EFFECTS OF PLANT POPULATION AND WATER STRESS ON YIELD OF SELECTED MAIZE VARIETIES IN MWEA AND BURA IN KENYA

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This thesis is my original work and it has not been presented for an award of a degree in this or any other university.

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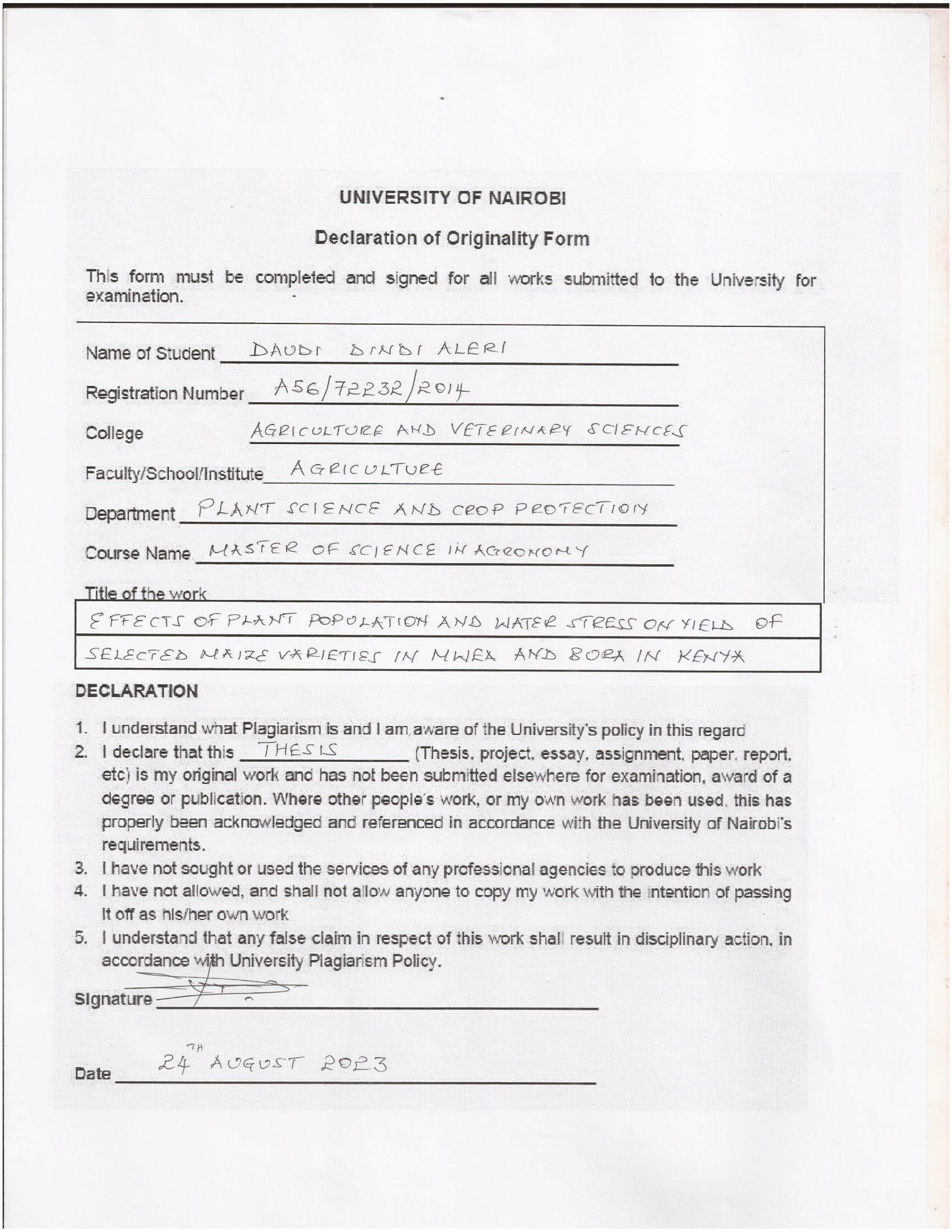

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To my wife, my sons and daughter, and every single family member and friends; people who have worked tirelessly to encourage the strides I have taken in this journey and also given me a reason to work hard towards this achievement.

May the almighty God bless you all.

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ABSTRACT

Maize (*Zea mays* L.) is currently a very crucial food source with over 1 X 10^9 tons being produced across the world, since 2013. It is Kenya's main food security crop with an annual demand of 3.6 million metric tons. The crop's productivity has been declining over the years partly due to inappropriate plant population densities by farmers, and water stress. Recent intense droughts have resulted to significantly reduced maize growth and consequently its grain yield. A study was conducted in the period December 2018 to April 2019 in Mwea Irrigation scheme in Kirinyaga County, and Bura Irrigation scheme in Tana River County. The objectives of the study were to determine the effects of plant population and water stress on growth, yield and yield components of selected maize varieties, in Mwea and Bura Irrigation Schemes, respectively. Experimental plots were set up in a randomized complete block design, in a split-split plot arrangement. *Pioneer (PHB30D79)*, *DH04*, *SC Sungura 301*, *SC Duma 413* and *DH02* maize varieties were planted at treatment plant population of 53,333, 66,666 and 88,888 plants ha^{-1}, respectively, under water stressed and well-watered conditions. Water stressed treatment was applied at the tasseling growth stage of maize (55-days after sowing) until physiological maturity. Data collected included: length of cob, height of ear from the soil level, plant height at maturity, above ground biomass, and grain yield. Data was analyzed using analysis of variance (ANOVA) and the means were separated using the least significant difference (LSD) test at P=0.05. The results showed that when plant population was increased, the growth parameters measured and grain yield of maize decreased significantly. The study established that the recommended population density for the study areas as 53,333 plants per hectare. The maize variety Pioneer (PHB30D79) grown at plant population of 53,333 plants ha^{-1} produced significantly more grain yield than all other maize variety against plant population interaction treatments. Plant population and water stress are important constraints limiting the productivity of maize. Water stress during the reproductive stage of maize significantly reduced its grain yield and yield components.

Key words: Above-ground biomass, grain yield, productivity, reproductive stage, water stress

CHAPTER ONE: INTRODUCTION

1.1 Background

Around 70% of food has to be sourced from the world's global agricultural system for a growing population by 2050 (Smith and Gregory, 2013). Maize is currently an important crop with a global food supply of 1 X 10^9 tons since 2013 (FAOSTAT, 2017). Recent intense droughts have reduced maize growth and its yield (Ahuja *et al.,* 2010). Drought is very important to the cumulative yield of maize (Banziger *et al.*, 2000). Majority of African countries located south of the Sahara Desert rely on maize as the dominant food in their diet. The crop's reliable supply and affordability have been key to sufficient supply of food in the region. Livestock and poultry feed comprise maize as the common ingredient due to its palatability across this important sector in agriculture (Hossain and Shahjahan, 2007). Maize production in Kenya has consistently been below the consumption requirements in the Country (Republic of Kenya Agriculture Sector development strategy, 2010-2020). Maize productivity in Kenya in 2009 stood at 1.3 tons per hectare, compared to 1.6 t ha^{-1}in 2013 (FAO, 2013). Kenya's average maize production for the period between 2016 and 2020 registered 3.684 million tons of grain, (FAO, 2021) (Table 1). During the year 2020, Kenya's average maize production was 4 million tons (Table 1). The quantity of maize produced is less than the high demand from increasing human and livestock population (Strassburg *et al.,* 2014; Mueller and Binder, 2015). The actual yield of maize and other cereal crops obtained by small scale farmers across Sub-Saharan Africa are below their potential yield because cultivation relies on rainfall. The potential yield is the yield realized when stresses brought about as a result of living things (biotic) and the availability of water and nutrients is well provided for. The yield gap (potential yield minus actual yield) varies at the local level, and this may be up to 10,000 kg ha^{-1} in certain zones in Kenya, Ethiopia, Tanzania and Uganda (Global Yield Gap Atlas, 2015). Yield gap caused by limited water provided to crops is quite common in countries south of the Sahara Desert in Africa since very few have taped the use of irrigation systems to supplement low rainfall. The plot topography and type of soil are a major determinant for water-limited yield potential (Global yield Gap Atlas, 2015). By managing biotic stress and using appropriate inputs, the yield gap may be reduced even when there are water constraints. Maize yield estimated from FAO Statistics for Kenya show that in the 10-year period 1993 to 2013, production was increasing, but average production remained the same at 1,500 kg ha^{-1}.

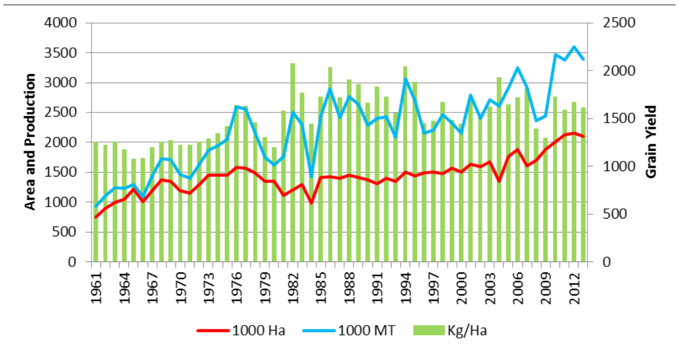

Figure 1: Maize production trend in Kenya (source: FAOSTAT, accessed on 28/02/2020)

Table 1: Average maize production for the period 2016 to 2020, and 2021 forecast for select Sub Sahara Africa Countries

Country	**2016-2022 Average**	**2020**	**2021 Forecast**	**Change 2021/2020**
		(million tons)		
South Africa	13.329	15.966	16.848	5.5
Egypt	7.27	7.577	7.5	-1
Tanzania	6.211	6.3	6.5	3.2
Kenya	3.684	4	3.5	-12.5
Malawi	3.142	3.692	4.58	24.1
Zambia	2.879	3.387	3.62	6.9
Uganda	2.647	2.575	2.75	6.8

(*Source: FAO, 2021)*

Kenya has over the years been experiencing a decline in yield of the main staple, due to among other factors the reducing and erratic rainfall patterns in the two main maize cropping seasons. The low productivity of maize in the main maize producing regions attributed to water stress, especially during the critical stages of maize growth has also compounded the problem leading to serious shortages in the Country.

Over the period between the year 2000 and 2010, the seed certification systems in Africa have greatly improved and this has increased the availability of various types of improved maize seed (Langytuo *et al.*, 2008). The varying climatic and soil conditions will determine the choice of maize cultivar, and recommended plant spacing. With modern hybrids, the spacing is about 75 cm to 100 cm between rows, and 15 cm to 25 cm from plant-to-plant, so as to have a total of about 50,000 to 80,000 plants per hectare. Maize water requirement and crop water use efficiencies varied with cultivars (Asare *et al.,* 2011). Irrigation water requirement differs significantly among all hybrids (Maria *et al.*, 2009).

The purpose of the study is to increase the productivity of maize production in Bura and Mwea Irrigation schemes, under water-stress and well-watered environments through recommendation of appropriate plant population and maize varieties.

1.2. Statement of the Problem

Amongst the various challenges of maize production in the semi-arid tropics, drought is cited as the most important (Diallo *et al.*, 2004). Due to rainfall that is low and unevenly distributed, the flowering and tasseling stages of maize are significantly negatively affected (Kinama *et al.*, 1990). For the period between 1995 and 2020, the demand for maize has risen from 282 million tons to more than 544 million tons (IFPRI, 2000). In a study where data of studies published from 1980 to 2015 reported up to 41% yield reductions in maize, mainly caused by changing rainfall trends, and also depressed rainfall that are causing drought to occur more (Lobell *et al.*, 2011; Daryanto *et al.,* 2016). Maize is a primary contributor to calories induced by Africa's population, accounting for up to between 17% and 60% of all the protein supplied in a day (FAO, 2001). Agriculture is Kenya's major contributor to its GDP with sub-sectors such as maize being the predominantly grown cereals (GoK, 2011). The importance of maize in Africa cuts across different culture and the crop is also categorized as politically important since it influences the food security situation of many Countries who rely on it as a staple food. This has resulted to major research and development efforts to improve its productivity (McCann, 2005). Though Kenya implemented an ambitious fertilizer subsidy program in 2009, the drought resulted in a historic shortage of maize due to low production. The Country imported 1 million tons of maize (Ariga and Jayne, 2009). There was an increase in imports for the main cereal crops consumed in Kenya; maize, wheat, rice in Kenya for the marketing year 2019/2020, brought about by the local supply deficit (USDA foreign agriculture service, 2019). Maize is the main staple food crop in Kenya. USDA foreign agriculture service, Nairobi correctly forecast an increase in total maize consumption in mid-year 2019/2020, mainly due to increase in population. The demand for manufactured feeds to support the growing poultry and dairy sectors has consequently increased maize consumption in the Country. Many developing Countries in Africa and Asian Countries have faced negative effects on agricultural production due to the increased temperatures and evapotranspiration caused by change in climate (Bates *et al.*, 2008). Over different years/seasons, the maize yields have remained minimal and not enough to meet the consumption demand of most Countries in Africa south of the Sahara Desert. This is as a result of drought and thus the average yield realized is a meagre 1.6 t ha^{-1} (FAO Statistics, 2010).

The main objective of the study was to determine the effect of plant population density and water stressed at the flowering stage of maize growth (from the 55th day after emergence), on the yield components and yield of maize. The flowering stage is one of the critical stages where the demand for water in the maize plant is high. In this stage, the silks emerge from the ear that is highest or second highest in the plant. This is followed by pollination and fertilization of the ear. This takes place 40 to 50 days after emergence depending on the variety and environmental conditions.

The Findings of this study will therefore assist smallholder farmers to make an informed investment such as to provide supplementary irrigation whenever rainfall fails during this critical stage of maize growth, and more so to reduce the yield gap in maize production that is currently at 10,000 kg ha^{-1} at research level, whereas the Country's National maize productivity average stands at 1,622 kg ha^{-1}.

1.3 Objectives

The general objective of the study is to assess maize productivity under water-stress and well-watered environments through recommendation of appropriate plant population and maize varieties. The study's specific objectives are to determine the effects of plant population and water stress on grain yield and yield components of selected maize varieties in Mwea and Bura Irrigation Schemes.

1.4. Hypothesis

i. The plant population treatments have no significant effect on the grain yield and yield components of the selected maize varieties in Mwea and Bura Irrigation schemes

ii. The water regime treatments have no significant effects on the grain yield components of the selected maize varieties in Mwea and Bura Irrigation schemes

1.5. Justification of the study

Amongst the main cereal crops cultivated in Kenya, maize is widely grown in the Country as a staple food (United States Agency for International Development, 2010). The 2011 - 2013 FAO Statistics indicate that out of 5.3 million hectares of all crop harvested, more than 2.1 million hectares was occupied by maize, thus 40% of the whole cropped area in Kenya. The consumption per capita is estimated as 103kg per year for every person. Over the period 1980 to 2013, Kenya's maize productivity has decreased by 1 $kgha^{-1}year^{-1}$, (FAO/GIEWS, 2021). Due to climate change; mainly unreliable rainfall and increasing temperatures, Kenya has had a shortfall in the supply of maize over the years; for example, in 2021 the Country produced 36.7 million bags, a decline by 12.8% compared to in 2020 where 42.1 million bags of maize were produced in the Country. Due to mainly, unfavorable weather conditions, this production in 2021 was lower than in 2017 where 37 million bags of maize were harvested against the demand then of 52.8 million bags (KIPPRA, 2022). The Kenya Maize Flour market report estimates the per capita consumption of maize is expected to increase to 60 million bags by 2025. Dry weather conditions in 2017 led to declines in the production of most agricultural commodities (KNBS, 2017). The gap in production against consumption demand for maize has been widening over the years due to an increase in Kenya's population and low yield (KNBS, 2022).

In agricultural production in the ASALs, availability of water is the single most important factor (Schneekloth *et al.,* 2012). For sustainable management of soil and water resources in the midst of climate change, understanding the crop water balance is imminent (Kinama *et al.,* 2005). Agriculture sector must increase crop water productivity (Zwart *et al.,* 2004) since less water is available for the sector (Ali *et al.,* 2006). There is need to validate and disseminate practical and sustainable research findings to smallholder farmers in an attempt to inform future investment towards their food production ventures, especially in Kenya's main staple, maize. One of the key strategies is transforming smallholder agriculture from the ancient to modern innovative technologies which will be accomplished through among others, expansion of crop and domestic animal production to arid and semi-arid lands through development of irrigable areas (Republic of Kenya Agriculture sector development strategy, 2010-2020). Maize yield improvement focus may need to improve strategies in crop management and in selection of hybrids that have less stress at higher plant populations (Tollenar and Lee, 2002). The total maize grains produced in an acre has a positive relationship with the total maize plant stand; it was established that there is significant effect of interaction of maize plant genus to the number of maize plants in a unit area of land, on the total grain harvested (De Bruin and Schussler, 2017). When plant-to-plant spacing of maize is decreased, yield increases as a result of improved light interception and increased efficiency by the plants to utilize space and other resources (Barbieri *et al.,* 2008). However, this increment of plant population has a peak where further increment would result to significant decrease in economic yield. There is a decrease in root weight by 1.2% when the plant population of maize is increased by 1,000 plants ha^{-1} (Bernhard *et al.,* 2020).

CHAPTER TWO: LITERATURE REVIEW

2.1 Ecology of maize

Being a grass suited for the tropical climate, maize is able to grow well in various climates and therefore days to maturity vary from 70 days to 210 days after sowing. The plants have little tillering capacity and grow erect to a height of up to 3 m (Colless, 1982). Globally, the crop is cultivated from 50^0N to 40^0S and from sea level up to 2,000 mm altitude (Birch, 1997).

2.1.1. Micronutrients requirements for maize

The most common micronutrient deficiency of maize and especially in alkaline calcareous soils with low organic matter content is Zinc deficiency. It is also commonly witnessed where there is a high supply of Phosphorous in the soil through fertilizer. To determine optimal Zinc fertilizer application, soil and plant tissue analysis, combined with local experience may be used as a basis. The most common methods of Zinc application are spraying and soil application. For example, 25 kg Zinc Sulphate (21% Zinc) mixed with 25 kg soil along the rows followed by hoeing and irrigation is a common practice to avail this nutrient to maize crops all over the world. Zinc deficiency in maize may be corrected by adding 3kg ha^{-1} of $ZnSO_4$ + 1.5 kg ha^{-1} of lime in 500 litres of water. Maize in-bred lines may be subject to more nutrient deficiencies since they have less extensive and vigorous root systems than hybrids (Wych, 1982).

2.1.2. Nutrition management in maize cultivation

For maize to produce 9.5 tons of grain per hectare, the grain and stover take up the following amounts of nutrients in kg ha^{-1} (International Fertilizer Industry Association, 1992): macronutrients- 191 kg nitrogen per hectare, 89 kg phosphates (P_2O_5 ha^{-1}), 235 kg K_2O ha^{-1}, 73 kg MgO ha^{-1}, 57 kg CaO ha^{-1}, and 21 kg S ha^{-1}; 2130 g Fe ha^{-1}, 380 g zn ha^{-1}, 340 g Mn ha^{-1}, 240 g Bo ha^{-1}, 110 g Cu g ha^{-1}, 9 g Mo g ha^{-1} and 81.2 g Cl ha^{-1}.

For sustainable nitrogen use, split application is recommended at planting and side dress at knee high stage (Jokela and Randall, 1989). When this system is used, the rates of nitrogen may be amended accordingly in the terminal stages of growth of the crop (Bierman *et al.,* 2012). The levels of Phosphorous and Potassium may accumulate in the soil because the two are immobile in the soil, and therefore the amounts that have not been used by the crop would accumulate (Amanullah *et al.,* 2009). To estimate the quantities of these two nutrients as either sufficient, deficient or in excess, soil testing is recommended (Huang *et al.,* 2021). Soil Phosphorous levels above 40ppm (80 Kg acre^{-1}) are in excess and should not need additional amounts. Phosphorous applications should match crop removal if soil levels are 15 to 30ppm (30 to 60 Kg acre^{-1}) (Amanullah *et al.*, 2009). A build-up program would need to be implemented if the Phosphorous levels in the soil are below 15 ppm (Ankerman and Large, 2001). Potassium recommendations follow the same philosophy as phosphorous except consideration is given for soil cation exchange capacity (CEC). If the soil CEC increases, Potassium is held more tightly by the soil. At soil levels above 200 ppm (400 Kg acre^{-1}) the maize yields would not respond to additional Potassium addition. Maize grown on soils that have a CEC < 10 would not respond to additional Potassium when the soil test level > 150 ppm (300 Kg acre^{-1}) (Hannan, 2008).

2.2. Trends in maize production in Kenya

Until the early 1990s, Kenya was generally maize sufficient with supply leaving a surplus for the export market Between the early 1990s up to 2003, the Country's annual maize production decreased by 1% per annum (MoA, 2015; KNBS, 2015; USAID, 2015). Approximately 1.5 million hectares of Kenya's arable land was cropped with maize in 2002, producing 2,600 million tons compared to a demand of 3,400 million tons of the staple (Kamau, 2003). Reforms that were highlighted in Kenya's vision 2030 development plan that was drawn in 2007 transferred the responsibility of provision of inputs for agriculture, development of rural infrastructure, research and provision of extension services to private entities, away from the Government's regulatory boards. (Monitoring and Analyzing Food and Agriculture Policies, 2013a). Following political unrest in 2007, maize prices begun to rise and this was compounded by drought in 2009 which further increased the price of the commodity (Monitoring and Analyzing Food and Agriculture Policies, 2013a). The high fertilizer prices between the period 2007 and 2009 further exuberated the low yields recorded in this period (KNBS, 2014). Smallholder maize farmers contribute up to and above 75% of the cumulative maize output, although a meagre 20% is sold in Kenya's market (Chemonics, 2010). When Kenya waived its import tariff on maize in 2009 resulting to increased imports, domestic wholesale prices remained high. The tariff was re-instated in 2010 (Ogada *et al.,* 2011).

Despite high expenditure in agriculture, yields remained relatively stagnant (Monitoring and Analyzing Food and Agriculture Policies, 2015). Being the Country's main staple, the land mass under the crop accounts for nearly 40% of cultivated area, 2.4% of the Country's Gross Domestic Product (GDP) and 12.65% of Gross Domestic Product (GDP) brought in by agricultural production (FAO, 2016). The Country's per capita consumption was estimated at an average of 103 kilograms per person per year (2012-2014), in comparison to 73 kilograms per person per year for Tanzania, and 52 kilograms per person per year for Ethiopia (FAO, 2016). The seed variety improvement and bulking in the maize subsector has been well developed by the Kenya government over the years. The rate of adoption of hybrid maize seed improved from 68% in 2000 to 82% in 2010. Within this period, yield increased by 16%. (Olwande *et al.*, 2015; Ogada *et al.*, 2011). For the period 2016 to 2020, Kenya harvested an average of 3.684 million tons of maize compared to Malawi's 3.142 million tons, United Republic of Tanzania at 6.211 million tons, Uganda at 2.647 million tons, and Rwanda at 0.416 million tons (FAO, 2021**).** In the bread-basket and in Kenya's capital city, Nairobi, maize prices were maintained mostly at a constant in the months June to September 2021, where they were at the similar levels as the same period for 2020. Prices were kept at low levels by high quantities of maize produced from within the Country, especially because of: reliable reserves from the relatively higher 2020 cereal production and continuous importation from neighboring Countries namely: Tanzania and Uganda (FAO/GIEWS, 2021).

2.2.1 Maize production challenges in Kenya

Due to a deficit in maize production, Kenya imported 700,000 metric tons of the commodity (Kenya National Bureau of Statistics, 2010). The prices of the commodity were too high for consumers and consequently, up to 30% of income earned by poor households was spent on it (Jaetzold *et al.*, 2013). The total "long rains" 2021 maize output was reported by the Government of Kenya as 2.88 million tons, 5 to 10% below par (FAO, 2021). According to weather projections by the Greater Horn of Africa Climate Outlook Forum (GHACOF) rainfall quantities were relatively lower than normal between October and December 2021. This reduced the productivity of the 2021 secondary "short-rains" crop at the onset of year 2022. Cumulative cereal output in the year 2021 is tentatively reported at 4.3 million tons, some 12% lower than 2020 and about 3% below par compared to the preceding 5 years (FAO/GIEWS 2021). Climate change resulting from human activities, which have interfered with the ecosystem more extensively in search of food, water, fuel and other raw material for industries, has greatly impacted on the decline in maize production (Mearns, 1995). Drought cycles have shortened from five-to-seven years, to two-to-three years. Consequently, this trend complimented by expansion of crop production in marginal areas has increased the occurrence of maize production in water-stress prone environments (Nyariki *et al.,* 2007). Maize production has been in stable decline due to several challenges including: climate variability, poor soils, low yielding seeds, post-harvest losses, among other challenges. The acquisition of resources and their use is hindered by drought stress (Karterji *et al.*, 2003). The reduction in per capita food produced is caused by abiotic and biotic challenges (De Vries *et al.*, 2001). The abiotic challenges comprise: water stress, high temperature and low soil fertility (Vanlauwe *et al.,* 2008). Maize is very sensitive to water stress (Pandey *et al.,* 2000). Drought experienced at the flowering stage of maize causes more yield losses compared to when experienced in other growth stages (Cakir *et al.,* 2004; Zaidi *et al.,* 2004). As much as 22% yield reduction may occur when water deficit is experienced in just one or two days during the tasseling or pollination growth stages (Moser *et al.,* 2006). Small scale farmers lack information on timely accurate information, have poor storage facilities and poor market access roads form their farms.

2.2.2 Effect of Plant population on growth, yield and yield components of maize

Attempts to improve maize productivity globally have been successful due to improved genetics and agronomic management (Ciampitti and Vyn, 2012). The key factors influencing grain yield of maize include plant population and row spacing (Van Roekel and Coulter, 2011). Several factors such as fertility of soil, water-holding capacity of soil, group of hybrid and management of the crop, determine the optimal plant population that would produce the highest yield achievable by a cultivar of maize (Mian, 2008; Sangoi, 2001). In modern hybrids, there is a positive relationship between the quantity of maize grains produced in an acre, and the total maize plant stand count in the same acre, since it was found that there is significant effect of interaction of the maize plant genus with number of maize plants in a unit area, on the total grain yield harvested (De Bruin and Schussler, 2017). Under optimal growth conditions of maize, plant population is considered as the major determining factor to the level of competition among plants for a cultivar, and this result to growth and yield variation (Sangakkara *et al.,* 2004). When subjected to stress due to crowding of plants, there is a reduced availability of resources needed for growth of the plant, and especially light needed for photosynthesis, and this will consequently reduce the quantity of maize grain harvested (Ali *et al.,* 2003; Luque *et al.,* 2006). Plant population changes crop canopy, growth behavior and developmental events and grain production of maize (Mian *et al.,* 2021). Utilization of high population densities increased demand for growth resources and thus plants compete for light, macro and micro-nutrients, water, among other growth resources; which might have a negative effect producing lower grain yield per plant (Abuzar *et al.,* 2011).

Plant density of maize significantly determines its yield since each plant produces individually. The effect of plant density varies amongst different hybrids (Sarvari and Pepo, 2014). Planting density and yield of maize are related very closely (Roekel *et al.,* 2011). Maize yield increased when plant density was increased (Hoshang *et al.,* 2012). Increasing the plant population from 60,000 plants ha^{-1} to 80,000 plants per hectare increased the yield of maize from 9.09 tons ha^{-1} to 11.14 tons ha^{-1}, respectively (Mohseni *et al.,* 2014). Plant population effect and organization of plants in a square meter on nutrient usage and grain yield of maize is significant (Wade *et al.,* 1998). Reducing the plant to plant spacing may increase resource capture and utilization by a plant (Widdicombe and Thelen, 2002; Pedersen *et al.,* 2008). Grain yield rises with rise in plant population up to a certain point where further addition of more maize plants will decrease total grain harvested (Duncan, 1984). This is due to the fact that when the plant population that may give the highest grain yield is achieved, the quantity lost due to crowding stress may not be reversed by growing plant population further. The level to which the plant density upsets grain yield is influenced by the hybrid and other ecological settings (Duncan, 1984; Fukai and Foale, 1988; Wade *et al.,* 1988). Light interception by plant leaves is determined by plant population and row width. This will consequently have an effect on photosynthesis (Stewart *et al.,* 2003). When the recommended plant population is ensured, an upsurge in crop yield from a rise in number of plant per hectare is associated to a rise in light capture (Nafziger, 2006).

2.2.3. Effect of Water stress on Yield and Yield components of maize

When water is scarce, the movement of water from the xylem to neighboring cells is rendered poor (Nonami, 1998). There is significant reduction in plant growth when water-limiting conditions are experienced, and this consequently hinders the uptake of key nutrients such as: Nitrogen, Silicon, Magnesium and Calcium which are obtained from the soil through the water uptake by roots through the processes of diffusion and mass transfer (Barber, 1995). When a crop is subject to drought, normal growth, nutrient & water relations, and consequently, a significant yield reduction is experienced (Farooq *et al.,* 2009b). It has been found by many studies that availability of water affects the plant development, growth and yield produced by crops cultivated. When there are low soil moisture conditions, the normal functioning of the plant is reduced and this results to reduced plant height, reduced weight and size of dry matter that the maize plant is able to accumulate, and reduced grain yield (Mahrous,1991). Growth of a plant mostly is supported by mitosis, and water stress disrupts this process, and others such as elongation of cells, thus growth of the plant becomes poor (Hussain *et al.,* 2008). A reduction of 9% and 10% for plants exposed to water stress during the pre-silking and post-silking period of maize growth, respectively occurs, compared to optimal irrigation of plants with sufficient quantity of water at these growth stages (Ibrahim *et al.,* 1992). When higher plants like maize are exposed to limited-water conditions during the reproductive stage of plant's life cycle, productivity is adversely affected (Anjum *et al.,* 2011). When drought stress is introduced at various stages of growth of maize, accumulation of stem is significantly affected (Kamara *et al.,* 2003). Availability of optimum quantities of water have a direct cause-effect relationship with important plant growth determining processes namely: respiration, synthesis of ATP in the mitochondria and to some extent, electron transport (Atkin *et al.,* 2009). The effect on grain filling when water stress is applied at the pre-anthesis and the post-anthesis periods of maize plant growth is that the time taken for this process is reduced significantly and this translates to reduced grain yield (Estrada-Campuzano *et al.,* 2008). The 4 enzymes which majorly control grain filling process in cereals are: Sucrose synthase, Starch synthase, Starch Branching enzyme and Adenosine Diphosphate Glucose Pyrophosphorylase (Taiz *et al.,* 2006). Under water-limiting environment, the activity of these enzymes has been found to reduce and consequently the yield of maize is reduced (Ahmadi *et al.*, 2001).

Photosynthesis rate reduction is one of the many factors that result from drought induced yield loss (Flexas *et al.,* 2004). Other factors resulting to yield loss are due to the disrupted partitioning of assimilates (Farooq *et al.,* 2009b). When maize is exposed to limited-water condition during the flowering stage, there is loss of yield that is economically important (Anjum *et al.,* 2011).

The maize stem height was significantly reduced by water stress Muhammad *et al.,* 2001. Maize grain yield is reduced when the plant experiences water stress (Jun-Chen *et al.,* 1996). This occurs since the leaf area, leaf chlorophyll content, and photosynthesis process is highly diminished due to this abiotic stress. Water stress to a large extent affects the relationship between nutrient of the plants. In order to take up nutrients which are not able to easily move around the soil, plants change their morphology by roots elongation and increasing its surface area (Lynch and Brown, 2001). Under soil moisture-limiting conditions, root growth may be reduced, and thus the uptake of nutrients which don't move around the soil easily such as Phosphorous, may be reduced (Garg, 2003).

Due to limited soil moisture, the yield components namely leaf size, leaf thickness and plant height, were significantly reduced in maize (Khan *et al.*, 2015). Plants treated with either limited available water in the soil for root uptake, or high transpiration rate; these two (2) conditions may perfectly describe water stressed condition. The destruction of potential storage sites for dry matter produced by the plant occur due to reduced cell turgor and reduced leaf size due to the water stress effect on various processes in the plant (Santos *et al.*, 2009). Moisture-limiting conditions results to the reduction of leaf area, photosynthesis, leaf chlorophyll contents and therefore the maize plant's grain yield (Jun-Chen *et al.*, 1996). Water stress can change lipid membranes' composition and as a result change metabolic activities occurring in the cell. Water deficits and dehydration can cause decreased leaf expansion and leaf shedding both of which reduce height area hence photosynthetic area. When under soil moisture-limiting conditions, the processes occurring in plants namely: absorption of photosynthetic active radiation is slowed down, efficiency of conversion of the intercepted photosynthetic active radiation (PAR) into plant dry weight is distorted and the reproductive efficiency i.e. the harvest index (ratio of quantity of grain produced versus total above ground dry matter) is reduced; these are the major factors resulting to reduction of yield (Earl and Davis, 2003).

2.2.4. Biology of maize at different growth stages

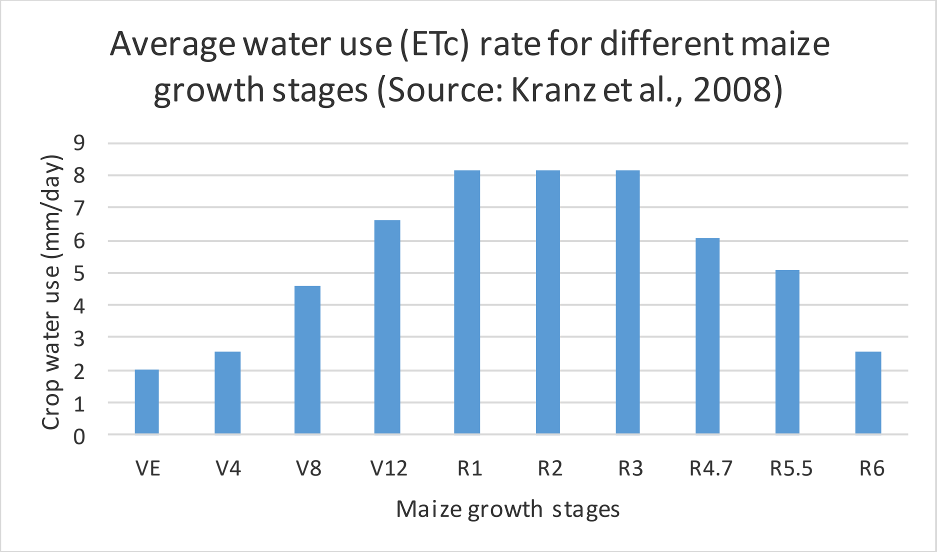

Figure 2: Average water use for different maize growth stages (source: Irrigation management for corn G1850), Kranz *et al.*, 2008

Germination and emergence (stages VE to V2) – the recommended soil temperature for optimal seed germination is 21^0C and above. This will ensure the seeds germinate within 2 to 3 days (Petrovic *et al.*, 2019). With temperatures in the soil less than 18^0C, germination slows and it may occur within a period of 6 to 8 days for radical emergence (Fancelli and Dourado, 2000). Radical emergence may also delay if planting depth is deeper than 8cm (Pomell *et al.*, 2002, Cox and Cherney, 2015). High temperatures in the soil and insufficient moisture may result to death of the seed (Khaeim *et al.*, 2022). Before the primary roots develop within a week of seedling growth to provide the plant with resources from the soil, it utilizes food reserves within it. With optimal soil moisture and temperature, the first internode of the stem will grow quickly and subsequently the seedling will emerge from the soil 4 to 5 days after seed sowing (Dwyer *et al.*, 2000; Forcella *et al.*, 2000).

Early vegetative development (stages V3 to V10) – The main root function is driven by adventitious roots which develop from the 1st stem node under the surface of the soil 10 days after seed emergence (Su *et al.*, 2017). Young maize plants are highly susceptible to water logged conditions, and more so combined with high temperature because at this stage, the growing point is below the ground (Laeur *et al.*, 2012). The growing point will determine the amount of leaves formed during the maize plant’s life. During the juvenile stages of maize plant growth, the growing point that is located just below the soil at period between week 2 and week 3 after emergence will form all the leaves that the plant will develop in that season (Farnham *et al.,* 2003). An embryonic tassel is formed from the growing point three weeks after emergence, and at this stage it is at the soil surface. Eight leaves fully emerge at 4 weeks since there is rapid formation of leaves at this stage (Irish and Jegla, 1997).

Late vegetative development (stages V11 to V16) – During this stage of growth, the plant has high water requirement, Nitrogen (N), Phosphorous (P) and potassium (K) requirement, and is also highly susceptible to insect damage, high plant population and these will irreversibly significantly affect the yield. The V12 stage of growth, five weeks after emergence is categorized by completion of leaf enlargement and filling of most of the root zone by the roots (Lee and Tollenaar, 2007). Though tassel initiation occurs from week five after emergence, it is the period between week five to week seven after emergence (V11 to V16) where the ear size is determined, as the highest one or two ears begin rapidly developing (Subedi and Ma, 2005). Firstly, the total rows in an ear is developed and then the kernel number in a row, respectively (Duncan, 1975).

Flowering (stage R1) – At this stage, the plants leaf formation will have been complete. Depending on variety and environmental conditions, the tassels will have completely have developed and emerge, and pollen grains are shed at 40 to 50 days after the seeds emerge from the ground (Paliwal *et al.,* 2000f). This growth stage of maize requires high water, N and P supply in which case the silks come up from the highest positioned ear and sometimes from the second ear (Farrell *et al.,* 2007). Pollination and fertilization of the ear occurs and K uptake by the plant is almost complete. Nutrient or water deficiency at this stage may delay silk development process or cause the destruction of kernel after pollination has occurred (Aylor, 2004). Hot dry weather during the flowering stage may stress the plant's growth and development requirements and this may cause silks to die and fall off prior to the occurrence of pollination of the ear. This will result to uneven fertilization with only a few kernels are fertilized and thus drastically reducing the formation of seeds in what is referred to as pollen blasting (Farrell *et al.*, 2007).

Cob and kernel development - By day 7 after silks formation, cobs, husks and shanks are fully developed and a lot of the plant's energy and nutrients is used for kernels to be developed in ears (Farrell and O'Keeffe, 2007). The kernels first appear as small swellings containing a colorless fluid, a stage called the kernel blister stage. The kernels undergo the following changes during this stage (Farnham *et al.,* 2003):

- Kernel blister stage- here, the kernels look like small blisters containing a clear fluid
- Milk stage- During this stage, the kernels become thicker and whiter in color
- Kernel dough stage- In this stage, the fluid within the kernels thickens as starch accumulates

In these kernel development stages, N and P uptake is rapid. The Kernel size is mostly affected during this stage since the ear and kernel number has already been determined, and this may have a direct effect on the yield if the size is small with low weight. When the embryos are fully developed, denting occurs; around 20 days after silking (Duncan, 1995). As the plant approaches physiological maturity, the milk line formed at denting stage moves towards the tip of the kernel. This line distinguishes the liquid and solid areas of the developing kernels (Farnham *et al.*, 2003).

Maturity – The maize plant reaches its maximum dry weight (physiological maturity) approximately 30 days after silk formation (Lee and Tollenaar, 2007). At the top of each kernel, a black layer is noticeable, and the milk line is no longer visible. Here the moisture content is around 30%. While moisture loss begins in grains and husks, the healthy stalks remain green, and after a while the drying of leaves occurs (Farnham *et al.,* 2003).

CHAPTER THREE: MATERIALS AND METHODS

3.1. Study sites

The experiments were set at two (2) sites: Mwea and Bura in Kenya, in December 2018. Mwea Irrigation Scheme is located in the County of Kirinyaga at an elevation of 1,159 meters above sea level, 0^0 37’S and 37^0 27’E. The County has tropical climate with characteristics of agro-ecological regions LM3 and LM4; and a medium high-altitude equatorial type of climate. Rainfall design is two seasons per year named as long-rainy and short rainy seasons, which run from March to May, and from October to November, respectively. Average rainfall in a year is around 930 mm, with 510 mm of this amount experienced in the long rainy season. The average temperature is 22^0C with a range between 17^0C and 28^0C. The relative humidity varies from 54.7% to 87.2%. Mwea is generally dry between August to September, and January to February. The soils are mostly Vertisols (LB 8) with poor drainage, and are dark grey to black in color, with heavy cracking when dry, and with calcareous deep sub soil. The quantities of nitrogen, Phosphorous and Potassium are 0.149%, 20 ppm and 0.1485 meq, respectively. The soil pH level is almost neutral at 6.6 (Jacobs *et al.*, 2007).

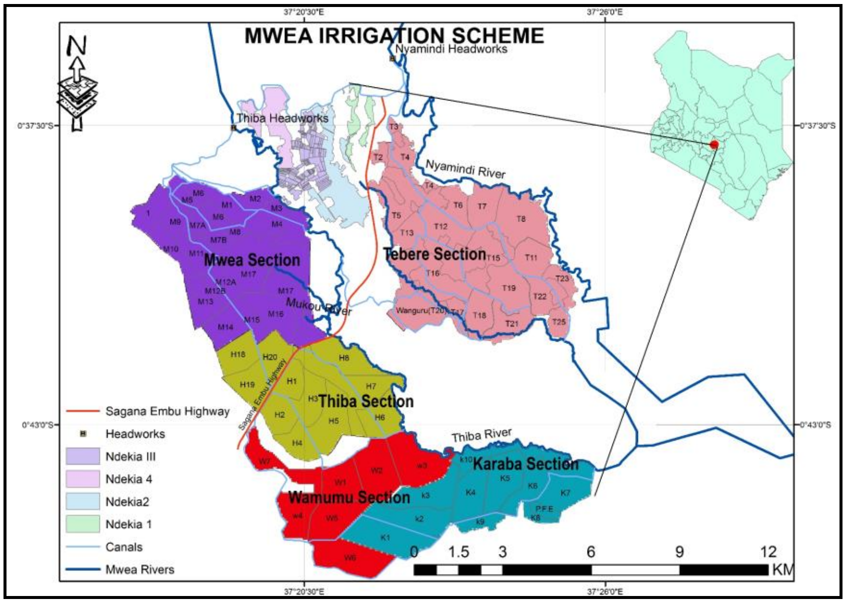

Figure 3: Location of Mwea Irrigation Scheme in Kenya (Source: National Irrigation Authority, 2019)

Bura Irrigation Scheme is situated on Latitude 1^0 9’ South and Longitude 39^0 52’ East. Bura falls in the dry and semi-arid region of Kenya characterized by hot and warm climate. The temperature range is between 20^0C and 30^0C (Tana River County Ministry of Lands, Agriculture, Livestock and Fisheries, 2016). There are four Agro-ecological zones in Tana River County, namely: Coastal L and 3, Coconut-Cassava zone; Coastal Land 4, and Cashew Nuts-Cassava zones. (Tana River County Ministry of Lands, Agriculture, Livestock and Fisheries, 2016). Bura has 2 rainy seasons, namely: March-May and October-December with highest rainfall received in 4th and 11th months of the year, respectively. The average annual rainfall in Bura is 400 mm (Kenya meteorological department, 2009). The soil in this area comprise loose sandy clay to sandy loam soils with pH ranges from 6.5 to 7.5 (Ministry of lands reclamation, regional and water development, 1997).

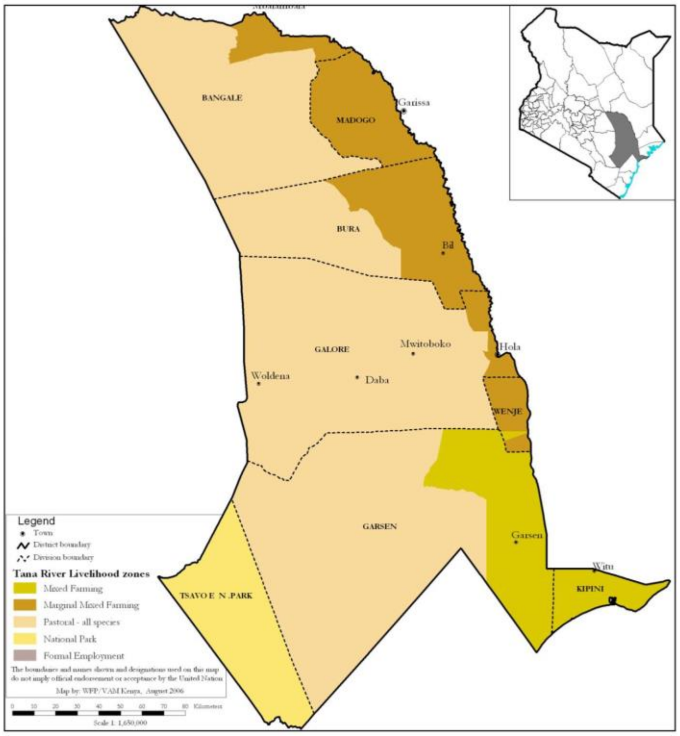

Figure 4: Location of Bura in Kenya (Source: Kenya Food security steering grooup and Tana River County steering group, 2018)

3.2 Treatments and experimental design

The experiment comprised three (3) treatments as follows:

3.2.1. Maize varieties selected

Due to farmers' re-use of saved harvest as seed for subsequent seasons in the study areas, low grain yields are obtained. Due to adulteration of seeds, and irregularities in the informal seed sector, yields have been reduced (Waiyaki *et al.*, 2006). Five (5) selected maize varieties used in the study were: *Pioneer (PHB30D79), DH04, SC DUMA 413, SC Sungura 301,* and *DH02*. The maize varieties were planted in a total of ninety (90) experimental plots per site, each measuring (5x4) meters at Mwea and Bura Irrigation Schemes under irrigated ecosystem.

Table 2: Characteristics of the selected maize varieties (source: KEPHIS National crop varieties list updated for 2020)

S. No.	Variety Name	Year of release in Kenya	Optimal production altitude range (masl)	Duration to maturity (Months)	Grain yield (tons ha^{-1})
1.	Pioneer (PHB30D79)	2008	1000-1800	4-5	7-11
2.	DH04	2001	900-1500	3-4	5-6
3.	SC Sungura 301	2015	300-1200	3	4-8
4.	SC Duma 413	2014	800-1800	3-3.5	5-7
5.	DH02	1995	900-1400	3-4	4-6

3.2.2. Water treatments

Prior to the 55th day after emergence when the water treatments were applied, each experimental plot received 500mm at an interval of four (4) days. Irrigation water treatments were done using furrow irrigation method, and the amount of water supplied to each experimental plot was measured using parshall flumes. The two (2) water treatments were achieved as follows:

i. Water stressed treatment: For the 45 experimental plots per experimental site that were scheduled to receive this treatment, 500mm of water was provided to each plot at an interval of 8 days. This treatment begun 55 days after emergence of the maize plants until maturity, prior to which all the maize plants received 500mm of water per plot at an interval of 4 days.

ii. Well-watered treatment: For the 45 experimental plots per experimental site that were scheduled to receive this treatment, 500mm of water was provided to each plot at an interval of 4 days until maturity of the crop. This treatment was applied throughout the experiment period until maturity of the maize plants.

A mean of 0.178 m^3m^{-3} moisture content in soil was achieved for the Mwea Site for the Water stressed treatment against a mean of 0.193 m^3m^{-3} for the Well-watered treatment in the site. A mean of 0.069 m^3m^{-3} was achieved for the Bura Site for the Water stressed treatment against a mean of 0.128 m^3m^{-3} for the Well-watered treatment in the site. Table 3 shows the available soil water quantities prior to every irrigation water application that was carried out fifty-five (55) days after sowing as per the intended protocol.

Table 3: Soil moisture content measurements obtained using the gravimetric method prior to application of irrigation water treatments, 55 days after sowing at Mwea in 2018

No.	Water treatment	Irrigation frequency 55 days after sowing	Average soil moisture content prior to irrigation water application (%)	Average volumetric soil moisture content (m^3m^{-3})
1	Water stressed	1st	15.1	0.151
2	Well-watered	1st	18.6	0.186
3	Water stressed	2nd	17.6	0.176
4	Well-watered	2nd	19.0	0.19
5	Water stressed	3rd	13.1	0.131
6	Well-watered	3rd	16.2	0.162
7	Water stressed	4th	19.4	0.194
8	Well-watered	4th	20.9	0.209
9	Water stressed	5th	17.9	0.179
10	Well-watered	5th	22.1	0.221
11	Water stressed	6th	23.6	0.236
12	Well-watered	6th	19.1	0.191
13.	Mean Moisture Content for Water stressed treatment (%)	17.8		0.178
14	Mean Moisture Content for Well-watered treatment (%)	19.3		0.193

Table 4: Soil moisture content measurements obtained using the gravimetric method prior to application of irrigation water treatments, 55 days after sowing at Bura in 2018

No.	Water treatment	Irrigation frequency 55 days after sowing	Average moisture content prior to irrigation water application (%)	Average volumetric soil moisture content (m^3m^{-3})
1	Well-watered	1st	7.6	0.076
2	Water stressed	1st	4.8	0.048
3	Well-watered	2nd	8.8	0.088
4	Water stressed	2nd	3.7	0.037
5	Well-watered	3rd	15.0	0.15
6	Water stressed	3rd	8.0	0.08
7	Well-watered	4th	13.9	0.139
8	Water stressed	4th	7.4	0.074
9	Well-watered	5th	18.8	0.188
10	Water stressed	5th	10.0	0.1
11	Well-watered	6th	14.0	0.14
12	Water stressed	6th	5.9	0.059
13	Well-watered	7th	11.6	0.116
14	Water stressed	7th	7.3	0.073
15	Well-watered	8th	13.0	0.13
16	Water stressed	8th	8.2	0.082
17	Mean Moisture Content for Water stressed treatment (%)	6.9		0.069
18	Mean Moisture Content for Well-watered treatment (%)	12.8		0.128

3.2.3. Plant population treatments

The three (3) plant population treatments of 53,333 plants ha^{-1}, 66,666 plants per hectare and 88,888 plants per hectare were achieved as follows:

I. 53,333 plants per hectare: This was achieved by providing spacing between rows of 0.75 meters and spacing between plants was 0.25 meters

II. 66,666 plants per hectare: This was achieved by providing spacing between rows at 0.75 meters and spacing between plants was 0.20 meters

III. 88,888 plants per hectare: This was achieved by providing spacing between rows of 0.75 meters and spacing between plants was 0.15 meters

The experiments were laid down in ninety (90) experimental plots for each of the 2 experimental sites, giving a total of one hundred and eighty (180) plots each measuring (5x4) meters. The trials were planted in a randomized complete block design, with treatments replicated three times. The main plots consisted of two (2) water treatments, and the sub plots were five (5) maize varieties selected, and three (3) plant population treatments. The planting dates were: 16th December 2018 for the Mwea study site and 7th December 2018 for Bura study site.

3.3. Data Collection

3.3.1. Growth and yield data

Data collected from the two experimental sites included: height of plants & biomass produced above the ground at physiological maturity, length of cobs, height of ears, and quantity of grains harvested at 13.5% moisture content. Moisture content in soil before every scheduled irrigation water treatment was recorded using the gravimetric method.

Plant height, length of cobs, height of ear, above ground biomass, and total grains harvested in a hectare parameters were recorded from 10 maize plants per experimental plot, plants which were tagged during their 10-leaf stage of growth.

The height of plant height and ear, respectively, were determined using a measuring tape. These measurements were taken by measuring from the soil surface contact point with the plant to the tip of the tassel of the maize plants, at maturity to record height of plant, and, from the soil surface contact with the plant to the ear of the plant to collect height of ear, respectively. (Rahman, 2017).

Length of cobs determined with the use of a measuring tape. This was done from 10-tagged maize plants per experimental plot. Measurements were recorded after kernels had been extracted from the cob and the average cob length recorded in centimeters.

On reaching physiological maturity, the ears were harvested from the 10-tagged plants in each experimental plot, and stored in labelled grain paper. The grains were air dried and the remaining moisture was extracted by oven-drying at 70^0C until a constant weight was achieved. The ears per plot were then shelled and the weight of grains determined using a digital weighing scale. The weight of the grain was recorded in unit's gm^{-2}. The weight of the maize plants' vegetative matter was recorded after the ears had been detached from the plant, and this remaining plant matter's weight measured using a suspended sling-weighing scale. The cumulative biomass produced above the ground was determined by adding up the oven-dried weight of the vegetative material, rachis and grain harvested from each experimental plot.

3.3.2. How to determine soil moisture content using gravimetric method?

The amount of moisture in the soil before every irrigation water regime treatment was determined using gravimetric method so as to ascertain that water stressed and well-watered treatments were effectively achieved.

The gravimetric method involves gathering a soil specimen using a soil auger, weighing up the specimen prior to and after drying it and computing its original soil moisture content. Whitney *et al.,* 1894, described some of the first scientific investigations of soil moisture using gravimetric methods. Prior to every irrigation water application to the experimental plots, the soil moisture content adjacent to the 10-tagged plants in each experimental plot was determined by gravimetric method. Soil samples were obtained using a hand-held soil auger up to a depth of 15cm below-ground. These were stored in labelled aluminum tins and the lid covers placed to make them airtight. The weight of each aluminum tin without the lid was recorded immediately to prevent any potential inaccuracy in weight collection. Further drying was done in a pre-heated oven to 100^0C for 12 hours and the weight of the aluminum tin containing the soil samples collected recorded. Subsequently, the aluminum tins containing the soil samples were dried at 100^0C for 2 hours and weighed again. This weighing and drying proceeded until a constant weight was achieved. The difference between the initial weight of the aluminum tins containing the soil sample and the final weight after oven-drying until there is no further change weight was achieved, is equal to the mass of water that was recorded as being available in the soil during sampling. The gravimetric amount of water in soil is calculated by dividing the mass of water to the mass of dry soil.

The soil sampling schedule that was implemented is highlighted in Tables 5 and 6.

Table 5: Dates of Soil sampling and irrigation for Mwea site

Irrigation frequency 55 days after sowing	Experiment plots with Well-watered treatment		Experiment plots with water-stress treatment	
	Dates of Soil sampling	Dates of Irrigation	Dates of Soil sampling	Dates of Irrigation
1st	15th February 2019	16th February 2019	24th February 2019	24th February 2019
2nd	19th February 2019	20th February 2019	4th March 2019	5th March 2019
3rd	24th February 2019	25th February 2019	12th March 2019	13th March 2019
4th	4th March 2019	5th March 2019	20th March 2019	21st March 2019
5th	8th March 2019	9th March 2019	Nil	Nil
6th	12th March 2019	13th March 2019	Nil	Nil

Table 6: Dates of Soil sampling and irrigation for Bura site

Irrigation frequency 55 days after sowing	Experiment plots with well-watered treatment		Experiment plots with water-stress treatment	
	Dates of Soil sampling	Dates of Irrigation	Dates of Soil sampling	Dates of Irrigation
1st	6th February 2019	7th February 2019	10th February 2019	11th February 2019
2nd	11th February 2019	12th February 2019	21st February 2019	22nd February 2019
3rd	16th February 2019	17th February 2019	3rd March 2019	4th March 2019
4th	21st February 2019	22nd February 2019	11th March 2019	12th March 2019
5th	26th February 2019	27th February 2019	Nil	Nil
6th	3rd March 2019	4th March 2019	Nil	Nil

3.4. Data analysis

The data for the parameters described for the study, was collected and this was analyzed using analysis of variance (ANOVA) method (Kothari *et al.,* 2004), using the software SAS version 9.1. (SAS version 9.1 users' guide). The means for the data collected were further analyzed using the Least Significant Difference (LSD) method at *p*=0.05 (Kothari *et al.,* 2004).

CHAPTER FOUR: RESULTS

4.1. Effect of variety on yield and yield components of maize in Mwea and Bura in 2018

Cob length: At Mwea, DH02 had significantly shorter cobs than all other varieties, whereas Pioneer (PHB30D79) had significantly longer cobs than all other varieties except SC Sungura 301 (Table 7). SC Sungura 301 had significantly longer cobs than DH04 though not significantly different from SC DUMA 413. There was no-significant difference of cob length of DH04 and SC Duma 413. At Bura, Pioneer (PHB30D79) had significantly the longest cobs than all other varieties. Whereas DH04, SC DUMA 413 and DH02 had no significant difference in their cob length at Bura, DH02 had significantly shorter cobs than Pioneer (PHB30D79) (Table 8). The average cob length was 17.9 cm at Mwea and 16.5 cm at Bura.

Ear height: At Mwea, Pioneer (PHB30D79) had the highest significant height of ears compared to all other varieties, whereas DH02 had significantly the lowest. DH04 had significantly higher ear height than SC Sungura 301 and SC DUMA 413 (Table 7). At Bura, Pioneer (PHB30D79) had significantly the highest ear height, whereas DH02 had significantly the lowest ear height than all other varieties except SC Sungura 301. DH04 had significantly higher ear height than SC Sungura 301, but this was not significantly different than that of SC DUMA 413. SC DUMA 413 had significantly higher ear height than SC Sungura 301 (Table 8).

The average ear height was 130.3cm in Mwea and 123.3.cm in Bura.

Plant height: At Mwea, DH02 had significantly the shortest plant height, whereas there weren’t differences which were significant for all the other varieties except for SC Sungura 301 which had significantly taller plants than DH04 (Table 7). At Bura, Pioneer (PHB30D79) had significantly taller plants than all other varieties, except for SC Duma 413 where their difference was not significant. In the same study site, on one hand SC DUMA 413 had significantly taller plants than all other varieties except Pioneer (PHB30D79), and on the other, SC Sungura 301 had significantly taller plants than DH02. DH04 had no-significant difference in their plant height in Bura (Table 8). Plants in Bura were significantly taller than those grown in Mwea.

The average height of plants was 221.1cm at Mwea and 277.4cm at Bura.

Above-ground biomass: At Mwea, SC Sungura 301 had significantly the highest above-ground biomass whereas DH02 had significantly the lowest except for with SC Duma 413 where they had no-significant difference (Table 7). Whereas DH04 had significantly higher above-ground biomass than Pioneer (PHB30D79) and SC Duma 413, SC Duma 413 had significantly more above-ground biomass than Pioneer (PHB30D79) (Table 7). At Bura, Pioneer (PHB30D79) had significantly the highest above-ground biomass, as DH02 had significantly the least above ground biomass than all other varieties. SC Sungura 301 had significantly more biomass produced above the ground than DH04 and SC Duma 413, and DH04 produced more than SC Duma 413 (Table 8). Maize varieties grown in Mwea had more biomass produced above-ground than those grown in Bura.

The averages for above-ground-biomass was 4,719.3 $kgha^{-1}$ at Mwea and 2,628.9 $kgha^{-1}$ at Bura.

Grain yield: At Mwea, Pioneer (PHB30D79) had significantly the least grain yield compared to all the other selected varieties in the study. All other varieties had no-significant difference in the grain yield recorded, except SC Sungura 301 which produced significantly more grain yield than SC Duma 413 (Table 7). At Bura, Pioneer (PHB30D79) had significantly the highest grain yield than all other varieties except SC Sungura 301, whereas DH04 had significantly the lowest grain yield for all varieties except for DH02 where the two had no-significant difference in grain yield. Whereas SC Sungura 301 had significantly higher grain yield than both SC Duma 413 and DH02, SC Duma 413 had more grains harvested than DH02 (Table 8). Plants in Mwea yielded more grains than those in Bura.

The average grain yield was 3,572.4 $kgha^{-1}$ at Mwea and 2,007.8 $kgha^{-1}$ at Bura.

4.2. Effect of Plant Population on the Yield and Yield Components of Maize in Mwea and Bura, 2018

In Mwea, the population of plants in a hectare of maize had significant effect on the quantity of biomass produced above the ground and total amount of grains harvested from the sampled maize varieties in Mwea. However, in Bura, significant differences in plant population were only noted in cob length and above-ground biomass.

Cob Length: At Mwea, whereas 88,888 maize plants grown in a hectare had significantly shorter cob length than all other plant population treatments, those at the population of 66,666 maize plants per hectare and 53,333 plants ha^{-1} had no significant difference in the length of their cobs. (Table 9). At Bura, the length of cobs for plant population treatments weren’t different (Table 10). Plants grown in Mwea under all population treatments had longer cobs than those in Bura.

Ear height: At Mwea and Bura, the ear height for all the plant population treatments were not significantly different (Table 9, Table 10, respectively). Plants in Mwea had significantly higher ear height than those in Bura

Plant height: At Mwea and Bura, the plant height for all the plant population treatments were not significantly different (Table 9, Table 10, respectively). Plants in Bura were significantly taller than those in Mwea at all plant population treatments.

Above-ground biomass: At Mwea, the population of 53,333 maize plants grown in a hectare produced significantly more biomass produced above the ground compared to all other plant population treatments. 66,666 maize plants grown in a hectare and 88,888 maize plants grown in a hectare had no differences which were significant in the biomass produced above ground (Table 9). At Bura, 53,333 maize plants grown in a hectare produced significantly the highest above-ground biomass than all other plant population treatments (Table 10). At 88,888 plants ha^{-1}, significantly more biomass was produced above the ground than at 66,666 plants ha^{-1} (Table 10). Plants in Mwea produced significantly higher above-ground biomass than those grown in Bura.

Grain yield: At Mwea, there were no differences which were significant in the grain yield produced by all the plant population treatments (Table 9). At Bura, 53,333 maize plants grown in a hectare produced significantly the highest grain yield compared to 66,666 maize and 88,888 maize plants grown in a hectare, respectively. Grain yield from 88,888 maize plants grown in a hectare was not significantly different from that produced by 66,666 maize plants in a hectare of land (Table 10). Plants in Mwea produced significantly higher grain yield than plants in Bura.

4.3. Effect of Water stress on the Yield and Yield Components of Maize in Mwea and Bura, 2018

In Mwea, water stress had significant effect on the grains yielded. Height of ear, length of cobs, height of plants, biomass produced above the ground and quantity of grain harvested were significantly reduced by water stress. This was not the case in Bura site as the water regime treatments were only significantly different for height of ears, height of plants and grains yielded.

Cob Length: At Mwea, well-watered regime treatment had significantly longer cob length than water-stressed plants (Table 11). At Bura, there was no significant difference in cob length of the two water regime treatments (Table 12). Plants in Mwea had significantly longer cobs than those in Bura.

Ear height: At Mwea and Bura, plants at well-watered treatments had higher ear height than those under water-stress (Table 11 and Table 12).

Plant height: At Mwea and Bura, well-watered treated plants had taller plants than those for water stressed treatment (Table 11 and Table 12). Plants in Bura were significantly taller than those grown in Mwea.

Above-ground biomass: At Mwea, well-watered treatment had plants that produced significantly more above ground biomass than water stressed treatment (Table 11). There was no significant difference in the biomass produced by plants for both water treatments at Bura (Table 12). Plants grown in Mwea under both water regime treatments accumulated more above ground biomass than those grown in Bura.

Grain yield: At Mwea and Bura, well-watered plants produced significantly higher grain yield than water stressed plants (Table 11 and Table 12).

Table 7: Effect of variety on the yield and yield components of maize in Mwea in 2018

Treatment	Cob length (cm)	Ear height (cm)	Plant height (cm)	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
Pioneer (PHB30D79)	19.1 a	154 a	228.2 a	4,302.1 d	2,884.50 c
DH04	17.6 c	132.5 b	224.3 a	5,245.3 b	3,590.50 a
SC Sungura 301	18.4 b	121.7 c	227.9 a	6,048.8 a	4,075.70 a
SC DUMA 413	18.2 b	129.9 b	224.8 a	4,546.7 c	3,475.80 b
DH02	16 d	113.2 c	200.5 b	4,453.6 c	3,835.50 a
Means	**17.9**	**130.3**	**221.1**	**4,919.3**	**3,572.40**
P-value	**<0.0001**	**<0.0001**	**0.0034**	**<0.0001**	**0.0002**
LSD	**0.7**	**8.8**	**15.7**	**183.4**	**493.9**
CV(%)	**5.9**	**10.1**	**10.6**	**9.1**	**2.7**

****Means with the same letters and within the same column are not statistically significantly different*

Table 8: Effect of variety on the yield and yield components of maize in Bura in 2018

Treatment	Cob length (cm)	Ear height (cm)	Plant height (cm)	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
Pioneer (PHB30D79)	17.7 a	147 a	293.6 a	2,928.2 a	2,256.00 a
DH04	16.1 b	125.4 b	269.1 b	2,521.3 d	1,754.30 c
SC Sungura 301	16.4 a	108.5 c	274 b	2,747.1 b	2,181.60 a
SC DUMA 413	16.4 a	122.8 b	287.2 a	2,676.5 c	2,037.30 b
DH02	15.9 b	112.9 c	263.3 c	2,271.3 e	1,809.50 c
Means	**16.5**	**123.3**	**277.4**	**2,628.9**	**2,007.80**
P-value	**0.01**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
LSD	**1.02**	**7.34**	**8.6**	**51.3**	**87**
CV(%)	**9.3**	**8.9**	**4.6**	**3.4**	**6.5**

****Means with the same letters and within the same column are not statistically significantly different*

Table 9: Effect of plant population on the yield and yield components in Mwea in 2018

Treatment	Cob length (cm)	Ear height (cm)	Plant height (cm)	Above ground biomass (kgha-1)	Grain yield (kgha-1)
88,888 plants ha^{-1}	17.4 b	131.7	224.3	4,556.8 b	3,579.00
66,666 plants ha^{-1}	18 a	128.7	217.1	4,630.8 b	3,467.50
53,333 plants ha^{-1}	18.3 a	130.4	222	4,970.2 a	3,670.60
Means	**17.9**	**130.3**	**221.1**	**4,719.3**	**3,572.40**
P-value	**0.0086**	**0.6893**	**0.475**	**0.0001**	**0.5706**
LSD	**0.5469**	**NS**	**NS**	**142.1**	**NS**
CV(%)	**5.9**	**10.1**	**10.6**	**9.1**	**2.7**

**** Means with the same letters and within the same column are not statistically significantly different*

Table 10: Effect of plant population on the yield and yield components in Bura in 2018

Treatment	Cob length (cm)	Ear height (cm)	Plant height (cm)	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
88,888 plants ha^{-1}	16.3	123.1	275.7	2,608.3 b	1,922.70 b
66,666 plants ha^{-1}	16.6	123.2	279.2	2,515.6 c	1,949.50 b
53,333 plants ha^{-1}	16.7	123.7	277.4	2,762.8 a	2,151.10 a
Means	**16.5**	**123.3**	**277.4**	**2,628.9**	**2,007.80**
P-value	**0.59**	**0.98**	**0.57**	**<0.0001**	**<0.0001**
LSD	**NS**	**NS**	**NS**	**39.7**	**67.4**
CV(%)	**9.3**	**8.9**	**4.6**	**3.4**	**6.5**

****Means with the same letters and within the same column are not statistically significantly different*

Table 11: Effect of water stress on the yield and yield components in Mwea in 2018

Treatment	Cob length (cm)	Ear height (cm)	Plant height (cm)	Above ground biomass (kgha-1)	Grain yield (kgha-1)
Well-watered	18.1 a	140.7 a	239.8 a	5,483.6 a	4,210.90 a
Water stressed	17.6 b	119.9 b	202.5 b	3,954.9 b	2,933.80 b
Means	**17.9**	**130.3**	**221.1**	**4,719.3**	**3,572.40**
P-value	**0.0309**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
LSD	**0.4465**	**5.6**	**9.9**	**116**	**312.4**
CV(%)	**5.9**	**4.1**	**6.6**	**9.1**	**2.7**

****Means with the same letters and within the same column are not statistically significantly different*

Table 12: Effect of water stress on the yield and yield components in Bura in 2018

Treatment	Cob length (cm)	Ear height (cm)	Plant height (cm)	Above ground biomass (kg ha^{-1})	Grain yield (kg ha^{-1})
Well-watered	16.6	126.4 a	283.1 a	2,649.5	2,026
Water stressed	16.3	120.3 b	271.7 b	2,608.3	1,989.50
Means	**16.5**	**123.3**	**277.4**	**2,628.9**	**2,007.80**
P-value	**0.37**	**0.01**	**<0.0001**	**0.77**	**0.19**
LSD	**NS**	**4.64**	**5.4**	**NS**	**NS**
CV(%)	**9.3**	**8.9**	**4.6**	**3.4**	**6.5**

****Means with the same letters and within the same column are not statistically significantly different*

4.4. Effects of interaction of treatments

4.4.1. Effect of interaction of Variety and Water regime on Grain yield of maize at Bura in 2018

At Bura, the interaction of Pioneer (PHB30D79) maize variety and water-stress regime produced the highest significant grain yield, whereas the interaction of DH02 variety x water-stress regime produced significantly the lower grain yield than all other variety x water regime interaction treatments; though not significantly lower than the interaction treatment of DH02 x Well-watered interaction treatment. (Table 13). The interaction treatment of SC DUMA 413 x Water stressed regime produced significantly higher grain yield than all other variety x water regime interaction treatments though this was not significantly different from the interaction treatments of Pioneer (PHB30D79) x Well-watered, and SC DUMA 413 x Well-watered. The interaction treatment of Pioneer (PHB30D79) x Well-watered regime produced significantly more grain yield than SC Sungura 301 x Water stressed, DH04 x Well-watered, SC Sungura 301 x well-watered, DH02 x Well-watered, DH02 x Water stressed and DH04 x Water stressed, interaction treatments, respectively. The interaction treatment of SC DUMA 413 x Well-watered interaction treatment produced significantly more grain yield than the interaction treatments of DH04 x Well-watered, SC Sungura 301 x Well-watered, DH02 x Well-watered, DH02 x Water stressed, DH04 x Water stressed, respectively. SC Sungura 301 x water stressed interaction treatment produced significantly more grain yield than the interaction treatments of DH04 x Well-watered, SC Sungura 301 x Well-watered, DH02 x Well-watered, DH02 x Water stressed, DH04 x Water stressed, respectively. The interaction treatment of DH04 x Well-watered significantly produced more grain yield than the interaction treatments of DH02 x Well-watered, DH02 x Water stressed, and DH04 x Water stressed, respectively, though not significantly different from the interaction treatment of SC Sungura 301 x Well-watered interaction treatment. The interaction treatment of SC Sungura 301 x Well-watered produced significantly more grain yield than the interaction treatments of DH02 x Well-watered, DH02 x Water stressed, and DH04 x Water stressed, respectively. The interaction treatment of DH02 x Well-watered interaction treatment produced more grain yield than the interaction treatment of DH04 x Water stressed regime (Table 13).

Table 13: Effect of Interaction of Variety and Water regime on grain yield of maize at Bura in 2018

Treatment	Grain yield (Kg ha^{-1})
Pioneer (PHB30D79) x Water stressed regime	2,302.1 a
SC Duma 413 x Water stressed regime	2,213.2 b
Pioneer (PHB30D79) x Well-watered regime	2,210.1 b
SC Duma 413 x Well-watered regime	2,150.0 bc
SC Sungura 301 x Water stressed regime	2,103.2 c
DH04 x Well-watered regime	1,984.0 d
SC Sungura 301 x Well-watered regime	1,971.4 d
DH02 x Well-watered regime	1,814.4 e
DH02 x Water stressed regime	1,804.5 e
DH04 x Water stressed regime	1,524.6 f
Mean	**2,007.8**
P-value	**<0.0001**
LSD	**67.4**
CV (%)	**6.5**

****Means with the same letters are not statistically significantly different*

4.4.2. Effect of interaction of Plant population and Water regime on Plant height of maize at Bura in 2018

At Bura, the interaction treatment of 53,333 plants ha^{-1} x water stressed regime had significantly taller plants than the interaction treatments of 53,333 plants ha^{-1} x well-watered regime, and 88,888 plants ha^{-1} x well-watered regime, respectively (Table 14). The interaction treatment of 88,888 plants ha^{-1} x water stressed regime had significantly taller plants than the interaction treatments of 53,333 plants ha^{-1} x Well-watered regime, and 88,888 x Well-watered regime, respectively. The interaction treatment of 66,666 x Water stressed regime produced significantly taller plants than interaction treatments of 53,333 x Well-watered regime, and 88,888 x Well-watered regime, respectively (Table 14).

Table 14: Effect of Interaction of Plant Population and Water regime treatments on Plant height and Grain yield of maize at Bura in 2018

Treatment	Plant height (cm)	Grain yield (Kgha^{-1})
53,333 plants ha^{-1} x Water stressed regime	283.5a	2,156.2a
88,888 plants ha^{-1} x Water stressed regime	283.0a	1,916.9cd
66,666 plants ha^{-1} x Water stressed regime	282.8a	1,895.4d
66,666 plants ha^{-1} x well-watered regime	275.6ab	2,003.7bc
53,333 plants ha^{-1} x Well-watered regime	271.3b	2,145.9a
88,888 plants ha^{-1} x Well-watered regime	268.3 b	1,928.4b
Mean	**277.4**	**2,007.8**
P-value	**<0.0001**	**<0.0001**
LSD (0.05)	**8.6**	**87**
CV (%)	**4.6**	**6.5**

****Means with the same letters and within the same column are not statistically significantly different*

4.4.3. Effect of interaction of Plant population and Water regime on Grain yield of maize at Bura in 2018

At Bura, the interaction treatment of plant population of 53,333 plants ha^{-1} and water-stress regime produced the highest significant grain yield compared to all other plant population-water regime interaction treatments, but this was not significantly different from the grain yield produced by the interaction treatment of 53,333 plants ha^{-1} x well-watered regime (Table 14). The interaction treatment of 53,333 plants ha^{-1} x well-watered regime produced significantly more grain yield than the interaction treatment of 66,666 plants ha^{-1} x Well-watered regime, 88,888 plants ha^{-1} x Well-watered regime, 88,888 plants ha^{-1} x Water stressed regime, and 66,666 plants ha^{-1} x water stressed regime, respectively (Table 14).

4.4.4. Effect of interaction of Variety and Plant population on Plant height of maize at Bura in 2018

At Bura, Pioneer (PHB30D79) grown at 53,333 plants ha^{-1} had significantly taller plants than all other variety-plant population interaction treatments, though not significantly taller than SC Sungura 301 grown at 88,888 plants ha^{-1} (Table 15). DH02 grown at plant population of 53,333 plants ha^{-1} had significantly the shortest plants than other variety x plant population interaction treatments. The interaction treatment of Pioneer (PHB30D79) x 66,666 plants ha^{-1} produced plants which were significantly taller than the interaction treatments of: DH04 x 53,333 plants ha^{-1}, SC Sungura 301 x 53,333 plants ha^{-1}, SC Duma 413 x 53,333 plants ha^{-1}, SC Duma 413 x 88,888 plants ha^{-1}, SC Duma 413 x 66,666 plants ha^{-1}, DH04 x 66,666 plants ha^{-1}, DH02 x 66,666 plants ha^{-1}, DH02 x 88,888 plants ha^{-1}, DH04 x 88,888 plants ha^{-1}, and DH02 x 53,333 plants ha^{-1}, respectively, though this plant height was not significantly different from plants of the interaction treatments: SC Sungura 301 x 88,888 plants ha^{-1}, SC Sungura 301 x 66,666 plants ha^{-1}, and Pioneer (PHB30D79) x 88,888 plants ha-^{1}, respectively. Plants grown under the interaction treatment of DH04 x 53,333 plants ha^{-1} were significantly taller than those of interaction treatments of: SC Duma 413 x 88,888 plants ha^{-1}, SC Duma 413 x 66,666 plants ha^{-1}, DH04 x 66,666 plants ha^{-1}, DH02 x 66,666 plants ha^{-1}, DH02 x 88,888 plants ha^{-1}, DH04 x 88,888 plants ha^{-1}, and DH02 x 53,333 plants ha^{-1}, respectively, though this plant height was not significantly different from plants of the interaction treatments of: SC Sungura 301 x 53,333 plants ha^{-1}, and SC Duma 413 x 53,333 plants ha^{-1}, respectively. The interaction treatment of SC Duma 413 x 88,888 plants ha^{-1} produced significantly taller plants than those of the interaction treatments of: DH02 x 66,666 plants ha^{-1}, DH02 x 88,888 plants ha^{-1}, DH04 x 88,888 plants ha^{-1}, DH02 x 53,333 plants ha^{-1}, though this plant height was not significantly different than plants grown under the interaction treatments of: SC Duma 413 x 66,666 plants ha^{-1}, and DH04 x 66,666 plants ha^{-1}, respectively. The interaction treatments of DH02 x 66,666 plants ha^{-1} produced plants which were significantly taller than those produced under the interaction treatments of: DH02 x 88,888 plants ha^{-1}, DH04 x 88,888 plants ha^{-1}, and DH02 x 53,333 plants ha^{-1}, respectively, though not significantly taller than those produced under the interaction treatment DH02 x 88,888 plants ha^{-1}. Plants grown under the interaction treatment DH04 x 88,888 plants ha^{-1} were not significantly taller than those grown under the interaction treatment of DH02 x 53,333 plants ha^{-1} (Table 15).

4.4.5. Effect of interaction of Variety and Plant population on Grain yield at Bura in 2018

At Bura, interactions of Pioneer (PHB30D79) grown at 53,333 plants per hectare yielded significantly the highest grain yield than all other variety x plant population interaction treatments, whereas the interaction treatment of DH04 grown at plant population of 88,888 plants per hectare had significantly the lowest grain yield compared to all other variety x plant population interaction treatments (Table 15). The interaction treatment of SC Duma 413 x 88,888 plants per hectare had their plants producing significantly higher grain yield than those of interaction treatments of: SC Duma 413 x 53,333 plants per hectare, SC Sungura 301 x 53,333 plants per hectare, SC Sungura 301 x 66,666 plants per hectare, DH04 x 66,666 plants per hectare, Pioneer (PHB30D79) x 66,666 plants per hectare, DH04 x 53,333 plants per hectare, SC Duma 413 x 66,666 plants per hectare, DH02 x 53,333 plants per hectare, SC Sungura 301 x 88,888 plants per hectare, DH02 x 66,666 plants per hectare, DH02 x 88,888 plants per hectare, and DH04 x 88,888 plants per hectare, respectively, though not significantly more than plants grown under the interaction treatment of Pioneer (PHB30D79) x 88,888 plants per hectare. The interaction treatments of SC Duma 413 x 53,333 plants per hectare had plants producing significantly more grain yield than those of the interaction treatments of: SC Sungura 301 x 53,333 plants per hectare, SC Sungura 301 x 66,666 plants per hectare, DH04 x 66,666 plants per hectare, Pioneer (PHB30D79) x 66,666 plants per hectare, DH04 x 53,333 plants per hectare, SC Duma 413 x 66,666 plants per hectare, DH02 x 53,333 plants per hectare, SC Sungura 301 x 88,888 plants per hectare, DH02 x 66,666 plants per hectare, DH02 x 88,888 plants per hectare, and DH04 x 88,888 plants per hectare, respectively. The interaction treatments of SC Sungura

301 x 53,333 plants per hectare had plants producing significantly more grain yield than those of the interaction treatments of: SC Sungura 301 x 66,666 plants ha^{-1}, DH04 x 66,666 plants ha^{-1}, Pioneer (PHB30D79) x 66,666 plants per hectare, DH04 x 53,333 plants per hectare, SC Duma 413 x 66,666 plants per hectare, DH02 x 53,333 plants per hectare, SC Sungura 301 x 88,888 plants per hectare, DH02 x 66,666 plants per hectare, DH02 x 88,888 plants per hectare, and DH04 x 88,888 plants per hectare, respectively. The interaction treatments of SC Sungura 301 x 66,666 plants per hectare had plants producing significantly more grain yield than those of the interaction treatments of: Pioneer (PHB30D79) x 66,666 plants per hectare, DH04 x 53,333 plants per hectare, SC Duma 413 x 66,666 plants per hectare, DH02 x 53,333 plants per hectare, SC Sungura 301 x 88,888 plants per hectare, DH02 x 66,666 plants per hectare, DH02 x 88,888 plants per hectare, and DH04 x 88,888 plants per hectare, respectively, though not significantly different compared to the interaction treatment of DH04 x 66,666 plants per hectare. The interaction treatment of SC Duma 413 x 66,666 plants per hectare produced significantly more grain yield than the interaction treatments of: DH02 x 66,666 plants ha^{-1}, DH02 x 88,888 plants per hectare, and DH04 x 88,888 plants per hectare, respectively, though not significantly different compared to the interaction treatment of DH02 x 53,333 plants per hectare, and SC Sungura 301 x 88,888 plants per hectare, respectively. The interaction treatment of DH02 x 66,666 plants per hectare produced significantly more grain yield than the interaction treatments of DH04 x 88,888 plants per hectare, though not significantly different compared to the interaction treatment of DH02 x 88,888 plants per hectare (Table 15).

Table 15: Effect of Interaction of Variety and Plant Population on Plant height and Grain yield of Maize at Bura in 2018

Treatment	Plant Height (cm)	Grain yield (Kgha^{-1})
Pioneer (PHB30D79)x53,333 plants ha^{-1}	298.7a	2,460.3a
SC Duma 413x88,888 plants ha^{-1}	274.2d	2368.7b
Pioneer (PHB30D79)x88,888 plants ha^{-1}	289.2b	2341.5b
SC Duma 413x53,333 plants ha^{-1}	275.3c	2288.4c
SC Sungura 301x53,333 plants ha^{-1}	277.6c	2204.2d
SC Sungura 301x66,666 plants ha^{-1}	290.1b	2061.2e
DH04x66,666 plants ha^{-1}	271.7d	2055.2e
Pioneer (PHB30D79)x66,666 plants ha^{-1}	293.0b	1966.4f
DH04x53,333 plants ha^{-1}	279.9c	1918.2f
SC Duma 413x66,666 plants ha^{-1}	272.4d	1887.7g
DH02x53,333 plants ha^{-1}	255.5f	1884.2g
SC Sungura 301x88,888 plants ha^{-1}	293.8ab	1846.5g
DH02x66,666 plants ha^{-1}	269.0e	1777.2h
DH02x88,888 plants ha^{-1}	265.6e	1767.0h
DH04x88,888 plants ha^{-1}	255.6f	1289.5i
Mean	**277.4**	**2,007.8**
P-value	**0.02**	**<0.0001**
LSD(0.05)	**5.4**	**55.1**
CV (%)	**4.6**	**6.5**

****Means with the same letters and within the same column are not statistically significantly different*

4.4.6. Effect of interaction of Variety, Plant population, and Water regime on Grain yield of maize at Bura in 2018

At Bura, the interaction treatment Pioneer (PHB30D79) grown under the population of 88,888 plants per hectare, and at Water stressed regime produced significantly the most maize grains in the hectare, relative to all other variety x plant population x water regime treatments. The interaction treatment of DH04 x 88,888 plants ha^{-1} x Water stressed regime yielded significantly the least grain quantity compared to all other variety x plant population x water regime interactions treatments (Table 16). The interaction treatments of SC Duma 413 x 53,333 plants ha^{-1} x Water stressed regime, Pioneer (PHB30D79) x 53,333 plants ha^{-1} x Well-watered regime, and SC Duma 413 x 88,888 plants ha^{-1} x Water stressed regime produced the 2nd highest, 3rd highest and 4th highest significant yield, respectively, compared to all other variety x plant population x water regime interactions treatments. The interaction treatment of Pioneer (PHB30D79) x 53,333 plants ha^{-1} x Water stressed regime produced the 5th highest significant grain yield compared to the other variety x plant population x water regime interaction treatments, though this was not significantly different from interaction treatments of: SC Duma 413 x 88,888 plants ha^{-1} x Well-watered regime, SC Duma 413 x 66,666 plants ha^{-1} x Well-watered regime, and DH04 x 66,666 plants ha^{-1} x Water stressed regime. The interaction treatment of SC Sungura 301 x 53,333 plants per hectare x Water stressed regime had significantly more grain yield than the interaction treatments of: DH04 x 88,888 plants ha^{-1} x Well-watered regime, SC Sungura 301 x 66,666 plants ha^{-1} x Well-watered regime, DH02 x 53,333 plants ha^{-1} x Well-watered regime, DH02 x 53,333 plants ha^{-1} x Water stressed regime, SC Duma 413 x 53,333 plants ha^{-1} x Well-watered, DH04 x 66,666 plants ha^{-1} x Well-watered regime, SC Sungura 301 x 88,888 plants ha^{-1} x Water stressed regime, SC Sungura 301 x 88,888 plants ha^{-1} x Well-watered regime, Pioneer (PHB30D79) x 88,888 plants ha^{-1} x Well-watered regime, DH02 x 66,666 plants ha^{-1} x Well-watered regime, DH02 x 88,888 plants ha^{-1} x Water stressed regime, DH02 x 66,666 plants ha^{-1} x Water stressed regime, DH02 x 88,888 plants ha^{-1} x Well-watered regime, Pioneer (PHB30D79) x 66,666 plants ha^{-1} x Water stressed regime, DH04 x 53,333 plants ha^{-1} x Water stressed regime, SC Duma 413 x 66,666 plants ha^{-1} x Water stressed regime, SC Sungura 301 x 53,333 plants ha^{-1} x Well-watered regime, and DH04 x 88,888 plants ha^{-1} x Water stressed regime, respectively, though this grain yield was not significantly different from grain yield of the interaction treatments of: SC Sungura 301 x 66,666 plants ha^{-1} x Water stressed regime, Pioneer (PHB30D79) x 66,666 plants ha^{-1} x Well-watered regime, and DH04 x 53,333 plants ha^{-1} x Well-watered regime (Table 16). The interaction treatment of DH04x88,888 plants ha^{-1} x Well-watered regime had plants producing significantly higher grain yield than the interaction treatments of: DH02 x 66,666 plants ha^{-1} x Well-watered regime, DH02 x 88,888 plants ha^{-1} x Water stressed regime, DH02 x 66,666 plants ha^{-1} x Water stressed regime, DH02 x 88,888 plants ha^{-1} x Well-watered regime, Pioneer (PHB30D79) x 66,666 plants ha^{-1} x Water stressed regime, DH04 x 53,333 plants ha^{-1} x Water stressed regime, SC Duma 413 x 66,666 plants ha^{-1} x Water stressed regime, SC Sungura 301 x 53,333 plants ha^{-1} x Well-watered regime, and DH04 x 88,888 plants ha^{-1} x Water stressed regime, respectively, though this grain yield was not significantly different from the grain yield of the interaction treatments of: SC Sungura 301 x 66,666 plants ha^{-1} x Well-watered regime, DH02x53,333 plants ha^{-1} x Well-watered regime, DH02 x 53,333 plants ha^{-1} x Water stressed regime, SC Duma 413 x 53,333 plants ha^{-1} x Well-watered, DH04 x 66,666 plants ha^{-1} x Well-watered regime, SC Sungura 301 x 88,888 plants ha^{-1} x Water stressed regime, SC Sungura 301 x 88,888 plants ha^{-1} x Well-watered regime, and

Pioneer (PHB30D79) x 88,888 plants ha^{-1} x Well-watered regime, respectively. The interaction treatment of DH02 x 66,666 plants ha^{-1} x Well-watered regime had plants producing significantly higher grain yield than the interaction treatments of: DH04 x 53,333 plants ha^{-1} x Water stressed regime, SC Duma 413 x 66,666 plants ha^{-1} x Water stressed regime, SC Sungura 301 x 53,333 plants ha^{-1} x Well-watered regime, and DH04 x 88,888 plants ha^{-1} x Water stressed regime, though this grain yield was not significantly different from the grain yield of the interaction treatments of: DH02 x 88,888 plants ha^{-1} x Water stressed regime, DH02 x 66,666 plants ha^{-1} x Water stressed regime, DH02 x 88,888 plants ha^{-1} x Well-watered regime, and Pioneer (PHB30D79) x 66,666 plants ha^{-1} x Water stressed regime, respectively. The interaction treatment of DH04 x 53,333 plants ha^{-1} x Water stressed regime produced significantly more grain yield than the interaction treatments of: SC Duma 413 x 66,666 plants ha^{-1} x Water stressed regime, SC Sungura 301 x 53,333 plants ha^{-1} x Well-watered regime, and DH04 x 88,888 plants ha^{-1} x Water stressed regime, respectively. Whereas the interaction treatment of SC Duma 413 x 66,666 plants ha^{-1} x Water stressed regime produced significantly more grain yield than the interaction treatments of: SC Sungura 301 x 53,333 plants ha^{-1} x Well-watered regime and DH04 x 88,888 plants ha^{-1} x Water stressed regime, respectively, the interaction treatment of SC Sungura 301 x 53,333 plants ha^{-1} x Well-watered regime produced significantly more grain yield than the interaction treatment of DH04 x 88,888 plants ha^{-1} x Water stressed regime (Table 16).

Table 16: Effect of Interaction of Variety, Plant population, and Water regime treatments on grain yield of Maize at Bura in 2018

Treatment	**Grain yield (Kgha^{-1})**
Pioneer (PHB30D79)x88,888 plants ha^{-1}xWater stressed regime	2,840.2 a
SC Duma 413x53,333 plants ha^{-1}xWater stressed regime	2,704.1b
Pioneer (PHB30D79)x53,333 plants ha^{-1}xWell-watered regime	2,602.2 c
SC Duma 413x88,888 plants ha^{-1}xWater stressed regime	2435.9 d
Pioneer (PHB30D79)x53,333 plants ha^{-1}xWater stressed regime	2,318.4 e
SC Duma 413x88,888 plants ha^{-1}xWell-watered	2,301.5 e
SC Duma 413x66,666 plants ha^{-1}xWell-watered	2,275.9 e
DH04x66,666 plants ha^{-1}xWater stressed regime	2,246.0 e
SC Sungura 301x53,333 plants ha^{-1}xWater stressed regime	2,224.8 f
SC Sungura 301x66,666 plants ha^{-1}xWater stressed regime	2,221.2 f
Pioneer (PHB30D79)x66,666 plants ha^{-1}xWell-watered regime	2,185.2 f
DH04x53,333 plants ha^{-1}xWell-watered regime	2,176.3 f
DH04x88,888 plants ha^{-1}xWell-watered regime	1,911.3 g
SC Sungura 301x66,666 plants ha^{-1}xWell-watered regime	1,901.2g
DH02x53,333 plants ha^{-1}xWell-watered regime	1,894.5 g
DH02x53,333 plants ha^{-1}xWater stressed regime	1,873.8 g
SC Duma 413x53,333 plants ha^{-1}xWell-watered	1,872.7 g
DH04x66,666 plants ha^{-1}xWell-watered regime	1,864.3 g
SC Sungura 301x88,888 plants ha^{-1}xWater stressed regime	1,863.7 g
SC Sungura 301x88,888 plants ha^{-1}xWell-watered regime	1,829.3 g
Pioneer (PHB30D79)x88,888 plants ha^{-1}xWell-watered regime	1,824.8 g
DH02x66,666 plants ha^{-1}xWell-watered regime	1,791.7 h
DH02x88,888 plants ha^{-1}xWater stressed regime	1,777.2 h
DH02x66,666 plants ha^{-1}xWater stressed regime	1,762.6 h
DH02x88,888 plants ha^{-1}xWell-watered regime	1,756.8 h
Pioneer (PHB30D79)x66,666 plants ha^{-1}xWater stressed regime	1,747.6 h
DH04x53,333 plants ha^{-1}xWater stressed regime	1,660.1 i
SC Duma 413x66,666 plants ha^{-1}xWater stressed regime	1,499.5 j
SC Sungura 301x53,333 plants ha^{-1}xWell-watered regime	1,183.6 k
DH04x88,888 plants ha^{-1}xWater stressed regime	676.7 l
Mean	**2,007.8**
P-value	**<0.0001**
LSD	**87**
C.V. (%)	**6.5**

****Means with the same letters and within the same column are not statistically significantly different*

CHAPTER FIVE: DISCUSSION

The grain yield obtained in Mwea study site was significantly higher than that obtained in Bura study site. This may be due to the higher and well distributed rainfall obtained in Mwea during the experiment period (Figure 6), as compared to in Bura where the rainfall during the experiment period was erratic and low during the later staged of maize crop growth in the experiment period (Figure 15). The maize grain yield and above ground biomass may also have been comparatively higher in Mwea than in Bura because during the experiment period, Mwea study site experienced optimal temperatures for maize growth and development compared to Bura where daily average temperatures were higher than the recommended for maize crop. The daily average temperature range in Mwea study site was between 22.5 ^{0}C and 26.2 ^{0}C (Table 17), whereas in Bura, the daily average temperature recorded during the experiment period had a range of between 31.1 ^{0}C and 32.44 ^{0}C (Table 18). Temperature and rainfall fluctuation have significant impact on maize yield. High temperature negatively affects maize yield (KIPPRA, 2022).

5.1 Effect of plant population on growth, yield and yield components of maize at Mwea and Bura in 2018

Under the study's conditions, as plant population was increased from 53,333 maize plants in a hectare to 88,888 maize plants in a hectare, the biomass produced above the ground and total weight of grains of maize harvested decreased. As plant population is increased, an increase in competition for resources which have high demand by the plants but can only be sustainably supplied in economic quantities, is experienced (Boomsma *et al.,* 2009). An increase in plant population will result to higher competition for limiting resources (Maddonni *et al.,* 2004; Pagano *et al.,* 2007; Boomsma *et al.,* 2009).

Under the study's conditions, the optimum plant population producing higher above-ground biomass and total weight of grain of maize harvested compared to other plant population treatments in the study was 53,333 maize plants in a hectare. Up to 25% more grains are produced at higher than at lower plant density (Yan *et al.,* 2021). As a result of low tillering capacity, maize is sensitive to planting density (Arif *et al.,* 2010). The findings that 53,333 maize plants grown in a hectare had more grains yielded than the 2 other higher number of plants grown in a hectare suggests that the current recommendation of 53,333 maize plants grown in a hectare applies to the tested varieties in the study area conditions.

5.2 Effect of water stress on growth, yield and yield components of maize at Mwea and Bura in 2018

At Mwea and Bura, water stress significantly reduced height of ear, length of cob, height of plant, above-ground biomass and quantity of grains harvested. Besides the reduction in parameters that indicate growth of the plant, namely: height of plant, amount of water in a plant's leaf at the time of sampling relative to the most water the leaf can hold, fresh weight of shoot and shoot dry weight, reduction in rate of photosynthesis occurs, when evaluating the effect of water stress in two maize hybrids which behave differently when subjected to drought (Aslam *et al.,* 2013). When maize plants are grown under limited water conditions for more than 12 days during the grain filling and flowering stages of maize, they produce significantly low grain yield (Monneveux *et al.,* 2006).

5.3 Effect of variety on growth, yield and yield components of maize at Mwea and Bura in 2018

Farmers' choice of maize variety must be informed by its adaptability and ability to yield high yield based that which is economically capable by the variety.

Pioneer (PHB30D79) had the longest cobs and this yield component may have influenced the relatively higher grain yield it recorded compared to all other varieties in the experiment's conditions in Bura. This finding was not consistent in Mwea though, where the longer cobs recorded by Pioneer (PHB30D79) did not translate to higher grain yield compared to other varieties. This may have been caused by the effect of variability of climate in Bura versus Mwea agro-climatic that may have eliminated maize variety Pioneer (PHB30D79) from being suitable for Mwea conditions, whereas relatively higher yield was obtained for the same variety under the experiment's conditions in Bura. When determining the effect of increase in temperature by 1% on the maize yield, analysis using linear specification found that there was a decline by 0.24%, whereas using a Cobb Douglas specification, the reduction in maize yield was determined as 2.98% (Chen *et al.,* 2004). When temperature and rainfall are highly variable, there is an increased risk to significantly affect crop yield (Porter *et al.,* 2005). Increase in rainfall reduced yield variability of corn (Chen *et al.,* 2004). Different crop processes are affected, and consequently reduced plant growth and development occur when there are variable temperatures and the mean also keeps changing (Porter *et al.,* 2005). This may also explain why the biomass produced above the ground and quantity of grains harvested and recorded under the experimental conditions in Mwea were significantly higher than those under the conditions of the experiment in Bura

Effect of variety traits of maize on biomass produced above the ground and quantity of grains produced

Grain yield of maize has several parameters which are significantly important when determining it in a plant. These include: number of leaves, number of nodes, amount of chlorophyll in the leaf, height of the plant, weight of seeds, length of the ear, number of cobs with seeds, number of seeds in a row of cob, cob weight, diameter of the stem, the dry and wet weight of 100 maize seeds, quantity of oil in the seeds, and, quantity of starch and proteins (Battaglia, 2014). Pioneer (PHB30D79) and SC Sungura 301 have huge potential to decrease the yield gap of maize production due to the significantly higher grain yield they produced at Mwea and Bura respectively, compared to the other selected maize varieties. For livestock farmers in Mwea and Bura, SC Sungura 301 and Pioneer (PHB30D79), respectively may be recommended due to the significantly higher biomass produced above the ground they produced in comparison to the other sampled varieties.

5.4 Effect of interaction of treatments on the plant height and grain yield of maize at Bura in 2018

Although under the experiment's conditions, the actual water productivity was not determined, in Bura, the effect of interactions of variety and water regime was found to be significant for plant height and grain yield. Pioneer (PHB30D79) seems to have had the highest water productivity as the results exhibited that the variety grown under water stressed regime produced significantly more grain yield relative to all the other variety x water regime treatment combinations.

Increase of plant population increased inter-plant competition for growth resources: nutrients, light, and water which might be detrimental producing lower grain yield per plant (Abuzar *et al.*, 2011). Under the experiment's conditions in Bura, Pioneer (PHB30D79) grown under the plant population of 53,333 plants per hectare produced the highest significant grain produced and may be a good recommendation to reduce the maize yield gap here. The key factors influencing grain yield of maize include plant population and row spacing (Van Roekel *et al.*, 2011). In modern hybrids, there is a positive relationship between the quantity of maize grains produced in an acre, and the total maize plant stand count in the same acre, since it was found that there is significant effect of interaction of the maize plant genus with number of maize plants in a unit area, on the total grain yield harvested (De Bruin and Schussler, 2017). Under optimal growth conditions of maize, plant population is considered as the key determining factor to the level of competition between plants for a cultivar, and this result to growth and yield variation (Sangakkara *et al.*, 2004). When plants are subjected to crowding stress, the light and other resources that would be available for it would be decreased and this would consequently result to reduced grain yield (Ali *et al.*, 2003; Luque *et al.*, 2006).

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The study found that there is an opportunity to increase the economic yield of maize, both the above ground biomass and quantity of maize grain harvested for these areas by using the recommended number of plants per hectare as 53,333 plants and no-stress water regime, especially during the critical reproductive growth stage of maize. Plant population and water stress significantly reduced the maize grain yield, and reduced parameters attributed to contribute to maize yield. Farmers in Bura and Mwea use high number of plants per hectare at 66,666 plants ha^{-1} and this has significant effect in grain yield reduction.

While selecting the recommended maize variety for a certain area, the variety's recommended plant population must also be considered. Plant population, described as the number of plants per unit area, is critical to ensure that maize grain yield potential is realized. In Bura, Pioneer (PHB30D79) produced significantly the highest above-ground biomass; SC Sungura 301 yielded significantly more grain yield compared to other sampled varieties at Mwea, as Pioneer (PHB30D79) took the lead at Bura. DH04 produced significantly the lowest grain yield at Bura, though not significantly different from DH02. Significant differences were found in the cob length of the varieties at both Mwea and Bura. Pioneer (PHB30D79) had the longest cobs in both sites, whereas DH02 had shorter cobs than all other varieties, though this was not significantly different from DH04, and SC Duma 413 at Bura. The position of emergence of the ear was significantly higher for Pioneer (PHB30D79) than for all other varieties in both study sites. DH02 had significantly lower ear point of emergence than all other varieties at Mwea site, though at Bura, this was true for all other varieties except SC Sungura 301. Whereas Pioneer (PHB30D79) had significantly taller plants than all other varieties at Bura, DH02 had significantly shorter plants than the other varieties, at both Mwea and Bura. SC Sungura 301 produced significantly the highest above-ground biomass at Mwea but at Bura, Maize shows different responses to stress resulting from plant population and water stress and these may be manifested as: cell elongation inhibition thus the results obtained in the study where height of plants, length of cobs, biomass produced above the ground and cumulative quantity of maize grain harvested were significantly reduced.

Though the experiment's findings were that under the conditions in Bura, 53,333 plants per hectare produced the most grains harvested for all the five sampled maize varieties in the study, on one hand, the interaction effect of variety with plant population showed that maize variety Pioneer (PHB30D79) grown under the plant population of 53,333 plants per hectare produced significantly the highest grain yield in Bura, and on the other hand, DH04 grown at the plant population of 88,888 plants per hectare produced significantly the lowest grain yield.

Water stress applied from day 55 after sowing through to maturity of maize, significantly reduced height of plants, biomass produced above the ground, grain yield, length of cobs and height of ears produced by the plants in both Bura and Mwea study sites. However, at Bura, the interactions of variety, plant population and water regime found significant difference in grain yield, where Pioneer (PHB30D79) grown at 88,888 plants ha^{-1} and under water stressed regime produced significantly more grain yield than all other similar interaction treatments.

6.2. Recommendations

a. For farmers:

Maize variety Pioneer (PHB30D79) grown under 53,333 plants per hectare produced the highest grain yield in Bura and these two treatments under irrigated conditions, may be recommended for farmers in this area.

b. For research:

The experiment used gravimetric methods to determine soil moisture changes prior to implementation of all the scheduled irrigation water treatments to the maize plants. An opportunity to utilize modern soil-moisture measuring devices that are more accurate and may enhance data collection for this important parameter in the study.

An opportunity to conduct an evaluation of a wide range of maize varieties under varying plant population and water stressed levels has presented itself as a result of gaps identified for the same, during the study. Also of interest would be the evaluation of the effect of plant population and water stress on the economic yield and yield components of maize grown with various farmer-preferred crops under intercropping system.

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APPENDICES

Appendix 1: Protocol for the determination of soil moisture content by the oven drying method

Formula:

$$\text{Water content (W)} = \frac{W_W}{W_D} \times 100\ (\%)$$

Where: W is the percentage of water in a given mass of soil in units %

W_W is the weight of water in soil in unit grams

W_D is the dry weight of soil particles in a given soil mass in unit grams

Materials and equipment:

1. Labelled Soil sample per experimental plot
2. Cylindrical containers
3. Weighing scale with a sensitivity of up to 0.01 grams
4. Thermostatically controlled oven
5. Desiccator
6. Desiccating agent (Silica gel self-indicating)
7. Data recording sheet

Procedure:

1. Obtain a clean labeled container with a lid and record the label number on the data recording sheet
2. Weigh the container and lid and record the reading as W_1 in grams
3. Take the required quantity of the soil specimen as per table 1 annexed below. Note that the drier the soil, the greater the amount of soil quantity will be taken

4. Crumble each soil specimen gently with fingers and place it loosely in the labeled containers as per the experimental plots where the soil specimen was obtained
5. Weigh the container + lid loaded with the soil specimen and record the weight in the data sheet as W_2 in grams
6. Place the container with the lid removed into the oven, and maintain the oven temperature at 100^0C for 24 hours. If the soil specimen contains a significant amount of gypsum or organic material, the prescribed oven temperature used will be between 60^0C to 90^0C for a period of 24 hours
7. Take out the specimen from the oven, replace the lid and place it into a desiccator so as to bring it to room temperature. The specimen is enclosed in the desiccator to avoid the absorption of atmospheric moisture
8. Once at room temperature, remove from the desiccator, weigh and record as W_3 in grams. Complete the calculations on the data recording sheet as indicated
9. Repeat the procedure with two specimens from the same experimental plot and determine the average water content for each experimental plot

Figure 5: Soil water content determination record

SITE: ______________________________ DATE: ________________________

EXPERIMENTAL PLOT NAME/ NUMBER: _____________________________________

Container Number	**I**	**II**	**III**
Weight of container W1 (g)			
Weight of container + Wet soil W2 (g)			
Weight of container + Dry soil W3 (g)			
Weight of moisture (W2 – W3) (g)			
Weight of dry soil (W3 – W1) (g)			
Water content (W) = $\frac{W_W}{W_D}$ x 100 (%)			

Appendix 2: Weather data for Mwea and Bura sites during the experiment's period

Table 17: Weather data for Mwea study site during the experiment period

Experiment period	**Daily minimum Temperature (°C)**	**Daily maximum Temperature (°C)**	**Daily Average Temperature (°C)**	**Total Rainfall (mm)**	**Daily Average Rainfall (mm/day)**	**Relative Humidity (%)**
16th Dec. 2018 to 15th Jan 2019	15.9	29.2	22.5	31.9	1.0	75.9
16th Jan. 2019 to 17th Feb. 2019	14.7	32.2	23.4	5.3	0.2	70.1
18th Feb. 2019 to 20th Mar. 2019	16.3	34.6	25.4	20.0	0.7	66.7
21st Mar. 2019 to 2nd Apr. 2019	17.4	35.0	26.2	27.0	2.1	63.1

The total rainfall recorded in Mwea during the experiment period was 84.2mm. Whereas the average daily minimum temperature in Mwea range recorded during the experiment period was between 14.7 ^{0}C and 17.4 ^{0}C, the daily maximum temperature range was between 29.2 ^{0}C and 35 ^{0}C. The daily average temperature ranged between 22.5 ^{0}C and 26.2 ^{0}C. The relative humidity for Mwea had a range of between 63.1% to 75.9% (Table 17).

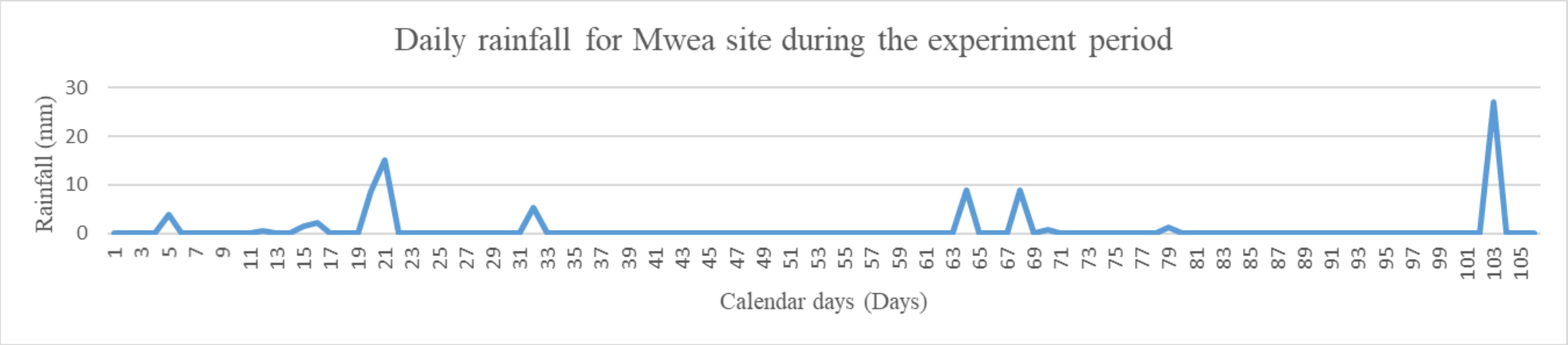


Figure 6: Daily rainfall for Mwea study site during the experiment period

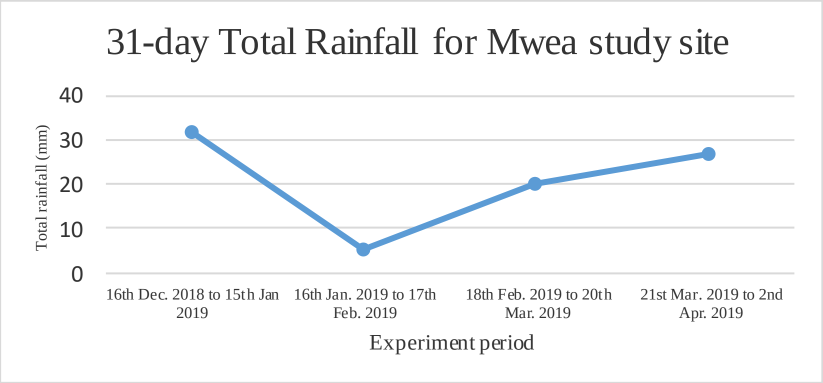


Figure 7: 31-day total rainfall for Mwea during the experiment period
period

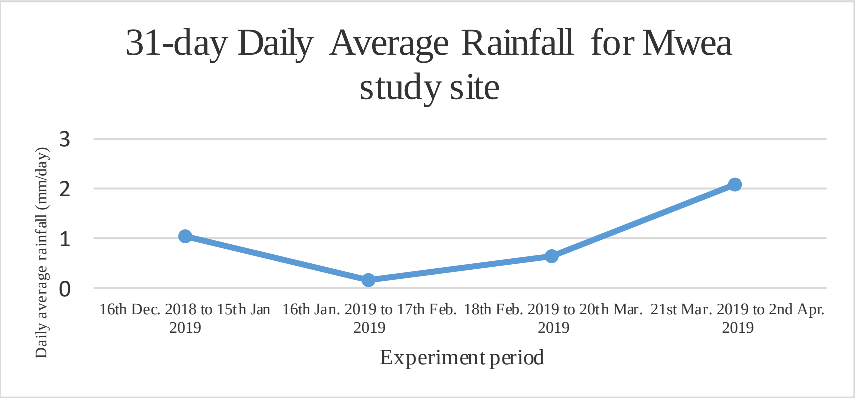


Figure: 8: 31-day average rainfall for Mwea during the experiment

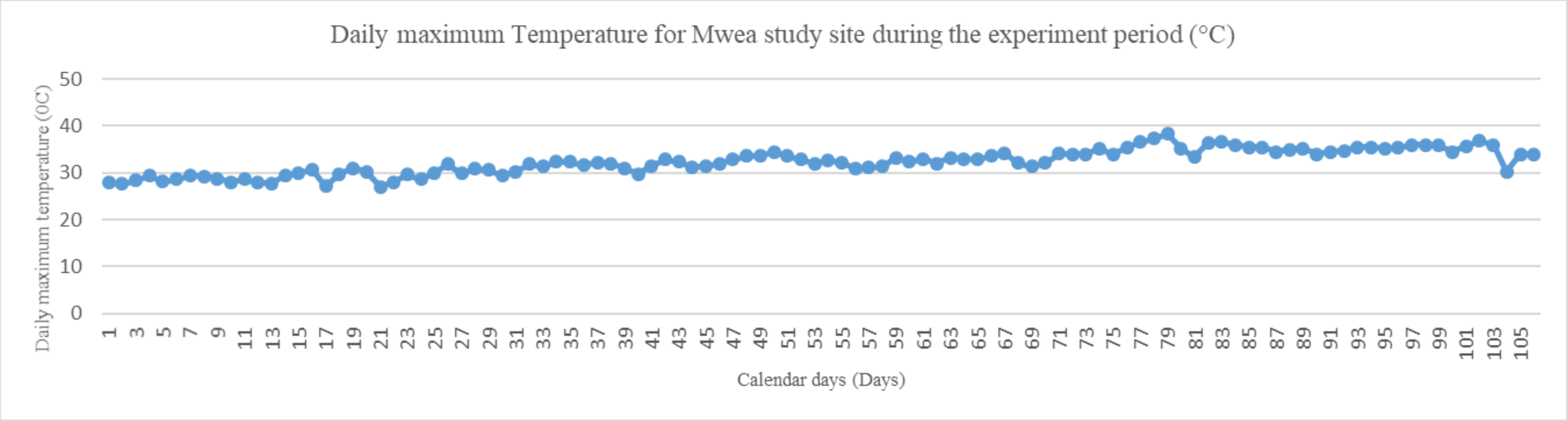


Figure 9: Daily maximum temperature for Mwea during the experiment period

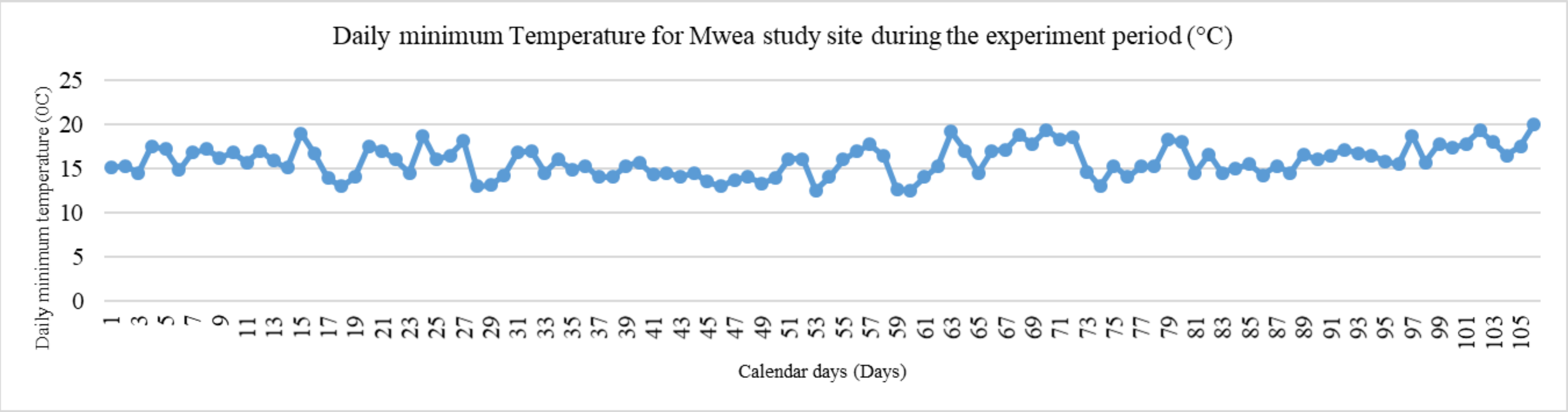


Figure 10: Daily minimum temperature for Mwea during the experiment period

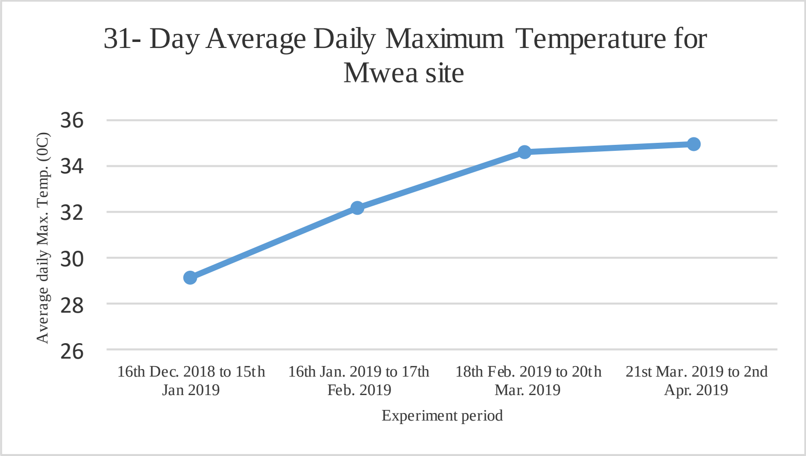


Figure 11: 31-day average daily maximum temperature for Mwea during the experiment period

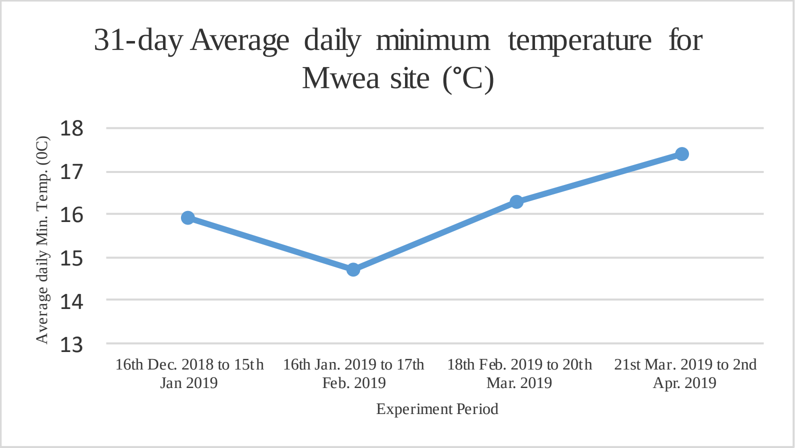


Figure 12: 31-day average daily minimum temperature for Mwea during the experiment period

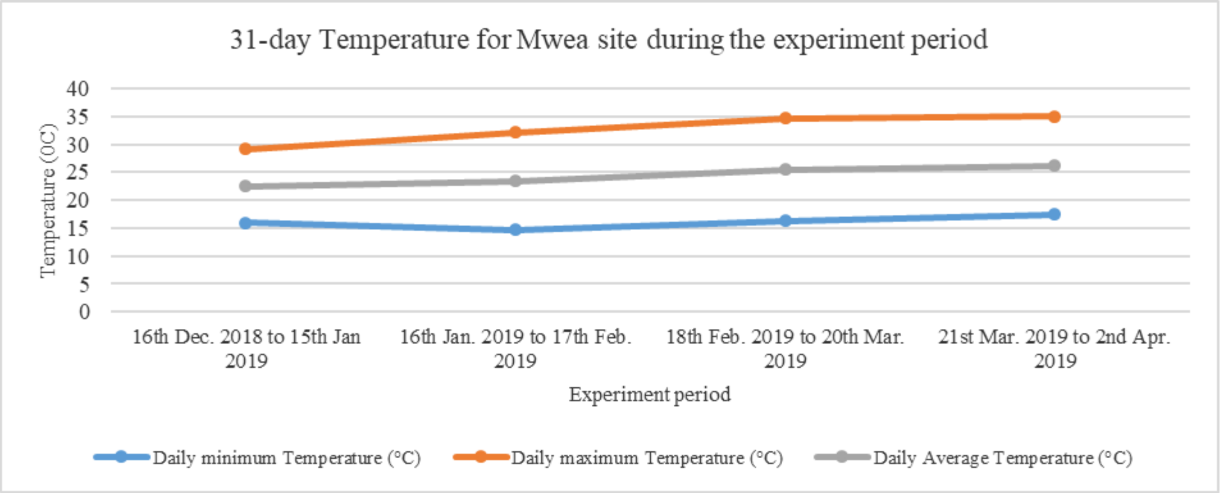


Figure 13: 31-day average temperature for Mwea during the study period

Table 18: Weather data for Bura study site during the experiment period

Experiment Period/ Weather parameter	**Relative humidity (%)**	**Total Rainfall (mm)**	**Daily Average Rainfall (mm/day)**	**Daily Average Temperature (°C)**
7th Dec 2018 to 7th Jan 2019	62.38	185.95	5.81	31.1
8th Jan 2019 to 7th Feb 2019	51.19	0.73	0.023	31.84
8th Feb 2019 to 11th Mar 2019	49.97	4.5	0.145	32.44
12th Mar 2019 to 25th Mar 2019	49.23	3.56	0.274	32.8

In Bura, the daily average temperature recorded during the experiment period had a range of between 31.1 ^{0}C and 32.44 ^{0}C. Whereas the total rainfall recorded in Bura during the experiment period was 194.74mm, the distribution was erratic; the bulk was recorded in the early stages of growth of maize.

The average relative humidity ranges for Bura during the experiment period was between 49.23% to 62.38% (Table 18).

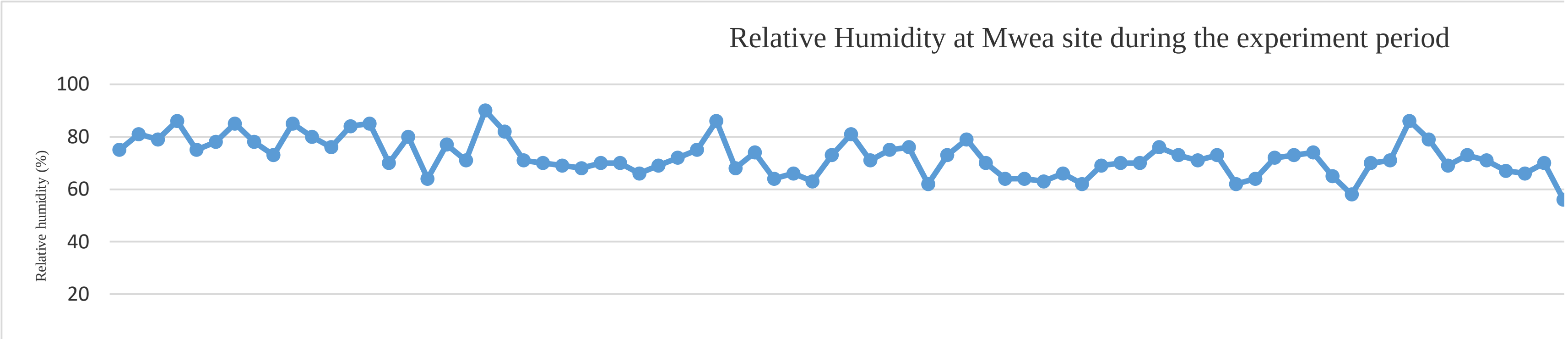


Figure 14:Relative humidity for Bura study site during the experiment

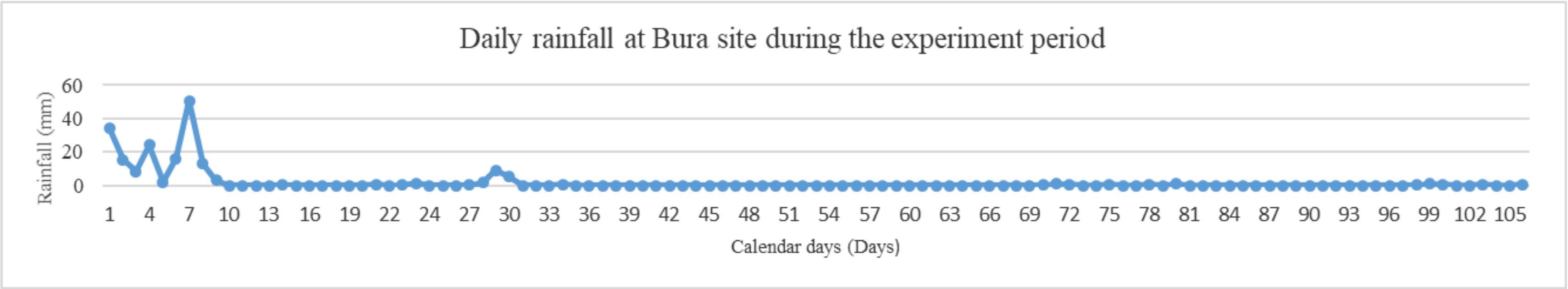
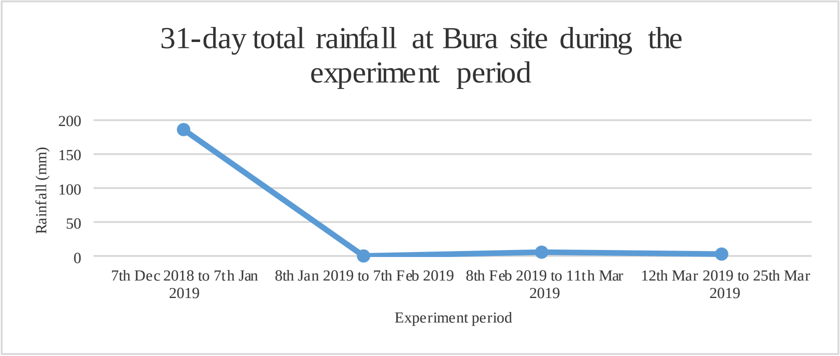


Figure 15: Daily rainfall for Bura during the experiment period



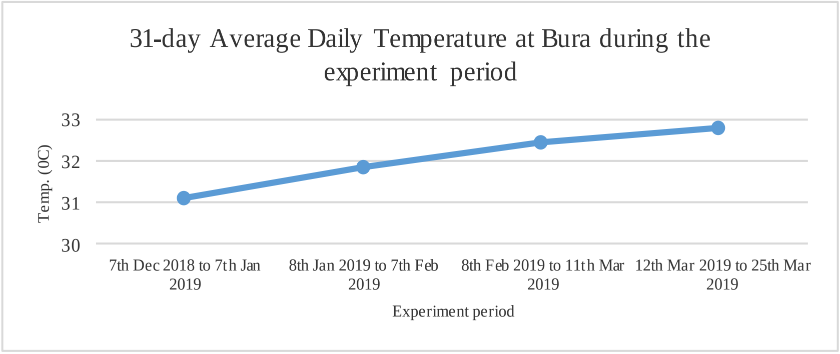


Figure 16: 31-day total rainfall for Bura during the experiment period

Figure 17: 31-day average daily temperature for Bura during the experiment period

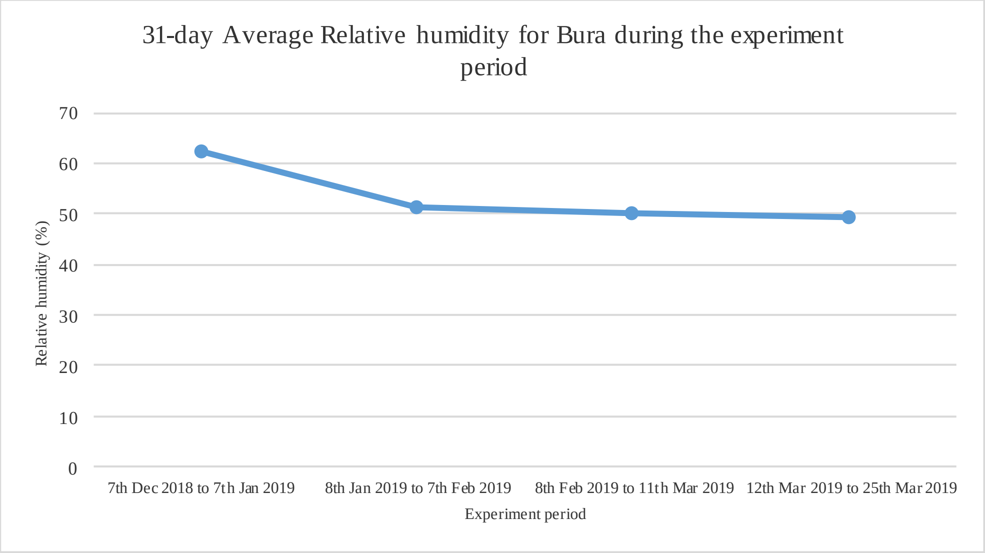


Figure 18: 31-day average relative humidity for Bura during the experiment period