |
|---|---|---|---|---|
| **Spacings (cm)** | | | | |
| 30x15 | 63.09a* | 7.66a | 69.58a | 115.21a |
| 20x15 | 61.97a | 7.14a | 69.46a | 118.71a |
| 20x10 | 64.29a | 8.01a | 70.08a | 117.83a |
| Mean | 63.12 | 7.60 | 69.71 | 117.25 |
| $p$ value | 0.191 | 0.240 | 0.455 | 0.448 |
| MSD | 3.027 | 1.315 | 1.258 | 6.871 |
| CV | 6.90 | 29.00 | 2.59 | 8.40 |
| F-Test | ns | ns | ns | ns |

*Means within a column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$.ns-non significant

Spacing had a significant ($p \leq 0.05$) effect on dry biomass, 1000 grain weight, grains per panicle, grain yields and harvest Index of rice but not on straw yields and panicle length (Table 4.2). Narrow spacing 20 cm x 10 cm attained higher values of all yield parameters. The highest grain weight 107.9g per $m^2$ was observed in this spacing. Maximum dry biomass 673.87g per $m^2$ was observed in 20 cm x 10 cm spacing while the lowest 570.25g per $m^2$ was obtained in 30 x 15 cm, which was not different from 20 cm x 15 cm. Maximum values for 1000 grain weight (27.46g) and harvest Index (8.80) were obtained in spacing 20 cm x10 cm.

Table 4.2: Grain weight, dry biomass, 1000 grain weight, panicle length, grains per panicle,straw yield and harvest index of rice as influenced by the main effects of spacing

| Treatments | Grain weight (g per $m^2$) | Dry biomass (g per $m^2$) | 1000 Grain weight (g) | Panicle length (cm) | Grains Per panicle | Straw yield (g per $m^2$) | Harvest Index (%) |
|---|---|---|---|---|---|---|---|
| **Spacings (cm)** | | | | | | | |
| 30x15 | 40.68b* | 570.25b | 24.76b | 19.77a | 24.54b | 515.9a | 6.72b |
| 20x15 | 40.88b | 575.47b | 23.81b | 17.23a | 29.50ab | 513.3a | 6.81b |
| 20x10 | 107.90a | 673.87a | 27.46a | 19.45a | 35.69a | 589.07a | 8.80 a |
| Mean | 63.153 | 606.53 | 25.18 | 19.49 | 29.91 | 539.42 | 7.45 |
| *p* value | <.0001 | 0.0220 | 0.0037 | 0.6703 | 0.0121 | 0.1626 | 0.0084 |
| MSD | 25.887 | 98.307 | 2.715 | 1.455 | 8.704 | 106.890 | 1.750 |
| CV | 50.03 | 23.33 | 15.5 | 10.7 | 41 | 28.5 | 33 |
| F-Test | | | | ns | | ns | |

*Means within a column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$ .ns-non significant

## 4.2 Effects of Seeding Rate on Growth and Yield of Nerica 10

There was no significant effect of seeding rate on plant height, tillers per hill, days to 50% heading and days to maturity of rice (Table 4.3).

Table 4.3: Plant height, tillers per hill, days to 50% heading and days to maturity of rice as influenced by the main effects of seeding rate

| Treatments | Plant Height (cm) | Tillers per hill | Days to 50% heading | Days to maturity |
|---|---|---|---|---|
| **Seedling rate** | | | | |
| Drill | 62.16a* | 7.43a | 70.10a | 116.39a |
| 1 seedling per hill | 63.12a | 7.39a | 69.83a | 119.06a |
| 2 seedlings per hill | 63.81a | 7.43a | 69.56a | 120.33a |
| 3 seedlings per hill | 63.38a | 8.17a | 69.33a | 113.22a |
| Mean | 63.12 | 7.61 | 69.71 | 117.25 |
| *p* value | 0.7109 | 0.6888 | 0.6020 | 0.1532 |
| MSD | 3.844 | 1.671 | 1.598 | 8.726 |
| F-Test | ns | ns | ns | ns |

*Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05. ns-non significant

Seeding rate significantly ($p \leq 0.05$) influenced 1000 grain weight and panicle length (Table 4.4). Single seedling per hill produced maximum 1000 grain weight (27.99 cm) while 2 seedlings per hill produced minimum values (22.84cm). The longest panicle (20.13 cm) was obtained at farmers practice of drilling.

Table 4.4: Grain weight, dry biomass, 1000 grain weight, panicle length, grains per panicle, straw yield and harvest index of rice as influenced by the main effects of seeding rate

| Treatments | Grain weight (g per $m^2$) | Dry biomass (g per $m^2$) | 1000 Grain weight (g) | Panicle length (cm) | Grains Per panicle | Straw yield (g per $m^2$) | Harvest Index (%) |
|---|---|---|---|---|---|---|---|
| **Seeding rate** | | | | | | | |
| Drill | 46.08a* | 572.25a | 24.64ab | 20.13a | 28.83a | 517.66a | 6.70a |
| 1 seedling per hill | 74.89a | 645.87a | 27.99a | 19.64ab | 31.25a | 578.81a | 8.20a |
| 2 seedlings per hill | 71.19a | 592.38a | 22.84b | 20.00ab | 32.99a | 515.82a | 7.07a |
| 3 seedlings per hill | 60.44a | 615.63a | 25.23ab | 18.20b | 26.56a | 545.40a | 7.72a |
| Mean | 63.15 | 606.53 | 25.18 | 19.49 | 29.91 | 539.42 | 7.42 |
| *p* value | 0.1021 | 0.4466 | 0.0025 | 0.0309 | 0.4440 | 0.5780 | 0.3320 |
| MSD | 32.87 | 124.84 | 3.45 | 1.85 | 11.05 | 135.74 | 2.22 |
| F-Test | ns | ns | | | ns | ns | ns |

*Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05. ns-non significant

## 4.3 The Interaction Between Plant Spacing and Seeding Rate on Growth and Yield of Nerica 10

### 4.3.1 Effect of Spacing and Seeding Rate Interaction on Plant Height

There was significant ($p \leq 0.05$) effect of interaction between spacing and seedling rate per hill on rice plant height (Table 4.5). The tallest plants (68.3 cm) were observed from spacing 20 cm × 10 cm at 1 seedling per hill but not different from other treatments except 30 cm × 15 cm at 1 seedling per hill that had the shortest plants (59.4 cm).

Table 4.5: Effect  spacing and seeding rate interaction on plant height (cm) at maturity

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 63.6ab | 59.4b | 66.4ab | 62.9ab |
| 20 × 15 | 61.8ab | 61.7ab | 62.4ab | 62.0ab |
| 20 × 10 | 61.1ab | 68.3a | 62.6ab | 65.2ab |
| *p* = 0.0488 | | | | |
| CV (%) = 6.74 | | | | |
| MSD: 8.4526 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill.

### 4.3.2 Effect of Spacing and Seeding Rate Interaction on Tillers per Hill .

There was no significant ($p \leq 0.05$) effect of interaction between spacing and seedling per hill on tiller number (Table 4.6)

Table 4.6: Effect of spacing and seeding rate interaction on tiller number per hill

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 8.2a | 7.3a | 7.4a | 7.8a |
| 20 × 15 | 6.5a | 6.2a | 7.4a | 8.4a |
| 20 × 10 | 7.6a | 8.7a | 7.5a | 8.3a |
| *p* = 0.8409 | | | | |
| CV(%) = 31.189 | | | | |
| MSD: 2.7028 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill.

### 4.3.3 Effect of Spacing and Seeding Rate Interaction on Days to 50% Heading

There was no significant ($p \leq 0.05$) effect of interaction between spacing and seedling rate per hill on rice plant on number of days to 50% heading. Similarly, spacing and number of seedling per hill did not have a significant effect on number of days to 50% heading (Table 4.7). However days to heading ranged from 68.8 to 70.3.

Table 4.7: Effect of spacing and seeding rate interaction on days to 50% heading

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 69.7a | 70.2a | 69.7a | 68.8a |
| 20 × 15 | 70.3a | 69.2a | 69.5a | 68.8a |
| 20 × 10 | 70.3a | 70.2a | 69.5a | 70.3a |
| $p = 0.8729$ | | | | |
| CV(%) = 2.7 | | | | |
| MSD: 3.775 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill.

### 4.3.4 Effect of Spacing and Seeding Rate Interaction on Days to 80% Maturity of Rice

There was no significant ($p \leq 0.05$) effect of interaction between spacing and seedling per hill on number of days from sowing to 80% maturity. Spacing and seedling per hill did not have a significant ($p \leq 0.05$) effect on number of days to 80% crop maturity (Table 4.8). Plants took between 111.3 to 126.2 days to reach physiological maturity.

Table 4.8: Effect of spacing and seeding rate interaction on days to 80% maturity of rice

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 116.3a | 111.3a | 120.0a | 113.2a |
| 20 × 15 | 118.2a | 119.7a | 124.0a | 113.0a |
| 20 × 10 | 114.7a | 126.2a | 117.0a | 113.5a |
| *p* = 0.2431 | | | | |
| CV(%) = 8.1 | | | | |
| MSD: 19.38 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill.

### 4.3.5 Effect of Spacing and Seeding Rate Interaction on Rice Grain Yield

There was significant ($p \leq 0.05$) effect of interaction between spacing and seedling per hill on rice grain yield (Table 4.9). Maximum values at 146.8g and 145.9g were obtained from the interaction of 20 cm × 10 cm at 2 seedling per hill and 20 cm x 10 cm at 1 seedling per hill, respectively. The lowest grain yield (28.3g) was obtained from spacing 20 cm x 15 cm at 2 seedling per hill.

Table 4.9: Effect of spacing and seeding rate interaction on rice grain yield (g per $m^2$)

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing(cm) | S0 | S1 | S2 | S3 |
| 30x15 | 45.9bc | 43.1bc | 38.5bc | 35.2c |
| 20x15 | 62.4bc | 35.7c | 28.3c | 37.2c |
| 20x10 | 29.9c | 145.9a | 146.8a | 109.0ab |
| *p* = <.0001 | | | | |
| CV(%) =57.01 | | | | |
| MSD: 89.926 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill

### 4.3.6 Effect of Spacing and Seeding Rate Interaction on Dry Plant Biomass

Dry biomass was significantly ($p \leq 0.05$) influenced by the interaction of plant spacing and seedling per hill. The highest biomass 872.8g was obtained from a spacing of 20 cm × 10 cm at single seedling per hill, which was not significantly ($p \leq 0.05$) different from 20 cm x 10 cm at 3 seedling rate per hill (Table 4.10).

Table 4.10: Effect of spacing and seeding rate interaction on dry plant biomass (g per $m^2$)

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 598.3b | 527.6b | 580.5b | 574.5b |
| 20 × 15 | 546.8b | 537.1b | 610.8b | 607.1b |
| 20 × 10 | 571.6b | 872.8a | 585.8b | 665.3ab |
| $p$ = 0.0049 | | | | |
| CV(%) = 21.54 | | | | |
| MSD: 259.55 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$; S0- control (drilling), S1- 1 seedlings per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill.
61.985

### 4.3.7 Effect of Spacing and Seedling Rate Interaction on Rice 1000 Grain Weight

There was significant ($p \leq 0.05$) effect of interaction between spacing and seedling per hill interaction on 1000 seed weight (Table 4.11). The highest 1000 seed weight (34.9g) was obtained from a spacing of 20 cm × 10 cm at one seedling per hill. The lowest value (21.7g) was obtained from a spacing 20 cm x 15 cm at 2 seedling per hill which was not significantly different from the rest of the treatments.

Table 4.11: Effect of spacing and seeding rate interaction on 1000 grain weight of rice

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 24.3b | 24.3b | 22.9b | 25.5b |
| 20 × 15 | 24.7b | 24.8b | 21.7b | 24.0b |
| 20 × 10 | 24.9b | 34.9a | 23.9b | 26.2b |
| $p$ = 0.0007 | | | | |
| CV(%) = 16.32 | | | | |
| MSD: 8.1643 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill.

### 4.3.8 Effect of Spacing and Seeding Rate Interaction on Panicle Length of Rice

There was no significant ($p \leq 0.05$) effect of interaction between spacing and seed rate per hill on the length of rice panicle. (Table 4.12).

Table 4.12: Effect of spacing and seeding rate interaction on rice panicle length (cm)

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 19.7a | 20.1a | 21.0a | 18.3a |
| 20 × 15 | 20.0a | 19.2a | 20.1a | 17.6a |
| 20 × 10 | 20.7a | 19.7a | 18.8a | 18.7a |
| $p$ = 0.2020 | | | | |
| CV(%) = 10.8 | | | | |
| MSD: 4.1319 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill

### 4.3.9 Effect of Spacing and Seeding Rate Interaction on Number of Grains per Panicle

There was significant ($p \leq 0.05$) effect of interaction between spacing and seedling per hill on number of grains per panicle (Table 4.13). Highest number of grains (54.2) was obtained from interaction between spacing of 20 cm × 10 cm and seedling rate of 1 seedling per hill while the lowest number (17.2) of grains was obtained from 20 cm × 10 cm by drilling.

Table 4.13: Effect of spacing and seeding rate interaction on number of grains per panicle

| | Seed rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 34.4abc | 19.8c | 23.3bc | 20.7c |
| 20 × 15 | 34.9abc | 19.7c | 28.0abc | 35.3abc |
| 20 × 10 | 17.2c | 54.2a | 47.7ab | 23.7bc |
| $p = 0.0001$ | | | | |
| CV(%) = 45 | | | | |
| MSD: 26.754 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill

### 4.3.10 Effect of Spacing and Seeding Rate Interaction on Straw Yield

There was significant ($p \leq 0.05$) effect of interaction between spacing and seedling rate per hill on the straw yield (Table 4.14). The highest (780.3g) straw yield was observed from spacing 20 cm × 10 cm at 1 seedling per hill which was not significantly ($p \leq 0.05$) different from other treatments except spacing 30 cm × 15 cm at 1 seedling per hill and 20 cm × 15 cm at 1 seedling per hill .The lowest (469.9g) straw yield was obtained in spacing 30 cm x 15 cm at 1 seedling per hill.

Table 4.14: Effect of spacing and seeding rate interaction on straw yield (g per $m^2$)

| | Seeding rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 545.8ab | 469.9b | 527ab | 521.0ab |
| 20 × 15 | 482.4b | 486.3b | 549.3ab | 535.3ab |
| 20 × 10 | 524.8ab | 780.3a | 471.3b | 579.9ab |
| $p = 0.0419$ | | | | |
| CV(%) = 26.2 | | | | |
| MSD: 280.82 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at $\alpha = 0.05$; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill

### 4.3.11 Effect of Spacing and Seeding Rate Interaction on Harvest Index

There was significant ($p \leq 0.05$) effect of interaction between spacing and seedling rate per hill on the harvest index (Table 4.15). The highest harvest index (12.7) was observed from a spacing of 20 cm × 10 cm and a seedling rate of 1 seedling per hill which was not different from spacing 20 cm × 10 cm at 2 seedling per hill, 20 cm × 15 cm at 3 seedling per hill and 30 cm ×15 cm by drilling. The lowest index (4.5) was obtained from spacing at 20 cm × 10 cm by drilling which was not significantly ($p \leq 0.05$) different from the rest.

Table 4.15: Effect of plant spacing and seed rate interaction on harvest index (%)

| | Seedling rate (per hill) | | | |
|---|---|---|---|---|
| Spacing (cm) | S0 | S1 | S2 | S3 |
| 30 × 15 | 9.7abc | 6.1bcd | 5.2cd | 5.9bcd |
| 20 × 15 | 6.1bcd | 5.9bcd | 5.8bcd | 9.4abc |
| 20 × 10 | 4.5d | 12.7a | 10.2ab | 7.8bcd |
| $p$ = <0.0001 | | | | |
| CV(%) = 33.8 | | | | |
| MSD: 4.7953 | | | | |

Means within a column followed by the same letter are not significantly different according to Tukey's test at α = 0.05; S0- control (drilling), S1- 1 seedling per hill, S2- 2 seedlings per hill, and S3- 3 seedlings per hill

# CHAPTER FIVE

# DISCUSSION

## 5.1 Main Effect of Spacing on Growth and Yield of Nerica 10

In present study main effect of spacing significantly ($p \leq 0.05$) influenced most yield parameters of Nerica 10, however plant height, tiller number per hill, days to 50% heading and days to maturity were not significantly influenced in the whole experimental period (Table 4.1). Plant height is a genetically made character which may not vary with the change of spacing levels Saju *et al*., (2019). Anwari *et al*. (2019) study on effects of planting distance on yield and agroMorphological characteristics of local rice observed that the use of various plant spacings had no significant ($p \leq 0.05$) effect on plant height of Bara rice variety. Similar to plant height, tiller number per hill, days to 50% heading and days to maturity (Table 4.1) were not significantly influenced by spacing, an indication that these parameters are strongly influenced by the genetic nature of Nerica 10 rice variety. Similar findings were reportd by Didik Hariyono and Akbar Hidayatullah Zaini (2018)

Narrow spacing 20 cm x 10 cm significantly improved grain weight, dry biomass ,1000 grain weight and grains per panicle compared to wider spacing 20 cm x 15 cm and control (Table 4.2). One thousand (1000)grain weight is an important parameter that defines the grain quality and the yield per hectare. Spacing 20 cm x 10 cm increased 1000 grain weight by 11% compared to wider spacings. Similarly Yasmin *et al.* (2018) study on effect of plant spacing and integrated nutrient management on the yield performance of Binadhan-14 rice variety obtained maximum 1000 grain weight in spacing 20 cm x 15 cm compared to wider spacings. Higher values of 1000 grain weight might have been due to optimum grain filling in narrow spacing as a result of optimum photosynthesis rate in narrow spacing.

Nerica 10 dry biomass yield was significantly higher by 15% in narrow spacing compared to the control spacing of 30 cm x15 cm. Similar results were reported by Sampath *et al*.

(2017) study on the effect of plant density and fertilizer levels on growth parameters of rice varieties under late sown conditions, where he obtained higher values of dry matter in narrow spacing of 15 cm x 10 cm. This may have been due to taller plants and increased plant population in spacing 20 cm x 10 cm, thus more number of leaves which occupied the same land area and subsequently trapped more light and carbon dioxide resulting in higher photosynthesis and producing more dry matter thus higher grain yield.

Spacing 20 cm x 10 cm produced 24% more grains per panicle compared to 30 cm x 15 cm spacing and farmers practice of drilling(control). Similar results were reported by Anwari *et al*., (2019) who obtained 92.3 grains per panicle in spacing of 10 cm ×10 cm compared to 84.4 in 20 cm x 20 cm spacing. The non-significant response of panicle length to different spacing levels might be due to the genetic characteristics of the variety used for the study. Similar results were reported by Anwari *et al*., (2019) and Saju *et al*. 2019), but contrary to Dejen (2018) who obtained longer panicle (20.44 cm) in 20 cm x 20 cm spacing. Narrow spacing 20 cm x 10 cm significantly improved grain yield of Nerica 10 by 62% compared to 20 cm x 15 cm and control (Table 4.2). Higher grain yield may have been a result of higher biomass per unit area thus increased surface area for photosynthetic activity. In addition heavier 1000 grain weight, higher dry biomass production and more grains per panicle in narrow spacing contributed to maximizing grain yield. Similar findings were reported by Yasmin *et al.* (2018) who obtained higher grain yield in narrow spacing 20 cm x 15 cm compared to wider spacings. The closely spaced rice plants are able to intercept maximum photosynthetically active radiation resulting in high dry matter production thus maximum yields. Similar to the current study, Munyithya *et al.* (2018); Bhowmik *et al*. (2013) and Raman (2014) obtained significantly higher grain yield in narrow spacing compared to the rest. Harvest index is the ratio of the weight of rice grains yields to the total above ground dry biomass (straw and grain) and it is an indicator of the efficiency of crops in seed production. Significantly higher (23.3%) harvest index was obtained from narrow spacing of  20 cm x 10 cm compared to wider spacings (Table 4.2). Similar findings were opinioned by Saju *et al*. (2019) who  recorded maximum harvest index with closer spacing  than others. The superior values of harvest index in narrow spacing might have been a result of greater partitioning of photosynthesis towards the production of straw and higher grain ratio to total biological yield.

## 5.2 Main Effect of  Seeding Rate  on Growth and Yield  of Nerica 10

Single seedling per hill significantly increased 1000 grain weight of Nerica 10 by 15%, whereas farmers practice of drill improved panicle length by 2% (Table 4.4). Better performance of 1000 grain weight at single seedling per hill may be due to healthy and efficient individual plant growth at lesser seedling density thus heavier grains. Also, grain filling is the process of remobilization from stored reserves, particularly from stem, leaves, and from current photosynthesis. So, it may be inferred that the effectiveness of grain filling is decided by the conditions of particular tiller. Hence, planting of fewer seedlings resulted in higher grain yield. Seedling rate had no significant effect on plant height, tillers per hill, Days to heading and days to maturity, grain yield,dry biomass,grains per panicle,straw yield and harvest index (Tables 4.3 and 4.4). This results are partly in consistent with those of  Chowdhury *et al*., (2019); Islam, T. and Salam, M., (2018) and Mahamud *et al*., (2013). Didik Hariyono and Akbar Hidayatullah Zaini (2019) reported that  productive tillers percentage, 100 grain weight and total grain per panicle are strongly influenced by the genetic nature of the plant itself (variety). Contrary to this study, Ullah *et al*. (2015) reported higher yields from 7 seedlings per hill compared to 5 seedlings per hill while Dejen (2018) reported taller plants (100.6 cm) at 3 seedlings per hill. Likewise Bhowmik *et al*. (2013) obtained higher values of grain yield, straw yield, biological yield and harvest index at 5 seedlings per hill compared to 4, 3 and 2 seedlings per hill.

## 5.3 The Interaction Between Plant Spacing and Seeding Rate on Growth and Yield of Nerica 10

The effect of interaction between spacing 20 cm x 10 cm at single seedling per hill significantly improved most parameters throughout the experimental period. Plant height of Nerica 10 rice was significantly increased (8%) due to the interaction between 20 cm x 10 cm spacing and single seedling per hill compared to the rest of the treatments (Table 4.5). Similar findings were opinioned by Ninad *et al.* (2017) who reported taller plants in denser plant population. The taller plant in highly populated plots might have been caused by competition for sunlight. The result showed that closer spacing provided 33% more dry biomass yield compared to the rest (Table 4.10). Similar findings were reported by Chowdhury *et al*., (2019). It might be due to the fact that closer spacing had taller plants and more population densities per unit area of land which added more biomass that was accumulated before flowering and translocated to the grains during grain filling.

The number of grain per panicle was significantly higher (48%) in the interaction between plant spacing 20 cm x10 cm and one seedling per hill compared to the rest (Table 4.13). This might be due to proper nutrient availability and easy light penetration up to the lower leaves because of fewer seedlings per hill which resulted to high dry matter accumulation per hill which contributes an increase in grain number per panicle. Thousand grain weights is an important character which determines the yield per hectare (Dejen, 2018). One thousand (1000) grain weight was higher by 30% in the interaction between 20 cm x 10 cm spacing and one seedling per hill,compared to the rest (Table 4.11). Results on harvest index show 45% higher values in the interaction between plant spacing 20 cm x 10 cm and single seedling per hill (Table 4.15). This treatment was the best converter of dry matter into grain yield. The interaction between narrow spacing 20 cm x 10 cm and single seedling per hill increased Nerica 10 rice grain yield by 58% compared to the rest of the treatments (Table 4.9). Similar observations were made by Dejen (2018); Raman (2014) and

Chowdhury *et al*., (2019) who reported higher yields and yield contributing factors at interaction of narrow spacings at fewer seedling per hill. This might be due to the fact that 20 cm x 10 cm spacing had optimum plant densities which led to maximization of growth resource  thus a good growth media for most parameters. These spacing benefited from the collective influence of effect of high plant population, more leaf area index, more of light interception thus increased photosynthesis resulting in increased dry biomass, maximum 1000 grain weight and maximum number of grains per panicles and ultimately maximum grain yields.

# CHAPTER SIX

# CONCLUSIONS AND RECOMENDATIONS

## 6.1 Summary of Findings

The results of this study revealed that narrow spacing significantly ($p \leq 0.05$) increased grain yields, dry biomass, grains per panicle, 1000 grain weight and harvest index of rice . There was no significant influence of seeding rate on most yield and yield contributing parameters of Nerica 10 except 1000 grain weight and panicle length. Single seedling per hill significantly ($p \leq 0.05$) increased 1000 grain weight by 15%, whereas farmers practice of drill improved panicle length by 2%.

The interaction between narrow spacing and single seedlings per hill significantly increased most parameters under study except days to 50% flowering, days to 80% maturity, tillering and rice plant panicle length ,

Nerica 10 tillering was not influenced by all treatments throughout the experimental period. These results are partly in accordance to those of Didik Hariyono and Akbar Hidayatullah Zaini who found that spacing had no significant effect on productive tillers percentage but was only influenced by rice varieties. Similar result were reported by Saphi *et al*. (2018).

## 6.2 Conclusions

The study concludes that the interaction between plant spacing 20 cm × 10 cm with single (1) seedling per hill as the best combination to obtain maximum grain yield of Nerica 10 in Taita Taveta County. This is contrary to recommended spacing of 30 cm x 15 cm by drill.

## 6.3 Recommendations

The results of this study will provide information on appropriate plant population for use in Taita Taveta County.

## 6.4 Suggestions for Further Research

The current investigation is among preliminary studies on Nerica 10 rice varieties in Taita Taveta County. Further research on optimum plant densities, should be carried out in various agro environments in the County before giving final recommendations.

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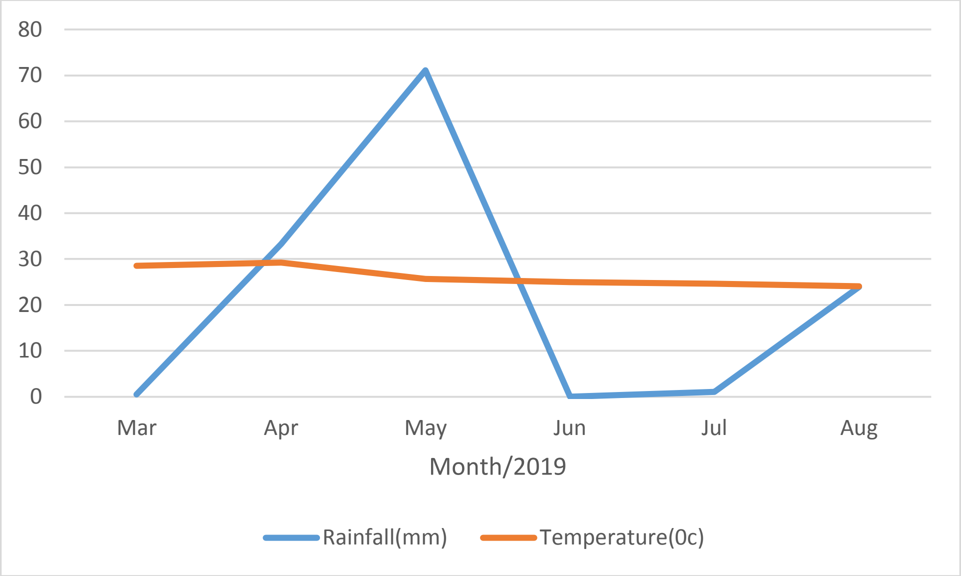
# APPENDICES

Appendix 1: Rainfall distribution and temperature at the study site



Appendix 1.1: Rainfall distribution and temperatures for March to August 2019

Appendix 2 : Effect of spacing, seedling per hill and their interaction on plant height of Nerica

| Sources of variation | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 185.7628 | 185.7628 | 9.780 | 0.0028 |
| Block | 2 | 134.9653 | 67.4827 | 3.550 | 0.0351 |
| Spacing | 2 | 64.796 | 32.398 | 1.71 | 0.1907 |
| Hills | 3 | 26.235 | 8.7450 | 0.46 | 0.7109 |
| Spacing x Hills | 6 | 309.886 | 51.6478 | 2.72 | 0.0488 |
| Error:MS(Error) | 57 | 1082.2958 | 18.9876 | | |

Appendix 3 : Effect of spacing, seedling per hill and their interaction on **tiller number** per hill of Nerica

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 321.6070 | 321.6070 | 63.34 | <.0001 |
| Block | 2 | 41.1079 | 20.5539 | 4.05 | 0.0227 |
| Spacing | 2 | 9.2631 | 4.6315 | 0.91 | 0.4074 |
| Hills | 3 | 7.5038 | 2.5012 | 0.49 | 0.6888 |
| Spacing x Hills | 6 | 18.7054 | 3.1175 | 0.61 | 0.8409 |
| Error:MS(Error) | 57 | 289.4262 | 5.0776 | | |

Appendix 4 : Effect of spacing, seedling per hill and their interaction on days for 50% heading

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 1830.125 | 1830.125 | 557.47 | <.0001 |
| Block | 2 | 162.5833 | 81.291 | 24,76 | <.0001 |
| Spacing | 2 | 5.2500 | 2.6250 | 0.8 | 0.4545 |
| Hills | 3 | 6.153 | 2.051 | 0.62 | 0.602 |
| Spacing x Hills | 6 | 9.639 | 1.606 | 0.49 | 0.8729 |
| Error: MS(Error) | | 187.125 | 3.283 | | |

Appendix 5 : Effect of spacing, seedling per hill and their interaction on days to 80% maturity

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 2964.500 | 2964.500 | 30.30 | <.0001 |
| Block | 2 | 310.083 | 155.042 | 1.58 | 0.2139 |
| Spacing | 2 | 159.250 | 79.625 | 0.81 | 0.4482 |
| Hills | 3 | 535.167 | 178.389 | 1.82 | 0.1532 |
| Spacing x Hills | 6 | 689.750 | 114.958 | 1.17 | 0.2431 |
| Error:MS(Error) | 57 | 5576.750 | 97.838 | | |

Appendix 6 : Effect of spacing, seedling per hill and their interaction on grain weight

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 4703.3454 | 2351.6727 | 1.69 | 0.1930 |
| Block | 2 | 6708.0434 | 6708.043 | 4.83 | 0.0320 |
| Spacing | 2 | 72097 | 36048 | 25.96 | <.0001 |
| Hills | 3 | 9019.512 | 3006.504 | 2.17 | 0.1021 |
| Spacing x Hills | 6 | 49615 | 8269.200 | 5.95 | 0.0019 |
| Error:MS(Error) | 57 | 79152 | 1388.625 | | |

Appendix 7 : Effect of spacing, seedling per hill and their interaction on dry biomass of rice

| Sources of variation | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 762621 | 762621 | 38.08 | <.0001 |
| Block | 2 | 29699 | 14849 | 0.74 | 0.4809 |
| Spacing | 2 | 163579 | 81790 | 4.08 | 0.0220 |
| Hills | 3 | 54106 | 18035 | 0.90 | 0.4466 |
| Spacing x Hills | 6 | 336786 | 56131 | 2.80 | 0.0049 |
| Error:MS(Error) | 57 | 1141505 | 20026 | | |

Appendix 8 : Effect of spacing, seedling per hill and their interaction on 1000 grain weight of Nerica

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 30.3810 | 30.381 | 1.99 | 0.1638 |
| Block | 2 | 62.634 | 31.317 | 2.05 | 0.1380 |
| Spacing | 2 | 189.173 | 94.587 | 6.19 | 0.0037 |
| Hills | 3 | 246.420 | 82.140 | 5.38 | 0.0025 |
| Spacing x Hills | 6 | 267.944 | 44.657 | 2.92 | 0.0007 |
| Error:MS(Error) |  | 870.325 | 15.269 |  |  |

Appendix 9 : Effect of spacing, seedling per hill and their interaction on rice panicle length

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 0.930 | 0.930 | 0.21 | 0.6471 |
| Block | 2 | 14.612 | 7.306 | 1.67 | 0.1982 |
| Spacing | 2 | 3.535 | 1.768 | 0.40 | 0.6703 |
| Hills | 3 | 41.803 | 13.934 | 3.18 | 0.0309 |
| Spacing x Hills | 6 | 21.636 | 3.606 | 0.82 | 0.2020 |
| Error:MS(Error) | 57 | 250.100 | 4.388 |  |  |

Appendix 10: Effect of spacing, seedling per hill and their interaction number of rice grains per panicle

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 150.222 | 150.222 | 0.96 | 0.3321 |
| Block | 2 | 1026.869 | 513.434 | 3.27 | 0.0452 |
| Spacing | 2 | 1497.954 | 748.977 | 4.77 | 0.0121 |
| Hills | 3 | 426.360 | 142.120 | 0.91 | 0.4443 |
| Spacing*Hills | 6 | 7210.428 | 1201.738 | 7.66 | <.0001 |
| Error:MS(Error) | 57 | 8947.879 | 156.980 |  |  |

Appendix 11: Effect of spacing, seedling per hill and their interaction on rice straw yield

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 556931 | 556931 | 23.52 | <.0001 |
| Block | 2 | 14185 | 7092.6758 | 0.30 | 0.7423 |
| Spacing | 2 | 88818 | 44409 | 1.88 | 0.1626 |
| Hills | 3 | 47118 | 15705 | 0.66 | 0.5780 |
| Spacing x Hills | 6 | 320475 | 53412 | 2.26 | 0.0419 |
| Error:MS(Error) | 57 | 1349667 | 23678 | | |

Appendix 12: Effect of spacing, seedling per hill and their interaction on harvest index

| Sources | DF | SS | Mean squares | F value | Pr(>F) |
|---|---|---|---|---|---|
| Site | 1 | 72.661 | 72.662 | 11.45 | 0.0013 |
| Block | 2 | 1.825 | 0.913 | 0.14 | 0.8664 |
| Spacing | 2 | 66.070 | 33.035 | 5.21 | 0.0084 |
| Hills | 3 | 22.114 | 7.371 | 1.16 | 0.3325 |
| Spacing x Hills | 6 | 326.811 | 54.468 | 8.58 | <.0001 |
| Error:MS(Error) | | 361.767 | 6.347 | | |