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Assessing the productivity of Mchare Banana under drip irrigation and rainfed conditions in Northern Tanzania

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ASSESSING THE PRODUCTIVITY OF MCHARE BANANA UNDER DRIP IRRIGATION AND RAINFED CONDITIONS IN NORTHERN TANZANIA

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A Dissertation Submitted in Partial Fulfillment of the Requirement for the Degree of Masters in Life Sciences of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Mchare banana (*Musa spp*. AA genome) is a primary household's source of diet and income-generating crop in the Northern part of Tanzania. Despite its importance and popularity, the yield records of Mchare - Huti Green (HG) cultivated under drip irrigation remain unavailable in the area. The overall objective was to quantify yield benefit of Mchare - Huti Green banana plant grown under full drip irrigation (FD) compared with rainfed - based (RF) in Meru District, Arusha Region. The performance of HG under FD and rainfed condition (RF) was quantified by recording the vegetative parameters and yield and yield components at harvest. The results for mean bunch weight in FD was 28.3 ± 1.75 kg $plant^{-1}$ and that of RF 19.6 ± 0.97 kg $plant^{-1}$ and fresh aboveground biomass (AGB) in FD was 78.81 ± 2.61kg $plant^{-1}$ compared with RF 59.23 ± 1.06 kg $plant^{-1}$. The correlation coefficient for banana growth parameters and bunch weight indicated significant exemplified by pseudostem girth base (r = 0.48, < 0.001),1 m height (r = 0.38, < = 0.05) and mid-height (r = 0.51, <0.01), pseudostem volume (r = 0.38, < 0.01), height (r = 0.47 < 0.01), LA (r = 0.32 < 0.05) and LAI (r = 0.29 < 0.05) with correlation range 0.44 to 0.73 respectively. Conversely, for banana bunch weight and its components, correlation ranged from 0.30 to 0.50. Based on the current findings, banana plants under the FD outperformed those under the RF in terms of growth and yield. Therefore, the FD is hereby highly recommended for application in a banana for improved yield of banana in the study area.

DECLARATION

I, Erick Ahobokile Kibona, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology (NM-AIST) that information contained in this dissertation has neither been consented nor presently being submitted for a higher degree award in any other University.

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CERTIFICATION

The cosignatories certify that they have revised the dissertation titled "Assessing the Productivity of Mchare Banana Under Drip Irrigation and Rainfed Conditions in Northern Tanzania" and endorsed for examination in partial fulfilment of the requirements for the degree of Master's in Life Science of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

I devote this part of work to my beloved wife, Beatrice Patrick and my three sons named by Victor Erick Kibona, Gift Erick Kibona and Elisha Erick Kibona. Their inspiration and devotion of family resources enabled me to reach this stage.

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LIST OF ABBREVIATIONS

AGB	Aboveground biomass
Bwt	Bunch weight
BXW	Banana Xanthomonas Wilt
CEC	Cation Exchange Capacity
cm	Centimetre
C/N	Carbon Nitrogen ratio
DI	Drip irrigation
DSM	Dar es salaam
ET	Evapotranspiration
FAO	Food and Agriculture Organization
FYM	Farmyard Manure
HG	Huti Green
IITA	International Institution of Tropical Agriculture
Kcal	Kilocalories
Kg	Kilogram
LA	Leaf Area
LAI	Leaf Area Index
LISBE	Life Science and Bioengineering
MAP	Month After Planting
MOP	Muriate of Potash
NPK	Nitrogen, Phosphorus, Potassium
RF	Rainfed condition
RCBD	Randomized Complete Block Design
SAM	Shoot Apical Meristem
Sed	Standard error of the difference
SE	Standard error of the mean
t/ha	ton per hectare
TAW	Total Available Water
TDR	Time Domain Reflectometry
TR4	Tropical Race 4
TSP	Triple Super Phosphate
$\mu 1$	Mean 1

µ2	Mean 2
VA	Vegetative Allocation
VWC	Volumetric Water Content
WRB	Word Reference Base
WUEs	Water Use Efficiencies

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Internationally, banana (*Musa* spp.) ranks as the fourth part highly essential indispensable crop and is crucial for food well-being in many humid and sub-humid tropical countries (Changadeya *et al.*, 2012; Nyombi *et al.*, 2009). In terms of global ranks, banana is among the 10 most important staples (Ortiz & Swennen, 2014). More than 30% of the total global banana production level originates from the Great lakes area of East and Central Africa (FAO, 2008). In East Africa, Tanzania ranks second to Uganda among the main banana producing countries in the area (Thurlow, 2011). The major four banana-growing regions in Tanzania are; Kagera, Kilimanjaro, Mbeya and Arusha (Ndunguru, 2009).

The banana productivity of banana in Tanzania and entire parts of East African highlands is affected by both abiotic and biotic factors namely; pests and diseases (Njukwe *et al.*, 2013), declining soil fertility (Gold, 1998), water shortage (Ngugi *et al.*, 2015, Nyombi, 2010, Asten *et al.*, 2011) to mention a few are reported to endanger banana productivity. The existing category of banana farming system in Tanzania is a permanent mixed whereby banana is intercropped with other annual and perennial crops in one land use system. The average land size per household range from 0.5 to 1.7 ha per household (Mbwana, 2009). Nevertheless, these production systems have been unable to cater to the overall requirements of the growing number of people in the major banana-growing regions. Given the fact that the banana plant grows well in a wide range area of tropical and sub-tropical climatic condition (Ndunguru, 2009). Thus, to improve banana productivity, extending the area under cultivation use of drip irrigation is of great importance.

Phenologically, banana plants are characterised by an extensive growth cycle (mostly 10 to 12 months), high-level of consumption of water, shallow root allocation and poor dispersion ability into the soil sphere and high vulnerability to moisture deficit (Sharma *et al.*, 2018). The optimal amount of rainfall to meet normal banana growth and maximum yield is reported to range from 1100 to 2650 mm uniformly distributed per year (Robinson & Alberts, 1986; Asten *et al.*, 2011). The soil water tension at different growth phases of the banana plant contributes to a substantial decrease in production (Alvarez *et al.*, 2001). Under comparatively slight soil moisture stress condition, banana plants do close their stomata, lower transpiration hence keep leaves hydrated and therefore lower photosynthesis (Turner *et al.*, 2007). The expanding tissues in the banana plant such as evolving leaves and developing fruits are amongst the first to be altered by drought. Leaf emergence rate is well-thought-out the most sensitive indicator of drought stress (Robinson & Saúco, 1996; Turner *et al.,* 2007). Nevertheless, the consequence of drought stress on a banana can diverge expressively between banana genotypes (Vanhove *et al.*, 2012). Thus, understanding banana makeup and the growth patterns are crucial when establishing diagnostic package to identify an appropriate time when the banana commences to be affected by drought stress (Alvarez *et al.*, 2001; Asten *et al.*, 2011). Therefore, banana productivity intensification ought to be through efficient use of both rainfall and irrigation, and enhancement of water use efficiencies (WUEs).

Different forms of irrigation exist which include, furrow irrigation, basin irrigation, drip irrigation, sprinkler irrigation, border irrigation and spate irrigation (Khalifa, 2012). In terms of the amount of water-saving, less labour and efficiency, drip irrigation is of more advantageous than the rest types of irrigation. (Ghosh *et al.*, 2018). Despite all these advantages over others, drip irrigation has a major disadvantage of high initial costs (Khalifa, 2012). Few studies have been conducted to assess the performance of banana under drip irrigation in Tanzania as compared to most horticultural annual crops (Ndunguru, 2009). Under prevailing conditions of water both excess and deficit are regarded as the largest preventive abiotic aspect affecting banana production (Carr, 2009; Asten *et al.*, 2011). This study, therefore, intended to evaluate the growth patterns and yield estimation in terms of bunch yield/plant under FD and RF for Mchare Huti Green so that a definite production awareness and records may be generated for the farmers as well as future researchers.

1.2 Statement of the problem

Rainfed agriculture remains susceptible to drought rendering low yield and sometimes crop failure. As an intervention, several approaches including traditional furrow irrigation, timely planting to take advantage of rainfed conditions and drip irrigation have been used to mitigate drought severity. Due to ongoing uncertainty of rainfall, irrigation could be a practical solution for ensuring stable agricultural production in Tanzania (Shaghude, 2006). Drip irrigation technology is gaining extra attention and performing a vital role in farming (Pescod, 1992), it is the most reliable type of irrigation, can be applied in a wide range crop and ensures water use efficiency. However, drip irrigation in banana farming is an uncommon practice as compared to other horticultural crops in Northern Tanzania highlands and the rest parts of

Tanzania (Ndunguru, 2009). Mchare banana cultivar grows well within the Mid and Foot slopes along with Mount Kilimanjaro and Mount Meru in Kilimanjaro and Arusha regions respectively. Despite its importance and popularity, the records of the yield of Mchare-Huti Green (HG) cultivated under drip irrigation remain unavailable in the study area.

1.3 Rationale of the study

In the Arusha region, 80% of the bananas grown are Mchare cooking bananas and remaining 20% comprise of other varieties (Thurlow, 2011). Given the importance of Mchare banana cultivar for food and income security for many smallholder banana farming communities in the region, there was a need for evaluating the benefits associated with increasing yield through the cultivation of banana under drip irrigation so that to reveal its potentiality and practicability in Northern Tanzania as a source of ensuring both food and income security.

1.4 Research objectives

1.4.1 Overall objective

The overall objective was to assess Mchare (Huti Green) banana plant productivity under drip irrigation and rain fade conditions.

1.4.2 Specific objectives

(i) To assess the effect of drip irrigation and rainfed conditions on growth parameters, yield and yield components of Mchare (Huti Green) banana plant.

(ii) To identify Mchare (Huti Green) banana plant parameters with high correlation to growth allometry for yield prediction cultivated under drip irrigation and rainfed water regimes**.**

1.5 Research hypotheses

1.5.1 Hypothesis for specific objective one

Null hypothesis (Ho): Huti Green (HG) growth parameters, yield and yield components are the same under both drip irrigation and rainfed water regimes.

Alternate hypothesis (Ha): Huti Green (HG) growth parameters, yield and yield components are not the same under both drip irrigation and rainfed water regimes.

1.5.2 Hypothesis for specific objective two

Null hypothesis (H_o): There is no relationship between vegetative and generative parameters of Mchare (Huti Green) banana plant characteristics.

Alternative hypothesis (H_a): There is a relationship between vegetative and generative parameters of Mchare (Huti Green) plant characteristics.

1.6 Research questions

(i) What is the status of banana yield (bunch weight) produced under drip irrigation in Tanzania?

(ii) To what extent does drip irrigation influence vegetative and generative parameters?

(iii) Is there any relationship between banana vegetative parameters and generative parameters?

1.7 Significance of the study

The proposed study contributes to a better understanding of the importance of drip irrigation for sustainable production of banana even at times of drought taking its advantages of continuous productivity throughout the year. This understanding provides a way forward to recommend the use of drip irrigation as a water-saving irrigation method and minimization of conflicts among water users during dry periods of the year and extreme weather (doughtiness). These recommendations contribute to improving crop yield and increasing household incomes and food security.

1.8 Delineation of the study

The study dealt exclusively with evaluating the benefits connected with increasing yield and yield components through of drip irrigation of Mchare-Huti Green. The study attempted to measure banana growth parameters, yield and yield components of only one production cycle.

CHAPTER TWO

LITERATURE REVIEW

2.1 Economic importance of banana

Generally, bananas are taken both either as a dessert fruit or as a food crop, offering an inexpensive good source of vitamins A, B6 and C, and they have a high content of carbohydrates and fibers, nevertheless are low in protein and fat (Kalyebara *et al.*, 2007). In the East African highlands, bananas remain to continue to be an indispensable and nutritional food source and are sold as a source of income to many smallholders farmers (Nyombi, 2013). In East Africa alone, banana production is of great importance because it is reported as a key basis of income for more than 50 million smallholder farming communities, with an estimated annual production worth US$ 4.3 billion, equivalent to approximately 5% of the gross domestic product of the entire region (FAOSTAT, 2014). Existing records indicate that banana consumption in the region is the highest in the world, providing 3-22% of total daily calorie consumption with an estimated 147 kcal per person (FAOSTAT, 2014).

Of all member states of East African countries, Tanzania and Uganda are reported to have the highest banana utilization (in total and per capita) in the region (Smale & Tushemereirwe, 2007). In Tanzania, the top four banana producing regions are led by Kagera, Kilimanjaro, Mbeya, and Arusha whereby approximately 70 – 95% of smallholder farmers grow bananas to meet basic needs of food and the surplus sold to generate income. The average banana field size range from 0.5 to 2.0 ha per household (Kalyebara *et al.*, 2007). The banana production and productivity regionwide of the Tanzania mainland is presented in Table 1.

Table 1: Banana production and productivity of each Region of Tanzania mainland year 2001 (estimated)

Regions	Tons ('000)	Productivity (t/ha)	Area ('000) ha	Rank
Kilimanjaro	1,383.8	10.5	131.6	1
Kagera	1,150.0	8.3	137.7	2
Mbeya	434.5	9.6	45.2	3
Kigoma	258.3	8.3	31.2	4
Arusha	232.5	10.0	23.0	5
Tanga	113.5	8.7	13.0	6
Mwanza	69.1	7.3	9.4	7
Morogoro	26.1	8.7	3.0	8
Rukwa	18.4	9.2	2.0	9
Mtwara	17.0	7.7	2.2	10
Tabora	13.5	8.3	1.6	11
Ruvuma	9.2	9.2	1.0	12
Coast/DSM	7.0	8.7	0.8	13
Lindi	6.6	8.2	0.8	14
Iringa	1.8	12.0	0.2	15
Mara	1.7	12.0	0.1	16
Dodoma	1.6	8.0	0.1	17
Singida	0.8	8.0	0.1	18

(Ndunguru, 2009)

Across the entire regions of East Africa and Great lakes, the East African highlands is known to be an important centre of range for a distinctive type of banana. In Uganda, for instance, the banana breeding programmes are centered mainly on the enhancement of East African Highland (cooking) bananas of (EAHB) (AAA-EA) of genomic groups (Brown *et al*., 2017). Distinctively, the East African Highland bananas (EAHBs) belong to a subgroup in the genus-group of *Musa spp* (Karamura, 1999). The main prescribed criteria for the classification of East African highland bananas are based on clone type and their ultimate use either for cooking or beer (Brown *et al*., 2017). Clone set can be distinguished morphologically by descriptive features like bunch form, pulp paste, and flower assets (Karamura, 1999). Five clone sets have been designated in Highland bananas, namely Beer, Musakala, Nakahulu, Nakitembe and Nfuuka and the majority are AAA (acuminata) triploids (Karamura, 1999). The East African Highlands bananas result from mixing potential characteristics host-plant resistance to pests and diseases namely the Sigatoka complex, weevils, and nematodes from wild diploid progenitors into the elite (Brown *et al*., 2017).

Table 2: Characteristics features of the model plant type of East African Highland cooking bananas under the breeding programme

Characteristic	Explanation
Yield potential	> 25t/ha/year
Bunch weight	> 15kg
Plant height	< 3m
Duration of flowering	210 - 270 days
Duration of bunch maturity	90 - 120 days
Quantity of hands	8 - 12/ bunch
Quantity of fruits	100 - 190/bunch
Fruit girth size	10 - 15 cm
Finger length	13 - 15 cm
The ability to produce sucker	75% follower sucker growth at harvest
The tendency of rooting	vigorous (fast-growing, deep, and branched)
Bunch alignment	Pendent
Reaction to prevalent diseases	Resistant to black Sigatoka complex and Bacterial wilt
Reaction to prevalent pests	Resistant to weevils and nematodes
Reaction to drought stress	Resistant/tolerant

(Brown, 2017)

Bananas can be processed into various food products, like snacks, feed, industrial spirits, crafts, and medicinal purposes. Due to a wide range of banana use, it is reported that some varieties are characterized by sweetness and flavoursome for desserts whereas others are can either be cooked or roasted (Smale & Tushemereirwe, 2007). More value chain includes flour and fermentation to produce local beverages such as banana juice, beer (e.g. *Mbege* processed locally by the Chagga tribe in the east northern highlands of Tanzania in Kilimanjaro region). Table 3 describes banana product segmentation as in the case of Tanzania.

Table 3: Banana product segmentation in Tanzania

Product	Demand locus	Growth in demand	Chief competitors	Principal buyers	Market requirement
Cooking type	Both production & urban buyers	High	Maize, rice, cassava sweet potatoes	Consumers with medium to high incomes	Efficient transportation good handling facilities
Brewing type	Within the production area	Medium	Industrial brews, beers & soft drinks	Local people	Production of good quality cultivars
Desert type	Both in rural	High	Fruits such as oranges, mangoes & mandarins	Traders & consumers	Improvement of transportation facilities
Local beer	In rural areas of production	Medium	Industrial beers & soft drinks	Low-income people	Improvement of quality
Roasting type	Both in rural urban	Low	Round potatoes	Traders & beer drinkers	Increases in the amount supplied & advance roasting techniques
Banana wine	In urban areas of major towns	Medium	Industrial beers & soft drinks	Medium & high-income people	Standardization of quality and mass production
Banana biscuits, Bread, flour & doughnuts etc.	In non-banana production areas & distant markets	Low-medium	Cereals products from maize, wheat & rice	Traders & consumers	Improvement of processing technologies, product differentiation

(Edmeades *et al.*, 2007)

Apart from the direct beneficial use of banana as a source of food for human consumption; discarded fruits, peels and various vegetative parts are widely used as fodder, many parts have also been used for medicinal purposes (Edmeades *et al.*, 2007). Moreover, women make handicrafts such as tablemats, handbags, envelopes, postcards, wall pictures and hats from dried midribs of leaves. Major bananas trading centers in Tanzania are situated in urban areas where the population is high as well as food demand; these are Mwanza, Shinyanga, Dodoma and Dar es Salaam supplied by Lake zone, Northern, Eastern and Southern Highland zones (Smale & Tushemereirwe, 2007) (Fig. 1).

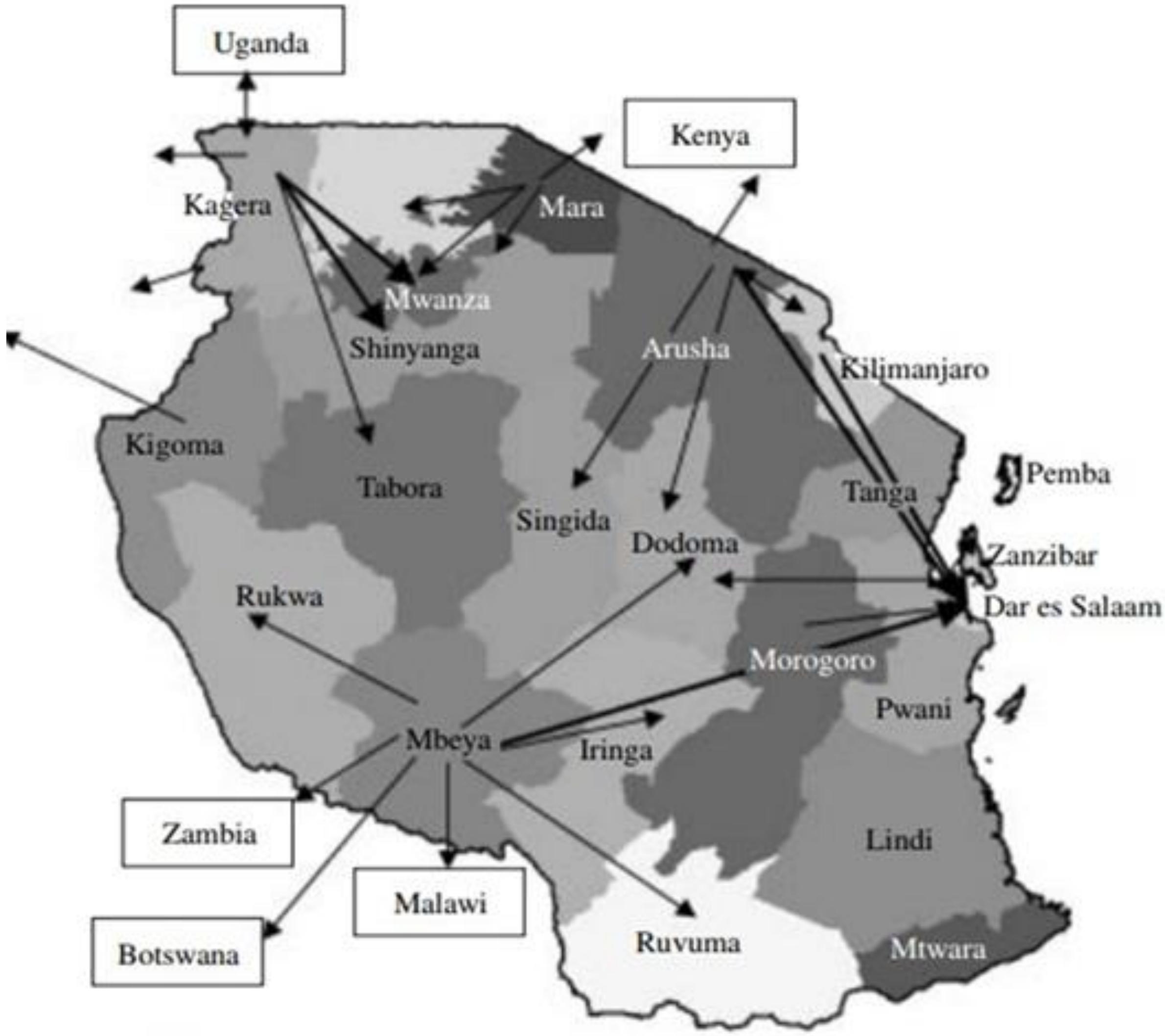


Figure 1: Major banana producing and trading areas in Tanzania (Smale & Tushemereirwe, 2007)

2.2 Banana morphology and physiology

The banana plant belongs to single cotyledon genomic groups in place of the recombinants of *M. acuminata* and *M. balbisiana* with the letters A and B correspondingly were categorized as AA, AB, AAA, AAB, ABB, AABB, AAAB, ABBB genomic groups (Vanhove *et al.*, 2012). Morphologically a banana plant is described by a pseudostem (false stem) holding of leaf sheath and underground true stem (corm) in which suckers are emerged thereby qualifying it to reproductive vegetative (Turner, 1972). The banana leaves emerge from the corm, as the results of successions, the leaves later are modified into pseudostem. An extension of the leaf sheath forms a petiole which leads to the midrib that supports the lamina. In the entire life span, the banana plant can produce approximately a total of 30 to 50 or more leaves on a shoot, but at least only 10 to 14 living leaves are present under healthy conditions until during when the bunch reaches its maturity stage ready for harvest. However, differences may exist due to variation of genotypes, climate and agronomic practices (Nakasone & Paull, 1998). Progressively when banana leaf grows within the pseudostem, the leaf blade increases in the area up until it commences arising from the top of the pseudostem. After every 7 to 14 days each newly leaf do appear (Turner *et al.*, 2007).

When the banana plant reaches the ultimate amount of leaf area on a shoot it usually matches with the rise of the bunch from the topmost of the pseudostem. In the banana plant, every pseudostem produces one inflorescence the female flowers which give rise to banana fruits. The emergence of the bunch in banana plants generally marks the end of the formation of new leaves and the existing ones begin to deteriorate over time as the older leaf senescence (Turner *et al.*, 2007). However, the suckering behaviours of banana mats make the banana a perennial crop. Approximately a total of 90 to 150 days flowers may develop into mature fruits after the emergence of inflorescence, however, this may vary due to prevailing environmental condition (Marriott & Palmer, 1980). In a heterogeneous plantation, bunch emergence can arise any time of the year, even though the number of bunches developing may be predisposed seasonally by ecological and soil factors negatively or positively influence plant to growth to name a few these factors include soil pH, soil water, soil toxicity, soil micro and macrofauna activities (Turner *et al.*, 2007).

2.2.1 Maturity indices of *Musa spp*

Proper timing for bunch harvest remains to be contradictory among researchers and banana smallholder farmers. However, there are two schools of thoughts on detecting the maturity of banana bunch ready for harvest. First, plant physiological maturity is defined as the duration when the photosynthetic assimilates buildup in the kernels or seeds or fruits ceases. Harvest maturity is defined as the growth stage of development when a plant or harvestable part of the plant reaches the prescribed qualities for use by consumers for a specific drive (Kader, 1997). Assessing maturity index before harvest is most imperative as it governs storage life and final fruit life (Kader, 1997). Harvesting banana fruit either too early before maturity stage or too late after its optimal harvesting time may render it to easily susceptible to physiological disorders.

Bananas require not less than three months from flower apex emergence until harvest (Solanke & Falade, 2011; Mustafa *et al.*, 2016). The assessment of maturity standards of banana focuses on qualitative and quantitative tools like fruit diameter, age of the bunch, the angularity of the fruit, length of the fruit, and peel colour. However, the maturity criteria for plantains are less precise than they are for banana (Solanke & Falade, 2011). Establishment of maturity index for banana is an important aspect of for harvest and post harvest operations to be of more effective and efficient (Muchui *et al.*, 2010). Indicators of banana fruits maturity include: fruit becomes plumpy and angles are filled in completely; provides metallic sound when tapped, desiccating up of fruit ends and transitional colour change of fruits from deep green to light green (Amin *et al.*, 2015). The moisture maturity of a banana plant is determined by various environmental conditions namely, temperature, rainfall, soil, latitude, elevation and nutrients (Nitrogen, Phosphorous and Potassium), edaphic factors, genotypes and many other factors. Among all listed factors temperature exhibit strong influence on the banana physiological maturity period (Erima *et al.*, 2016).

2.3 Limiting factors for banana production and productivity

The stagnant productivity in bananas in the highlands of East African is markedly triggered by both environmental factors belonging to either biotic or abiotic factors (Bekunda & Woomer, 1996; Nyombi, 2010). Biotic stress can be defined as stress caused due to impairment by living factors such as diseases and pests. Biotic factors are comprised of living factors namely, diseases pathogenicity by fungal, bacterial and viral both play an important role altering banana growth hence rendering it to reduced its yield potential (Blomme *et al.*, 2017; Thurlow, 2011). The abiotic factors alternatively mean the non-living factors drought, declining soil fertility, floods just to mention a few. It is reported that banana losses caused by pests and diseases can range from 30-100% when they act in combination.

2.3.1 Prevalence of pests and diseases

Existence of pests and diseases incidences in the banana plant have been reported to lowering the yield of highland banana between 5-30 t ha^{-1} yr^{-1} from the actual potential yields of 70 t ha^{-1} yr^{-1} due to the severity of pests and disease prevalence (Asten *et al.*, 2004). The prominent diseases and insect pests found in Tanzania which affect banana crop are weevils (*Cosmopolites sordidus*), Black Sigatoka (*Mycosphaerella fijiensis*) and fusarium wilt (*Fusarium oxysporum cv science*) and Banana Xanthomonas Wilt (Thurlow, 2011). Banana Xanthomonas wilt (BXM) and other pests such as banana weevils and nematodes can reduce yields up to 30-70% caused by *Xanthomonas vasicola pv*. *Musacearum* (previously named by *Xanthomonas campestris* pv.*musacearum*) has been reported to threaten banana growth and production in Eastern Africa (Biruma *et al.*, 2007; Shimwela *et al.*, 2017).

Banana weevils can infect all categories of banana cultivars, though the intensity of its harm decreases with altitude (Gold *et al.*, 1994). Yield losses caused by banana weevil are linked with, stunting, sucker death, plant damage, condensed bunch size and weights and shorter life duration (Abera *et al.*, 1996; Gold *et al.*, 2001). The reported yield caused weevils in some Africa and countries and some regions where the severity of the pest effects was observed are presented in Table 4.

Table 4: Reported yield losses contributed by banana weevils

Country	Yield loss (%)	Clone	Methods	Source
Congo	Up to 90			Ghesquiére (1925)
Ghana	25 – 90	AAB		Gorenz (1963)
Kenya	16 – 53	AAA-EA		Ngode (1998)
	Up to 100	AAA-EA		Koppenhöfer and Schmutte (1993)
	22 - 76	AAA-AE	Trials	Musabyimana (1999)
Tanzania				
Kagera	30	AAA-EA		Walker and Deitz (1979)
	30	AAA-EA		
	15		Trials	Uronu (1992)
Uganda	5 – 44	AAA-EA	Trials	Rukazambuga *et al.* (1998)
	40 – 50	AAA-EA	Trials	Gold (1998)
Central	20 – 60	AAA-EA	Damage	Gold *et al.* (1999)
Masaka	Up to 100	AAA-EA	Observed	Gold *et al.* (1999)
	> 50%	AAA-EA	Observed	Sebasigari and Stover (1988)

Banana Xanthomonas Wilt (BXW) and Panama (*Fusarium wilt*) pathogen can lessen banana yields up to approximately 100% (Shimwela *et al.*, 2016; Wairegi *et al.*, 2010; Stoian *et al.*, 2018). According to Tripathi (2009), they also pinpointed the BXW to have a significant economic impact on yield loss by reducing the size and bunch weights, and death of both banana parent plant and daughters (suckers) important for subsequent production cycles. Its pathogenicity is estimated to be approximately 6 - 8 months rendering to the prohibition of replanting of newly propagules. Banana wilt was first recognized in Uganda, Eastern Democratic Republic of Congo, Rwanda and later in Tanzania (Biruma *et al.*, 2007). Distinctive symptoms of plant parts affected by banana wilt include a turn in yellow colour and flaccid of leaves, discharge of a yellow in the colour of bacterial ooze, untimely bunch ripening, decaying of fruit and inner yellow bruising of the vascular bundles (Biruma *et al.*, 2007; Tripathi, 2009; Shimwela *et al.*, 2016).

Fusarium wilt in the banana plant is a soil-borne fungus caused by pathogen named by *Fusarium oxysporum* fsp *cubense* (Foc) which pass on the disease through roots to unaffected bananas (Tinzaara *et al.*, 2018). Once the soil planted with banana crop plant is contaminated, the extinction of the fungus becomes impossible (Lorenzen *et al.*, 2007). The ascospores can be hosted in the soil for more than ten years in the absence of host banana plant (Ploetz, 2015). The main mode of dispersion is a slow movement in the soil, though unsafe transportation of infected planting materials, irrigation and overflow water and in mud or soil attached to machinery or footwear (Stover, 1962). Two significant races of Race 1 and (Tropical) (TR4) Race 4 significantly affect banana production. The Cavendish banana plant type and some few East African highland bananas are reported to remain resilient to Foc Race 1 but 'Ladyfinger' in Australia and 'Sukari Ndizi' in Uganda are prone as are many other cultivars (Smale & Tushemereirwe, 2007).

2.3.2 Drought

A drought is an incident of prolonged scarcities in the water supply (can be below-average precipitation, surface water or groundwater) linked with climate change that significantly affects banana production (Asten *et al*., 2011; Brown *et al.*, 2017; Wairegi *et al*., 2010). The rainfed ecology of East African highland banana farming systems in recent years experiences drought-induced banana yield losses (Asten *et al*., 2011; Nyombi, 2010). The drought phenomenon causes the banana plant to grieve from desiccation and increased temperature of its cellular and tissue environment (Ravi *et al.*, 2013), it also decreases the rate of photosynthesis, alteration in leaf expansion, and entire plant allocation of resources (Fahad *et al.*, 2017). It may also impair banana plant mitotic cell process and cell elongation through reduced turgor pressure resulting in poor growth (Fahad *et al.*, 2017). Drought stress contributes to decreasing in banana leaf size, leaf water potential, transpiration rate and number which are highly dependent on turgor pressure, the concentration of nutrients, and carbon assimilates significantly reduced by drought condition (Fahad *et al.*, 2017). In some growth phenological stages of the banana plant, particularly during flower head initiation, soil moisture significantly contribute to the reduction in the number of hands per bunch and fingers per hand and maximum lessening in fruit sizes in terms of its length and circumference (Ravi *et al.*, 2013). In areas characterised with the amount of rainfall of less than 1100 mm per year experiences prolonged drought significantly contribute to yield losses to approximately around 20 - 65% loss in the bunch weight (Asten *et al.,* 2011). According to a study by Asten *et al.* (2011), he reported drought stress on AAA - AE bananas affected bunch weight losses between 1.5 – 3.1 kg or 8 – 10% at every 100 mm a decline in rainfall and the number of fingers per bunch, but not finger weight. Conversely, banana-like other plants under drought conditions, trigger some adaptive mechanisms like banana roots respond to this environmental stress through producing signals that direct the plant to close stomata, permitting the banana to remain highly hydrated, thereby reducing photosynthetic assimilate in turn leading to decreased banana yield (Turner *et al.*, 2007). Nevertheless, the response of banana varieties throughout the phases of drought is reported to be genotype-dependent (Ravi *et al.*, 2013; Vanhove *et al.*, 2012). Genetically, banana cultivars with genome “B” are reported to be more drought tolerant than those solely based on “A” genome. Banana plants with characterized by “ABB” genomes are further tolerant to drought and wide range of abiotic stresses comparable to genotypes “AAA”(Ekanayake, 1989; Ravi *et al.*, 2013).

2.3.3 Influence of drought stress on leaves, root and stem biomass allocation in plants

Drought is well thought out as the single utmost overwhelming ecological stress, which hampers crop productivity more than the rest factors in the environment (Lambers *et al.*, 2008). The drought impact to banana array from plant structural to molecular levels and are manifested at plant growth phenological stages when water deficit takes place (Farooq *et al.*, 2009). Drought imposes a massive effect on the growth processes and productivity of wide range crop plants (Fahad *et al.*, 2017; Asten *et al.*, 2011). The reduced banana plant growth brought by drought effects accelerates the lowering in the capacity of stomatal conductance and leaf dimension leading to a reduced in photosynthetic activity (Kallarackal *et al.*, 1990) with amplified leaf senescence (Turner *et al.*, 2007). Drought stress may also impair mitotic cell process and cell elongation causing loss of turgor pressure resulting in poor growth, water relations and nutrients, photosynthesis, assimilate apportioning and eventually trigger a substantial drop in crop yields (Fahad *et al.*, 2017; Farooq *et al.*, 2009; Milburn *et al.*, 1990). It also accelerates plant grieve from desiccation and overheating of cells (Ravi *et al.*, 2013). In all plants, leaves are the first parts which are affected first thereby leading to decreased rate of photosynthesis, variations in leaf emergence and development and the entire processes of resources allocation in plants is affected (Fahad *et al.*, 2017; Zak *et al.*, 2000). Under drought condition, is also reported a considerable decrease in leaf dimension, increased stem height, extensive spread of root, disturbed stomata oscillations, leaf water potential, transpiration rate and number. All these plants vegetative attributes which are highly dependent on turgor pressure, the concentration of nutrients, and carbon assimilate significantly reduced (Fahad *et al.*, 2017). Due to drought effect, vegetative allocation (VA) becomes highly affected causing apportionment resources to stem mass fraction and leaf mass fraction reduced significantly (Aroca, 2012). Herbaceous and perennial plants life forms have different responses to drought as well as resources allocation to roots, leaves, stems and reproductive parts (Eziz *et al.*, 2017).

Characteristically woody plants have big and deep roots which provide them with ability to buffer effects of drought as opposed to herbaceous plants with fibrous root systems always tend to be affected more abruptly (Chiatante *et al.*, 1999; Nepstad *et al.*, 1994). Whereas, the banana plant belongs to the perennial herb with a lengthy growth cycle, great consumption of soil moisture, a light roots delivery and roots with a considerable feeble penetration potency into the soil and extreme vulnerability to drought stress (Fermont & Benson, 2011). Robinson and Saúco (1996) summarized salient features of banana plant that dispose of it prone to drought, (a) A high possibility of water loss through transpiration because of the big, expansive leaves size and a high LAI, (b) Light roots in contrary to other fruit crops, (c) A poor aptitude to extract water from desiccating soil and (d) quick functional reaction to soil moisture stress. Moreover, banana plants have their ways of responding to harsh ecological conditions like drought; banana plants roots can respond to environmental stress by producing signs that direct the plant to close stomata, allowing the banana to stay highly filled up with water, hence dropping its ability to assimilate carbon (Milburn *et al.*, 1990; Turner *et al.*, 2007).

However, crop plants vary extensively in their response to changing in environmental factors, can be among cultivars within a wide range of species, and among stages of development within a cultivar, for example, the response of banana varieties throughout the phases of (Asten *et al.*, 2011; Vanhove *et al.*, 2012).

2.3.4 Effects of drought on biomass allocation in reproductive parts of plants

In accord to the ideal portioning theory, plants allocate an extra proportionate amount of reproductive mass to structures such as flowers, seeds and fruits (Eziz *et al.*, 2017) by which the restraining potential resources in the environment for its growth performance (Bloom *et al.*, 1985; Greer & McCarthy, 2000). The transfer of resources (assimilates) from photosynthetic active part to the storage structures (sink) generally relies on the degree of photosynthesis and assimilation of carbohydrate concentration in leaves (Komor, 2000). Under drought condition and when nutrients are scarce plants do invest extra biomass to the roots more than that invested in shoots (Poorter *et al.*, 2012) and the translocated assimilates to roots to permit them to gain more water and nutrients from deeper horizons than plants in water and nutrients rich (Leport *et al.*, 1999; McCarthy & Enquist, 2007). The opposite is true if atmospheric resources are restrictive like Carbon dioxide or sunlight (Davidson, 1969; McCarthy & Enquist, 2007). One of the most crucial phases in development in flowering plants is the decision to flower. The duration of flowering has a key influence on plant aptness (Chaurasia *et al.,* 2017). Many external influences such as abiotic stresses, temperature, photoperiod and internal factors comparably hormone levels, C/N ratios and age perform a great role in controlling flowering of the plant (Turck *et al.*, 2008). The transition period of growth from the vegetative stage of growth, as opposed to a reproductive stage in plants, is controlled by the day length in varied plant species (Eziz *et al.*, 2017; Turck *et al.*, 2008). Leaves are plants inception point of day length light followed by induction of florigen a universal indication that moves over the phloem to the shoot apex (Turck *et al.*, 2008). The florigen influences variations in gene appearance that reprogram the shoot apical meristem (SAM) to form flowers as a substitute of leaves (Turck *et al.*, 2008). Effects of drought on biomass allocation to reproductive parts are not prompt action, it begins with vegetative phase later progress to generative parts exemplified by of flowers, fruits, hands and bunches for the banana plant (Mahouachi, 2007; Surendar *et al.*, 2013). A sudden change in an environmental conditions also affects banana plant in terms of fruit quality, yield and crop cycle length (Robinson & Saúco, 1996; Turner *et al.*, 2007). Taking the example of banana plant growing in areas with a rainfall of fewer than 1100 mm yr^{-1}, when experiences prolonged drought it does significantly contributes to yield losses approximately 20 - 65% loss in a bunch size and weight of banana (Surendar *et al.*, 2013). According to (Goenaga & Irizarry, 1998) he discovered a loss due to drought stress in bunch biomass at a range of 2.5 –2.7 kg and a 2.4 – 3.1 kg for Cavendish banana cultivars.

A better understanding of ideal plants growth will help us to manipulate better environment conditions for plant growth. Plants will apportion biomass favourable to the organ that accesses the most growing - limiting resources (Poorter *et al.*, 2012). Human intervention through good agronomic and environmentally friendly practices will create a conducive ecological atmosphere. For instance, considering the case of drought effects on a cropped land for below the ground resources, various integrated soil-water-nutrients conservation practices be deployed to curb restrain water stress in banana fields, like, mixed farming system, use of mulch, Farmyard manure (FYM) interplanting, mechanical conservation measures in steep slope lands, use of drip irrigation and the like. A study by McIntyre *et al.* (2003) pinpointed that in a field with soil mulched, the highland banana produced weightier bunch mass, though they grieved more widely with weevil damage than no- mulched fields.

2.4 Threat of climate change on banana production and productivity in East Africa

Climate change explains the long-standing variations in the usual form of the climate accelerated by the alteration in the composition of the global atmosphere (WMO, 2013). Natural climate variability is brought by different atmospheric state resulting into a different natural phenomenon like incoming solar radiation, the atmosphere's chemical composition, ocean circulation, the biosphere and much more occurring on different time scales cause natural climate variability (WMO, 2013). Climate variations affect all forms of life in ecosystems, including drastic alteration of rainfall patterns (floods and droughts), relative humidity, soil moisture as well as temperature variations (Wairegi *et al.*, 2010). The greater part of the farming social group in developing World, Africa is most vulnerable to climate unpredictability and change and irrigated farming account nearly 5 - 10% of total agricultural production (Slingo *et al.*, 2005).

Evidently, the study was done in Ondo State, Nigeria within 1998 - 2012 between cropping seasons, results revealed a considerable change in weather parameters like rainfall and extremely high temperature significantly reduced banana output as well as when both rainfall and temperature are very low with poor humidity (Salau *et al.*, 2016). Recent findings reveal that the climate change is projected to increase the median temperature by 1.4 - 5.5°C and median precipitation by −2% to 20% by the end of the 21st century (Adhikari *et al.*, 2015).

2.4.1 Effects of climate change on water sources

The effects of climate change are real and have been reported to promote a decrease in crop water accessibility and threaten the productivity of the rainfall - dependent agriculture system in East Africa, Africa and Worldwide at large (Adhikari *et al.*, 2015; Hemp, 2009; Lambi & Forbang, 2009) reported a changing in rain patterns and water availability are results of climate change. The climate change is more often than not observed through variations in know climatic variable such as temperature, rainfall and relative humidity have which have great impacts on banana production (Salau *et al.*, 2016). The prevalence of erratic of rainfall distribution has reported endangering banana productivity in a wider part of the East African Highlands, of which mostly situated within the humid and sub-humid tropics where bananas are popularly cultivated (Okech *et al.*, 2004; Asten *et al.*, 2011). Stable agricultural production is always dependence stability and optimal supply of environmental factors such as sunlight, heat, soil water and other climatic factors (Rosenzweig & Liverman, 1992) The disparity in weather and climate variation will have an important impact on banana yields and productivity, which relies on rain for growth and performance in East Africa (Sabiiti *et al*., 2016). According to Dai (2011), agricultural drought is the period with which the soil dries, as a result, below-average rainfall, or above-ordinary evaporation hence lead to reduced crop production and plant growth performance.

2.4.2 Effects of climate change of pests and diseases prevalence

Different studies have reported a change of climate of the Globe which in turn has accelerated the incidence of pest and diseases in an environment (Adhikari *et al.*, 2015; Dai, 2011; Rosenzweig *et al.*, 2001). Climate change is proved to alter stages and rate of development of the pathogen, modify host resistance, and result in changes in the physiology of host-pathogen interactions (Coakley *et al.*, 1999). Severity of banana Black Sigatoka in the banana plant to a greater extent is influenced by the change in temperature regimes (Elad & Pertot, 2014). Considering the uncertainty of climatic variables as a result of climate change condition; different coping strategies must be put in place to overcome this threat including; early planting, planting of drought and disease resilient banana genotypes, invest heavily in weather forecasting, use of irrigation and chemicals (Salau *et al.*, 2016). The existence of a crisis of Fusarium wilt (race 1) was reported earlier in the 1950s demonstrates the probable impact factors on banana production (for a drought) (Musa balbisiana colla, Musa nagensium Prain) (INIBAP, 2006).

2.5 Irrigation and banana

Globally, water remains the main limiting factors of crop productivity, in areas where banana is cultivated banana production worsened by increased drought due to climate change (Mustaffa & Kumar, 2012). Banana production in the tropical and humid subtropics of Africa and East Africa at large is highly dependent on rainfall and therefore a change in rainfall regimes imposes a great threat to this crop (Mustaffa & Kumar, 2012). Considering the importance of water as a non-biological factor required at all stages of banana growth phases, irrigation is required to supplement the rainfall deficit (Mustaffa & Kumar, 2012). For successful banana production, the optimum amount of rainfall required is 25 mm/week for satisfactory growth and nearly 900 - 1200 mm for an entire life cycle (Ghosh *et al.*, 2018; Mustaffa & Kumar, 2012). The banana plant is correspondingly susceptible to waterlogging, and the soil airing condition directly defines the growth status of its root system (Goenaga &

Irizarry, 1998). Due to the changing environment and weather patterns, banana production and productivity cannot be achieved by solely relying on a single source, that is rainfall. This scenario of the unpredictability of rainfall necessitates the use of irrigation to supplement water which cannot be met by rainfall only. This study will focus mainly on the use of drip irrigation in a banana plantation.

2.5.1 Importance of irrigation in banana production

The productivity of crops under optimal irrigation is relatively higher compared with that under rainfall. An effective irrigation method is one which ensures a lower volume of water applied with higher irrigation water use efficiency (Zeng *et al.*, 2009). The banana plant is reported to be of the more sensitive herbaceous plant that is vulnerable to water tension than other fruit crops (Surendar *et al.*, 2013) and needs considerable amounts of water to keep its productivity (Girona *et al.*, 1993).

2.5.2 Drip irrigation

Drip irrigation refers to a form of irrigation whereby water is supplied directly to plant rhizosphere with low pressure and flow rate to meet the crop water requirement (Elamin *et al.*, 2017; Mustaffa & Kumar, 2012). As the farming communities experiencing shrinking of water resources as a result of global climate change, use of drip irrigation can be applied as a robust solution to water problems (Adhikari *et al.*, 2015; Munishi & Sawere, 2014). By comparing, drip irrigation and other methods of irrigation like basin or furrow irrigation, drip irrigation ensures more vigorous growth, higher yields, minimal weed growth and high water use efficiency and can thus is considered water-saving irrigation type (Ghosh *et al.*, 2018; Hanson & May 2007; Pawar *et al.*, 2017). Similarly, an increase of evapotranspiration (ET) from 0 to 120% consequently increased banana bunch weight from 5 to 20 kg when in Malawi (Chizala *et al.*, 1995). Moreover, Robinson and Alberts (1986) reported the addition of water from 25 to 75% of ET had influence increased in banana bunch weight from 31.7 to 44.6 kg as well as annual yield increase from 55.1 to 83.4 kg. This strong response detected from the banana plant to the applied water indicated the need for water application through irrigation to be most important banana production to counteract effects of drought (Robinson *et al.*, 1995). Nevertheless, during rainy season irrigation is provided occasionally to protect banana plant roots from congestion due to depletion of air from soil pores thereby upsetting plant growth (Ghosh *et al.*, 2018).

2.5.3 Influence of optimal soil water level on biomass allocation in crop plants

Plants biomass accumulation is successfully achieved only if environmental resources are available at optimal levels (Mundim & Pringle, 2018). Climate change aggravated by global climate change can provoke significant shifts in the timing, location, amount and form of precipitation (water resources allocation). The reproductive phase is the most critical stage to plants which requires a vast amount of energy and water to enhance reproductive investment (Karlsson & Méndez, 2005). The extreme drought may sometimes render a plant to change its phenology for example through shortening growing period and timely flowering hence contributing to a decrease in biomass allocation to generative parts (Farooq *et al.*, 2009). Integrated soil water management, good agronomic practice, breeding of elite crop cultivars which are resistant to drought could create favourable condition for crop plants to effectively abstract water and nutrients within their rhizospheres hence normal apportionment of resources to the respective parts as per plants growth and development trajectories. Among all listed proposed methods to achieve the optimal supply of water to plants, this review work intended to explore more on one aspect which is soil water management by drip irrigation.

Drip irrigation and other means of irrigation can provide optimal moistures level hence improve crop plants productivity. Integration of drip irrigation together with other soil-water-nutrients conservation practices reliable solutions rather than relying on rainfall which is sometimes unpredictable (Ekanayake, 1989; Surendar *et al.*, 2013).Through drip irrigation, water is brought straight to plant rhizosphere with moderately low pressure and flow rate to meet the plant crop water requirements (Widaa *et al.*, 2017; Mustaffa & Kumar, 2012). It is reported as unique of the utmost well - organized irrigation methods due to its compatibility for a wide range of crop genotypes, soil types especially textural class, weather patterns and topography despite few potential constraints (Widaa *et al*., 2017; Nyombi, 2017; Goenaga & Irizarry, 2000). Use of drip production overcome the impact of climate change contributing to the shrinking of water resources in humid tropics of East Africa (Adhikari *et al.*, 2015; Munishi & Sawere, 2014). Drip irrigation when compared with conventional basin irrigation, it ensures extra-strong banana growth, higher yields, slight weed infestation and high water use efficiency and can thus be considered water-saving irrigation type (Ghosh *et al.*, 2018; Pawar *et al.*, 2017). According to Srinivas *et al.* (1991) who studied that banana plants flowered 15 days earlier when grown under drip irrigation, not only that, also recorded higher yields with a higher finger, hand and bunch weight as compared to basin-irrigation. These results justify the fact that irrigation is essential in banana production because it provides optimal soil moisture hence rendering better chemical, biological and physical properties of the soil for plant growth. Though, throughout rainy season irrigation need to be provided occasionally to avoid plant congestion due to depletion of air from soil pores, thus upsetting plant establishment and growth (Ghosh *et al.,* 2018).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Site characterization

The experiment was conducted within a banana research-based farm owned by the Nelson Mandela African Institution of Science and Technology (NM-AIST). It is situated in Meru District, Arusha Region, Tanzania in the South West within the mid-slope of Mount Meru between Latitude 3° 23′ 58″ S and Longitude 36° 47′ 48″ E at an altitude of 1188 meters above sea level. The area receives a bimodal pattern of rainfall with the long rainy spell ("Masika") distributed from late March to early June and the short rain spell ("Vuli") from October to December. The soils class in the area are Phaeozems as per FAO soil classification system (WRB, 2014). The chemical properties are, neutral pH (around 7), high Cation Exchange Capacity (CEC) of around (60 $cmol_c$/kg), high percentage base saturation (PBS %) (based on pH), and total organic carbon range from moderate to high, total nitrogen and very high P - Olsen contents). The chemical and physical properties of soils in the area satisfactorily suit banana production. The physical properties are brownish-black colour, silty clay loam to silty clay textural class, well-drained, brownish-black colour and its depth range from moderately shallow 60 - 90 cm to > 120 cm.

3.2 Plant Materials

In vitro, banana cv. Mchare-Huti Green (HG) EAHB of the age of 14 months was used as planting material. Mchare Huti Green was planted on 3 May 2017. Plants were spaced 2 x 3 m (row x line) in holes with dimensions of 60 cm width x 60 cm length x 60 cm deep with a density of 1666 plants /ha. Two plants were maintained per hole comprising of a mother (cycle 1) and daughter (cycle 2).

3.3 Experimental trial and treatments allocation

The experimental design was blocked but could not abide by normal Randomized Complete Block Design (RCBD) due to the nature of the layout of drip lines. However, it comprised of two blocks each with five rows of 15 plants spaced at 3 m x 2 m. Block one was Rainfed condition (RF) dependent treatment and block two Full drip irrigation (FD). Individual blocks of HG with five rows of 15 plants/ row were split to three plots with a total of 25 plants within which three replications (rows) of nine plants (3 x 3). The central nine plants (3 x 3) belonging to two split plots were used for continuous data collection throughout the experimental time frame. The remaining plants were used as a borderline (Fig. 2).

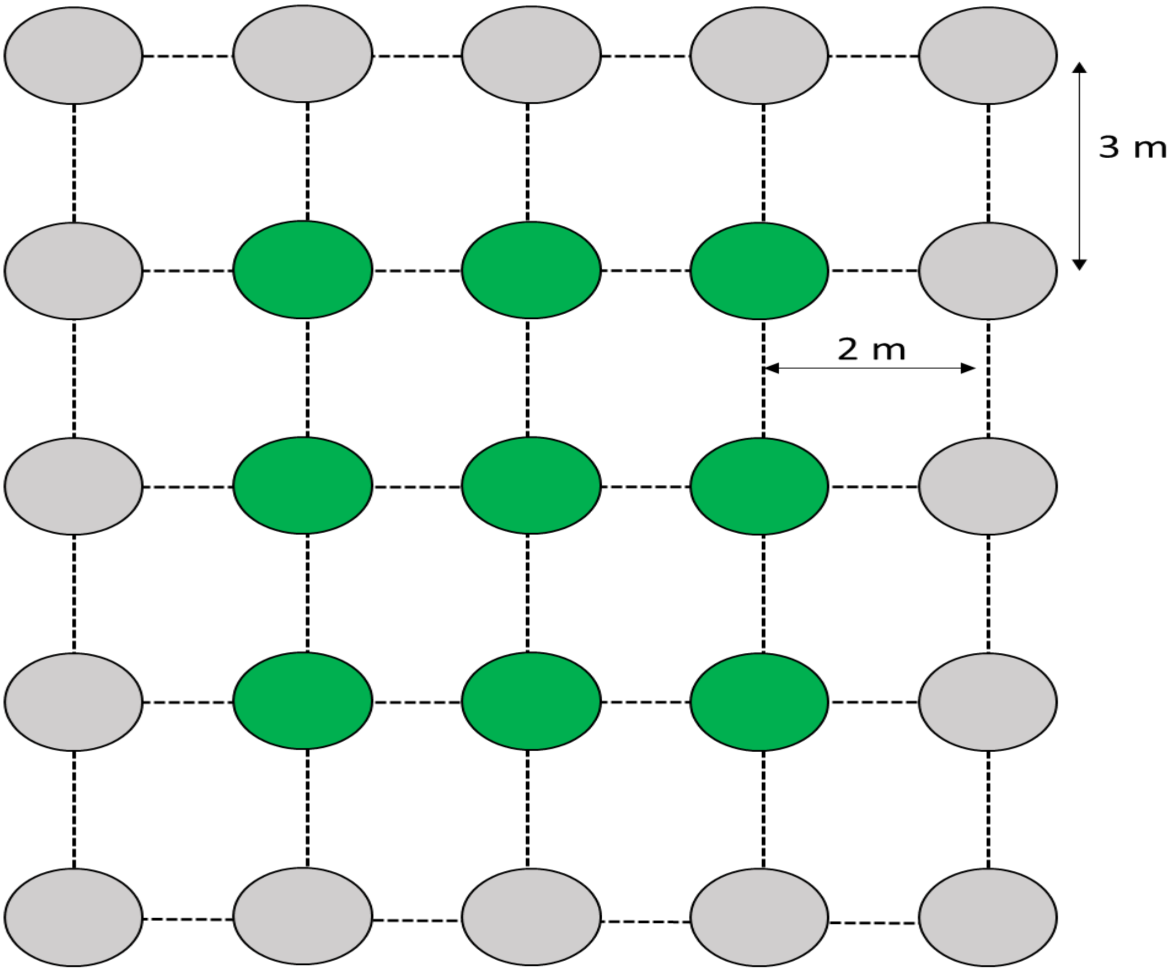


Figure 2: Part of the experimental layout showing continuous sampling plants (dark) and borderline in (grey)

3.4 Irrigation system

Drip irrigation pipes were installed together with water flow meters reading irrigation water amounts per two driplines. The drip system comprised of two driplines per banana row, with 4 emitters per plant, each dispensing 4 l h^{-1} at 110 kPa pressure. Daily, soil moisture remained checked by Time Domain Reflectometry (TDR). Every day, continuous measurement plot where plant data were collected, was fitted with two in-house built 30 cm long TDR probes installed vertically, reading soil moisture at two soil depths, one at the outermost layer of soil (0 - 30 cm) and another at the soil under the topsoil (30 - 60 cm). Every morning before irrigation, TDR-probes were read out individually by a TDR-200 (Campbell Scientific, Inc). Based on TDR volumetric water contents, the need for irrigation by the plant was determined.

Before splitting plots into respective treatments FD and RF, all plants were irrigated until four months after planting (MAP). Both FD and RF were all performed during dry season i.e. the second week of June 2018 to the second week of October 2018. During dry season normally banana plants do survive but changeover of vegetative growth parameters and generative parameters occurred due to continuous moisture depletion from the end of rain season to on the set of the rainy season. The limitation of this study occurred when there were light showers in some early days of commencement of the experiment. The plot allocated with treatment FD received water when a critical moisture level reached 25% total available water (TAW) in the first (0-30 cm) or (30 - 60 cm) depth in five days of the week. This corresponded to 37.5% and 41% volumetric water content (VWC). In the RF plots, no water was applied until plants showed visible water-stressed signs like petiole collapse and leaf wilting, after which irrigation was supplied. This situation was experienced during extreme dry season month of October.

3.5 Experimental management

Apart from irrigation, plants received both mineral and organic fertilizers. Mineral fertilizers were applied in splits both in the rainy season and dry season. Mineral fertilizers composed of Urea (46% N) at the rate of 333 kg ha^{-1} yr^{-1}, Muriate of potash (MOP) (60% K) (416 kg ha^{-1} yr^{-1}, Mg, and S as MgS (16% MgO, 32% SO_3) (200 kg ha^{-1} yr^{-1}). During the rainy season, mineral fertilizers were applied every month and every two months in the dry season, while TSP (46% P_2O_5) (200 kg $ha^{-1}yr^{-1}$) was applied every five months. The fertilizer materials were placed in a ring at 0.4 - 0.5 m a distance from the base of the pseudostem during the wet season while during dry season fertilizers were placed within the wetted zone by the drippers. Organic fertilizer was applied twice yearly right at the beginning of the rainy season. The type of organic fertilizer applied was farmyard manure at the rate of 20 L per plant hole. The emerged suckers were left to grow until four months after planting (MAP) when all suckers were pruned except for one sucker of 30 cm height situated at the south side of the plant with the reason of maintaining outcoming sucker into position. Afterwards, sucker assortment and removal of unselected ones were carried out monthly. Removal of dead leaves was performed every month and regular weeding manually using a hand hoe.

3.6 Data collection

Data on banana bunch weights and other vegetative and generative plant characteristics were collected throughout two growth cycles from planting to harvest. A distinction was made between vegetative growth parameters and generative growth parameters.

3.6.1 Data collection at vegetative phase

Measurements were taken monthly from the central nine plants in each measuring plot. Phenotypic vegetative descriptors measured were pseudostem girth at (base, 1 m high and mid-height), the stature of the plant measured right from ground surface level up to the part with "V" shaped structure formed by petioles of the two last issued leaves fully open, the number of useful leaves existing at harvest stage, the number of dead leaves, the lamina length and width of the third photosynthetic active youngest fully expanded leaf and internode distances (Table 5).

3.6.2 Data collection at harvest

The destructive sampling of the proven mature bunch was done referring to standard morphological descriptors for banana (Nyombi *et al.*, 2009). At harvest, the following parameters were measured: Vegetative growth parameters and generative growth parameters which included bunch weight, peduncle weight, the number of hands per bunch, fresh weight of individual hands and fruits, the length of the convex side and circumference of every fruit of the bunch. Weights were measured using a Kern EOC 100 K - 3 L balance (60 kg ± 2 g).

Table 5: Summary of the plant growth parameters measured between growth phases (Vegetative & destructive sampling at harvest)

Time resolution	Variable measured	Units
	Vegetative growth parameters	
Monthly	Pseudostem girth at the base, at 1 m and height, pseudostem (base girth, 1 m, m & mid) Leaf length &width	Centimetres (cm)
Monthly	Number of dead leaves	Number
Monthly	Number standing functional leaves	Number
Monthly	Internode distance of 4^{th}, 5^{th} and 6^{th} youngest leaf	Number
	Harvest	
At harvest	Weight of pseudostem, leaves, and petioles, bunch characteristics (weight of bunch, weight hands, the weight of fruits)	Grams (g)
At harvest	Number of hands, number of fruits per bunch, number of fruits per hand	Number

3.7 Statistical analysis

From raw data of growth parameters (plant height, lamina length, lamina width) conversion were done before doing direct analysis (Table 1). New variables created through calculations were the volume of pseudostem, leaf area (LA) and leaf area index (LAI). An assumption was made to calculate the radius of a plant from the girth of the plant $circumference\ (c) = girth = 2\pi$; thus $r = c/2\pi$, then the volume of the pseudostem was first computed as a cylinder, then as a cone considering that pseudostem possesses both two shapes.

$$Vcylinder = \pi * r^2 * h \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots .. (1)$$

$$Vcone = Vcylinder * \frac{1}{3} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. \ldots .. \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (2)$$

Leaf area (LA) was calculated following (Nyombi *et al.*, 2009) as follows,

$$LA = laf \times l \times w \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. \ldots \ldots \ldots \ldots (3)$$

Whereas;

LA = Leaf area

Laf = Lamina area factor

l = Lamina length (m)

w = Greatest part of lamina width

$$LAI = \frac{laf}{area} \sum_{i=1}^{n} (li \times wi \times ni) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots (4)$$

Whereas;

Laf = Lamina area factor

li = Leaf length (m)

wi = Maximum lamina width (m)

area = total ground area

ni = number of leaves

Pearson correlation coefficients were obtained using Origin Pro 2015 software, means and variances equality test through t-test between treatments were obtained using GenStat Discovery version 4th edition statistical software and boxplots figures were obtained by R statistical software. Fisher’s least significance was used to compare means at the $P = 0.05$ level of significance.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Effects of water regimes on growth parameters, yield and yield components

The results for the growth parameters and yield and yield components in two water regimes are shown in Table 6 and Fig. 3,4 and 5. Growth parameters of pseudostem girth, height, leaf width and LAI in RF plants were significantly lower than those in FD plants (P <0.001) while the leaf length was insignificantly at (P >0.05) (Fig. 3a, 3b, 3d and 3c). The weight in (Kg) for petioles, pseudostem and Aboveground sampled during destructive sampling at harvest in FD and that of RF were significantly different at (P <0.05). In some of the growth parameters of the Mchare banana plant crop, full drip irrigation did not affect rainfed condition particularly of leaf length (2664 - 3149) cm and leaf weight (5.4 - 6) kg.

Similarly, for Mchare yield in bunch weight per plant, full drip irrigation had effects on bunch weight was FD 28.3 ± 1.75 kg plant per plant and RF 19.06 ± 0.97 kg plant per plant significantly different P <0.001 (Table 6 and Fig. 5n). Each yield components varied significantly at different levels of probabilities between two water conditions fruits per bunch in FD 56.26 ± 3.67 and RF 38.76.23 ± 2.65 was also significantly different (P <0.001) (Table 6 and Fig.5j), fruit weight (kg) 0.18 ± 0.006 and RF 0.12 ± 0.007 at (P <0.001) (Table 6 and Fig. 5k), fruit girth (cm) FD 24.5 ± 2.03 and RF 113.2 ± 3.48 (P =0.008) (Table 6 and Fig. 5p) ,fruits length (cm) FD 270.5 ± 21.30 and RF 244.9 ± 6.39 (P =0.002) (Table 6 and Fig. 5o), hand weight (kg) FD 3.07 ± 0.16 and RF 2.41 ± 0.14 (P =0.003) (Table 6 and Fig. 5l). Full drip irrigation had no effect on fruit per hand (16-18) and hands per bunch (9-9) respectively.

4.1.2 Pearson correlation coefficients of banana vegetative plant characteristics and bunch weight

For Mchare plants, correlation coefficients established from allometric growth parameters sampled during destructive sampling at harvest are presented in Table 7. The aboveground biomass (AGB) was significantly positively correlated with pseudostem girth, pseudostem volume, height and bunch weight. The Pearson correlation of coefficient (r) ranged from 0.44 to 0.73. Bunch weight was also significantly and positively correlated with pseudostem girth base (r= 0.48, < 0.001), 1 m height (r = 0.38, < = 0.05) and mid-height (r = 0.51, < 0.01), pseudostem volume (r = 0.38, < 0.01), height (r = 0.47 <0.01), LA (r = 0.32 < 0.05) and LAI (r = 29 < 0.05).

Table 6: Banana bunch yield and yield attributing components differences between FD and RF and their respective correlation with bunch yield

Bunch components	Mean differences (mean ± SE)		*P*-value (Variation)	Correlation coefficient (r)	*P*-value (Correlation)
	FD	RF			
Bunch weight (kg)	28.30 ± 1.75	$19.06 \pm 0.97^{***}$	< 0.001		
Fruits/bunch (kg)	56.26 ± 3.67	$38.76 \pm 2.65^{***}$	<0.001	0.40^{**}	0.004
Fruit girth (cm)	124.5 ± 2.03	$113.2 \pm 3.48^{**}$	0.008	0.50^{***}	0.0000
Fruit/hand (nr)	18.00 ± 0.34	16.37 ± 0.76^{ns}	0.058	0.30^{*}	0.0253
Fruits length (cm)	270.5 ± 21.30	$244.9 \pm 6.39^{**}$	0.002	0.42^{***}	0.0028
Fruit weight (kg)	0.18 ± 0.006	$0.12 \pm 0.007^{***}$	< 0.001	0.45^{***}	0.0013
Hand weight (kg)	3.07 ± 0.16	$2.41 \pm 0.14^{**}$	0.003	0.30^{*}	0.0256
Hands/bunch(nr)	9.37(± 0.34)	$9.19(\pm 0.18)^{ns}$	0.630	-0.11^{ns}	0.7635

Two tailed t-test summary

Bunch components	**µ1- µ2**	**Sed**	**t-value**	***P*-value**
Bunch weight (kg)	9.246	1.998	4.63	< 0.001
Fruits per bunch (kg)	23.704	9.201	2.58	0.014
Fruit girth (cm)	11.259	4.030	2.79	0.008
Fruit per hand (nr)	1.630	0.832	1.95	0.058
Fruits length (cm)	25.630	7.587	3.38	0.002
Fruit weight (kg)	0.044	0.009	4.51	< 0.001
Hand weight (kg)	2.238	0.144	15.50	< 0.001

Test of null hypotheses that means of RF variables are equal to means of FD variables
Note: The results of values presented are means with Standard error of (means ±SE); DF; Degree of freedom (26); µ1- µ2; estimate for mean difference; Sed= Standard error of difference; *** asterisks connote significant at *P* =0.001; **= significant at *P* =0.01; *= Significant at *P*= 0.05 and ns non- significant and FD= Full drip irrigation, RF= Rainfed condition, nr= number.

Table 7: The Pearson correlation coefficient (r) values of bunch weight (Bwt) and aboveground biomass (AGB) in association with the allometric growth parameters of the banana plant

AGB	Girth base	Girth lm	Girth mid	Height	LA	LAI	Bwt	Volume
Girth base	0.52***							
Girth1m	0.53***	0.71***						
Girth mid	0.50***	0.67***	0.56***					
Height	0.45***	0.61***	0.76***	0.68***				
LA	0.23ns	0.51***	0.32*	0.40***	0.38**			
LAI	0.23ns	0.58***	0.34*	0.41***	0.32*	0.86***		
Bwt	0.74***	0.48***	0.38*	0.51**	0.47***	0.32*	0.29*	
Volume	0.14ns	0.68***	0.41***	0.49***	0.51***	0.86***	0.80***	0.38**

AGB = Above ground biomass, LA = Leaf area, LAI = Leaf area index, Bwt = Mass of the bunch, Volume = Volume of pseudostem, *** = *P* <0.001 level of significant, ** = *P* <0.01 level of significant, * = *P* <0.05 level of significant and ns = none significant.

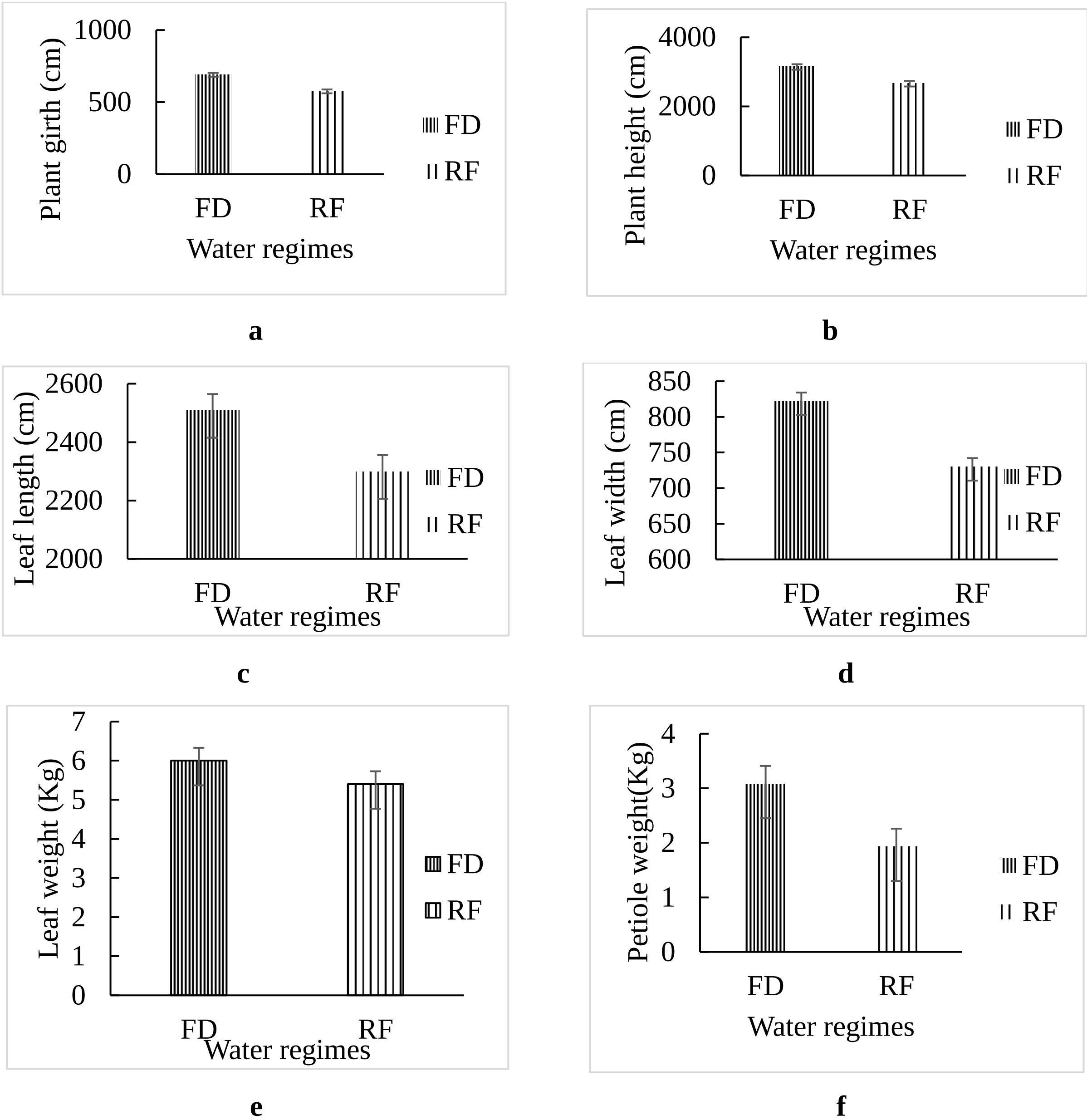
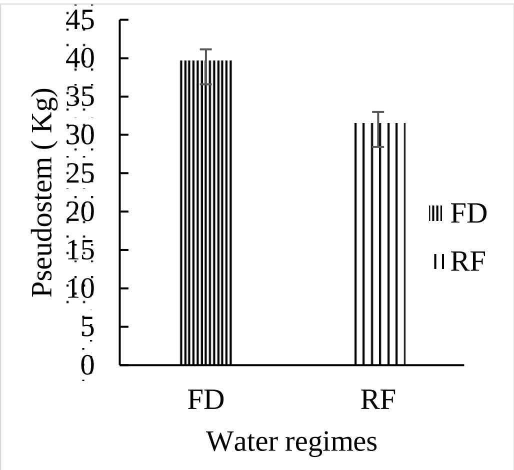


Figure 3: Bar charts depict the water regimes effects of the banana allometric growth parameters measured during destructive sampling at harvest; (a) girth), (b) height, (c) Lamina length, (d) Lamina width, (e) Leaf weight and (f) Petiole weight compared under FD, Full drip irrigation and RF, Rainfed condition



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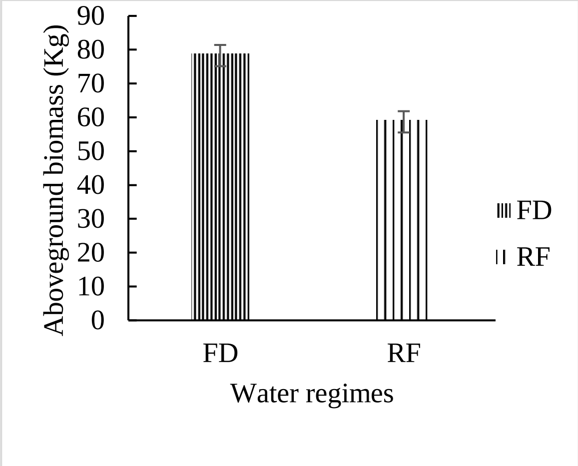

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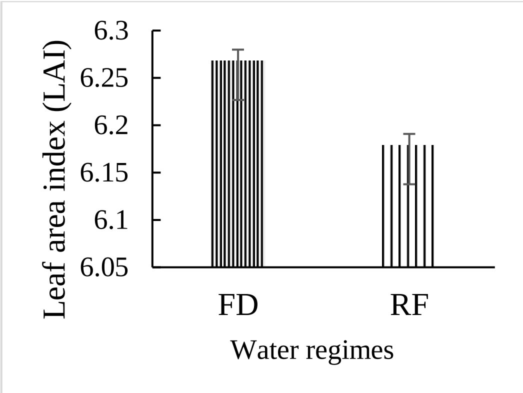

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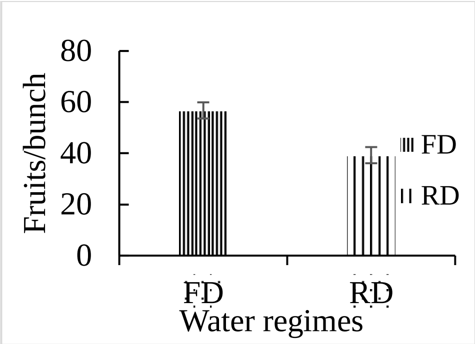
Figure 4: Bar charts depict the water regimes effects of the banana allometric growth parameters measured during destructive sampling at harvest (g) pseudostem weight and (h) aboveground biomass (i) LAI, compared under FD and RF. Note: Above ground biomass (ABG): contains pseudostem, leaves and bunch



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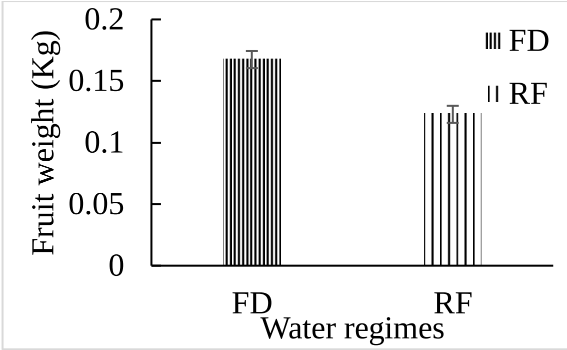

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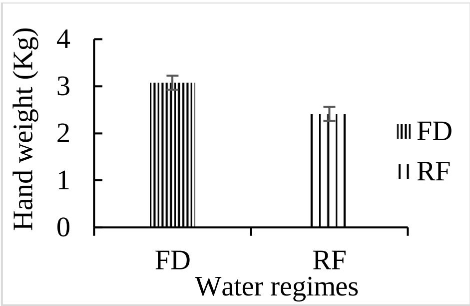

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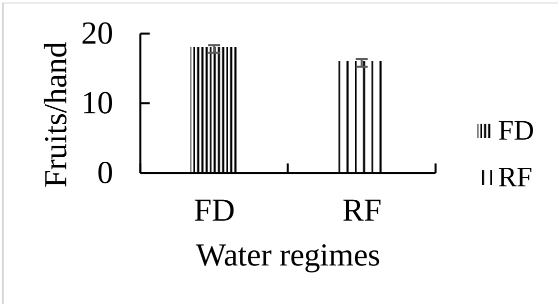

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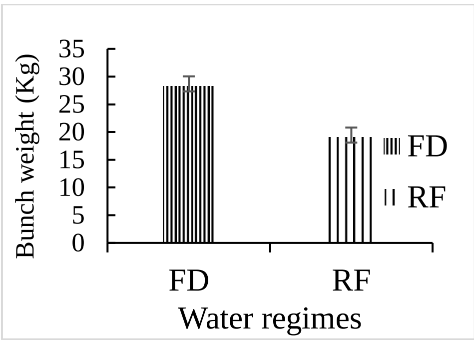

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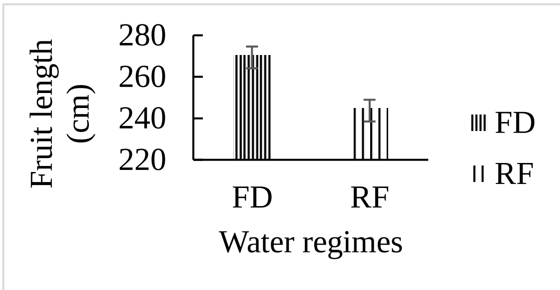

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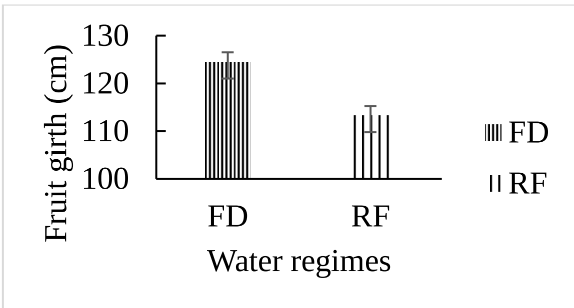

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Figure 5: Bar charts depict effects of water regimes on the yield and yield components recorded during destructive sampling at harvest; (j) Fruits per bunch, (k) Fruit weight, (l) Hand weight, (m) Fruit/hand, (n) Bunch weight, (o) Fruit length and (p) Fruit girth as compared under FD and RF

4.2 Discussion

4.2.1 Effects of water regimes on growth parameters, yield and yield components

The experiment aimed to quantify growth parameters, yield, and yield responses of Mchare to conditions of water variations. Maximum growth was recorded in D as compared with those in RF. This growth pattern is likely to have been due to moisture variability in two trial plots which imposed effects on an overall plant growth trajectory. Most recorded growth parameters exhibited significant variations in growth between FD and RF. The growth disparity existed between FD and RF suggests that moisture stress significantly had an impact on the growth and performance of Mchare plant morphological parts. Similar findings were reported by Pramanik and Patra (2016) who recorded maximum values of banana biometrical characteristics (height of the plant, girth of pseudostem, number of leaves, lamina length, lamina width, and leaf area index (LAI) with drip irrigation at 70% cumulative pan evaporation. Similar findings recorded reduced banana productivity by 30 to 50% due to the impact of moisture stress during vegetative and generative growth stages (Surendar *et al.*, 2013). Use of drip irrigation in banana cultivation is of great advantage to smallholder farmers as revealed from this study. In recent years, climate change is of great threat to rainfed Agriculture, therefore through drip irrigation even in a small scale, it can enable smallholder farmers to secure food, income as well animal feed from the rest of banana biomass.

In terms of yield and yield components, there were yield advantages of Mchare with a drip for about 10 kg per plant higher than that of rainfed condition. Mchare bunch weight/plant in FD was 28.3 ± 1.75 kg per plant and in RF 19.06 ± 0.97 kg per plant respectively. This justifies that Mchare banana plant when supplied with water during dry periods someone can still fetch a high price and secured from hunger. These results are conforming with the results previously obtained by Robinson and Alberts (1986) who spotted increased banana bunch weight from 31.7 to 44.6 kg as a result of the increase in crop coefficient from 0.25 to 0.75. Also, Goenaga and Irizarry (1998) reported a significant increase of bunch components with an increase of water levels from 0.25 to 1.25 in a class A evaporation pan. Reduced bunch weight, fruit weight, hand as detected in RF match with what found by Alvarez *et al.* (2001), Ravi *et al.* (2013) and Turner *et al.* (2007) who reported moisture stress to have considerably reduced banana productivity due to reduced dry matter accumulation and hence decrease in yield. Likewise, Fahad *et al.* (2017) also reported reduced fruit fresh and dry weights which lessened banana bunch weight due to decreased photosynthetic rate and soil moisture content at times of stress and hands which are easily affected by the water stress, especially at the flowering time.

4.2.2 Relationships of allometric growth parameters and bunch weight

Correlations between the bunch weight and the vegetative growth parameters; pseudostem girth at ground level,1 m and mid in height, plant height, leaf area, leaf area index and pseudostem volume at harvest for at harvest, for the Mchare-Huti Green banana, were significant and positive for all variables with correlation coefficients ranged from (r) 0.29 to 0.74 (Table 7). This association obtained in this study indicates the variation of bunch weight with the vegetative growth parameters variables presented in bar charts (Fig. 3 and 4). Moreover, relationships encountered in this study strengthen the connection of the effect of water regimes throughout the Mchare growth by increasing yield through optimal water supply to ensure improved growth-yield components trajectories, ultimately the economic yield. These findings are comparable to the results of Guimarães *et al.* (2013), Kamusingize *et al.* (2018) and Nyombi *et al.* (2009) who established a relationship between allometric growth parameters with biomass and bunch weight.

Quantification of banana yield and production per unit area is difficult because of the nature of the crop plant characterized by different stages of development (Wairegi *et al.*, 2009). The conventional method of quantification of banana yield is through destructive at harvest. The positive association of Mchare agronomic traits detected in this study can be used to derive a model for yield estimation as seen in Table 7. For example, the relationship of LAI of Mchare versus bunch weight is an indication of healthier leaves which play a great role of manufacturing dry matter from leaves later is translocated to storage parts in this case for banana stored in fruits. Thus, applying variables with influence, to a greater extent on Mchare production can be added to the study of harvest/yield prediction of the correlation analysis.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Generally, FD improved Mchare growth parameters and bunch yield and yield components compared to RF. The yield per hectare was 14.9 tonnes more under FD than RF (46.65 t/ha and 31.75 t/ha). Concerning yield components, most of the Mchare yield attributes performed better in FD compared with RF except the number of fruits per hand as well as hands per bunch. Findings from this study reveal the importance of soil moisture on growth and yield and yield components of Mchare banana. Since banana plants are in a category of perennial crops, use of drip irrigation could be of great importance rather than relying on rain which recently has been unreliable due to global climate change.

5.2 Recommendations

(i) Economic analysis needs to be done on the use of drip irrigation in a large-scale banana plantation.

(ii) In-situ rainwater harvesting using basins around the plant hills, which is being used in drier regions like Dodoma and Singida.

(iii) Apart from the use of drip irrigation alone, there is a need to incorporate drip irrigation with other integrated soil and water conservation practices such as the use of organic manure, mulch and inter-planting with cover crops such as lablab beans.

(iv) Need to identify the minimum amount of water required to optimize farm incomes.

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