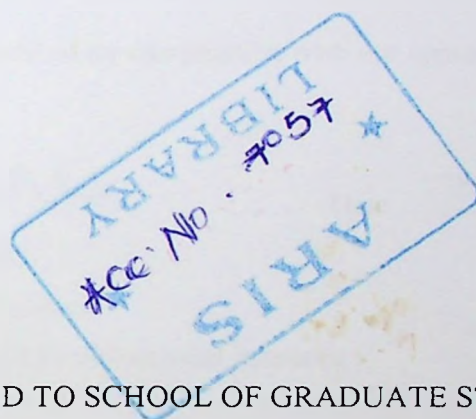


**RESPONSES OF SELECTED EAST AFRICAN HIGHLAND BANANA
(AAA-EAHB) CULTIVARS TO DROUGHT STRESS**

NJUKI KAYONGO SAMUEL

BAGM. (Hons, MUK)



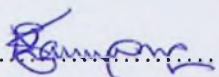
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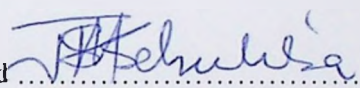
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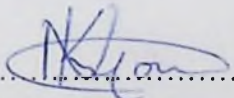
DECLARATION

I NJUKI KAYONGO SAMUEL, declare that the work presented in this thesis is my original work and has not been presented for a degree award in any University.

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DEDICATION

This thesis is dedicated to my family.

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To you all readers I say God bless you.

Abstract

Drought stress has and continues to be a limiting factor to banana productivity. The effects are significant on crop growth and its yield. However significant increases in yield depend on moisture availability and expression of drought stress avoiding mechanisms. Physiological processes important in determining cultivar sensitivity to drought stress were not critically quantified in earlier studies hence this study.

This study aimed at quantifying the threshold responses of physiological parameters such as plant biomass development, leaf orientation behaviour, chlorophyll breakdown and transpiration for their sensitivity to drought stress. The EAHB triploid cultivars of *Mpologoma* and *Kisansa* (AAA) were used in the study in comparison to considered drought tolerant cultivars of *Kayinja* (ABB), *Sukali Ndiizi* (AAB) and a low land cultivar *Yangambi Km5* (AAA). All cultivars were subjected to three contrasting regimes of soil moisture.

Moisture availability (M.A.) application levels were determined based on soil moisture retention factor (pF) ranging from 2.0-2.1 (0.1 - 0.13 bar) for free drainage soil level; 2.5-2.7 (0.32 - 0.51 bars) for semi moist level; 2.8-2.9 (0.64 - 0.8 bars) and drier soil.

The progressive increase in moisture deficit from free drainage (90%) indicated a proportional loss in fresh weight ranging from 12.7% to 19.4% at semi moist soil level with 46.5-54.4% to cooking cultivars; 40-43.0% to dessert and plantain cultivars at drier soil level hence the sensitivity of expressive traits adaptable to drought. Most root sizes were less than 1cm in diameter with dense mass and length developed higher at semi moist soil level especially for cooking cultivars than at free drainage. The lowest specific root length (SRL) were significantly exhibited by cv *Mpologoma* (0.130m g^{-1}), cv. *Kisansa* (0.198m g^{-1}) and cv. *Sukali Ndiizi* (0.143m g^{-1}) at moist soil level correlating with larger leaf surface area for efficient utilization of available moisture.

Results for responsive biomass were significantly different with plant height across moisture regimes. Plant height ranged from 67 - 86cm and 64 - 93cm high at moist soil level (2008b & 2009a season) and 60 - 83cm high for semi moist soil level and 46-64cm for drier soil level during 2009a season indicating the effect of moisture deficit stress on the plant's growth potential. A decrease in soil moisture deficit from moist to semi moist soil level caused a significant reduction in height for cvs. *Sukali Ndiizi* and

Kayinja than moisture reduction from semi moist to drier soil level. Leaf area expansion was large at moist soil level and diminished with increase in soil water deficit. The fresh tissue weight quantification at harvest showed the highest total weight with cv. *Sukali Ndiizi* at 2240g, 1181g, and 515.0g for moist, semi moist and drier soil levels respectively and decreased at 58.0% and 48.0% upon soil moisture reduction from moist to semi moist and to drier soil level. The total fresh tissue weight of cooking cultivars were determined at 1887g, 1396g and 476g (cv. *Kisansa*) and 1700g, 998g and 466g (cv. *Mpologoma*) for moist, semi moist and drier soil levels respectively with proportional decrease of 69% and 52% when available soil moisture was reduced from semi moist to drier soil level.

Cultivars exhibited regulatory survival mechanisms to drought stress through leaf folding. The cultivar potential for orienting leaves open showed significant differences across moisture regimes with cv. *Yangambi Km5* (126^0), cv. *Kayinja* (125^0) and cv. *Kisansa* (124^0) spreading leaves widely open at moist soil level. At drier soil level, cv. *Sukali Ndiizi* (74.2^0), *Mpologoma* (109^0) and cv. *Kisansa* (103.7^0) exhibited more open leaves from 180^0 surface orientation increasing the leaf exposure for high transpiration. The decrease in soil water content from the field capacity led to plant dehydration and deterred leaf lamina expansion due to reduced leaf water potential (LWP).

Leaves for all genotypes were turgid (93.2 – 95.4% RWC) at moist soil level enhancing cell expansion for CO_2 assimilation, high transpiration rate and biomass development. Moisture deficit increment semi moist to drier soil level indicated higher water saturation deficit especially for cultivars *Mpologoma* (20.5%) and *Kisansa* (21.4%) exhibiting severe sensitivity to drought stress. Full turgid leaves enhanced cells to remain extended for high transpiration causing the rate of lost water to be far higher than the replaceable in soil hence sensitivity and difficult survival in adverse dry conditions.

Transpiration rates were significantly different across water regimes, varieties and time (weeks). The results from stressful treatment structure indicated the actual expression of traits for spending and saving water for plant growth. Generally average rates of transpiration were quantified at 1.868 L wk^{-1} (cv. *Sukali Ndiizi*), 1.749 L wk^{-1} (*Kisansa*), 1.730 L wk^{-1} (*Mpologoma*), 1.693 L wk^{-1} (*Yangambi Km5*) and 1.702 L wk^{-1} (*Kayinja*) at moist soil level. However at drier soil level, cv *Kayinja* (0.421 L wk^{-1}) transpired the least mean volume of water, validating its potential to save water. Cultivar *Mpologoma* (0.659 L wk^{-1}) and *Kisansa* (0.696 L wk^{-1}) significantly transpired more water and were therefore regarded as water spenders.

The stressful condition put cv. *Kisansa* and *Mpologoma* to being water spenders hence their sensitivity and therefore could only get acclimatized to the environment than being adaptive whereas cv. *Sukalindiizi*, *Yangambi Km5* and *Kayinja* exhibited relative traits of water saving. The potential of cultivars to save water was considered a good trait for plant adaptability to survive in stressful conditions but not productive.

The identification of variables predicting transpiration rates were determined with a stepwise regression analysis and correlation coefficient. The regression coefficient variables identified were used to determine the rate of transpiration per unit change in variable development. The developed models for transpiration prediction across moisture deficit regimes were: Cultivar *Kayinja* (ABB): $Y = [a (0.517) + \beta_1 * b_1 (0.024)]$ and $Y = [a (-3.68) + \beta_1 * b_1 (0.020) + \beta_2 * b_2 (0.338)]$ during 2008b&2009a seasons respectively for each developed and unfolded leaf. Cultivar *Sukali Ndiizi* (AAB): $Y = [a (0.217) + \beta_1 * b_1 (6.76)]$ and $Y = [a (-2.408) + \beta_1 * b_1 (0.012) + \beta_2 * b_2 (0.207) + \beta_3 * b_4 (0.013)]$ during 2008A&B seasons respectively for increase in leaf area, leaf unfolding, developed healthy leaf and plant height accumulation. Cultivar *Mpologoma* (AAA): $Y = [a (0.418) + \beta_1 * b_5 (0.001)]$ and $Y = [a (-0.890) + \beta_1 * b_1 (0.016) + \beta_2 * b_6 (0.001)]$ during 2008b&2009a seasons respectively for developed leaf area, leaf unfolding and fresh leaf biomass. Cultivar *Kisansa* (AAA): $Y = [a (-0.160) + \beta_1 * b_3 (9.00) + \beta_2 * b_1 (0.010)]$ and $Y = [a (-0.139) + \beta_1 * b_1 (0.009) + \beta_2 * b_6 (0.001)]$ during 2008b&2009a seasons respectively for developed leaf area, leaf unfolding and fresh leaf biomass. Cultivar *Yangambi Km5* (AAA-Lowland): $Y = [a (-0.134) + \beta_1 * b_3 (11.54)]$ and $Y = [a (3.97) + \beta_1 * b_2 (0.232) + \beta_2 * b_6 (0.002) + \beta_3 * b_4 (-0.04)]$ during 2008b&2009a seasons respectively for developed leaf area, healthy leaf, fresh leaf biomass and gain in height

All plants expressed high nitrogen levels across moisture deficit regimes with cv. *Kayinja* exhibiting the immobilization potential.

Based on the results of this study important to carry out a molecular characterization to find which genes trigger the expression of drought avoidance mechanisms among cultivars with B-genome composition. During the study it was found that highly stressed plants were vulnerable to pest attack causing multiple stresses to the plant hence warrant to ascertain the cause.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

1.1.1 Morphology, origin and distribution

The cultivated banana is believed to have originated in Southeast Asia-India, Indochina, Malaysia and the Philippines and became domesticated before historical times. In East Africa, bananas were introduced by Arab traders (Reynolds, 1951) during the first millennium A.D. The propagation of bananas occurred naturally by vegetative means enhancing the perpetuation of seedless types for selections of progenitors of present day cultivars (Egbert, 1977).

Plantains and banana (*Musa* spp) were developed from intra-specific and inter-specific hybridization between the two wild species of *Musa acuminata* Colla and *Musa balbisiana* Colla which contributed the A and B genome compositions respectively (Simmonds, 1995). Polyploidy and hybridization gave rise to a number of ploidy clones such as diploid, triploid, and tetraploids with different permutations of A and B genome compositions. Thus the bananas constitute a hybrid-polyploid complex that are classified by genome composition thus; AA, AAA, AB, AAB, ABB, BBB and the tetraploids. Broadly, *M. balbisiana* (B) genome was reported to confer hardiness, disease resistance and acid-starchy fruit quality (Pillay *et al.*, 2007).

Bananas are plants of the humid tropics occurring within the region lying 30°N and 30°S of the equator (Simmonds, 1959). Banana (*Musa* spp) is a tropical herbaceous evergreen plant with no natural dormant phase. The plant has a high leaf area index, and a very shallow root system (Robinson, 1995) that constitute the link between the plant and the soil thereby providing anchorage and guaranteeing nutrient and water uptake for development of lateral shoot (suckers)

and perennial growth (Price, 1995; Lahav *et al.*, 1989). Ideal conditions for banana growth requires mean atmospheric temperature of 27°C, monthly rainfall of 100cm, exposure to full sunlight, deep soil of high fertility and free drainage, and a soil pH of 6.5-7.0.

1.1.2 Production of banana in Uganda

Uganda is one of the world's leading countries in terms of banana production and consumption (Edmeades *et al.*, 2005). Banana production dates way back to 13 A.D and is estimated to have been produced for 6000 years in Uganda (Lejju *et al.*, 2006) compared to 2,500 years in Cameroon (Mindzie *et al.*, 2001). The crop production has been sustained by the cultural, social and economic values attached to the crop and ideal soil types that enhanced growth especially in regional areas of central, southern and southwestern of the country which are characterized by a bimodal rainfall pattern. Bananas occupy the largest cultivated area among the staple food crops and are primarily grown on small subsistence farms of less than 0.5ha (Edmeades *et al.*, 2005). About 84 distinct varieties endemic to East African highlands are grown and recognized as a secondary center of banana diversity.

Bananas are categorized in different forms with the most abundant being the cooking type (Matooke group) of *Musa* AAA triploids, then the desert types (plantains) of ABB, triploids, and the beer type (Mbidde group) of AAB triploids (Karamura *et al.*, 1994), which are hybrid products from wild species of *M. acuminata* (genome A) and *M. balbisiana* (genome B) respectively. However, on international trade the dominant cultivar is the Cavendish sub-group (AAA) accounting for 15% of the world's annual production (FAO, 2006).

Bananas grow in a range of environments producing fruits all year round, thus playing an important role in bridging the hunger-gap between crop harvests. The production is, however, at

subsistence level mainly around the homesteads where part of a surplus is sold to raise income for the households (Adupa *et al.*, 1994). Large scale plantations also exist in some parts of the country particularly south western Uganda (Mugisha *et al.*, 1993).

Bananas have been produced at optimal rainfall conditions of 1300 mm per year, equivalent to 25 mm of rainfall per week (Purseglove, 1972) with soil moisture determining the nature and growth habit of a banana crop and or its potential susceptibility to drought stress. The most drought affected cultivated type of banana are the cooking cultivars (Matooke group AAA) that are characterized by a shallow rooting system. However, despite the above effects farmers persistently grow bananas and are predominantly preferred as a staple food and for beer production (FAO, 1987).

1.1.3 Constraints to banana production in Ugandan

The growth of the banana industry has been achieved through cultural management practices and expansion of cultivatable land. But the crop production is constrained by several factors. In general, susceptibility to both abiotic and biotic factors presents the most serious constraints (Rubaihayo *et al.*, 1993) to banana production especially the cooking type. The most important unpredictable abiotic factors include drought stress, characterized by long dry spells, low levels of moisture in the soil, low soil fertility (Okech *et al.*, 1996) and the reduction of input farm use such as mulches for replenishing the soil fertility. With the unpredictable climatic conditions of the above mentioned effects, yield is steadily continuing to decline (Van Asten, 2004).

Drought stress being the most common unpredictable factor, affects plant growth by reducing the growth mechanisms which determines the yield potential. Significant effects include poor root and shoot growth with lower leaf area index, stomata closure that limits carbon assimilation.

chlorophyll break down and high rate of senescence which cause low yield of bananas (Bananuka, 1999).

1.2 Effects of drought stress on banana plant growth

1.2.1 Underground plant biomass (root system)

The roots are responsible for anchorage, nutrient supply, and exchange of various growth substances with the shoots, including plant growth hormones (Itai *et al.*, 1996; Barber, 1992).

The below ground biomass contribute to lateral responsive biomass development and thus perennial growth (Price 1995; Lahav *et al.*, 1989). Similar relationships were observed among the EAH bananas (AAA-EA group) (Sebuwufu *et al.*, 2004) accounting for 90% of the variation in root growth to variation in shoot development.

However, under drought conditions, roots produce transduction cascades to enhance the adaptability mechanisms of closing the stomata, allowing the banana plant to remain highly hydrated, but at reduced carbon assimilation. The capacity of banana roots to withdraw water from drying soil is therefore subject to knowledge of quantitative models for characterization of the most sensitive features of the root system (Turner, 2008). Significant effects to root system development are attributed to variations in soil moisture, structure, type, drainage, and climatic conditions (Blomme *et al.*, 2002; Dorel, 2002) which affect the root extension and distribution. The influencing factors cause a variation in fresh weight among genotypes showing large difference in root size (especially for Cavendish subgroup cv. 'Yangambi Km5' -AAA). The root variation in size due to drought affects the plant potential to extract water from the soil (Araya, 2005) and as well depress yield potentials (Robinson, 1996). Other factors of sensitivity to drought effects on roots are attributed to genomic group, ploidy level and the health of the plant

(Blomme, 2000; Blomme *et al.*, 2000, 2003). Therefore modification of the root system through genetic manipulation to less sensitivity to soil drying is the most reliable mechanism for enhancing plant ability to extract water from the soil for efficient use in growth.

1.2.2 Responsive plant biomass and physiological processes

Productivity of banana is greatly influenced by soil moisture and nitrogen supply (Holder *et al.*, 1983) that determine the biomass development. However, the susceptibility to drought stress is influenced by sensitivity to soil moisture depletion (Robinson *et al.*, 1987; Robinson, 1996) and many indirect effects on physiological processes (Brun, 1960; Robinson *et al.*, 1987) which affect the rates of organ development (Watson *et al.*, 1983) and reduce the plant growth mechanisms which determines the yield potential. Significant effects include poor biomass accumulation (Holder *et al.*, 1982), poor canopy architectural behaviors, stomata closure, chlorophyll break down, low rate of transpiration and high rate of senescence which are important physiological components for high yields.

The reduction in soil moisture from total available soil moisture (TAM) restricts stomatal opening (Shmueli, 1953) and reduces the potential for maintaining a positive water balance which limits transpiration and affect the turgidity and lower dry matter content of leaves causing the plant to adapt drought survival mechanisms. Similar effects were observed by Ke (1979) where soils below 70% of TAM affected the build up of chlorophyll, leaf dry mass, leaf conductance, leaf area index, photosynthetic rate and yield than plants in soil above 80% TAM.

1.3 Problem Statement

Drought is one of the most serious constraints to agriculture and is responsible for limiting the potential of a banana crop from attaining a reasonable yield. A low yield of banana can lead to a significant loss of food and cash to both consumers and producers, especially where bananas are a staple food crop or where it is the main source of income for the household. The potential for food security would be affected especially where bananas are a major food crop, and cause a loss to the overall macro-economic performance in Uganda, (Abele, 2007).

In Uganda, actual banana yield levels are low ($5\text{--}30\text{MT ha}^{-1}\text{ yr}^{-1}$) (van Asten *et al.*, 2004) compared to potential yield of $>60\text{MT ha}^{-1}\text{ yr}^{-1}$ (Smithson *et al.*, 2001). Increased banana production in Uganda can be achieved through expansion in area under cultivation. However, expansion of banana production area is difficult to achieve due to increasing population pressure. Further increases in production to feed the growing population will have to be achieved by yield increases per unit area.

Optimal growth and production of bananas requires at least 1300 mm of rainfall per year, equivalent to 25 mm of rainfall per week (Purseglove, 1972) for a high yield. However, the major East African Highland banana producing areas are characterized with a bimodal rainfall pattern and annual rainfall averaging around 1200 mm yr^{-1} . The low rainfall intensity is attributed to drought a phenomenon which strongly correlates with low yield of bananas.

An increase in moisture is significant in overcoming the plant growth retarding mechanisms for enhancing yield increase. Research by Van Asten *et al.*, 2007 showed a linearly strong correlation

coefficient of moisture provision with yield increase, suggesting the crucial role of moisture in enhancing drought avoidance mechanisms for a better yield.

The study was therefore aimed at characterizing drought stress effect on the East African Highland Banana (AAA-EAHB) cultivars at a rational crop growth stage, to specifically identify /quantify threshold values for drought avoiding mechanisms. The results will be useful in this regard for identifying the most important trait that is greatly affected and limit the potential for higher yields.

1.4 Objectives

The main objective is to characterize drought stress in the East African Highland Banana (AAA-EAHB) varieties at different crop growth stages.

The specific objectives are to;

1. Assessing the response of selected EAHB cultivar growth traits to drought stress
2. Determine threshold quantification of drought stress avoidance mechanisms of selected EAHB cultivars
3. Determining the influence of drought stress on selected physiological processes for plant growth

1.5 Hypotheses

1. High soil moisture stress affected the potential for plant biomass growth and development
2. Plant stress avoidance mechanisms were expressed upon increase of moisture stress from field capacity to $pF\ 2.5$
3. Excessive plant dehydration enhanced the expression of plant survival mechanisms in *Kayinja* and *Sukalindiizi* varieties.

1.6 Justification of the study

The accrual effects of biotic and abiotic factors are important in Uganda. Despite advances in significant research interventions (viable pest control mechanisms and development of disease resistant varieties) on biotic factors (pests and diseases), yields are continuing to decline. In appraisal surveys, biotic factors were the highly farmer ranked constraints to banana productivity (Van Asten *et al.*, 2004. Drought being the major component of abiotic factors is least mentioned, yet research by Van Asten *et al.*, 2007, reported linearly increasing yields with increasing rainfall and soil moisture hence the potential for higher yields.

Low yields are therefore mostly attributed to dry spells of drought stress. Similarly, the Intergovernmental Panel on Climate Change (IPCC, 2001) reported global climate change scenarios and further predicted a future increase in the risk of drought with average temperature increasing in a range of 1.4 to 5.8⁰C and average sea level rising in a range of 0.09 to 0.88M by 2100. But generally there is inadequate understanding of the magnitude of stress mechanisms in causing yield loss especially among the cooking type of East African highland banana varieties. The abnormally low rainfall and low soil moisture are the principle causes of drought stress mechanisms which limits the plant growth from the potential high yield (>60MT ha⁻¹y⁻¹). Actual banana yields in Uganda are low (5-30MT ha⁻¹y⁻¹) but with the increasing population pressure, the demand for food is high and further land expansion cannot be feasible. The most reliable mechanism for increasing yields is by increasing yields per unit area (economies of scale).

Characterization of the EAH banana cultivars response to water stress was important in quantifying their threshold values for the survival mechanisms, and breeding of crop varieties for improved water use efficiency (Condon *et al.*, 2004) to manage drought. The results will further be used in modeling an intervention strategy for determining yield increase per unit area.

CHAPTER TWO

2.0

LITERATURE REVIEW

2.1

Importance of bananas in Uganda.

Globally, bananas (*Musa spp*) are ranked as the most important food crop after rice, wheat and maize (INIBAP, 2000). In developing countries, Uganda in particular, the crop is reported to provide dietary supplement for more than 14 million Ugandans (FAO, 2008) and for over 100 million people in sub-Saharan Africa. Studies on banana by Kalyebala *et al.*, (2005), reported a 30% contribution to total food consumption and 14% of the total crop value. According to INIBAP (2000), bananas are consumed in more than 100 countries throughout the tropics and subtropics from the estimated total cultivable land size of 1.3 million hectares (about 33% of all cropped land) with the annual production of 10.5 Million tones (FAO, 2006). Whilst, FAOSTAT (2006) estimated banana productivity in East Africa at 18 million tons year⁻¹ and 99 million tones per annum for the world's total productivity of which approximately one third is produced in sub-Saharan Africa (Karamura, 1998).

In Uganda, the EAH bananas are particularly grown for food (Musa AAA, Matooke group) as the main source of carbohydrates in the diet (Rubaihayo *et al.*, 1993; Karamura, 1993) and for beer (Musa AAA, Mbidde group) (Karamura *et al.*, 1994), juice and a variety of post-harvest products (Ssebuliba *et al.*, 2000).

Over 1000 banana cultivars or landraces are cultivated world wide but in Uganda the most cultivated bananas are the predominant East African Highland Banana (EAHB) cultivars, grown in the high land areas of central and western parts, particularly in Masaka, Rakai, Mbarara, Bushenyi and Ntugamo districts. Enough food is produced for family use and the surplus sold to earn a living.

Based on integrated house hold staple food consumption survey 1992-1993, Uganda was ranked the highest consumer of banana world wide (150-500kg/person per year) to Rwanda (197 kg/cap/year), Gabon (161 kg/cap/year) and Cameroon (128 kg/cap/year) among others (FAO, 1998).

The actual banana production rates range from 5-30t/ ha⁻¹ yr⁻¹ (Wairegi *et al.*, 2007; Bagamba, 2007; van Asten *et al.*, 2004;), despite the highest reported highland banana fresh yields reaching 67 t ha⁻¹ yr⁻¹ (Smithson *et al.*, 2001). The variability shows a potential for higher yield, but the discrepancies between potential and actual yields in the region are variously attributed to low soil fertility, pests and diseases, poor crop management and drought stress (Bananuka *et al.*, 1999; Woomer *et al.*, 1998; Bekunda *et al.*, 1996). The integrated management of these constraints especially pests and diseases, soil fertility have been intensively researched than drought stress. Bananas are genetically diverse and the widest variations are found in Asia, with different types being specifically adapted to different sub regions. In East Africa, highland AAA cooking and beer bananas are predominant and it is in this region that the bananas reach the greatest importance as a staple food crop.

2.2 Constraints to production of banana (AAA-EAHB)

In recent years in East Africa, banana were produced under a permanent farming system, where they were grown in association with tree crops e.g. coffee and cocoa. Well managed fields could last for up to 50 years (Frison *et al.*, 1998) however to-day banana plantations are anticipated to deteriorate after an average of four years as the case in parts of Uganda. Yields are low on farmer's farms with the loss being attributed to both abiotic and biotic factors that affects the crop from attaining optimal growth.

2.2.1 Biotic factors affecting banana production

Banana production is constrained by several important pests and diseases that affect the normal growth of the plant. Burrowing nematodes (*Meloidogyne spp*) are considered the most devastating pests for bananas (Price, 2006) production decline in Uganda (Speijer *et al.*, 1994a; Gowen *et al.*, 1990). Other pests of economic importance are the banana weevil (*Cosmopolites sordidus*) (Gold *et al.*, 2004; Gowen, 1995), more importantly in the EAHB plantations causing a yield loss of up to 44% (Rukazambuga, 1998). Nematodes together with weevil infestations were reported in Masaka and Rakai districts (Sengooba, 1986) to have led to wide spread toppling of bananas. The management strategies to reduce on the effect of weevils have been through the application of an integrated control strategy using *Beauveria bassiana* and *Metarhizium* (Metchnikoff) (Nankinga *et al.*, 1996; Nankinga, 1994), and chemicals, in addition for managing nematodes (Gowen, 1995). Banana crops are also affected by several important pathogens, some of which are fungal, viral and bacterial. These include banana bacterial wilt disease (*Xanthomonas campestris* pv. *Musacearum*) (Tushemereirwe *et al.*, 2001, un pub.) which is the most recent epidemic to affect bananas, causing 70 -90% yield loss.

The fungal diseases include black sigatoka (*Mycosphaerella fijiensis*) which is an important pathogen of EAH banana and plantains causing heavy defoliation that severely suppresses finger filling, leading to yield loss of up to 37% in bunch weight (Jerger *et al.*, 1995). Yellow sigatoka (*Mycosphaerella musicola*), banana leaf spot complex of (*Mycosphaerella musicola* and *Periconiella sapientumicola* (*Cladosporium musae*) also attacks EAHB. Panama wilt (*Fusarium wilt*) is other pathogens which also affect banana productivity.

The most important viral disease in Uganda is the Banana streak virus (BSV) (Tushemereirwe *et al.*, 1996). BSV belongs to badnavirus group of viruses which are bacilliform (Harper *et al.*, 2004) in

shape and contain double stranded DNA (Lockhart *et al.*, 1993) and is transmitted through mealybug infestation and vegetative propagation. Attempts to control BSV have been through application of phytosanitary measures (Tushemereirwe *et al.*, 1996). Intensive research activities towards management of biotic factors have been conducted and correlations with yield were found to be nonlinear but the control model for management practices is still lacking.

2.2.2 A biotic factors affecting banana production

Despite the large banana production potential, the demand for food (Banana) by rapidly increasing population has not been met. This is in part due to production constraint including abiotic factors. They include population pressure on land which has led to shortened fallow periods due to excessive land cultivation, low levels of soil fertility (Table 1.) due to nutrient replenishment.

Table 1. Soil nutrients in typical lake crescent soils inadequate

Element	Typical lake crescent soil
Available Phosphorus (ppm)	1.40
Total Nitrogen (%)	0.09
Exchangeable Potassium (cmol.kg ⁻¹)	0.36
Sodium (cmol.kg ⁻¹)	0.04
Magnesium (cmol.kg ⁻¹)	3.35
Calcium (cmol.kg ⁻¹)	8.06
Organic Matter (%)	2.89
Soil pH	5.30

Source; African Agricultural Technology Foundation (AATF-SGM, 2003)

and drought/ water stress and management use of poor mulches for soil conservation (Bekunda *et al.*, 1996) hence soil moisture stress, deforestation, leading to increased drought stress that favour the effect of pests and diseases, causing considerable losses to banana production. Where there is prolonged effect of abiotic factors especially drought, the effect on banana plants is characterized

by leaves turning pale green, chlorophyll breakdown, senescence and stomata closure. The pseudostem may collapse and the total yield is lost.

2.2.2.1 Drought stress phenomenon

Banana and plantain water requirement ranges from 900–1800 mm during the growth and production cycle equivalent of 3–6.3 mm/day (Purseglove, 1972). The important characteristics of the banana in respect of plant water requirement include shallow root system compared to other fruit crops, poor ability to withdraw water from drying soil and rapid physiological response to soil water deficit in conditions of high evaporative demand. Most of the production areas in sub-Saharan Africa (SSA) experience marked dry seasons and yet most production in SSA is rain-fed with water conservation methods hardly practiced. Yield losses due to water stress range between 30–50%, however, irrigation would give a quick win but has a high capital investment which is prohibitive (SMG, 2003).

2.3 Trends in banana production in Uganda

Karugaba *et al.*, (1999); Dale (1955) reported a long tradition of banana cultivation to date back to the thirteenth century. However, in Uganda, it is estimated to have been produced for 6000 years in Uganda (Lejju *et al.*, 2006). Banana crop production sustained due to cultural, social and economic values attached to it and the ideal soil types that enhanced growth especially in regional areas of central and southwestern of the country. However, the shift of hired labour from central to southern affected the potential increase of banana yield in central Uganda. According to survey results by Gold *et al.*, (1999), the yield of bananas in Africa, particularly Uganda was estimated to have declined from 8 t/ha to 5 t/ha. However, today the average

potential yield of banana is estimated at 5-30t/ha (Van Asten *et al.*, 2004). In Sub-Saharan Africa, banana production is estimated at 30.56% of the world's bananas and plantains (FAO, 2007).

Table 2. Leading banana (Metric tones) producing countries in Africa

Country	Banana Production (1000 MT/Yr)
Uganda	9,846
Rwanda	2,600
Nigeria	1,990
Democratic R. Congo	1,831
Tanzania	1,656
Burundi	1,506
Cameroon	1,274
Cote d'Ivoire	1,194

Source: Food and Agricultural Organization (FAO) statistics, 2007

2.3.1 Main Varieties

Bananas are described by their genomic structure, each with specific region of adaptability. The most common genome groups in Uganda is AAA (triploid evolved from *M. acuminata*) of the East African Highland Bananas which are steamed to make 'Matooke' for consumption, but are also used for beer making. Studies carried out in Uganda (Karamura, 1998) classified five EAHB clone sets as Mbidde, Musakala, Nakabululu, Nakitembe and Nfuuka. The naming is in reference to phenotypic analysis and for communication purposes.

2.5 Resource Management of Bananas

2.5.1 Climatic requirements

According to Simmonds (1966), banana production falls between 30° N and S of the equator with an optimal mean monthly temperature of 27°C in the world. Banana growth and rate of fruit maturation were reported by Sys *et al.*, (1993) to reduce and slow respectively at temperatures below 22°C whilst the lowest mean annual temperature of banana growth at 14°C. High temperatures of above 37°C scorch the leaves and growth was reported to stop at 38-40°C (Turner *et al.*, 1983). Sys *et al.*, (1993) observed also poor growth of bananas at high altitudes especially on the period to shooting. The observation showed that banana takes 6-7 months to shoot while growing at 0-137m; 9-10 months at 183 -365m; and 11-13 months at 397-641 meters above sea level (masl) rendering areas of high altitude unsuitable for banana production.

Bananas are also reported to require 25- 50 mm of water per week for satisfactorily growth (Purseglove, 1988). The success of banana production was reported to be achieved in areas with rainfall intensity of not less than 1400mm, though use of drought tolerant cultivars along with water and soil conservation practices, cooler climate with less evaporation but with high moisture retention by the soils is an advantage. However, an annual average rainfall of 1500-2500 mm was considered most satisfactorily if well distributed over the year (Sys *et al.*, 1993). According to Purseglove (1988) bananas are less resistant to water stress but have a considerable range of tolerance, though some cultivars are severely affected by drought. Better growth and development was achieved when the relative humidity is greater than 60% (Sys *et al.*, 1993) with optimal soil moisture content. A single day transpiration loss can amount to 30-60 m³ha⁻¹ depending on radiation, wind and atmospheric humidity (Stover *et al.*, 1987). Where the crop is

grown in the shade, the pseudostem becomes thin and tall, leaf production and suckers are reduced and small bunches are produced.

2.5.2 Weather influences on banana production

Weather measurements in banana plantations helps to provide a historical base of data for predicting seasonal production trends and determining soil and water conservation needs. Temperature and solar radiation are equally parameters for predicting rate of plant growth and fruit development. Rainfall and average daily pan are also useful in determining conservation practices. Pan-evaporation data in absence of rainfall can be used to indicate how rapidly drought stress is developing.

2.5.3 Soil Requirements

Bananas are reported to grow well on drained loam soil with high humus content (Purseqlore, 1988) and in areas with adequate supply of Phosphorus (P), Nitrogen (N), Magnesium (Mg), Calcium (Ca) and Potassium (K) (Sys *et al.*, 1993). However, banana plants do not withstand poor drainage though tolerate a wide range of soil parent materials, textures and nutrient status. Highly acidic soils are not suitable for banana production and would require considerable amounts of mineral nutrients addition to enhance obtaining high yields. A pH range of 5.6 – 7.5, salt level of less than 500mg/kg and Exchangeable Sodium Percentage (ESP) of less than 4%, were considered optimal soil conditions for banana growth (Purseglove, 1988).

2.6 Effect of drought stress on physiology of banana plants growth

2.6.1 Plant biomass development

Periods of drought can lead to reduction of root and shoot growth reduction and tip death. Pattison *et al.*, (2007) reported that when sufficient water become available, shoots recommence growing and result into multiple branching. Plants can tolerate short periods of drought due to their filled energy reserves but may only produce small bunches of banana (Nelson *et al.*, 2006). Soil moisture deficit is reported to result into reduced biomass and bunches (Broadley *et al.*, 2004). Most banana plants are reported to produce 30-40 leaves in life time (Pillay *et al.*, 2007) but as older leaves are pushed outwards they eventually senesce leaving 5-15 fully functional leaves on a mature plant. Studies have shown that root system development during vegetative growth may be estimated from the above ground shoot growth characteristics and diseases such as black sigatoka adversely affect root growth and development due to reduction in functional leaf area (Blomme *et al.*, 2001). Whilst, Nelson *et al.* (2006) reported the effect of periodic water stress that cause the discolouration of mature banana and cracking of the skin.

2.6.2 Effect of drought stress to canopy leaf orientation

2.6.2.1 Leaf angle architectural behaviour

Canopy leaf orientation is an important parameter for plant growth modeling. The behavioural component of the leaves in terms of leaf angle and folding, are reported to be the mechanisms for combating the adverse effects of drought stress especially heat and moisture deficit. Leaves lamina is liable to change the standing angle and also fold to avoid excessive transpiration. Due to the stress and environmental effects induced in leaf angles (Tosserams *et al.*, 1997), determination of canopy architecture is important in characterization of susceptible cultivars. These effects are important since leaf inclination angles influence canopy light absorption and therefore photosynthesis.

Consequently, average canopy leaf angle is used as a functional parameter in most photosynthetic models (Aries *et al.*, 1993; Thornley *et al.*, 1993).

Techniques used in earlier studies to determine leaf angles include height and blade length measurements (Deckmyn, *et al.* 2000) on two grass species, *Dactylis glomerata* and *Festuca arundinacea*, grown under different UV-B levels; a 3D digitizing device for accurate measurement (Sinoquet *et al.*, 1997); use of laser beams (Sinoquet *et al.*, 1993); and point-quadrant measurements (Warren-Wilson, 1963) based on a fine needle pushed into the vegetation in a fixed direction. Despite high variation in leaf angle results due to the large error term on single leaf angle calculation, the techniques used were reasonably accurate but generally very time-consuming or require special equipment.

2.6.2.2 Leaf folding behavior

A drastic decrease of soil water content from the field capacity is reported to cause a stress situation of plant dehydration due to lack of total available moisture (TAM) for plant growth. Leaf biomass is mostly deterred from expansion due to reduced leaf water potential (LWP) and reduced expansion of leaf cells (Tardieu, 2000) yet transpiration rate remains high. In advanced stages of moisture stress, leaf folding may be followed by withering, shrivel and senescence from the lower to the upper most leaves.

By avoiding a dehydration phenomenon of excessive loss of leaf water, banana plants develop a mechanism of reducing the leaf evaporative surface area through folding. Studies on pearl millet by Kusaka (2005) found that leaf morphology of susceptible varieties changed by drooping and folding the midrib of upper leaves. However, leaf orientation mechanism for avoiding drought stress reduces

the leaf surface area for light interception (Kramer 1983) and increases the diffusion resistance to carbon dioxide. Shmueli (1953) reported that leaf folding mechanisms were observed to improve plant water use efficiency and maintaining positive leaf water potential and efficient stomata regulation of transpiration. Earlier studies by Oppenheimer (1960) on xerophytic grasses and rice, showed that leaf folding and rolling decreased transpiration rate by 50-70% in xerophytic grasses and 36-47% in rice during drought stress. Apart from leaf folding, plants may also adapt other survival mechanisms of avoiding drought stress by changing leaf morphology of young leaves at the expense of lower leaves withering and rapidly decrease the leaf canopy area (Do *et al.*, 1996). Similarly, (Turner *et al.*, 1980) reported an important adaptive response of osmotic adjustment to water stress. The adaptation involved accumulation of low molecular weight organic compounds of amino acids, quaternary amines (betaines) and sugars (sucrose and glucose) (Kusaka, 2005; Bajji *et al.*, 2001) and inorganic solutes (Patakas *et al.*, 2002) in the plant stem.

In a study by Alves (2004) on cassava plants grown in a microenvironment condition, upon optimal water availability, the leaves remained unfolded and fully expanded in a uniform and sequential pattern. Therefore, despite the effects on leaf unfolding involving stress delay in leaf initiation (Alves, 2004), other earlier studies also indicated that leaf unfolding rate is responsive to stress and can have a large impact on leaf area production (Vendeland *et al.*, 1982) which is similarly important on banana growth.

2.6.3 Drought stress effect on transpiration process

The sensitivity of banana plants to levels of soil moisture depletion may justify the need for characterization of physiological parameters especially transpiration rate to enhance planning for drought management accordingly. Transpiration as a parameter is important in plant growth for enhancing metabolic processes for nutrient distribution and absorption and cooling of the plant.

Transpiration and stomatal conductance processes are reported to depend directly on leaf water potential, which in turn depends on the balance between evaporative demand and the ability of the plant to extract soil moisture (Azam-Ali, 1983). Stomatal diffusion accounts for 90-95% of water loss from leaves and the remaining 5-10% accounted for by cuticle transpiration (Kramer, 1983). Therefore transpiration can be taken as a reliable indicator of stress initiation in the banana plants, although indirectly related to soil water deficits, humidity, and temperature and wind speed.

The rate of transpiration is influenced by diurnal cycles. At the same soil moisture potential transpiration is reported to remain high in the morning and reduce in afternoon (Robinson *et al.*, 1986), however, normal turgor is re-established overnight by extraction of moisture from the soil, in addition to evaporative demand. The probable increase of transpiration in afternoon seems to correspond to increase in photosynthetic active radiation (PAR). Studies by Ashizawa (1983) on citrus reported a significant reduction in transpiration rate with decreasing PAR and DweUe *et al.*, (1983) reported decreased stomatal conductance in potatoes. However, in banana leaves, Brun (1960) reported that transpiration and photosynthesis processes tend to fluctuate similarly in relation to the degree of stomatal opening regulated by leaf water content.

Earlier studies on quantification of transpiration rate were based on two principle methods of weight loss, use of a lysimeter and gas exchange method (Kramer, 1983). Weight loss method involved covering of a well watered potted plants to prevent evaporation from the soil and then cumulatively weighing a whole set of potted plant at predetermined intervals. Any weight loss was attributed to loss of water via transpiration through the shoot. Besides the former method, the latter is often used in conjunction with experiments on photosynthesis, where a leaf is sealed in a transparent chamber

with a flowing air stream. Transpiration is then estimated as the difference in water content of the air entering and leaving the chamber (Kramer, 1983).

2.6.3.1 Sensitivity of Leaf water to drought stress

The relative water content of a leaf is a relevant physiological component necessary for assessing the leaf osmotic potential. The importance lies in determination of turgidity through estimation of current water content of the leaf tissue relative to the maximal water content it can hold at full turgidity in a situation of moisture deficits. The assessment of the relative water content (RWC) of the leaves helps also to determine the turgor cells expansion behavior in relation to the leaf osmotic potential content.

The use of leaf water potential as a tool in assessing the sensitivity of genotypes to drought stress has not been widely used, probably due to the tendency of banana plants in developing positive water potentials as an avoidance mechanism, and the very efficient stomatal regulation of transpiration (Shmueli, 1953) which, in turn, can induce a misleading leaf water potential (Jones, 1983). However, most importantly leaf water potential was used as a tool to determine the relationship between water status and physiological performance of vine crops in morning and afternoon (Pilar, 2007). A study on banana water stress physiology by Shmueli (1953) established that when soil moisture content diminished progressively from 66% of total available moisture (TAM), leaf water content also diminished and stomatal openings were restricted, followed by a rapid reduction in the transpiration rate and in dry-matter content of the leaves. Shoot growth decreased linearly with decreasing leaf water potential.

The quantification of relative water content (RWC) as influenced by drought stresses was determined on wheat for response to drought (Rampino, 2006). The success in determining the sensitivity of genotypes to dehydration was based on the following formula; $RWC (\%) = [(FW - DW) / (TW - DW)] \times 100$ (Rampino, 2006; Barr *et al.*, 1962) and Water loss rate (WLR) (Suprunova *et al.*, 2004), where FW = Fresh weight, TW or SW= turgidity or saturation weight and DW= dry weight. Therefore the maintenance of a positive turgor under water stress is an indication of osmotic adjustment which is drought avoiding mechanism.

2.6.4 Effect of light on banana plant growth

Excessive sunlight is reported to cause photochemical damage to leaf lamina and reduces the potential for maximum net photosynthesis of many plant species (Corrcia *et al.*, 1990). Eastman *et al.*, (1995) established that photo-inhibition can be affected when excessive sunlight interacts with soil water deficit. Greater photochemical damage leading to reductions in net photosynthesis were reported to occur when plants are drought stressed (Boyer *et al.*, 1987). However, research by Gamon *et al.*, (1990) on drought stressed *Vitis vinifera* crop leaves, it was concluded that the reduction in net photosynthesis was due to reduction in stomatal conductance and not photochemical damage. But banana plants orient the mechanisms of avoiding photochemical damage effect by folding and shading off the leaves however, the expression affects plants potential of attaining the maximum chlorophyll and therefore cause a limitation to net photosynthesis attainment. Whilst, Ludlow *et al.*, (1984) observed that banana plants have a mechanism of avoiding high direct light rays through paraheliotropic leaf movements and leaf temperature through leaf lamina folding to reduce sunlight interception and thus avoid over heating (Milburn *et al.*, 1990).

The significance of photo chemical damage is measured in conjunction of chlorophyll fluorescence with net photosynthesis. The adaxial leaf surface of banana is more photochemical damaged by

direct sunlight reception than the abaxial that receive transmitted or indirect light. In the field grown plants the interaction of soil water deficit with light reduce the ratio of variable per maximum chlorophyll fluorescence with the greatest reduction occurring in the afternoon on the adaxial leaf surfaces.

2.6.4.1 Chlorophyll build-up during drought stress

Plant nutrition is a major determinant of maximum stomata conductance and is scaled with photosynthetic capacity. Leaf nitrogen is correlated with stomata conductance which is the function of photosynthesis. However, it is affected by leaf longevity, specific leaf area and leaf nitrogen (Niinemets, 2002) and photosynthetic photon flux density (PPFD).

Factors that include photo-inhibition, high temperature, radiation levels, trunk and foliar diseases and soil drought are reported to be pivotal in chlorophyll breakdown (Hortensteiner *et al.*, 2005). Under high temperature, drought stress enhances inhibition of electron transport (Lu *et al.*, 2002), reduces valuable fluorescence, and alters fluorescence and quantum yield. Lauer *et al.* (1992) established that the biochemical reactions malfunction when the photosynthetic process is affected. The malfunction of biochemical reactions also causes non-photochemical quenching to be increased and photochemical quenching to be decreased (Lu *et al.*, 2002).

The buildup of chlorophyll is reported to help in provision of information between structure and function of photosystem II (PS), reaction center (RC) and their core complexes. PSII, its reaction center and chemical reaction are reported to be highly sensitive to environmental limiting factors that are adversely affected by drought stress (Vazan, 2002). Hortensteiner *et al.* (2005) reported an increase in the minimal chlorophyll among bean varieties to be attributed to PSII inactivation. Similarly the decrease in maximum photochemical efficiency of PSII is considered to indicate the

increase in a non photochemical quenching process at or close to the reaction centre (Baker *et al.*, 1987). However, most methods of chlorophyll measurement used in earlier studies on various crops involved using fluorometers in dark adapted leaves using modulated light intensities.

2.6.5 Leaf senescence processes in plants

Responses of drought stress may range from changes in gene expression pattern to changes in plant metabolism and growth. Such responses may be induced within a short period of exposure to drought and at a slow rate which is the induction of senescence. Ferreira *et al.* (2005) indicated the response of plants to drought stress to be regulated through signal transduction and defense mechanisms.

Senescence is reported to play a crucial role in the plant's survival by contributing nutrient allocation to productive leaves through the death of unproductive leaves as a result of accelerated senescence accompanied by abscission, which reduce water loss through transpiration and in turn contributing to water balance of the plant (Munne *et al.*, 2004).

Drought induced senescence has been studied for different plant species including crops of economic importance grown under field conditions, such as wheat, rice and sorghum (Munne *et al.*, 2004; Yang *et al.* 2003). Regulation of drought induced senescence has been investigated at the molecular level and its effect on endogenous levels of plant hormones has been demonstrated for cytokintins and abscissic acid (ABA) (Munne *et al.*, 2004) to have a positive and significant correlation with carbon remobilization from senescing leaves in drought stressed cereals. However cytokinin levels decrease under drought stress and show positive correlation with photosynthetic rate and chlorophyll content thus possibly preventing senescence.

CHAPTER THREE

3.0 METHODOLOGY OF THE STUDY

3.1 Study Area

Screen house studies were conducted at Sendusu, where the International Institute of Tropical Agriculture (IITA) field and lab crop experimental sites are situated. Sendusu is situated at Namulonge along Kampala-Gayaza-Ziobwe road, 37km north of Kampala at 0°53N, 32.35E; 1150m above sea level. The climate of the area is tropical, with minimum and maximum temperatures of 15 and 31°C respectively. The station experiences a bimodal rainfall distribution of 968.8mm annually, with the main rains occurring from March to June (127.3mm per month), while short rains fall between September and December (78.3 mm per month) (MAAIF, 2005).

3.2 Materials and methods

The study was conducted in a screen house for imposing a micro-climatic environment. It focused on establishing the response of five banana cultivars categorized in three forms as follows;

- 1- Cooking cultivars; *Mpologoma* and *Kisansa* (EAHB-AAA) which are prone to drought stress (Bananuka, 1999) and therefore control cultivars.
- 2- Dessert and beer cultivars of *Sukali Ndiizi* (AAB) and *Kayinja* (ABB) due to their tolerance to drought stress (Araya, 2005).
- 3- Cultivar *Yangambi Km5* (AAA-lowland) which is a low-land adapted triploid cultivar but equally tolerant to drought stress possibly due to its water use efficiency and its responsive erectophile morphological trait.

The nature of the experiment involved intensive management through use of some tissue culture raised banana seedlings, steam sterilized soils (free from soil microbes) and perforated buckets of 30 liter volume to set individual functional potted plants. The ability to control soil evaporation led to use of polythene plastic for covering the bucket to eliminate at least 95% of soil evaporation (Fig 2A-2B).

In order to obtain the data, the following equipments were used;

- 1- A chlorophyll meter to measure the chlorophyll content of the plants across treatments.
- 2- A protractor and compass for assessing the canopy structural behaviour (angle and folding) of the leaves.
- 3- A highly sensitive scale to determine the weight loss of potted plants (Kramer, 1983).
- 4- Porometer



1_A- Experimental Screen house



1_B-95% controlled soil evaporation via polythene shooting

Figure 1. Drought stress experimental (1_A-1_B) set up at IITA-Sendusu

3.3 Experimental Layout / design

The experimental design used was Randomized Complete Block Design (RCBD) with two factors namely; moisture regime and variety. The three levels of moisture regime were adopted as follows: pF (soil water retention potential) 2.0-2.1 (moist; 0.1 - 0.13 bars) equivalent to field capacity of 90% M.A. (10% moisture deficit) pF 2.5-2.7 (semi-moist; 0.4 - 0.51 bars) equivalent to soil moisture availability of 60% (40% moisture deficit) and pF 2.8-2.9 (dry; 0.74 - 0.8 bars) equivalent to soil moisture availability of 30% (70% moisture deficit) (1 bar = 0.986923 atm = 100 kPa = 1.02 kg cm⁻²). However, the involved banana cultivars included; *Mporogoma*, *Kibuzi* (AAA-EA), *Yangambi Km5* (AAA-lowland), *Sukali Ndiizi* (AAB) *Kayinja* (ABB). Data on the different parameters were collected at different time intervals with transpiration data collected after every 48 hours to avoid overlapping moisture deficit levels. Plant biomass accumulation data collected on monthly basis and leaf orientation behaviour (angle and folding) data were collected on a weekly basis.

3.3.1 Soil tests at the experimental set up

Prior to experimental set up, soil analyses were done to determine the nutrient content, texture and bulk density. Soil texture and bulk density were used to assess the porosity of soil for determining the pF curves.

The nutrient analysis was carried out on a thoroughly mixed soil sample to determine the level of soil fertility for actions in managing nutrients for plant growth based on imposed soil moisture regimes. The analysis for amount of macro nutrients was carried out on nitrogen (ppm N kg⁻¹), phosphorus (ppm P kg⁻¹), potassium (ppm K kg⁻¹), calcium (ppm Ca kg⁻¹) and magnesium (ppm Mg kg⁻¹) as described by Okalebo *et al.* (2002). The soil pH level based on soil base saturation with nitrates (NO₃⁻) was determined for corrective application action to be taken and avoid the phenomenon of nutrient imbalance at the beginning of the experiment.

3.3.2 *pF*-curve determination

The potential for moisture extraction was determined using a pressure extraction machine at Makerere University, department of soil science on a mixture of soil sample for the experiment. Basing on the soil texture, the type of soil was sandy clay loam (65% sand, 21% clay and 19% silt) and therefore porous. The result meant that the potential for moisture loss would be fast initially and then gradually decrease forming an inverse curve. The pressure extractions in bars for best results were setup at an average of 0.15 bars equivalent of $\log_{1.0} (10^2) - \log_{1.5} (10^2)$ for *pF* 2.0-2.1; 0.45bars equivalent of $(\log_{3.5} (10^2) - \log_5 (10^2))$ for *pF* 2.5-2.7; and 0.8bars equivalent of $(\log_7 (10^2) - \log_{8.5} (10^2))$ for *pF* 2.8-2.9) through using ceramic plates. However, the ideal curve for *pF* (moisture retention potential) was obtained from literature by Kumar (2010) (Appendix 1)

3.3.3 Soil Tension determination

The *pF*-ranges for soil moisture deficit regimes were maintained and monitored with pressure gauged tensiometers placed around the root zone of the selected potted plants per treatment structure. Tensiometers were directly used to measure soil volumetric potential by gauging the soil water equilibrium with the extraction pressure through a permeable cup in contact with the soil. The measured pressure (in centibars) was directly related to the ability of the plant to extract water from the soil. By operation, tensiometers were placed firmly in contact with soil around the root zone of the potted plant. Upon drying of the soil, water potential decreases and the pressure increases in the tensiometer vacuum. Conversely, the increase in soil water content through water addition for maintaining the *pF* ranges, decreases tension and lowers the vacuum gauge reading. In this way, a tensiometer continuously recorded fluctuations in soil water potential.

3.3.4 Treatment Imposition

Five banana tissue culture seedlings (three months old) were planted each in a 30L bucket corresponding to the three moisture deficit (M.D.) levels. Moisture treatments were quantified based on the pF curves of $\log_{10}$ matrix head of soil water ($-h/m/cm$) that ranged from 2.0-2.1 (field capacity); 2.5-2.7 (semi moist soil); and 2.8-2.9 (dry soil) on sandy loam soils. Prior to treatment imposition, the potted plants were allowed to grow till development of the 5th leaf, and then moisture stressed for a week to determine a similar level of moisture availability across varieties. Initial water volumes of 0.8, 0.6 and 0.4L were applied to plants in their respective treatment structures at after every 48 hours to replace water lost through leaf transpiration. The treatments imposed were;

- (1) $MD_1 = pF\ 2.0-2.1$: (Control): Moist / or Free drainage for plant growth.
- (2) $MD_2 = pF\ 2.5-2.7$: Semi moist condition of water availability for plant growth.
- (3) $MD_3 = pF\ 2.8-2.9$: Dry soil level throughout the growing period.

The treatment regimes were monitored after every 48 hours to maintain them within the required pF ranges. The calibration of moisture treatment adjustments for maintenance within the required moisture ranges involved developing a weight loss model (Kramer, 1983) with functional components of soil mass, water volume and the cumulative plant weight. A linear model (Fig. 2) was first developed first to determine the correlation of dependable variables of plant biomass and volume.

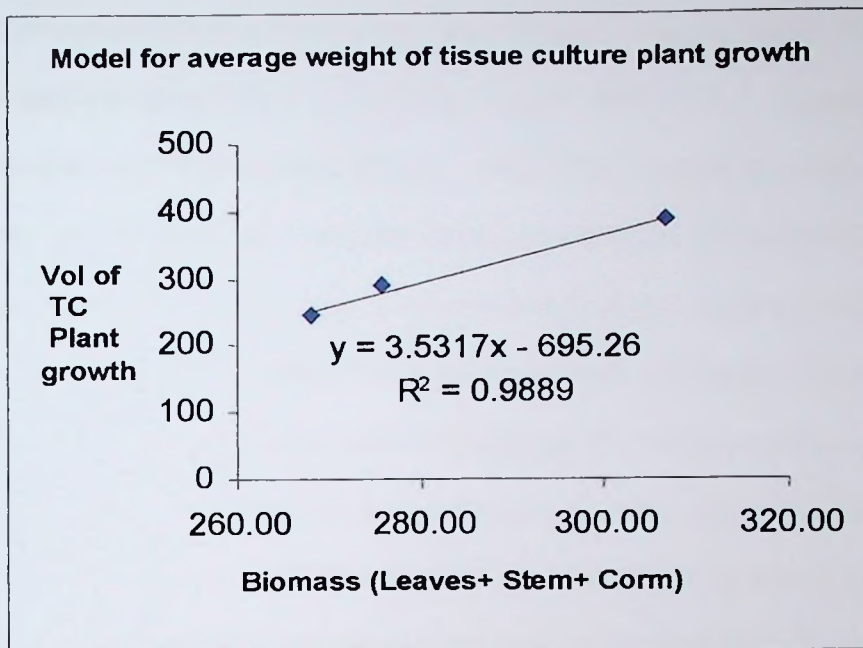


Figure 2. Linear model for biomass accumulative based on plant volume

The significance of the model is the function $Y = 3.5317x - 695.26$ where; Y = plant weight (PH), X = observed weight of biomass growth at a slope value of 3.5 less the intercept of plant volume at biomass axis. Biomass assessment was a destructive method at a monthly interval and correlated with the volume of plant growth.

3.3.4.1 Weight loss allometric nonlinear model

The calibration for weight loss depended on the developed logistic nonlinear model involving discrete variables of plant biomass accumulation weight and soil mass at corresponding pF ranges, to predict the final weight for plant growth structures at free drainage as follows:-

$Y = ((TFW = (BAW) + (A = \pi r^2 h)) + (WSp_{i-j} = SMV \cdot PVF \cdot RS) + Wb + VWA)$, $Y = 3.5317x - 695.26$; $R^2 = 0.9889$. Y = Final weight of plant, TFW = Total fresh weight of plant, BAW = Biomass Accumulation Weight, A = Volume of plant based on $a = mx - b$, where predicted A is based on slope of observed biomass less the intercept value on vertical axis. WSp_{i-j} = Weight of

soil at corresponding soil pF ranges, W_b =Weight of empty bucket, V_{I120} = Volume of water at indicated pF level, SMV = Soil mass volume, PVF = Pore volume fraction, RS = Relative saturation and VWA =Volume of water Added. The biomass accumulative weight was based on below ground (roots and corm) and above ground (stem, leaf number, leaf weight and area) and plant volume ($\pi r^2 h$ of the stem). Leaf area was based on length and width of the third most fully developed leaf (Turner, 2005) from the top of plant. One plant per variety and treatment were destructively harvested every month to determine the corresponding weight of root and corm as a unit structure for the remaining plants in the experiment. Stem weight was based on plant height and girth (average top and bottom girth). The total weight of potted plant (plant, pot, water and soil) at corresponding soil pF ranges was determined as follows: Total weight of potted plant = ($pFR * pFM * RS * W_{bfd} * W_{eb} * W_{plt} * W_{spFL} * SV * PVF * B/d * DMS * W_b * Sw$). The quantified pF ranges for minimum and maximum levels for water addition to the bucket for the three moisture regimes (Moist, semi-moist and dry) was determined as follows:

1 min	2	0.260	0.611764706	43.69	0.8	0.2201	42.669938	29	0.578323	1.1174433	32.405857	10.2601352	42.67	43.69
1 max	2.1	0.240	0.564705882	43.69	0.8	0.2201	42.669938	29	0.578323	1.1174433	32.405857	9.47089405	41.88	42.90
2 min	2.5	0.19	0.447058824	43.74	0.8	0.1928	42.7472111	29	0.577016	1.1209081	32.506334	7.48084038	39.99	40.98
2 max	2.7	0.175	0.411764706	43.74	0.8	0.1928	42.7472111	29	0.577016	1.1209081	32.506334	6.89024771	39.40	40.39
3 min	2.8	0.165	0.388235294	43.29	0.8	0.1517	42.338303	29	0.583935	1.1025736	31.974633	6.57441552	38.55	39.50
3 max	2.9	0.155	0.364705882	43.29	0.8	0.1517	42.338303	29	0.583935	1.1025736	31.974633	6.1759661	38.15	39.10

Whereby: pF range (Min. and Max) (pFR); pF moisture level ($pFML$); Relative saturation (RS) (Relative saturation = fraction of pores filled with water at the indicated pF level); weight of bucket after free drainage (W_{bfd}); weight of empty bucket (W_{eb}); weight of plant (w_{plt}); Weight of soil at pF level (W_{spFL}); W_{spFL} = Wgt of bucket after free drainage - weight empty bucket - weight of plant; Soil vol. (SV); Pore vol. fraction (PVF); $100 * (1 - Bd / 2.65)$; Bulk Density (Bd); $(1 - PVF) * 2.65$ or (weight of dry soil/ vol. of container); Dry mass soil in bucket (DMS); $B/d * PVF$; Water in bucket at indicated pF level (W_b); Soil volume $* PVF * RS$; Soil weight at indicated pF level (Sw); Dry mass soil + Water in bucket at indicated pF level.

3.4 Crop management

Water soluble NPK Fertilizer (ratio; 19:9:19) was initially applied at a rate of 1 g L^{-1} to the potted plants across treatments. Additionally an emulsifiable concentrate insecticide (a.i. Abamectin 18 g L^{-1}) was applied as a foliar spray at a rate of 1 ml/5 litres of water to control red spider mites damage from a further economic injury level (IEL) to the plants especially the drought stressed plots (ie treatment MD₃). The entire experiment was also treated with the nematicide nemacur (ai fenamiphos) at a rate of 15 g/plant to control the nematode potential infestation.

3.5 Data collection

3.5.1 Biomass growth assessment

The responsive biomass accumulation was assessed fortnightly beginning at one month after planting (MAP) by taking measurements of plant height, girth, root length, weight, and number of developed leaves and the size of leaf lamina (Leaf length x width). All measurements on leaves were taken on the third leaf (Kumar, 2002) from the top due to its full expansion. The leaf area was calculated from the leaf lamina size (length by width) by the constant factor of 0.688. Biomass accumulation parameters were assessed after every two weeks to enhance the determination of the cumulative increase in size of plant for corrective calibration of soil pF range treatments based on the plant absorption rate of moisture. Root growth and distribution were determined using morphological parameters of root girth size and specific root length (SRL, m g^{-1}) Ostonen (2007) adopted similar parameter of SRL as an indicator of environmental change in determining the length of fine roots. After the thirteen weeks of plants growth, the experiment was terminated and all plants were harvested to assess the dry matter of the responsive and under ground biomass (roots).

3.5.2 Canopy structural architecture

3.5.2.1 Leaf angle architectural behavior

Canopy leaf orientation is an important parameter for plant growth modeling. The behavioural component of the leaves in terms of leaf angle and folding, are a mechanism for combating the adverse effects of drought stress especially heat and moisture deficit. Leaf lamina is liable to change the standing angle and also fold to avoid excessive transpiration (preserve leaf turgidity). The leaf angle behavioral data (degrees) were collected on weekly basis using a geometry protractor for an exponential vertical-horizontal relationship between the mid leaf and the third most fully expanded leaf. Due to the stress and environmental effects induced in leaf angles (Tosserams *et al.*, 1997), determination of canopy architecture is important in characterization of susceptible cultivars. These effects are important since leaf inclination angles influence canopy light absorption and therefore photosynthesis. Consequently, average canopy leaf angle is used as a functional parameter in most photosynthetic models (Aries *et al.*, 1993; Thornley, 1993).

3.5.2.2 Leaf folding behavior

The decrease in soil water content from the field capacity can cause a stress situation of plant dehydration due to lack of total available moisture (TAM) for plant growth. By avoiding a dehydration phenomenon of excessive loss of leaf water, plants develops a mechanism of reducing the leaf evaporative surface area through folding. The data were collected on a weekly basis to assess the threshold degrees to which leaves of different EAH banana begin to exhibit the folding mechanism for dehydration avoidance. A geometry compass was used at the middle of the third most developed leaf lamina and determined the folding by reading corresponding degrees on a protractor.

3.5.3 Potential for leaf turgidity

The leaf relative water content (RWC) is a relevant physiological component for assessing the leaf osmotic potential. This is important in estimation of current water content of the leaf tissue relative to the maximal water content it can hold at full turgidity in a situation of moisture deficits. At harvesting, a direct approach method for assessment of leaf water content was adopted, where a third fully expanded leaf from the plant apex was selected and five leaf discs (diameter 0.5cm) were excised from the middle region. The leaf discs were put in a vial after determining their fresh weight, and then rehydrated with 5 ml of distilled water and refrigerated at 4°C for 48 hours. The leaf discs were then blotted with a dry piece of cloth and recorded the weight and then dried in the oven at 70°C for 72 hours. The weight of the dried discs was also recorded. The final determination of leaf relative water content was based on obtained results of leaf fresh weight (FW), saturation weight (SW) and dry weight (DW), where $RWC = (FW - DW) / (SW - DW)$ (Rampino, 2006; Barr and Weatherley, 1962).

3.5.4 Transpiration assessment of the banana plant

The sensitivity of banana plants to levels of soil moisture depletion justifies the need for characterization of physiological parameters especially transpiration rate to water stress in identifying the initiation of stress, and in planning drought management accordingly.

In obtaining the data, a weight loss method was adopted where potted buckets were covered with a plastic polythene sheet to control 95 percent of soil evaporation and only allow loss of water through the leaves (weight loss model). Treatments were maintained at determined pF levels corresponding to weight ranges of the soil mass, and the plant biomass. Volumes of transpired water were assessed after every 48 hours through weight loss in soil water model.

3.5.5 Response of chlorophyll accumulation to drought stress

Chlorophyll content being a function of leaf nitrogen and involved in photosynthetic efficiency, the evaluation for its build-up during plant growth is a valuable index method for assessing tolerance to drought stress (Paknejad *et al.*, 2007) and general plant growth. Factors that include photo-inhibition, high temperature, radiation levels, trunk and foliar diseases and soil drought) can lead to chlorophyll breakdown (Hortensteiner *et al.*, 2005). The data readings were taken from a noninvasive chlorophyll meter (SPAD; Minolta, Osaka, Japan) attached on the third unfolding banana leaf to determine the response of N accumulation in leaves at varying moisture deficits. Data were collected at a monthly basis starting from the time when treatments were imposed to harvesting. A chlorophyll meter reading correlates well with analytical measurements of the chlorophyll content and with N concentrations in the leaves (Vos, 1993).

3.5.6 Leaf senescence responses to drought stress

Senescence plays a role in the plant's survival by contributing nutrient allocation to productive leaves through the death of unproductive leaves as a result of accelerated senescence accompanied by abscission, which reduce water loss through transpiration and in turn contributing to water balance of the plant (Munne, 2004). Such indicative responses may be induced within a short period of exposure to drought and at a slow rate which is the induction of senescence. The data was collected on monthly basis by determining the cumulative number of unproductive tillers (75% dead leaf) for assessing the threshold values for on set senescence at increasing moisture deficit.

3.6 Statistical analysis

Mean values of all the parameters were generated and subjected to analysis of variance (ANOVA) using a Genstat statistical package. The least significance difference (LSD) at 5% level of significance was used for mean separation. A GXE interaction using the Additive Main Effect and Multiplicative interaction (Kempton, 1994) was generated to determine the varieties that are adaptable to different soil moisture conditions. Graphical representations were generated in Microsoft excel to determine the response of banana varieties at varying moisture deficit levels.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0

4.1. Below ground biomass

4.1.1 Fresh root Weight

Results presented in Table 3 indicate both fresh and dry root weights under different levels of moisture deficit in both seasons (2008a and 2008b). The reduction in moisture availability from pF 2.0 to pF 2.5 showed a proportional reduction in fresh weight ranging from 12.7% to 19.4% except for cv. *Sukali Ndiizi* that was more affected and exhibited a 35.3% loss in weight. Further reduction of moisture availability from pF 2.5 to pF 2.8 (0.64 - 0.8 bars) significantly affected the cooking cv. *Mpologoma* which exhibited 54.4% reduction in weight and was followed by cv. *Kisansa* which showed 46.5%, *Sukali Ndiizi* with 43.0%, *Kayinja* showed 42.0% and *Yangambi Km5* with 40.0% reduction in fresh root weight. Overall results therefore showed that highland banana cultivars conforming to triple AAA genome composition were more sensitive to moisture stress reduction than cultivars belonging to AAB and ABB genomes. However, lowland cultivar *Yangambi Km5* was least affected by moisture reduction, suggesting the possibility of possessing expressive traits adaptable to drought.

However, significantly higher proportions in root weight reductions between pF 2.0 and pF 2.8 moisture availability were determined. Cultivar *Mpologoma* showed 63.0% wt. loss in root weight whereas cultivar *Sukali Ndiizi* had 63.1% wt. loss. These two cultivars were more affected compared to cv. *Kisansa* and *Kayinja* which both showed significantly lower weight losses of 53.3%. *Yangambi Km5* was least affected with 48.4% of wt. loss. The observations

correlate to a likely occurring effect from typical phenomenon when moisture is drastically lost from soil for a long period of time.

In earlier studies by Sebuwufu *et al.* (2004), 90% of the variations in root growth were attributed to variation in shoot development which is similarly affected by moisture deficit. Similarly, Blomme (1996) also reported positive correlations between root traits and above ground plant characteristics. Therefore, with the reduction in fresh weights, suggestions of resulting effects were attributed to affected plant shoot due to moisture deficit.

There were no significant seasonal variations across seasons but rather across moisture deficit levels. Much impact on root weight reduction was attributed to moisture deficit than seasonal variation.

4.1.2 Root size, average length, tissue density and Mass

Results of root size (RS), average root length (ARL) tissue density (RTD) and root mass (RM) were presented in Table 3. Most root sizes were less than 1cm in diameter with girth size not significantly different across cultivars and but rather across moisture regimes. The small root size and girth indicated the presence of more lateral roots and therefore led to suggestion that more root length occurred in small roots with diameter <1cm (Fig. 3.). Therefore most lateral roots attained an average root length.

Significant average root lengths across moisture deficit levels were observed with cv. *Mpologoma* at 38.4 cm, 49.4 cm, 29.4 cm, and cv *Sukali Ndiizi* at 53.3 cm, 45.9 cm, and 32.7 cm for *pF* 2.0, *pF* 2.5, and *pF* 2.8 respectively (Table 3.). The average root lengths of other cultivars were not significantly different across moisture deficit levels.

Cooking type of cultivars attained the maximum root lengths (MRL) with *Kisansa* (AAA-EA) exhibiting 118cm, 114.4cm and 80.9cm at pF 2.0, pF 2.5 and pF 2.8 respectively. The cultivar also attained a root tissue density of 161, 74 and 69 corresponding to pF 2.0, pF 2.5 and pF 2.8 respectively; whilst, cv. *Mpologoma* had 96.9cm, 109.2cm and 84.3cm and root tissue density of 130, 100 and 71 for the respective moisture levels (pF 2.0, pF 2.5 and pF 2.8) (Table3.). Cultivar *Sukali Ndiizi* deviated from the cooking cultivars and exhibited a relatively less length root system of 102.8cm, 102.6cm and 72.3cm and the root tissue density of 90, 81 and 72 for pF 2.0, pF 2.5 and pF 2.8 respectively (Table 3.). The observation suggests that a higher proportion of tissue density and length potentially develops in a more moisture stressful condition partly due to search for moisture.

Despite the variation in root length among cultivars, the total root length results were not significantly different across moisture deficit levels. However, the high total root lengths among the cooking type of cultivars (conforming to triple AAA genome) developed extensively hence attributing the effect partly to optimal availability of moisture in soil and secondly due to the potential of shoot /root ratio as similarly was observed by Sebuwufu *et al.* (2004). However, these cultivars exhibited significantly reduced root length with increased moisture deficit (pF 2.8) indicating the effect of moisture stress to root development potential and hence sensitivity to drought stress.

Cultivar *Kayinja* (77.4 cm, 91.8 cm, and 73.3 cm) and *Yangambi Km5* (76.9 cm, 81.8 cm, and 83.2 cm) exhibited the most limited length of root and were not significantly different across moisture deficit levels. Cultivar *Yangambi Km5* had the lowest density of roots at 30, 24, and 19

for the pF 2.0, pF 2.5 and pF 2.8 respectively. The low root tissue density was attributed to the narrow shoot nature of cv. *Yangambi Km5* from the compensation point, than to the effect of moisture deficit.

The proportional change in average root length (ARL) (Fig 3) as result of increased moisture deficit showed a tremendous effect of drought stress. The increment of moisture deficit from pF 2.0 to pF 2.5 did not significantly affect the root length of cv. *Kayinja* and *Mpologoma*.

The root mass (RM) based on root tissue density and volumes were determined. Cultivar *Mpologoma* exhibited more root mass 296.4g, 349.0g, 142.6g and cv. *Kisansa* with 241.7g, 262.6g and 134.7g for the pF 2.0, pF 2.5 and pF 2.8 respectively. Cultivar *Sukali Ndiizi* equally exhibited high root mass of 373.7g, 168.1g and 115.5g for pF 2.0, pF 2.5 and pF 2.8 respectively. The exhibition of high root mass among the cooking type of cultivars is an indication of efficient shoot/root ratio. High root mass therefore puts the cooking type of cultivars to being sensitive to drought stress during the phenomenon of moisture deficit. Cultivar *Kayinja* and *Yangambi Km5* exhibited lower root mass of 127.3g, 138.0g, 104.6g and 50.3g, 50.0g, and 47.1g for the pF 2.0, pF 2.5 and pF 2.8 respectively. The possession of low root mass was suggested to be a drought adaptative mechanism to the plant since relatively little volume of water may be absorbed for plant growth.

4.1.3 Specific root length (SRL)

Specific root length (SRL, g^{-1}) being the most frequently measured morphological parameter, is used as an indicator of environmental changes (Ostonen *et al.*, 2007). Specific root length was calculated based on length-to-mass ratio (L/M) of a root fragment. The root mass can be replaced

by the product of root tissue density (RTD) and volume by a fraction of root length diameter (D) and π (3.14). Therefore $SRL = L/M = L / RTD * V = L / RTD (\pi D^2/4) * L$

The lowest SRL were exhibited by cv *Mpologoma* (0.130m g⁻¹), cv. *Kisansa* (0.198m g⁻¹) and cv. *Sukali Ndiizi* (0.143 m g⁻¹) (Table 3.) at *pF* 2.5. correlating with a larger leaf surface area. However, cultivars *Kayinja* and *Yangambi Km5* scored significantly higher SRL of 0.3 and 0.7 m g⁻¹ respectively, hence proving the increase of SRL to decreasing leaf area (Fig. 3 and 4). Progressively increased SRL with increased moisture deficit were observed to coincide with reduced leaf surface hence a low shoot/root ratio. With similar phenomena, Eissenstat & Yanai (1997) assumed root length and root mass (RM) to be proportional to resource acquisition and plant maintenance respectively. High SRL with decreased moisture deficit concurred with what Philips *et al.* (2006) reported that long and thin roots (high SRL) were the below ground equivalent of thin leaves and leaf area could be estimated from cord roots (Gousseland, 1983), and changes in the rate of shoot growth result on an effect in root growth. Similarly, Lahav & Turner 1989; Price (1995) correspondently reported that roots of plantain and banana (*Musa* spp.) were sources of plant growth regulators that contribute to lateral shoot development and thus perennial growth.

Although cv. *Mpologoma*, and cv. *Kisansa* (AAA-EA) attained a higher root length, their proportion of root length and density reduction due to moisture deficit indicated that they were most susceptible to moisture deficit. But their potential for a large leaf area proved a relationship for efficient utilization of available moisture but not water saving due to limited root distribution across continued moisture deficit levels. Similarly, cv. *Yangambi Km5* (AAA-LL) had root density affected by low moisture than the root length. But based on the results, its suggested that neither of

the root/shoot ratios shifted in favour of the other basically due to possession of low but long roots and narrow leaves for limited total carbon investment in root system. Other cultivars, eg *Sukali Ndiizi* (AAB) the highly affected root length meant development of more root densities and were water spenders than savers and therefore not tolerant to drought in regard to root architecture. Contrary, cv. *Kayinja* (ABB) developed proportionally longer but few roots suggesting the potential for the plant sustainability through drought conditions and possession of traits for enhancing water saving for tolerance to drought.

At pF 2.5 values of 0.142 m g^{-1} and 0.163 m g^{-1} were observed as levels for the specific root length development of cv. *Mpologoma* and *Kisansa* respectively (Fig. 4). Further increment in moisture deficit level to pF 2.8 would increase the SRL value with limited root mass. Similarly, by increasing the available moisture to pF 2.0, the SRL is lowered with increase in root tissue density. However, cv. *Sukali Ndiizi* developed high root tissue density (RD) due increased availability soil moisture (pF 2.0) than the lowered moisture levels, suggesting $\leq pF$ 2.5 as the threshold level at a value of 0.273 m g^{-1} (Table 3. and Fig. 3.). The SRL for cv. *Kayinja* was not affected by the root tissue density and mass development across moisture deficit levels. Cultivar *Yangambi Km5* exhibited the highest SRL due to very limited root tissue density and mass (Fig. 4). The validity of the observation could be proved with the narrow leaf length and low shoot/root ratio.

Table 3. Root growth, development and distribution of selected banana cultivars across different moisture regimes

Cultivar (M.A)	Moisture Regime	Root biomass				Root Length				
		2008 ^a		2008 ^b		Average Root Length (cm)	Max. Root Length (cm)	Root Tissue Density (n)	Root Mass (gm)	Specific Root (m g ⁻¹)
		Fresh Weight (g)	Dry Weight (g)	Fresh Weight (g)	Dry Weight (g)					
<i>Kayinja</i> (ABB)	<i>pF</i> 2.0	79.7 ^a	14.5 ^a	58.7 ^{ab}	12.7 ^a	36.4 ^a	77.4 ^a	88	127.3	0.286
	<i>pF</i> 2.5	35.9 ^b	10.7 ^b	75.7 ^a	14.5 ^a	43.4 ^a	91.8 ^a	80	138.0	0.315
	<i>pF</i> 2.8	27.2 ^b	10.2 ^b	37.5 ^b	13.4 ^a	34.4 ^a	73.3 ^a	62	104.6	0.329
	LSD	15.9	2.56	30.6	7.95	7.11	30.3			
	CV%	12.9	8.4	23.6	26.0	8.2	16.6			
<i>Mpologoma</i> (AAA)	<i>pF</i> 2.0	91.5 ^a	14.8 ^a	69.7 ^a	12.9 ^a	38.4 ^b	96.9 ^a	130	296.4	0.130
	<i>pF</i> 2.5	53.5 ^a	11.2 ^b	77.5 ^a	13.2 ^a	49.4 ^a	109.2 ^a	100	349.0	0.142
	<i>pF</i> 2.8	19.6 ^a	9.6 ^b	40.1 ^a	10.5 ^a	29.4 ^c	84.3 ^a	71	142.6	0.206
	LSD	86.3	6.03	30.8	3.88	8.25	72.6			
	CV%	44.8	14.5	21.8	14.0	9.3	33.1			
<i>Sukali Ndiizi</i> (AAB)	<i>pF</i> 2.0	80.8 ^a	14.9 ^a	107.9 ^a	18.5 ^a	53.3 ^a	102.8 ^a	90	373.7	0.143
	<i>pF</i> 2.5	32.0 ^b	10.9 ^{ab}	90.1 ^a	14.4 ^{ab}	45.9 ^a	102.6 ^a	81	168.1	0.273
	<i>pF</i> 2.8	29.8 ^b	10.2 ^b	39.8 ^b	10.9 ^b	32.7 ^b	72.3 ^a	72	115.5	0.283
	LSD	39.6	3.52	47.3	5.8	12.2	34.6			
	CV%	32.0	11.3	26.3	17.5	12.3	16.5			
<i>Yangambi</i> (AAA-LL)	<i>pF</i> 2.0	95.8 ^a	12.8 ^a	62.9 ^a	10.8 ^a	37.1 ^a	76.9 ^a	30	50.3	0.737
	<i>pF</i> 2.5	66.7 ^a	9.61 ^a	69.9 ^a	12.4 ^a	37.8 ^a	81.8 ^a	24	50.0	0.756
	<i>pF</i> 2.8	49.9 ^a	10.8 ^a	32.0 ^b	13.4 ^a	40.3 ^a	83.2 ^a	19	47.1	0.855
	LSD	35.2	1.47	35.8	5.65	9.04	34.6			
	CV%	19.1	5.1	28.8	20.5	10.4	16.5			
<i>Kisansa</i> (AAA)	<i>pF</i> 2.0	73.8 ^a	13.1 ^a	65.4 ^a	11.9 ^a	47.8 ^a	118.0 ^a	161	241.7	0.198
	<i>pF</i> 2.5	32.8 ^b	11.1 ^a	88.7 ^a	17.2 ^a	42.8 ^a	114.4 ^a	74	262.6	0.163
	<i>pF</i> 2.8	26.3 ^b	9.38 ^a	38.7 ^a	12.1 ^a	34.1 ^a	80.9 ^a	69	134.7	0.253
	LSD	17.8	3.96	35.3	8.67	17.1	67.8			
	CV%	15.4	13.6	24.2	27.8	18.2	28.6			

LSD = Least significant difference, M.A. = Moisture Available, LL = Lowland, ARL = Average Root Length, TRI = Total Root Length, SRL = Specific Root Length, CV% = Coefficient of variation, RTD = Root tissue density, RM = Root Mass, PFV = Proportional Fresh Root Weight, FW = Fresh Weight, DW = Dry Weight, PARL = Proportional Average Root Length. *means followed by the same letter within a column are not significantly different according to student newman keuls (S N K) test



Fig. 3. Banana root length at harvest

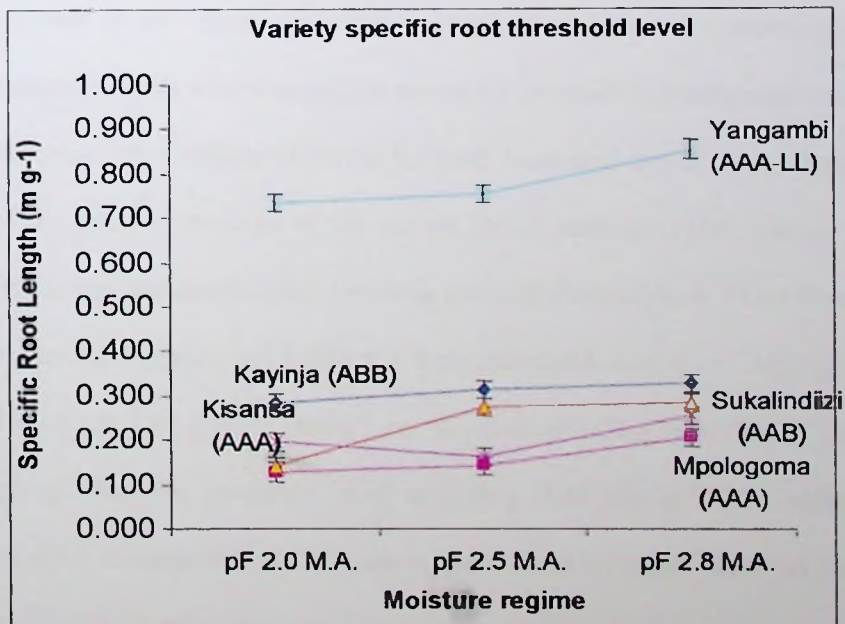


Figure. 4. Root length of selected banana cultivars across moisture deficit regimes

4.1.4 Relative root dry weight

Contrary to the fresh root weight, the dry weight exhibited non significant differences in root weights across seasons than moisture availability for few cultivars (Table 3). The mean root dry weight was expressed as relative percentage to the fresh weight (Table 4). Presented results showed that the relative dry matter of root was generally higher among plants at pF 2.8 M.A (stressed cultivars) than plant growth at free drainage level (Fig. 5).

Cultivar *Kayinja* exhibited the highest percentage of dry root weight at 36.5%, followed by cv. *Mpologoma* at 33.7%, cv. *Sukali Ndiizi* at 30.3% and cv. *Kisansa* at 33.0% and cv. *Yangambi Km5* at 29.5% for the pF 2.8 (Table 4.). Significant differences in relative dry root weight were observed across moisture deficit levels than across varieties. However, cv. *Yangambi Km5* exhibited the highest percentage of relative fresh root weight with 87.1% followed by cv. *Mpologoma* at 85.3%, cv. *Sukali Ndiizi* at 85.0%, cv. *Kisansa* at 84.8% and cv. *Kayinja* at 83.6% for the pF 2.5. (Table 4).

The suggestion to the results was the potential for substrates concentration in moisture stressed than non stressed roots which could be driven by increase in temperature and probably the pressure in the root zone. The threshold levels for both fresh and dry biomass matter were observed at pF 2.5 based on the relative slope of the curves for all cultivars. The cultivar potential for dry matter production across moisture deficit levels is presented on table 4. The hierarchal order of hydration within the stressed plants (pF 2.8M.A.) were indicated among cv. *Kayinja* at 1.74g H₂O/ DM g⁻¹, cv. *Mpologoma* at 1.97 g H₂O/ DM g⁻¹, cv. *Kisansa* at 2.03 g H₂O/ DM g⁻¹, and *Sukali Ndiizi* at 2.30 g H₂O/ DM g⁻¹ and cv. *Yangambi Km5* at 2.38 g H₂O/ DM g⁻¹. The order indicated that cultivar *Yangambi Km5*, *Sukalindiizi* and *Kisansa* used relatively more water to produce a single gram of dry matter (Table 4), suggesting the potential for root desiccation during drought period.

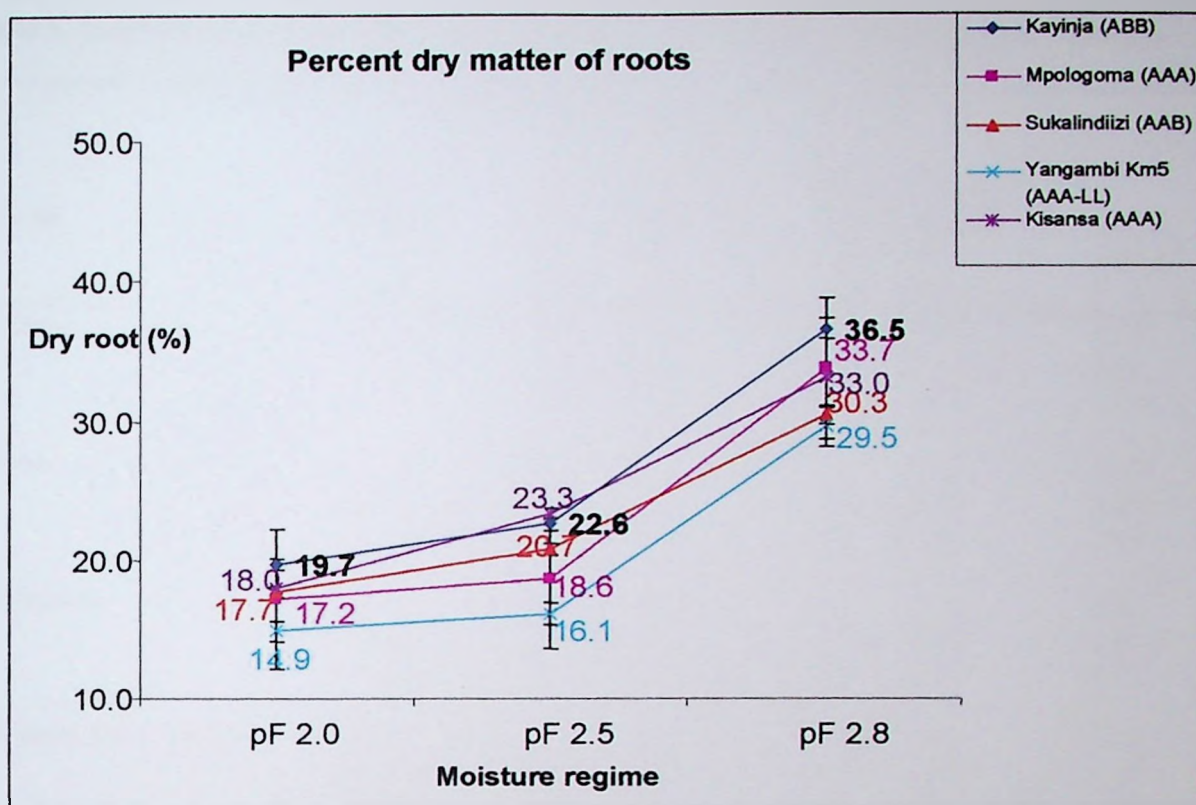


Figure 5. Percent dry matter of roots for different banana cultivars across different moisture regimes

Table 4. Root dry matter production per gram of water used by selected banana cultivars

2008a and b Seasons							
Cultivar	Genome	Moisture Regime (M.A.)	Root Fresh Wt. (gms)	Relative Fresh Wt. (%)	Dry Root Wt (gms)	Percent dry root Wt (%)	gH ₂ O/ DM g ⁻¹
<i>Kayinja</i>	ABB	<i>pF</i> 2.0	69.2	83.6	13.6	19.7	4.09
		<i>pF</i> 2.5	55.8	81.6	12.6	22.6	3.43
		<i>pF</i> 2.8	32.4	73.3	11.8	36.5	1.74
<i>Kisansa</i>	AAA	<i>pF</i> 2.0	69.6	84.8	12.5	18.0	4.57
		<i>pF</i> 2.5	60.8	81.1	14.2	23.3	3.29
		<i>pF</i> 2.8	32.5	75.2	10.7	33.0	2.03
<i>Mpologoma</i>	AAA	<i>pF</i> 2.0	80.6	85.3	13.9	17.2	4.82
		<i>pF</i> 2.5	65.5	84.3	12.2	18.6	4.37
		<i>pF</i> 2.8	29.9	74.8	10.1	33.7	1.97
<i>Yangambi Km5</i>	AAA-LL	<i>pF</i> 2.0	79.4	87.1	11.8	14.9	5.72
		<i>pF</i> 2.5	68.3	86.1	11.0	16.1	5.21
		<i>pF</i> 2.8	41.0	77.2	12.1	29.5	3.38
<i>Sukali Ndiizi</i>	AAB	<i>pF</i> 2.0	94.4	85.0	16.7	17.7	4.65
		<i>pF</i> 2.5	61.1	82.8	12.7	20.7	3.80
		<i>pF</i> 2.8	34.8	76.7	10.6	30.3	2.30

M.A.=Moisture Availability, wt = weight, Gms = grams, DM= Dry matter, RFR= relative fresh root, RDR= relative dry root, Dw =dry weight, Fw = Fresh weight. gH₂O / DMg-l= (Fresh Root Weight – Dry Root Weight)/ Dry Root Weight; %DW = (100*DW)/FW

4.2 Above ground Biomass

4.2.1 Plant height (1MAT imposition)

Results presented in table 5 indicated a cumulative increase in height of plants from one month after treatment imposition (1MAT) across varieties over time. Plants under pF 2.0 MA level of treatment attained highest plant height that ranged from 67 - 86cm and 64 - 93cm high for first and second season respectively. Subsequent plant growth in height ranged from 60 -83cm high for pF 2.5 M.A and 46-64cm for pF 2.8 M.A during 2008b season. The difference in height across moisture deficit levels was therefore a clear indication of the impact of moisture stress on the plant's potential to grow tall. Cultivars, *Mpologoma*, *Kisansa*, *Kayinja* and *Yangambi Km5* were found to be relatively short species (67-76cm and 64-82cm for 2008A and B seasons) even after subjecting the plants to field capacity level. Cultivar *Sukali Ndiizi* exhibited a trait for highest height (86cm and 93cm) during 2008A and B seasons (Table 5) (Fig. 6).

The observed significant reductions in plant height were attributed to decreased available moisture (table 5). The effect of moisture stress on plant height was exhibited with retarded growth plant structures in particular the height of plant (Fig. 7). Plant height increased over time as the plant grew but the cumulative rate of increases were significantly limited by continued moisture deficit state. A decrease in moisture stress from pF 2.1 to pF 2.5 caused a much more reduction in height for cv. *Sukali Ndiizi* (AAB) (Fig. 7), and cv. *Kayinja* (ABB) than reduction from 60 to pF 2.8, indicating pF 2.0M.A. as the threshold critical point for justifying moisture maintenance for better plant growth. However, cv. *Mpologoma* (AAA) and *Yangambi Km5* (AAA-LL) gradually reduced similarly in height across moisture deficit levels indicating that a deviation from pF 2.0 justified reduced plant growth in height. Unlike other cultivars trend of moisture deficit stress on plant height, cv. *Kisansa* (AAA) differed in exhibiting the effect.

Table 5. Plant height (cm) of selected banana cultivars across different moisture regimes

		Season1 (2008 _a)					Season2 (2008 _b)				
Cultivety	Moisture Regime	Month				Percent Increase from1-4	Month				Percent Increase from1-4
		1	2	3	4		1	2	3	4	
		cm					cm				
Wanjia	pF 2.0	51.1	60.1	66.2	74.1	45.0	25.6	38.2	51.9	70.8	85.6
BB)	pF 2.5	41.2	47.5	49.8	54.2	31.6	27.5	37.1	55.2	68.2	58.5
	pF 2.8	43.9	50.2	49.2	51.8	18.0	23.3	31.0	39.0	45.8	50.5
Pollogoma	pF 2.0	47.5	51.3	60.6	67.4	41.9	28.9	39.7	57.5	75.4	68.5
AA)	pF 2.5	43.6	47.8	50.2	56.9	30.5	32.9	39.2	54.3	60.1	29.8
	pF 2.8	47.7	49.2	49.1	49.9	4.6	29.3	40.6	47.8	56.9	57.6
Ali Ndiizi	pF 2.0	60.0	72.9	80.4	85.9	43.2	48.8	62.2	81.1	92.5	41.5
AB)	pF 2.5	54.5	59.6	61.6	67.8	24.4	38.4	47.5	59.5	67.0	36.3
	pF 2.8	55.2	61.3	62.3	61.9	12.1	48.4	55.8	55.9	63.6	29.1
Ngambi	pF 2.0	58.2	66.1	72.0	76.1	30.8	26.7	36.3	50.1	64.1	63.9
AA-LL)	pF 2.5	53.6	58.0	58.4	63.9	19.2	28.5	36.4	52.4	67.3	56.2
	pF 2.8	53.1	57.4	62.8	58.6	10.4	28.3	33.8	42.3	47.7	32.2
ansa	pF 2.0	53.3	56.3	62.8	67.6	26.8	28.7	52.4	57.9	82.1	124.4
AA)	pF 2.5	50.3	53.1	54.5	57.2	13.7	33.0	41.6	59.1	82.8	66.2
	pF 2.8	43.6	44.6	47.2	45.8	5.1	30.5	37.1	44.4	58.3	52.9
D (M.A)		3.30	3.38	4.08	4.58		5.23	5.52	4.68	5.35	
D (M.A.*V)		7.37	7.56	9.12	10.2		11.7	12.4	10.45	11.96	
%		8.7	8.0	9.2	9.7		22.0	17.7	11.6	10.7	

= Moisture Available, *means followed by the same letter within a column are not significantly different according to student-newman-keuls (S-N-K) test.

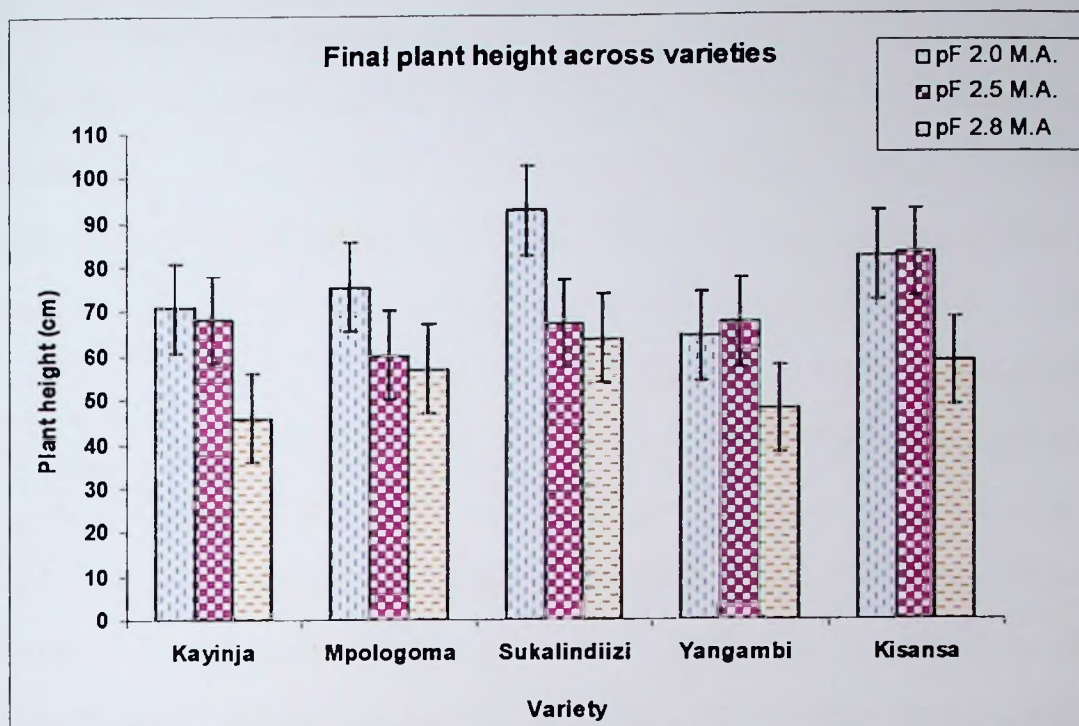


Fig. 6

Fig. 6. Mean plant heights of selected banana cultivars across various moisture regimes

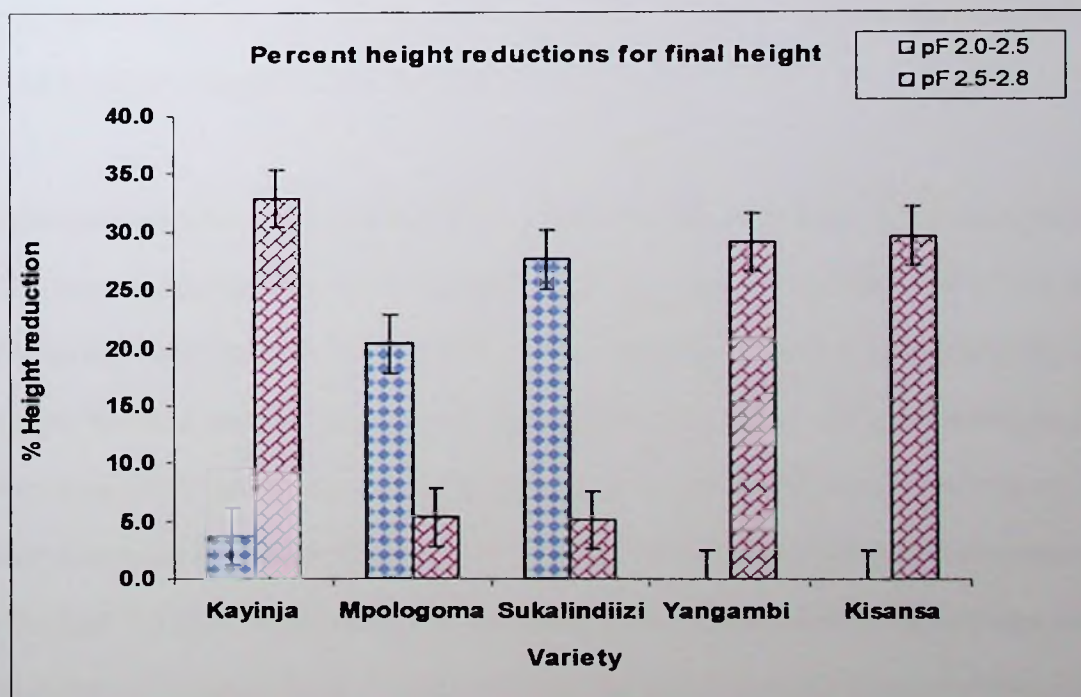


Fig. 7

Fig. 7. Percent plant height reduction due to drought stress

4.2.2 Stem girth development

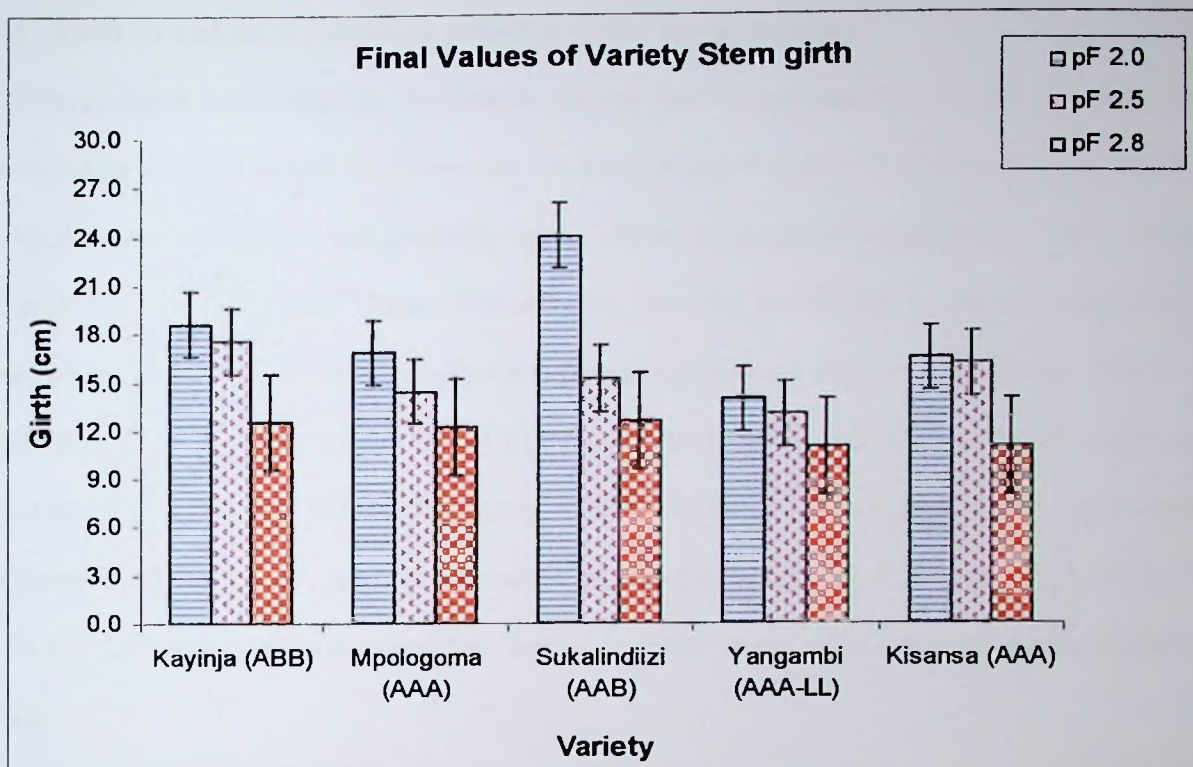
Despite the effect of seasonal variation on stem enlargement, there was significant limitation of stem development due to moisture deficit stress (Table 5). At harvest, with pF 2.5, cv. *Sukali Ndiizi* (19.3cm;24.0cm) and cv. *Kayinja* (18.8cm; 18.6cm) cv. *Mpologoma* (16.5cm; 16.8cm) exhibited the largest stem circumference than cv. *Yangambi Km5* (15.5cm; 13.9cm) and cv. *Kisansa* (15.2cm; 16.4cm) (Fig. 8_A) for 2008 A and B seasons respectively. The results therefore indicated the variety potential for photosynthates translocation in the stem sink especially for ABB and AAB genome cultivars. However, at pF 2.5, the stem enlargement potential of cv. *Kayinja*, *Sukali Ndiizi* and cv. *Kisansa* tolerated the reduction in available moisture much more than cv. *Yangambi Km5*, cv. *Mpologoma*. With the increased moisture deficit of severe stress environment (pF 2.8), cv. *Kisansa* (10.2cm; 11.0cm), cv. *Yangambi Km5* (10.6, 11.0cm) and cv. *Mpologoma* (10.5; 12.2cm) were highly stressed than cv. *Kayinja* (12.6cm; 12.5cm) and cv. *Sukali Ndiizi* (12.2; 12.5cm) (Fig. 8_A) for 2008 A and B seasons respectively. The results therefore put the cooking type of cultivars to drought susceptibility while the dessert and plantain types to a significant degree of tolerance to pseudo-stem development.

The final percent reduction in girth showed that when the available moisture was reduced from pF 2.5-2.8, cultivar *Kisansa* and *Kayinja* were mostly affected (Fig. 8_B). However, cv. *Sukalindiizi* was more affected upon reducing available moisture from pF 2.0-2.5 (Fig. 8_B). The threshold points for girth size reduction based on reduction in available water showed all cultivars to reduce in size upon decreasing in available water. The initial signs in stem size reduction were determined at cultivar basis where cv. *Kayinja* and *Sukalindiizi* started significant deviation at pF 2.5. Other cultivars deviated upon decreasing the available moisture from pF 2.5 hence suggesting their susceptibility to moisture deficit. The average threshold girth sizes were 12.6cm (*Yangambi Km5*), 13.5cm (*Mpologoma*) and 14.0cm for *Kisansa* (Table 6) (Fig. 7_B).

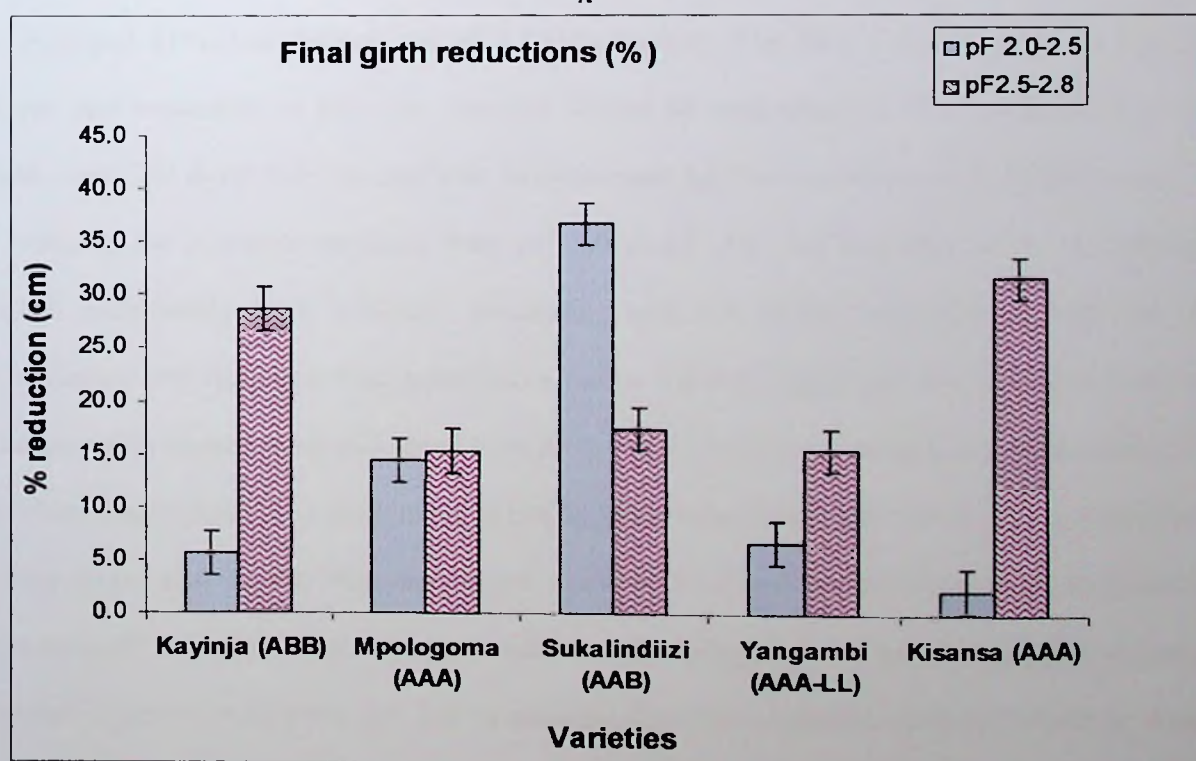
Table 6. Stem girth (cm) of selected banana cultivars across different moisture regimes

		Season1 (2008 _a)					Season2 (2008 _b)						
		Sampling intervals (Month)				Percent Increase	Sampling intervals (Month)				Percent Increase		
		1	2	3	4		1	2	3	4			
Moisture Regime (M.A.)		cm					cm						
ety													
Enja	pF 2.0		13.53	16.43	17.23	18.77	38.7		8.80	9.27	16.63	18.63	111.7
B)	pF 2.5		10.93	14.43	13.33	13.93	27.4		8.70	8.70	16.30	17.57	102.0
	pF 2.8		10.14	13.09	12.33	12.58	24.1		7.77	7.77	11.80	12.53	61.3
goma	pF 2.0		10.83	13.27	14.17	16.50	52.4		8.33	8.33	15.63	16.83	102.0
A)	pF 2.5		9.47	10.87	11.17	12.57	32.7		8.50	8.50	14.33	14.40	69.4
	pF 2.8		9.09	10.34	10.12	10.53	15.8		7.97	8.50	10.87	12.20	53.1
Ndiizi	pF 2.0		10.73	14.33	16.23	19.33	80.1		10.63	10.63	21.17	23.97	125.5
i)	pF 2.5		10.17	12.33	12.6	14.10	38.6		8.70	8.70	14.93	15.17	74.4
	pF 2.8		8.99	12.29	11.02	12.23	36.0		9.80	9.80	13.17	12.53	27.9
ambi	pF 2.0		10.60	12.80	14.30	15.47	45.9		7.97	8.20	12.30	13.90	74.4
(AAA-LL)	pF 2.5		9.07	11.50	11.00	12.20	34.5		7.47	7.47	13.03	12.97	73.6
	pF 2.8		10.17	10.97	11.87	10.60	4.2		7.47	7.47	9.60	10.97	46.9
sa	pF 2.0		11.43	12.87	13.70	15.20	33.0		8.00	8.17	14.93	16.40	105.0
A)	pF 2.5		11.00	11.40	11.03	12.03	9.4		7.97	7.97	14.17	16.03	101.1
	pF 2.8		9.09	10.24	10.22	10.18	12.0		8.17	7.50	10.10	10.97	34.3
SD (M.A.)		1.066	0.581		0.94			0.650	0.627	1.369	0.655		
SD (M.A.*V)		2.383	1.299		2.10			1.453	1.403	3.062	1.465		
CV%		13.7	6.2	8.5	9.1			10.3	9.9	13.1	12.0		
Moisture Availability													

Moisture Availability



8_A



8_B

Figure 8. Mean stem girth reduction due to drought stress (8_A -8_B)

4.2.3 Cultivar leaf area expansion potential under drought stress

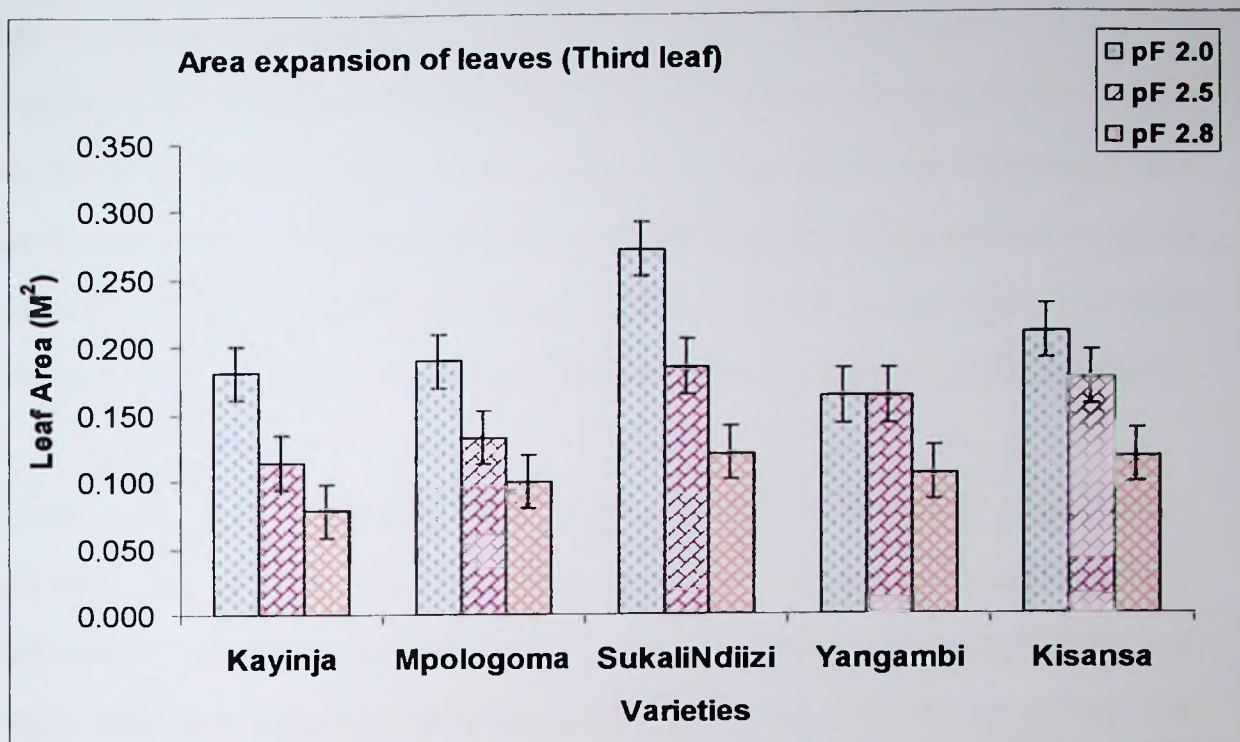
In spite of the variation across seasons, the results showed that the potential for leaf expansion increased with maximum water availability (pF 2.0) based on the morphological nature of the cultivar leaf, and diminished subsequently upon reduction in soil available water. The effect therefore suggested that water deficit slowed the advance in plant development (Table 7) limiting the potential for full leaf expansion. Similar effects were observed by Alves (2004) on limited leaf area expansion of cassava due to water deficit. However at field capacity (free drainage), cv. *Sukali Ndiizi* (0.275cm^2 ; 0.271cm^2), and *Kisansa* (0.519cm^2 ; 0.209cm^2) produced the largest leaf area. But cv. *Kayinja* (0.191cm^2 ; 0.181cm^2), *Mpologoma* (0.171cm^2 ; 0.189cm^2) and *Yangambi Km5* (0.092cm^2) produced narrow leaf area for 2008 A & B seasons respectively. However, there was leaf area expansion interaction across varieties at the subsequent reduced available moisture (Fig. 9A).

The increase in available moisture from pF 2.0-2.5 affected the plant's potential for leaf area expansion by 1.7% (*Kayinja*), 31% (*Sukalindiizi*) and pF 2.8 (*Mpologoma*) (Fig. 9B). The scores led to a suggestion that for proper leaf expansion in size, the moisture should be maintained at field capacity level hence the threshold controlled at pF 2.0. The leaf area reduction per variety was observed at different water regimes. Upon reducing the available moisture from pF 2.0 to pF 2.5, the leaf area of cv. *Kayinja* gradually diminished immediately from 0.162cm^2 , correlating with the 18.3% proportion of leaf size reduction. Cultivar *Kisansa* and *Yangambi Km5* possessed a similar mode of significant deviated in leaf size reduction when the available moisture was decreased from pF 2.5 to 2.8 hence indicating a threshold value of 0.099cm^2 and 0.090cm^2 respectively. A similar trend of leaf expansion threshold between cv. *Kayinja* and *Mpologoma* were observed but significantly reducing the leaf size from 0.114cm^2 and 0.107cm^2 upon decreased available moisture from pF 2.0- pF 2.5 (Fig. 9A). The results therefore suggested cv. *Sukali Ndiizi*, cv. *Kayinja* and cv. *Mpologoma* require a lot of water (pF 2.0) to maintain their leaf expansion potential whilst cv. *Kisansa* and *Yangambi Km5* required little additional water to pF 2.5 to be able to expand fully.

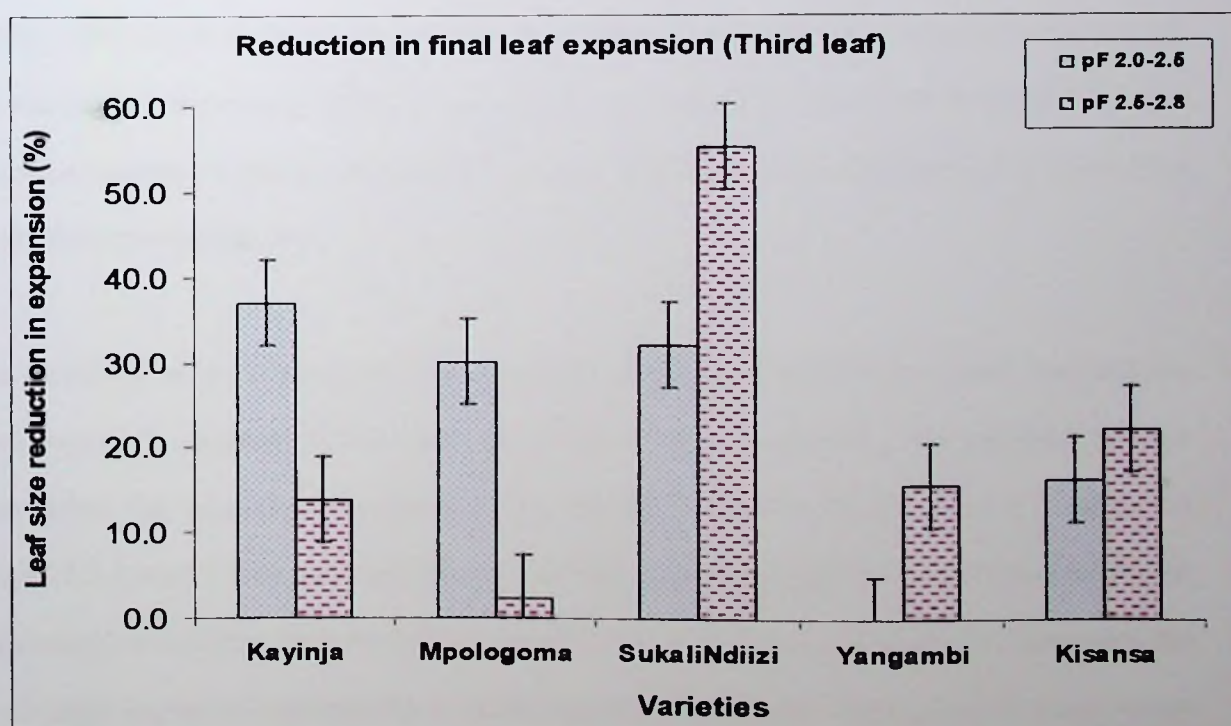
Table 7. Leaf area expansion of selected banana cultivars across different moisture regimes

		Season1 (2008 _a)					Season2 (2008 _b)				
Variety	Moisture Regimes (M.A.)	Sampling Interval (Month)				Leaf Increase —%—	Sampling Interval (Month)				Leaf Increase —%—
		1	2	3	4		1	2	3	4	
		cm					cm				
Yinja	pF 2.0	0.093	0.109	0.150	0.191	51.3	0.042	0.086	0.097	0.181	76.8
BB)	pF 2.5	0.067	0.086	0.112	0.127	47.2	0.041	0.065	0.064	0.114	64.0
	pF 2.8	0.080	0.091	0.108	0.129	38.0	0.035	0.051	0.055	0.078	55.1
Pologoma	pF 2.0	0.065	0.095	0.116	0.171	62.0	0.044	0.083	0.105	0.189	76.7
	pF 2.5	0.052	0.086	0.097	0.115	54.8	0.050	0.056	0.060	0.132	62.1
	pF 2.8	0.078	0.093	0.087	0.098	20.4	0.039	0.072	0.066	0.099	60.6
Kali Ndiizi	pF 2.0	0.057	0.123	0.171	0.275	79.3	0.082	0.134	0.175	0.271	69.7
	pF 2.5	0.070	0.096	0.133	0.164	57.3	0.057	0.095	0.092	0.184	69.0
	pF 2.8	0.074	0.103	0.085	0.139	46.8	0.083	0.099	0.096	0.120	30.8
Ngambi	pF 2.0	0.067	0.093	0.131	0.158	57.6	0.044	0.077	0.083	0.162	72.8
	pF 2.5	0.062	0.079	0.098	0.117	47.0	0.045	0.071	0.088	0.162	72.2
	pF 2.8	0.082	0.079	0.090	0.097	15.5	0.041	0.064	0.058	0.105	61.0
Wansa	pF 2.0	0.094	0.099	0.120	0.159	40.9	0.046	0.084	0.103	0.209	78.0
	pF 2.5	0.091	0.102	0.110	0.126	27.8	0.048	0.069	0.072	0.175	72.6
	pF 2.8	0.073	0.085	0.094	0.109	33.0	0.051	0.071	0.071	0.117	56.4
D (M.A.)		0.017	0.008		0.016		0.011	0.016	0.023	0.034	
D (MA*V)		0.038	0.018		0.036		0.025	0.035	0.053	0.076	
r%.		30.0	11.2	15.7	14.8		29.9	26.5	36.7	30.0	

M.A. = Moisture Availability



9_A



9_B

Figure 9. Leaf expansion and reduction potential of selected banana cultivars (9_A-9_B)

4.2.4 Fresh plant weight

The results in Table 8 indicated the cumulative biomass weight for four months across moisture deficit levels and genotypes more distinctly during the 2008_B season. The difference in plant tissue development potentials were attributed to both moisture deficit and seasonal variations. Tissue weights reduced significantly across increased moisture deficit levels with more significant cumulative variation were observed in second than first season over months (Table 8).

The fresh tissue weight quantification results at harvest showed the highest total weight with cv. *Sukali Ndiizi* (AAB) at 2240g, 1181g, and 515.0g for *pF* 2.0, *pF* 2.5 and *pF* 2.8 respectively for 2008_B season (Table 8) (Fig. 10A), indicating a cumulative proportion decrease of 58.0% and 48.0% in weight upon available moisture reduction from *pF* 2.0 to *pF* 2.5 and *pF* 2.5 to *pF* 2.8 levels. The cooking cultivars (*Kisansa* and *Mpologoma*) equally performed well by weighing 1887g, 1396g and 476g (cv. *Kisansa*) and 1700g, 998g and 466g (cv. *Mpologoma*) for *pF* 2.0, *pF* 2.5 and *pF* 2.8 respectively indicating a cumulative proportion decrease of 29% and 42% with increased moisture reduction from *pF* 2.0 to *pF* 2.5; with 69% and 52% from *pF* 2.5 to *pF* 2.8 levels respectively (Fig. 10_B)

The sensitivity of cv. *Kisansa* and *Mpologoma* to drought stress effect increased cumulatively upon increased moisture deficit level (*pF* 2.5-2.8) hence suggesting the potential for less adaptability. Subsequently, cv. *Kayinja* (ABB) finally weighed 1664g, 1154g, and 374g for *pF* 2.0, *pF* 2.5 and *pF* 2.8 levels (Table 8) with cumulative proportion decrease of 31% and 68% for moisture reduction from *pF* 2.0 to *pF* 2.5 and *pF* 2.5 to *pF* 2.8 levels respectively. The results for cv. *Kayinja* showed its susceptibility to fresh biomass accumulation when moisture deficit levels were decreased especially from *pF* 2.5 to *pF* 2.8. Ultimately cv *Yangumbi Km5* (AAA-lowland)

exhibited the lowest fresh weight at 1479g, 1172g and 391g for pF 2.0, pF 2.5 and pF 2.8 respectively.

The threshold critical points for initial signs of susceptibility to drought stress were determined, first through comparison of highland cooking cultivars with genomic composition of AAA (*Mpologoma* and *Kisansa*) together with the dessert cultivar of AAB (*Sukali Ndiizi*) (Fig 10_B). Despite cv. *Sukali Ndiizi* weighing heavily in plant tissue than cv. *Mpologoma* and *Kisansa*, the initial signs of stress were observed when moisture deficit levels were increased from pF 2.0 to pF 2.5. With further increase in moisture deficit, the deviation in tissue weight across moisture regimes were equally high hence the potential for susceptibility. The cooking cultivars showed susceptibility to moisture stress especially when moisture deficit was increased from pF 2.0 to pF 2.5, with cv. *Kisansa* exhibiting the greatest effect than cv. *Mpologoma* and cv. *Sukali Ndiizi* (Fig. 10_B).

The second comparisons for threshold determination were between the plantain with ABB genomic composition (cv. *Kayinja*) and highland cooking cultivars (*Mpologoma* and *Kisansa*) of AAA genome (Fig. 10_A). Cultivar *Kayinja* produced the lowest tissue at pF 2.0. and produced a less gradual decrease in weight than the cooking cultivars of *Mpologoma* and cv. *Kisansa*. However, despite the non significance in percentage of proportional decrease in weight at pF 2.0., the initial signs were observed upon increased moisture deficit (pF 2.0 to pF 2.5) from the optimal point. Cultivar *Kisansa* and *Kayinja* showed the greatest signs of reduced weight than cv. *Mpologoma* when moisture deficit level was increased from pF 2.5 to pF 2.8 M.A indicating the highest level of susceptibility. However, cv *Mpologoma* exhibited some level of resistance to drought stress at pF 2.5 to pF 2.8 though not significantly different (Fig. 10_B).

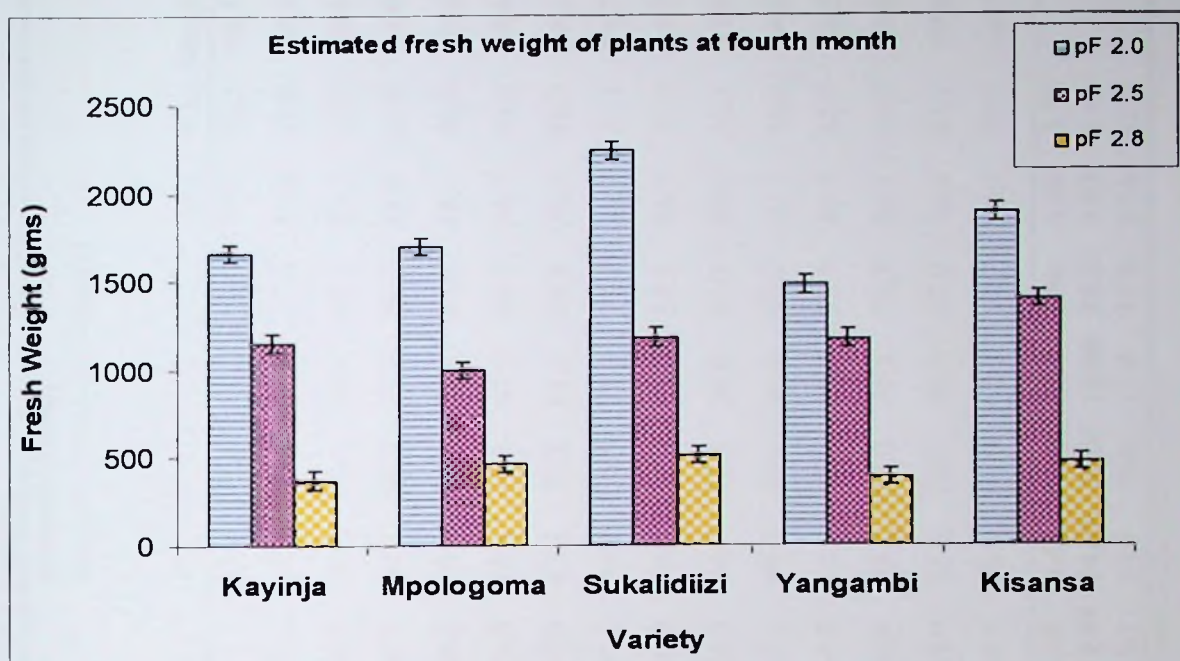
The third final comparisons for threshold level of susceptibility were between the cooking highland cultivars of (*Kisansa* and *Mpologoma*) of AAA genome and the low land cultivar (*Yangambi Km5*) of the AAA genome (Fig. 10E). All the cultivars (AAA) exhibited decreased tissue weight upon moisture deficit increase from pF 2.0 to pF 2.5 with cv. *Kisansa* and *Yangambi km5* proportionally more affected but significant interactions of susceptibility and tolerance were observed upon increased moisture deficit from pF 2.5 to pF 2.8 (Fig. 10B). Cultivar *Kisansa* and *Yangambi km5* proportionally suffered more tissue weight loss than cv. *Mpologoma*.

Table 8. Estimated fresh weight (leaf, stem, corm and roots) of selected banana cultivars across different moisture regimes

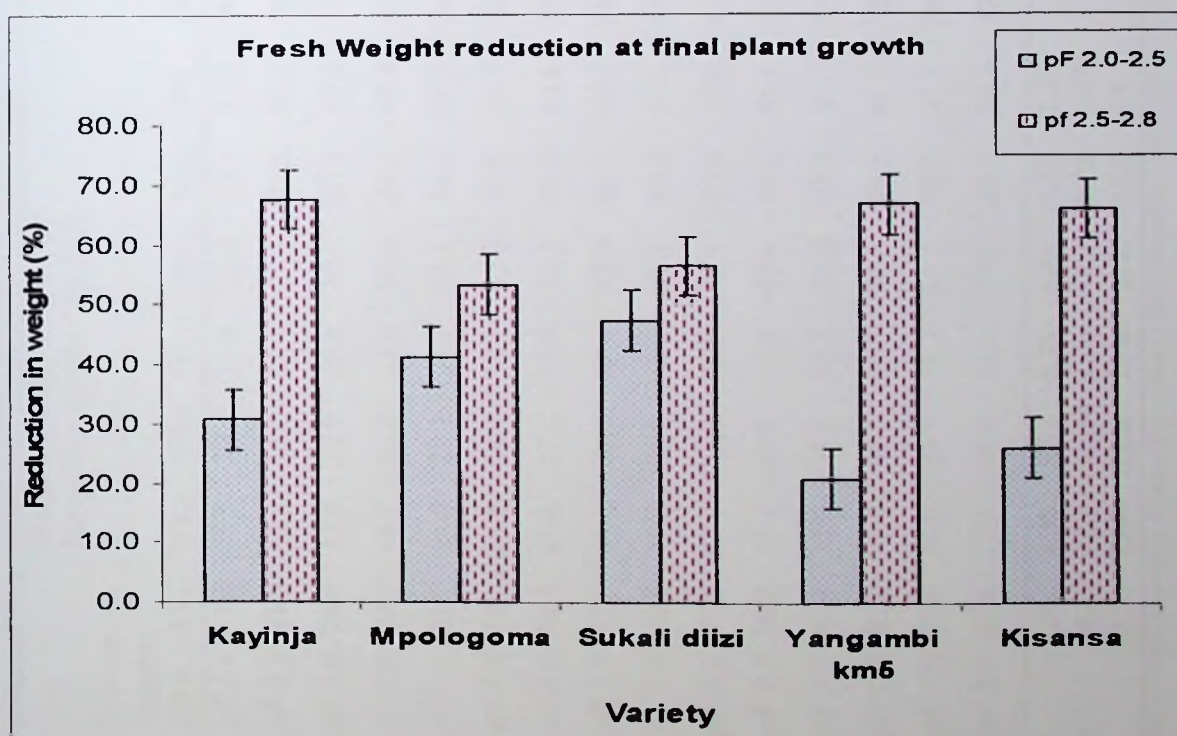
Variety	Moisture Regimes (MA)	Season1 (2008 _a)					Season2 (2008 _b)					Weight PL wgt (%)
		Sampling Interval (Month)					Sampling Interval (Month)					
		Fresh					Fresh					
		1	2	3	4	Increase %	1	2	3	4	Increase %	
		gms					gms					
<i>Kayinja</i>	<i>pF</i> 2.0	361.3	1270	2451	3053	745.0	204	501	774	1664	715.7	
(ABB)	<i>pF</i> 2.5	288.4	955	1742	1072	271.7	220	386	675	1154	424.5	30.6
	<i>pF</i> 2.8	309.1	1053	1725	945	205.7	187	187	335	374	100.0	67.6
<i>Mpologoma</i>	<i>pF</i> 2.0	328.8	1077	2193	2735	731.8	231	516	846	1700	635.9	
(AAA)	<i>pF</i> 2.5	299.6	993	1725	1103	268.2	263	361	654	998	279.5	41.3
	<i>pF</i> 2.8	332.2	1018	1658	904	172.1	233	350	472	466	100.0	53.3
<i>Sukalidiizi</i>	<i>pF</i> 2.0	410.3	1536	2948	3719	806.4	394	823	1245	2241	468.8	
(AAB)	<i>pF</i> 2.5	378.4	1239	2166	1347	256.0	308	498	742	1181	283.4	47.3
	<i>pF</i> 2.8	383.5	1279	2123	1123	192.8	392	357	334	515	31.4	56.4
<i>Yangambi km5</i>	<i>pF</i> 2.0	410.3	1383	2610	3059	645.6	214	469	730	1479	591.1	
(AAA-LL)	<i>pF</i> 2.5	368.3	1201	2026	1174	218.8	229	376	659	1172	411.8	20.8
	<i>pF</i> 2.8	371.8	1189	2173	1014	172.7	226	229	252	391	73.0	66.6
<i>Kisansa</i>	<i>pF</i> 2.0	375.1	1171	2216	2670	611.8	229	662	847	1887	724.0	
(AAA)	<i>pF</i> 2.5	353.8	1098	1849	1135	220.8	262	424	713	1396	432.8	26.0
	<i>pF</i> 2.8	302.7	923	1613	833	175.2	245	343	279	476	94.3	65.9
LSD (M.A.)		23.48	70.3		151.0		32.05	71.5		121.3		
LSD (M.A.*V)		52.51	157.1		337.6		71.67	159.9		271.1		
CV%		8.9	8.0	9.7	11.6		16.7	22.1	18.6	14.2		

Moisture Available, PL wgt = proportional loss in biomass weight

MA=Moisture Available, PL wgt = proportional loss in biomass weight



10_A



10_B

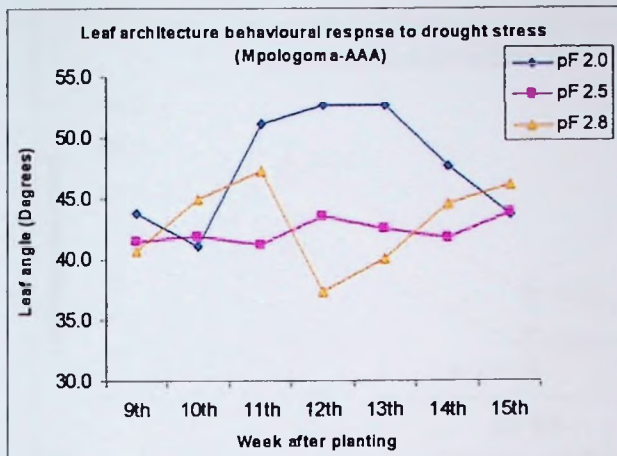
Figure 10. Fresh biomass accumulation and percent reduction in wgt of selected banana cultivars (Fig. 10_A & 10_B)

Table 9 Leaf angle of selected banana cultivars across moisture deficit regimes

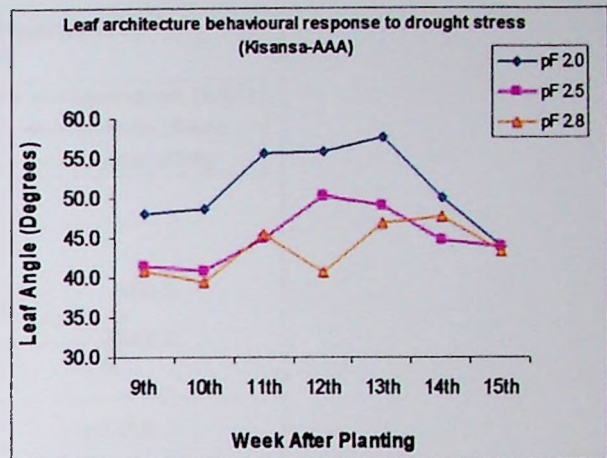
Season1 (2008 _a)															Season2 (2008 _b)				
Sampling intervals (Weekly)															Sampling intervals (Weekly)				
Moisture Regimes																			
Variety	(M.A.)	Wk ₉	Wk ₁₀	Wk ₁₁	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Mean	Wk ₉	Wk ₁₀	Wk ₁₁	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Mean		
<i>Kayinja</i>	<i>pF</i> 2.0	33.8	25.5	30.7	23.8	22.2	50.3	52.9	34.2 ^{a*}	61.3	63.7	75.0	81.3	85.0	49.0	43.3	65.5 ^a		
(ABB)	<i>pF</i> 2.5	31.7	32.3	22.0	21.5	21.1	37.5	45.2	30.2 ^a	60.3	63.3	50.0	56.3	61.0	45.0	43.0	54.1 ^b		
	<i>pF</i> 2.8	24.4	33.4	31.9	28.3	30.8	42.3	40.4	32.4 ^a	57.0	59.3	53.0	60.3	62.7	53.7	47.0	56.1 ^b		
<i>Mpologoma</i>	<i>pF</i> 2.0	24.5	18.1	36.2	33.6	28.6	44.5	47.4	33.3 ^a	63.3	64.3	66.0	71.7	76.7	51.0	40.0	61.9 ^a		
(AAA)	<i>pF</i> 2.5	13.7	13.5	25.3	24.1	21.2	34.9	41.8	24.9 ^b	69.3	70.3	57.3	63.0	64.0	48.7	46.0	59.8 ^a		
	<i>pF</i> 2.8	7.6	13.8	24.4	10.9	13.6	34.6	43.3	20.6 ^b	74.0	76.3	70.3	64.0	66.7	54.7	49.0	65.0 ^a		
<i>Sukali Ndiizi</i>	<i>pF</i> 2.0	34.8	27.2	37.4	32.9	32.3	48.6	53.6	38.1 ^a	43.0	45.3	75.3	81.3	84.3	34.7	42.7	58.1 ^a		
(AAB)	<i>pF</i> 2.5	32.9	34.1	30.2	32.4	32.9	46.1	49.5	36.9 ^a	51.3	54.7	64.3	71.3	77.7	35.7	34.7	55.7 ^a		
	<i>pF</i> 2.8	45.1	16.3	34.8	33.8	39.1	40.6	55.6	37.4 ^a	49.7	52.0	44.0	51.0	55.3	44.3	37.7	47.7 ^a		
<i>Yangambi km5</i>	<i>pF</i> 2.0	37.3	35.9	43.3	43.0	42.8	56.6	57.0	45.1 ^a	43.0	44.7	52.3	58.0	60.7	40.0	36.7	47.9 ^a		
(AAA-LL)	<i>pF</i> 2.5	26.2	35.4	43.8	45.6	43.4	49.6	56.1	42.9 ^a	47.3	49.3	41.0	46.0	51.0	40.7	36.0	44.5 ^a		
	<i>pF</i> 2.8	25.4	32.6	38.1	29.2	33.2	53.9	58.3	39.6 ^a	61.0	63.0	43.3	50.0	52.3	40.3	32.7	48.5 ^a		
<i>Kisansa</i>	<i>pF</i> 2.0	40.2	38.4	39.1	35.3	36.8	46.5	41.7	39.7 ^a	56.0	58.7	72.0	76.3	78.3	53.7	45.7	63.0 ^a		
(AAA)	<i>pF</i> 2.5	22.9	20.0	24.7	31.3	31.2	39.3	43.1	30.4 ^b	60.0	61.7	64.7	69.3	67.0	50.0	44.7	59.6 ^a		
	<i>pF</i> 2.8	17.4	12.7	34.7	18.6	29.1	36.5	34.3	25.6 ^b	64.3	66.0	56.0	62.7	64.7	58.7	52.3	60.7 ^a		
LSD (M.A.)		6.54	4.25	5.52	5.73	5.01	4.15	2.45		6.48	6.35	9.10	8.36	8.98	4.40	3.58			
LSD (M.A.*V)		14.62	9.51	12.34	25.6	11.19	9.28	5.47		14.49	14.21	20.34	18.69	20.07	9.83	8.00			
CV%		31.1	21.9	21.6	25.6	21.6	12.6	6.8		15.1	14.3	20.6	17.4	17.9	12.6	11.4			

AAV = Moisture Availability. *means followed by the same letter within a column are not significantly different according to student-new-man-Keuls (S-S-N-K) test

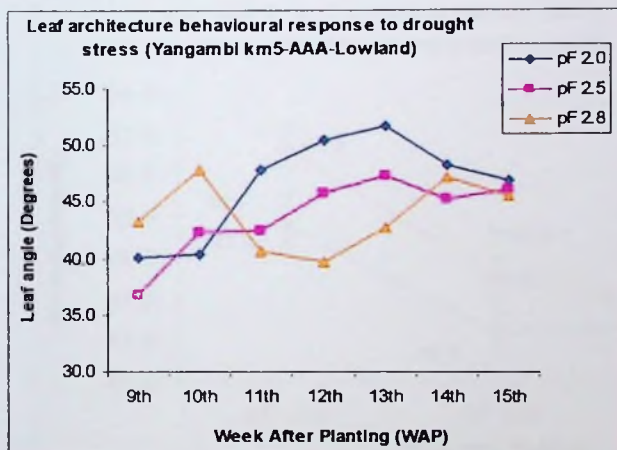
M.A. = Moisture Availability. *means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test



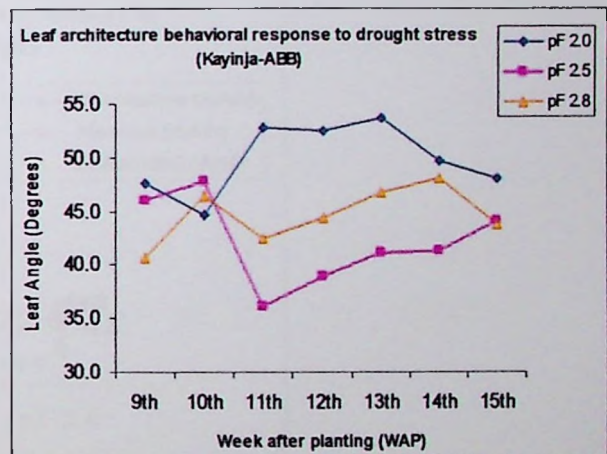
11_A- Mpologoma



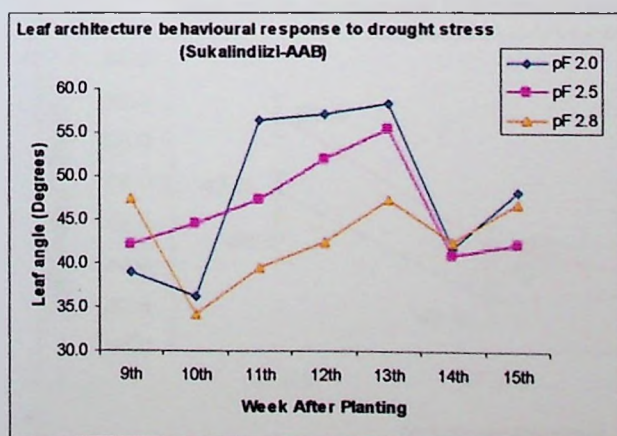
11_B-Kisansa



11_C-Yangambi Km5

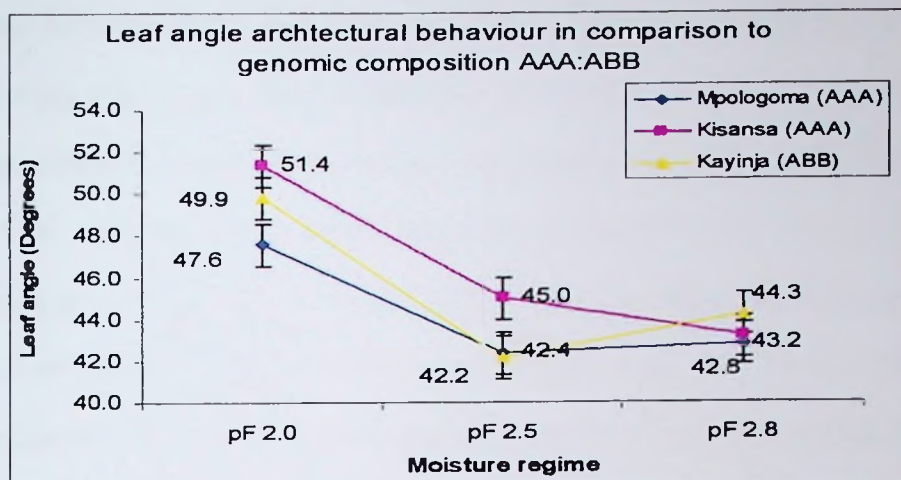


11_D- Kayinja

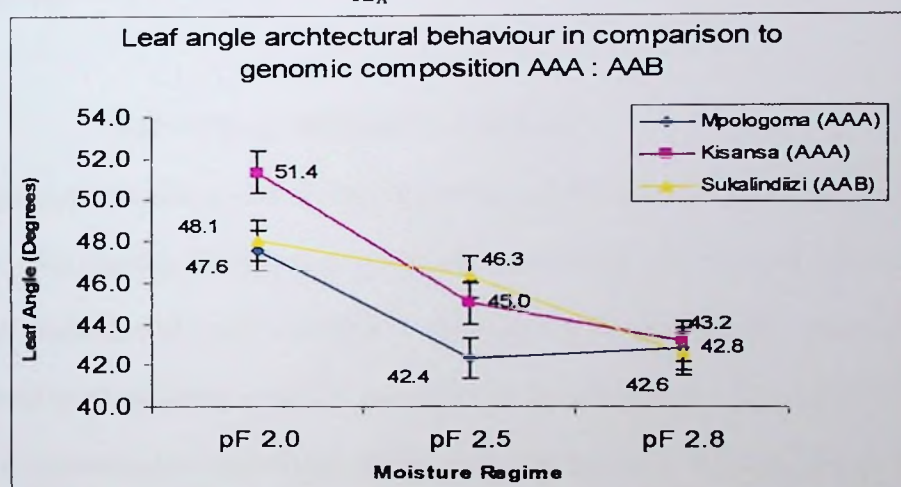


11_E-Sukali Ndiizi

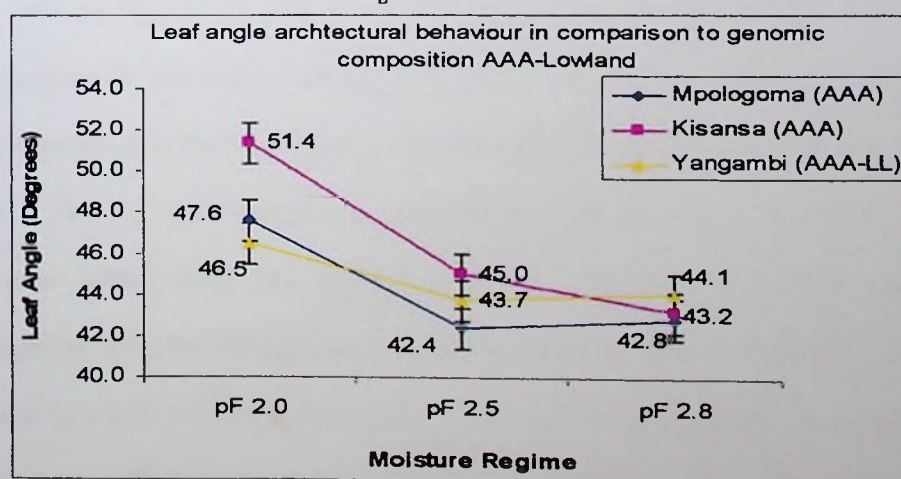
Figure 11. Leaf angle orientation of selected banana cultivars across moisture deficit levels for 15 weeks



12_A



12_B



12_C

Figure 12_{A-C} Comparison of average leaf angle architecture of selected banana cultivars based on genomic composition

Variety leaf orientations showed no significant differences across moisture deficit levels and over weeks (Fig 11_{A-E}). The leaf standing angles were not consistent over weeks due to the changing diurnal periods. However, the comparison of cooking cultivars (AAA-EA genome) with ABB, AAB and AAA-lowland genomic cultivars showed cv. *Kayinja* with higher potential of drooping leaves hence wider angles (Fig 12_{A-C}). The angle interactions were observed at pF 2.5 and pF 2.8. levels with relatively narrow angles between the pseudo-axial and the third leaf. Leaf angle interactions were attributed partly to changing diurnal periods and leaf structure at the young stage of plant growth.

4.3.2 Leaf folding architectural behavior

The genotype results of leaf folding behaviour across moisture deficit levels from ninth to fifteen weeks after planting (WAP) were presented in the Table 10. The leaf orientation indicated larger surface opening with more available water in soil. The potential for leaves to remain spread were observed in all varieties at pF 2.0 and folded with increased moisture deficit levels of pF 2.5 and pF 2.8 respectively. Significant differences among water regimes were observed though and there were no significant interaction between genotypes and moisture deficit levels over time. The decrease in soil water content (pF 2.5 and pF 2.8 M.A.) from the field capacity caused a stress situation of plant dehydration and deterred leaf lamina expansion due to reduced leaf water potential (LWP). By avoiding a dehydration phenomenon of excessive loss of leaf water, genotypes folded their leaf lamina to reduce the leaf evaporative surface and lowered transpiration rate. In addition to lowered transpiration, the drought avoidance mechanism was reported to improve plant water use efficiency and maintaining relatively positive leaf water potential and efficient stomata regulation of transpiration (Shmueli, 1953). The phenomena of leaf midrib folding potentials were similarly observed and reported by Kusaka (2005) on pearl

millet. However, despite an avoidance mechanism to drought stress, the leaf orientation potential were also reported to lower photosynthetic activity through reduced the surface area for light interception and increased diffusion resistance to carbon dioxide (CO₂) (Kusaka, 2005).

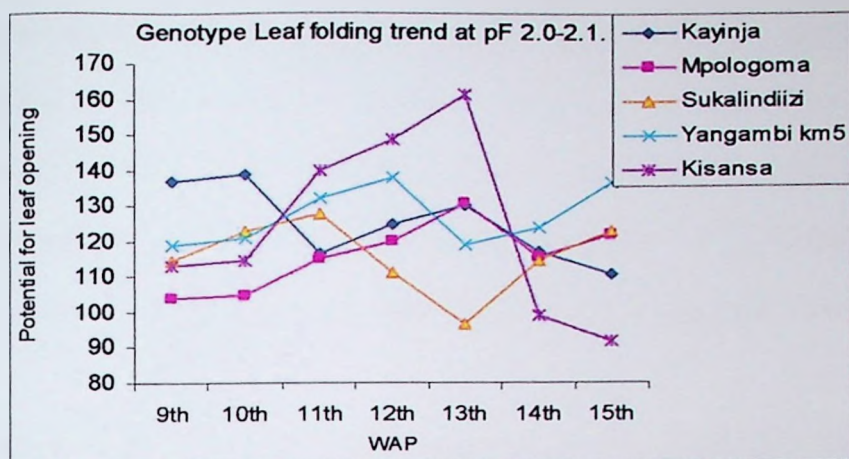
Among the genotypes potential for orienting leaves open, cv. *Yangambi Km5* (126⁰), cv. *Kayinja* (125⁰) and cv *Kisansa* (124⁰) were found to bear the leaves wide spread at *pF* 2.0. (Table10) on average, and the least orientation were observed among cv. *Sukali Ndiizi* (115.7⁰), cv. *Mpologoma* (116⁰) (Fig. 13_A) despite growing on free drainage media. However, at *pF* 2.5, unlike other genotypes, cv. *Yangambi Km5* (129⁰) was not affected by moisture deficit increment, but cv. *Kisansa* (105⁰) and *Mpologoma* (109⁰) began to fold leaves than cv. *Kayinja* (111.7⁰) and cv. *Sukali Ndiizi* (111.7⁰) (Fig. 13_B). At *pF* 2.8, cv. *Sukali Ndiizi* (74.2⁰), *Mpologoma* (109⁰) and cv. *Kisansa* (103.7⁰) exhibited more folded leaves from 180⁰ surface orientation. Other cultivars leaves were relatively oriented open though not significantly different (Fig. 13_C).

The results of leaf orientation exhibited a significant difference across moisture deficit levels. The observed increase in moisture deficit (*pF* 2.5 M.A) from free drainage led to a conclusion that cv. *Kisansa* and cv. *Mpologoma* (cooking genotypes) exhibited the folding mechanism much more than other cultivars. The observation meant the cultivars potential to avoid excessive dehydration and therefore some level of turgidity to facilitate dry matter translocation. However, in a more stressful situation (*pF* 2.8), still cooking cultivars and cv. *Sukali Ndiizi* exhibited sensitivity to drought stress and folded the leaves (Table 10). The initial signs of folding mechanism (failure to orient leaves open to 180⁰) were observed upon moisture deficit increment at *pF* 2.5 and were more distinct at *pF* 2.8 in the order of cv. *Sukali Ndiizi* at 74.2⁰, cv. *Mpologoma* at 98.9⁰ and cv. *Kisansa* at 103.7⁰ open respectively.

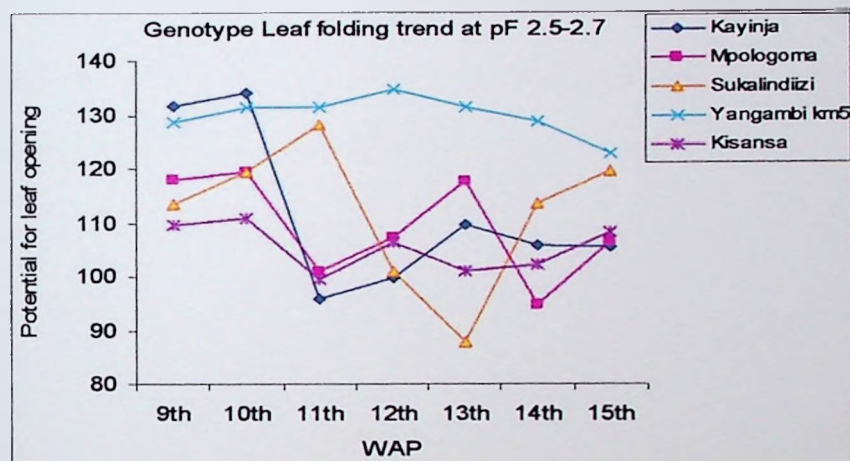
Table 10. Leaf folding behavior of selected banana cultivars across different moisture regimes

Variety	Moisture Regimes (M.A.)	Season2 (2008 _b)							
		Sampling intervals (Weekly)							
		Leaf surface opening (inner midrib)							
		Wk ₉	Wk ₁₀	Wk ₁₁	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Mean
		Degrees							
<i>Kayinja</i>	<i>pF</i> 2.0	137.0	139.0	116.7	124.7	130.0	117.0	110.7	125.1 ^{a**}
(ABB)	<i>pF</i> 2.5	131.7	134.0	95.7	99.7	109.7	105.7	105.3	111.7 ^b
	<i>pF</i> 2.8	127.7	130.0	106.7	112.3	115.3	85.3	85.3	109.0 ^b
<i>Mpologoma</i>	<i>pF</i> 2.0	103.7	104.7	115.0	120.0	130.7	115.7	122.0	116.0 ^a
(AAA)	<i>pF</i> 2.5	118.0	119.3	101.0	107.3	117.7	94.7	106.3	109.2 ^b
	<i>pF</i> 2.8	106.0	107.7	93.7	98.3	103.7	88.0	95.0	98.9 ^b
<i>Sukali Ndiizi</i>	<i>pF</i> 2.0	114.3	122.7	127.7	111.3	96.7	114.3	122.7	115.7 ^a
(AAB)	<i>pF</i> 2.5	113.3	119.3	128.0	101.0	87.7	113.3	119.3	111.7 ^a
	<i>pF</i> 2.8	70.0	78.0	88.7	58.7	75.7	70.0	78.0	74.1 ^b
<i>Yangambi Km5</i>	<i>pF</i> 2.0	118.7	120.7	132.0	137.7	118.7	123.7	136.3	126.8 ^a
(AAA-LL)	<i>pF</i> 2.5	128.7	131.3	131.3	134.7	131.3	128.7	122.7	129.8 ^a
	<i>pF</i> 2.8	110.7	117.0	120.7	100.0	129.0	95.7	120.3	113.3 ^b
<i>Kisansa</i>	<i>pF</i> 2.0	113.3	114.3	140.0	148.7	161.3	99.0	91.7	124.1 ^a
(AAA)	<i>pF</i> 2.5	109.7	110.7	99.3	106.3	101.0	102.0	108.0	105.3 ^b
	<i>pF</i> 2.8	121.0	120.7	94.7	99.3	105.0	90.0	95.0	103.5 ^b
LSD (M.A.)		10.74	11.24	9.67	10.67	12.20	8.66	10.91	
LSD (M.A.*V)		24.02	25.13	21.63	23.86	27.28	19.35	24.39	
CV%		12.5	12.7	11.5	12.9	14.3	11.2	13.5	

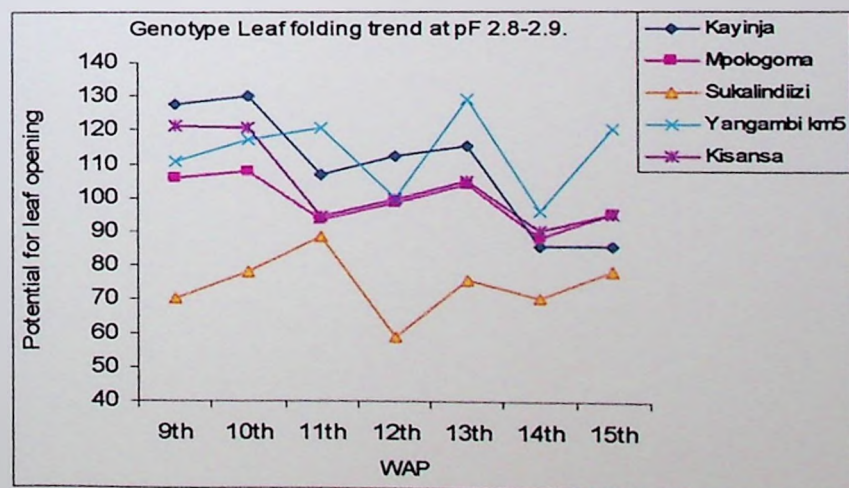
M.A. = Moisture Available, *means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test.



13_A



13_B

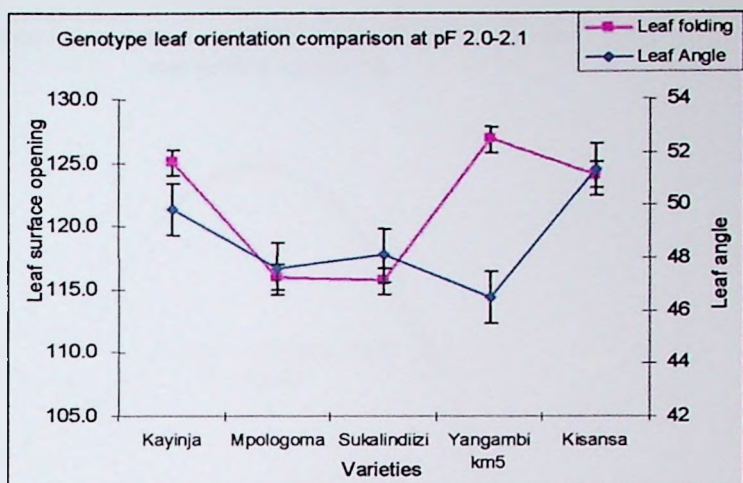


13_C

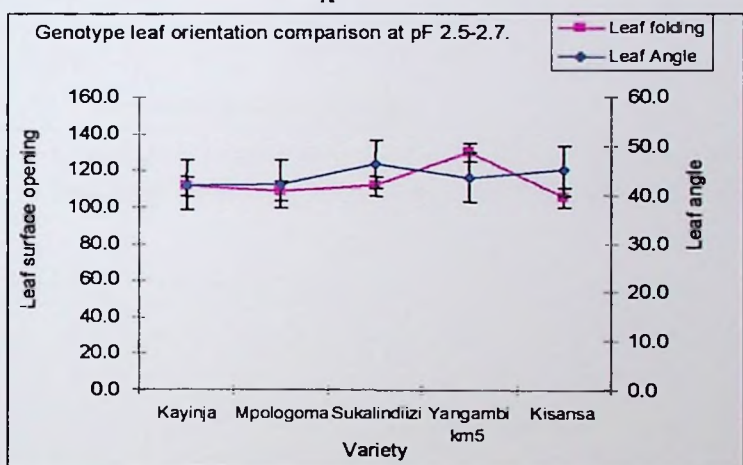
Figure 13. Trend of genotypic leaf folding for pF 2.0; 2.5; 2.8 (Fig 13_{A-C})

Despite drought avoidance mechanisms of leaf angle and folding orientation being subject to regulating the transpiration rate based on surface area exposure, were found not to exhibit correlation orientation with increased moisture deficit levels of pF 2.5 and pF 2.8 Leaf folding was not based on leaf drooping mechanism (Fig 15_{A-C}). However, at pF 2.0, turgid leaves were found to droop and simultaneously folded significantly across genotypes.

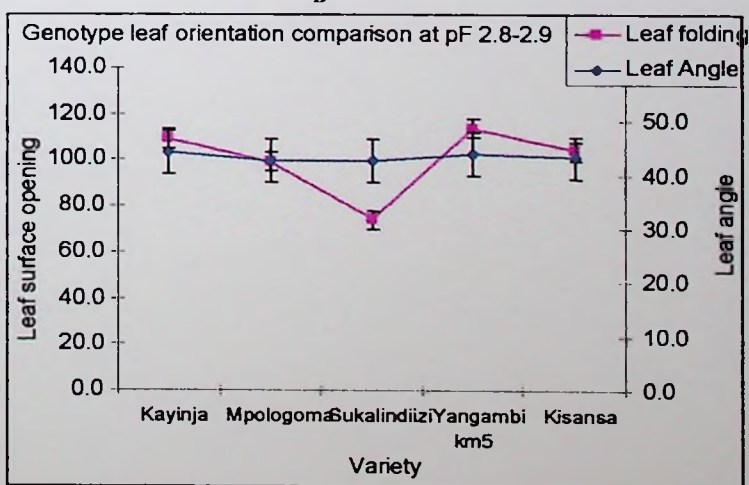
Leaves folded as the standing angle changed by drooping especially for cv. *Kisansa* and cv *Mpologoma*. The polynomial regression trend showed a positive correlation of leaf angle and the potential to open wide at pF 2.0 (Fig.16). The correlation was partly attributed to the leaf turgidity and size relative to proximal stem.



15_A



15_B



15_C

Figure 15_{A-C} Leaf orientation (Leaf angle and folding) comparisons of selected E.A banana cultivars

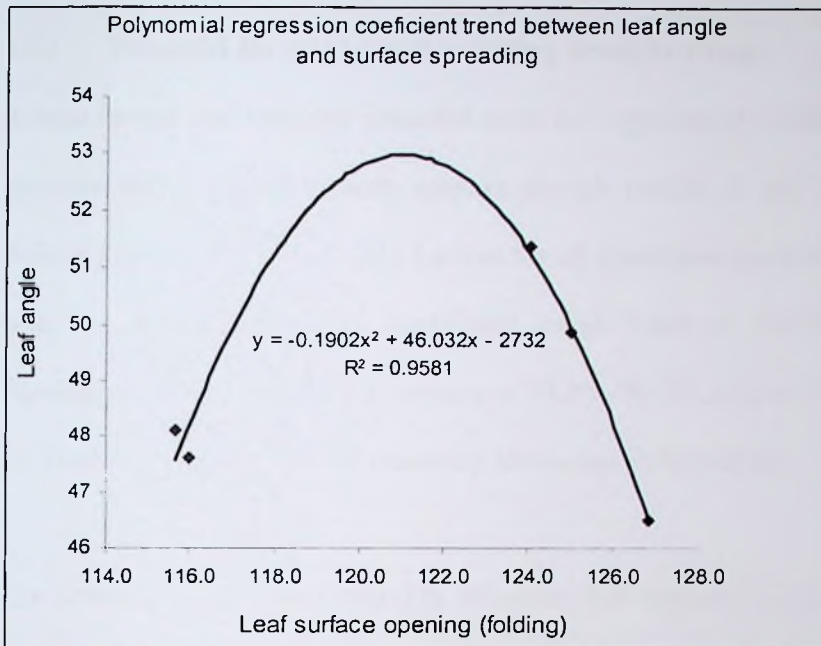


Figure 16. Correlation coefficient between leaf angle and potential for folding among four selected EA highland and one lowland banana cultivars

4.3.3 Potential for leaf turgidity during drought stress

Results for the leaf turgidity potential were not significantly different across genotypes and moisture deficit levels in both seasons though results in the second season were more definite (Table 11) (Fig. 17). The Leaves for all genotypes expressed full turgidity at pF 2.0. with cv. *Kayinja* averagely containing more water at 95.4% RWC, followed by cv. *Mpologoma*, *Sukali Ndiizi* and *Kisansa* at 93.9%, 93.3% and 93.2% RWC respectively. But cv. *Yangambi Km5* contained relatively less water at 92% RWC.

The potential for full leaf turgidity enhanced cell expansion for CO_2 conductance through stomata and similarly led to high transpiration rate (Fig. 18B) and biomass development (Fig 10_A). At pF 2.5 M.A., the genotypes leaf RWC dropped though not significantly. *Mpologoma* (cooking cultivar) retained relatively higher leaf turgidity at 92.5% than cv. *Sukali ndiizi* (90.5%), cv. *Kayinja* and *Kisansa* (90.0% RWC), and *Yangambi Km5* at 88.1% in second season (Table 11) (Fig.17). The increment of moisture deficit from pF 2.0-2.5 indicated a significantly different proportion of reduction from full leaf turgidity potential. Cultivar *Kayinja* and *Yangamb km5* were more affected proportionally at 7.0% and 7.4% RWC reduction respectively than cv. *Sukali Ndiizi* (4.8%), cv. *Kisansa* (3.6%) and cv. *Mpologoma* (0.3%).

The effects of turgidity reduction due to moisture deficit increment from pF 2.0-2.5 were therefore considered of less impact to cooking banana cultivars but rather drought sensitivity to the desert and plantain type which justify the need to express the dehydration avoidance mechanisms for plant survival. Further increment of moisture deficit in soil from

pF 2.5--2.8, indicated a higher water saturation deficit hence low turgidity in leaves. The cooking banana types of cv. *Mpologoma* (85.4% RWC) and *Kisansa* (78.6% RWC) were more dehydrated hence the severe sensitivity to drought stress than cv. *Sukali ndiizi* at 90.2% (Table 11, second season).

The relative leaf turgidity enhanced cells to remain extended for transpiration yet the lost water was far higher than the replaceable in soil hence the sensitivity and failure to survive in adverse conditions. The leaves of other genotypes (*Kayinja*, *Sukali Ndiizi* and *Yangambi Km5*) were relatively hydrated (83.3- 90.2 RWC). The hydration potential was attributed to possession of behavioral traits that enhanced mechanisms for drought avoidance. The average proportions of leaf dehydration due to moisture deficit increment from 60 to pF 2.8 were higher for cv. *Mpologoma* (10.2%) and cv. *Kisansa* (7.4) compared to cv. *Kayinja* and cv. *Sukali Ndiizi* at 3.5% and 3.2% respectively. Cultivar *Yangambi Km5* was proportionally the least affected in leaf turgidity due to moisture deficit increment.

Table 11. Relative leaf water content of selected banana cultivars across different moisture regimes

Variety	Moisture Regime (M.A.)	(2008 _a Season)					(2008 _b Season)				
		FW	SW	DW	RWC	WSD	FW	SW	DW	RWC	WSD
		— gms		— gms		— %	— gms		— gms		— %
<i>Kayinja</i> (ABB)	<i>pF</i> 2.0	0.48	0.48	0.10	98.4	1.6	0.43	0.46	0.07	92.3	7.7
	<i>pF</i> 2.5	0.48	0.53	0.09	87.8	12.2	0.42	0.46	0.06	90.0	10.0
	<i>pF</i> 2.8	0.45	0.50	0.10	86.4	13.7	0.41	0.47	0.06	85.4	14.6
	Lsd (M.A.)	0.08	0.07	0.01			0.06	0.05	0.02		
	CV%	6.6	5.1	4.3			5.7	4.6	12.1		
<i>Mpologoma</i> (AAA)	<i>pF</i> 2.0	0.53	0.55	0.10	95.4	4.6	0.44	0.47	0.07	92.5	7.5
	<i>pF</i> 2.5	0.50	0.52	0.10	94.8	5.2	0.44	0.47	0.07	92.5	7.5
	<i>pF</i> 2.8	0.48	0.52	0.10	89.6	10.4	0.42	0.51	0.07	79.5	20.5
	Lsd (M.A.)	0.11	0.07	0.02			0.04	0.04	0.03		
	CV%	8.8	4.9	6.0			3.9	3.6	22.3		
<i>Sukali Ndiizi</i> (AAB)	<i>pF</i> 2.0	0.46	0.47	0.09	95.6	4.0	0.45	0.49	0.06	90.7	9.3
	<i>pF</i> 2.5	0.42	0.47	0.09	87.1	12.9	0.44	0.48	0.06	90.5	9.5
	<i>pF</i> 2.8	0.43	0.51	0.08	81.7	18.3	0.43	0.47	0.06	90.2	9.8
	Lsd (M.A.)	0.03	0.06	0.01			0.06	0.08	0.02		
	CV%	2.3	4.4	4.9			6.4	7.6	16.9		
<i>Yangambi</i> (AAA-LL)	<i>pF</i> 2.0	0.47	0.50	0.09	93.8	6.2	0.43	0.47	0.06	90.1	9.8
	<i>pF</i> 2.5	0.45	0.52	0.10	82.9	17.1	0.42	0.47	0.05	88.1	11.9
	<i>pF</i> 2.8	0.45	0.50	0.09	87.4	12.6	0.40	0.47	0.05	83.3	16.7
	Lsd (M.A.)	0.07	0.07	0.01			0.03	0.02	0.03		
	CV%	6.9	5.6	4.5			3.1	1.4	24.2		
<i>Kisansa</i> (AAA)	<i>pF</i> 2.0	0.48	0.50	0.09	94.0	6.0	0.43	0.46	0.06	92.5	7.5
	<i>pF</i> 2.5	0.49	0.53	0.10	89.9	10.1	0.42	0.46	0.06	90.0	10.0
	<i>pF</i> 2.8	0.46	0.53	0.09	85.5	14.5	0.40	0.49	0.07	78.6	21.4
	Lsd (M.A.)	0.12	0.01	0.01			0.06	0.07	0.02		
	CV%	9.3	0.6	4.6							

RWC=Relative Water Content, $RWC=(FW-DW)/(Sw-Dw)$; WSD ie Water saturation deficit= $(Sw-Fw)/(Sw-Dw)$ ie 1-RWC; (Rampino, 2006) FW=Fresh Weight, SW=Saturated Weight, DW=Dry weight

4.4 Selected metabolic processes of banana cultivar

4.4.1 Transpiration rates of selected banana cultivars across different moisture regimes

The results presented in Table 12 showed significant difference across water regimes, varieties and time (weeks) however, no seasonal variations were observed. In the first season, the average transpired water was estimated at 1.631 L wk^{-1} , 1.209 L wk^{-1} , 0.660 L wk^{-1} for pF 2.0, pF 2.5 and pF 2.8 respectively across genotypes. The rates of transpiration across genotypes were estimated at 1.715 L wk^{-1} (cv. *Sukali Ndiizi*), 1.670 L wk^{-1} (cv. *Mpologoma*), 1.595 L wk^{-1} (cv. *Kisansa*), 1.595 L wk^{-1} (cv. *Kayinja*) and 1.595 L wk^{-1} (cv. *Yangambi Km5*) for the pF 2.0. The results correlated with significantly with the level of leaf surface expansion to enhance high transpiration rate.

However, at pF 2.5, the significant rates of transpiration trend were estimated at 1.245 L wk^{-1} (cv. *Yangambi Km5*), 1.238 L wk^{-1} (cv. *Sukali Ndiizi*), 1.222 L wk^{-1} (cv. *Kayinja*), 1.186 L wk^{-1} (cv. *Mpologoma*) and 1.156 L wk^{-1} (cv. *Kisansa*). Similarly the potential for spending a lot of water was correlated to the leaf surface expansion and opening for cv. *Yangambi Km5* and cv. *Sukali Ndiizi*. In the most stressful environment (pF 2.8), plants showed distinct signs of dehydration which necessitated the cultivar potential to save water from transpiration. Cultivars *Kayinja* (0.553 L wk^{-1}) and *Sukali Ndiizi* (0.620 L wk^{-1}) exhibited potentials for water saving, contrary to cv. *Kisansa* (0.770 L wk^{-1}), cv. *Mpologoma* (0.719 L wk^{-1}) and cv. *Yangambi Km5* (0.637 L wk^{-1}) that transpired significantly more water. The observations were found valid with genotypic sensitivity to drought stress.

Despite no seasonal variations across treatment structures, the weekly sampling period for second season were repeatedly conducted longer (9-20WAP) to enhance distinct variations among genotypes and across moisture deficit levels (Table 13_B). The average transpiration rates

for genotypes were estimated at 1.881 L wk^{-1} , 1.222 L wk^{-1} , and 0.460 L wk^{-1} for pF 2.0, 2.5 and 2.8 respectively. However, at pF 2.0, the transpiration rates for cv. *Sukali Ndiizi* and *Kisansa* were estimated at 2.020 L wk^{-1} and 1.903 L wk^{-1} respectively per week, significantly different from cv. *Yangambi Km5* (1.869 L wk^{-1}), cv. *Kayinja* (1.822 L wk^{-1}) and cv. *Mpologoma* (1.790 L wk^{-1}). Similarly, high rates of transpiration were attributed to leaf surface expansion and the potential to open wide. Contrary to free drainage level, the initiation of stress at pF 2.5, caused a significant change cultivar transpiration with some cultivars beginning to express dehydration avoidance mechanism. Only cv. *Kisansa* significantly transpired more water at 1.306 L wk^{-1} than other cultivars. The trend was observed at 1.2 L wk^{-1} (cv. *Yangambi Km5*, *Kayinja*, *Mpologoma* and *Sukali Ndiizi*).

The results from stressful treatment structure indicated the actual expression of traits for spending and saving water for plant growth. Cultivars *Kisansa* and *Mpologoma* significantly transpired more water at estimated rates of 0.6 L wk^{-1} respectively more than 0.4 L wk^{-1} for cv. *Sukali Ndiizi* and *Yangambi Km5*; and 0.3 L wk^{-1} for cv. *Kayinja*. The stressful condition put cv. *Kisansa* and *Mpologoma* to being water spenders hence their sensitivity and therefore could only get acclimatized to the environment than being adaptive. whereas cv. *Sukali Ndiizi*, *yangambi* and *Kayinja* exhibited relative traits of water saving. The potential of cultivars to save water was considered a good trait for plant adaptability to survive in stressful conditions but not to be productive. However, the GxE results (Tab 13_A) showed cvs *Sikalindiizi* and *Yangambi km5* expressing stability at pF 2.0, while the cooking cvs *Mpologoma* and *Kisansa* were stable at pF 2.5 proving the susceptibility to moisture stress while cv *Kayinja* exhibited stability at both pF 2.5 and pF 2.8 confirming its adaptability in drought stressed environments (Tab 13_A).

Table 12. Mean values of transpiration rates for selected banana cultivars across different moisture regimes

		Weekly sampling interval (SeasonI 2008 _a)						
Variety	Moisture Regime	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Wk ₁₆	Wk ₁₇	Means
		Liters						
<i>Kayinja</i>	<i>pF</i> 2.0	1.046	1.071	1.541	1.773	1.871	2.184	1.581 ^{a**}
(ABB)	<i>pF</i> 2.5	0.822	0.899	1.199	1.349	1.455	1.600	1.222 ^b
	<i>pF</i> 2.8	0.538	0.549	0.441	0.537	0.572	0.595	0.553 ^c
<i>Mpologoma</i>	<i>pF</i> 2.0	1.063	1.183	1.664	1.946	1.963	2.200	1.670 ^a
(AAA)	<i>pF</i> 2.5	0.771	0.889	1.157	1.349	1.432	1.516	1.186 ^b
	<i>pF</i> 2.8	0.690	0.723	0.614	0.741	0.724	0.735	0.719 ^c
<i>Sukali Ndiizi</i>	<i>pF</i> 2.0	1.051	1.251	1.667	1.929	2.071	2.323	1.715 ^a
(AAB)	<i>pF</i> 2.5	0.864	1.031	1.084	1.366	1.485	1.594	1.238 ^b
	<i>pF</i> 2.8	0.568	0.660	0.519	0.631	0.611	0.666	0.620 ^c
<i>Yangambi Km5</i>	<i>pF</i> 2.0	1.053	1.132	1.468	1.595	1.826	2.029	1.517 ^a
(AAA-LL)	<i>pF</i> 2.5	0.891	0.988	1.130	1.377	1.512	1.571	1.245 ^b
	<i>pF</i> 2.8	0.601	0.648	0.572	0.631	0.674	0.685	0.637 ^c
<i>Kisansa</i>	<i>pF</i> 2.0	1.020	1.143	1.506	1.743	1.963	2.197	1.595 ^a
(AAA)	<i>pF</i> 2.5	0.779	0.867	1.114	1.307	1.396	1.470	1.156 ^b
	<i>pF</i> 2.8	0.804	0.767	0.693	0.752	0.761	0.759	0.770 ^c
LSD (M.A.)		0.062	0.086	0.107	0.115	0.085	0.081	
LSD (M.A*V)		0.139	0.193	0.240	0.258	0.190	0.180	
CV%		9.8	12.4	13.1	12.1	8.3	7.2	

M.A.= Moisture Available, *means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test.

Plot of Genotype and Environment IPCA 1 scores versus means

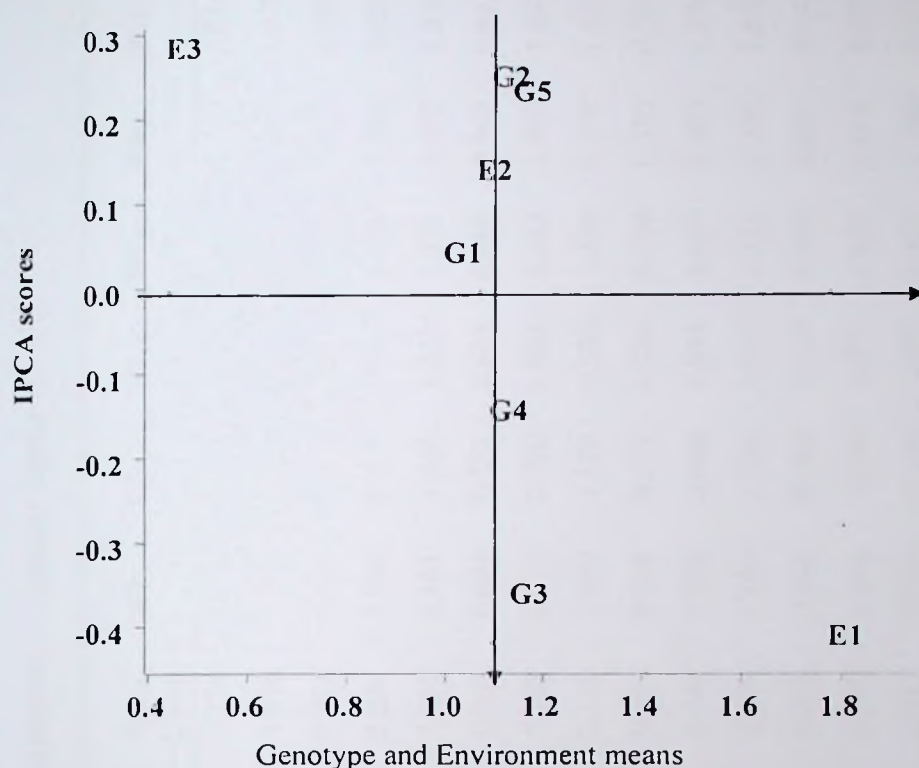


Figure 18_A Genotype by Environmental interaction for selected cultivars

Table13_A showing the genotype performance (AMMI estimates)

Environment	Genotype Ranking	Transpiration rates (Ltr/48hrs)	Potential for transpiration	Genotype x Environment Interaction
pF 2.0-2.1 (E1)	<i>Sukali ndiizi</i> (G3)	1.973	More Water spender	Stable
	<i>Yangambi Km5</i> (G4)	1.828	Water spender	Stable
	<i>Kisansa</i> (G5)	1.728	Water spender	Not stable
	<i>Mpologoma</i> (G2)	1.682	Less Water spender	Not stable
	<i>Kayinja</i> (G1)	1.647	Less Water spender	Not stable
pF 2.5-2.7 (E2)	<i>Kisansa</i>	1.125	Water spender	Stable
	<i>Yangambi Km5</i>	1.067	Water spender	Not stable
	<i>Mpologoma</i>	1.063	Water spender	Stable
	<i>Kayinja</i>	1.048	Water saver	Stable
	<i>Sukali ndiizi</i>	1.017	Water saver	Not stable
pF 2.8-2.9 (E3)	<i>Kisansa</i>	0.562	Water spender	Not stable
	<i>Mpologoma</i>	0.541	Water spender	Not stable
	<i>Sukalindiizi</i>	0.407	Water spender	Not stable
	<i>Yangambi Km5</i>	0.378	Water saver	Not stable
	<i>Kayinja</i>	0.298	Water saver	Stable

Weekly sampling interval (Season1 2008₆)

Variety	Moisture Regimes (M.A.)	Liters												Mean
		Wk ₉	Wk ₁₀	Wk ₁₁	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Wk ₁₆	Wk ₁₇	Wk ₁₈	Wk ₁₉	Wk ₂₀	
<i>Kayinja</i> (ABB)	<i>pF</i> 2.0	0.943	1.248	1.676	2.068	2.011	2.224	1.971	2.208	1.726	1.789	1.970	2.014	1.822 ^{a*}
	<i>pF</i> 2.5	0.558	0.841	1.195	1.404	1.277	1.470	1.322	1.396	1.220	1.245	1.356	1.433	1.226 ^b
	<i>pF</i> 2.8	0.264	0.345	0.359	0.340	0.393	0.274	0.225	0.173	0.173	0.215	0.234	0.256	0.271 ^c
<i>Mpologoma</i> (AAA)	<i>pF</i> 2.0	1.002	1.190	1.521	1.941	1.996	2.224	2.090	2.219	1.640	1.686	1.938	2.030	1.790 ^a
	<i>pF</i> 2.5	0.598	0.857	1.206	1.446	1.167	1.253	1.161	1.225	1.223	1.322	1.432	1.510	1.200 ^b
	<i>pF</i> 2.8	0.519	0.648	0.673	0.682	0.541	0.562	0.604	0.531	0.643	0.589	0.568	0.622	0.599 ^c
<i>Sukali Ndiizi</i> (AAB)	<i>pF</i> 2.0	0.920	1.285	1.716	2.095	2.444	2.792	2.577	2.720	1.883	1.913	1.995	1.897	2.020 ^a
	<i>pF</i> 2.5	0.625	0.868	1.139	1.267	1.195	1.179	1.059	1.122	1.220	1.276	1.378	1.439	1.147 ^b
	<i>pF</i> 2.8	0.492	0.439	0.523	0.504	0.431	0.366	0.365	0.321	0.388	0.394	0.335	0.387	0.412 ^c
Yangambi (AAA-LL)	<i>pF</i> 2.0	0.858	1.173	1.576	1.959	2.235	2.441	2.392	2.602	1.632	1.694	1.906	1.954	1.869 ^a
	<i>pF</i> 2.5	0.574	0.843	1.179	1.392	1.160	1.279	1.264	1.384	1.341	1.312	1.497	1.544	1.231 ^b
	<i>pF</i> 2.8	0.293	0.441	0.443	0.457	0.542	0.435	0.394	0.345	0.329	0.392	0.321	0.358	0.396 ^c
<i>Kisansa</i> (AAA)	<i>pF</i> 2.0	1.025	1.270	1.719	2.223	2.071	2.240	2.134	2.268	1.797	1.857	2.098	2.137	1.903 ^a
	<i>pF</i> 2.5	0.611	0.896	1.244	1.382	1.190	1.381	1.359	1.598	1.382	1.428	1.550	1.654	1.306 ^b
	<i>pF</i> 2.8	0.510	0.587	0.694	0.666	0.565	0.593	0.594	0.549	0.708	0.682	0.653	0.645	0.621 ^c
LSD (MD)		0.068	0.091	0.088	0.086	0.132	0.156	0.133	0.149	0.111	0.114	0.112	0.104	
LSD (MD*V)		0.152	0.202	0.197	0.192	0.294	0.348	0.298	0.333	0.249	0.256	0.251	0.233	
CV%		14.0	14.1	10.5	8.7	13.7	15.0	13.7	14.4	12.9	12.9	11.7	10.5	

M.A. = Moisture Available, * means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test.

Due to non significant variations in transpiration rates across seasons, varieties mean transpiration rates across moisture deficit levels were determined (Fig. 18B). The results indicated significant transpiration rate differences across moisture deficit levels than varieties. Generally highest rates of transpiration were observed among cv. *Sukali Ndiizi* (1.868 L wk⁻¹), cv. *Kisansa* (1.749 L wk⁻¹) and cv. *Mpologoma* (1.730 L wk⁻¹). Least transpiration rates were observed among cv *Yangambi Km5* (1.693 L wk⁻¹) and *Kayinja* (1.702 L wk⁻¹). Therefore the potential for water spending at *pF* 2.0 was identified in all varieties but exclusively more in cv. *Sukali Ndiizi* and least in cv. *Yangambi Km5*. At *pF* 2.5, the rates of transpiration were non significant but apparently more with cv. *Yangambi Km5*. The observation was true and possibly supported by the erectophileness structure of the leaves.

The reductions in transpiration rate for other varieties were attributed to the demand for preserving water due to initiated water deficit stress. At the more characterized level of *pF* 2.8, cv *Kayinja* (0.421 L wk⁻¹) transpired the least mean volume of water (0.412 L wk⁻¹), validating its potential to save water. Cultivar *Mpologoma* (0.659 L wk⁻¹) and *Kisansa* (0.696 L wk⁻¹) transpired more water though non significantly with other varieties and therefore were regarded as water spenders. Moderate volumes of water (0.52 L wk⁻¹) were transpired by cv. *Sukali Ndiizi* and *Yangambi Km5* respectively (Fig. 18B) hence suggesting conditionally expressed drought avoidance mechanism.

The increment of moisture deficit from *pF* 2.0 to *pF* 2.5 mostly reduced the transpiration rate of cv *Sukali Ndiizi* by a proportion of 22.1%, cv. *Mpologoma* (18.4%), cv. *Kisansa* (17.4%), cv *Kayinja* (16.3%) and cv. *Yangambi Km5* was the least affected at 15.5% (Fig. 19). However, the reduction of available soil moisture from optimum condition to wilting point mostly

affected transpiration rate of cv. *Kayinja* by a proportion of 49.6%, cv. *Yangambi Km5* by 41.1% and cv *Sukali Ndiizi* by 39.6%. Cultivars of cooking type were least affected at a proportion of 28.8% and 27.8% for cv *Mpologoma* and *Kisansa* respectively (Fig. 19). The results confirmed the genotypes potential to save water from excessive transpiration through avoidance mechanisms. Contrary, the cooking cultivars with relatively less affected transpiration potential were regarded as water spenders (Tab. 13A) (Fig.18_A).

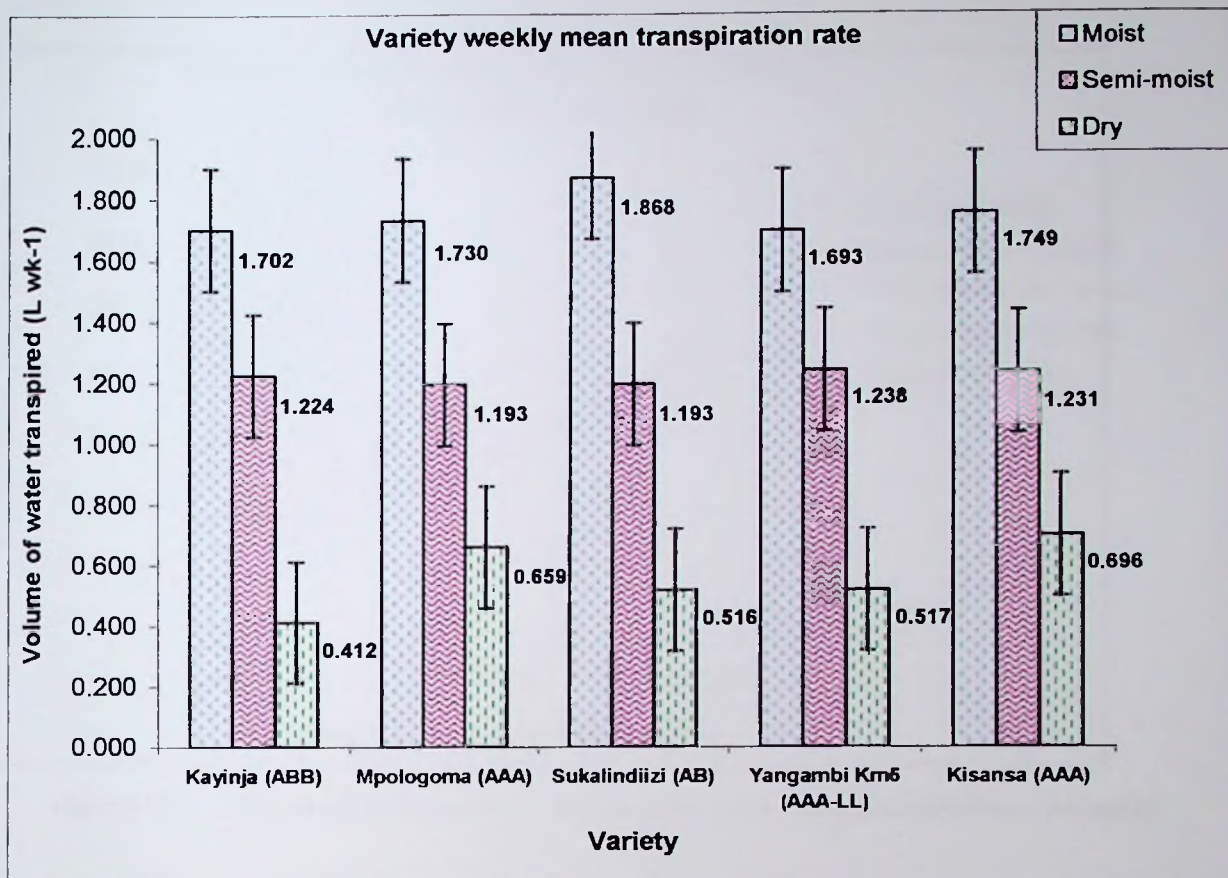


Figure 18_B. Mean weekly transpiration rates of cultivars across different moisture levels

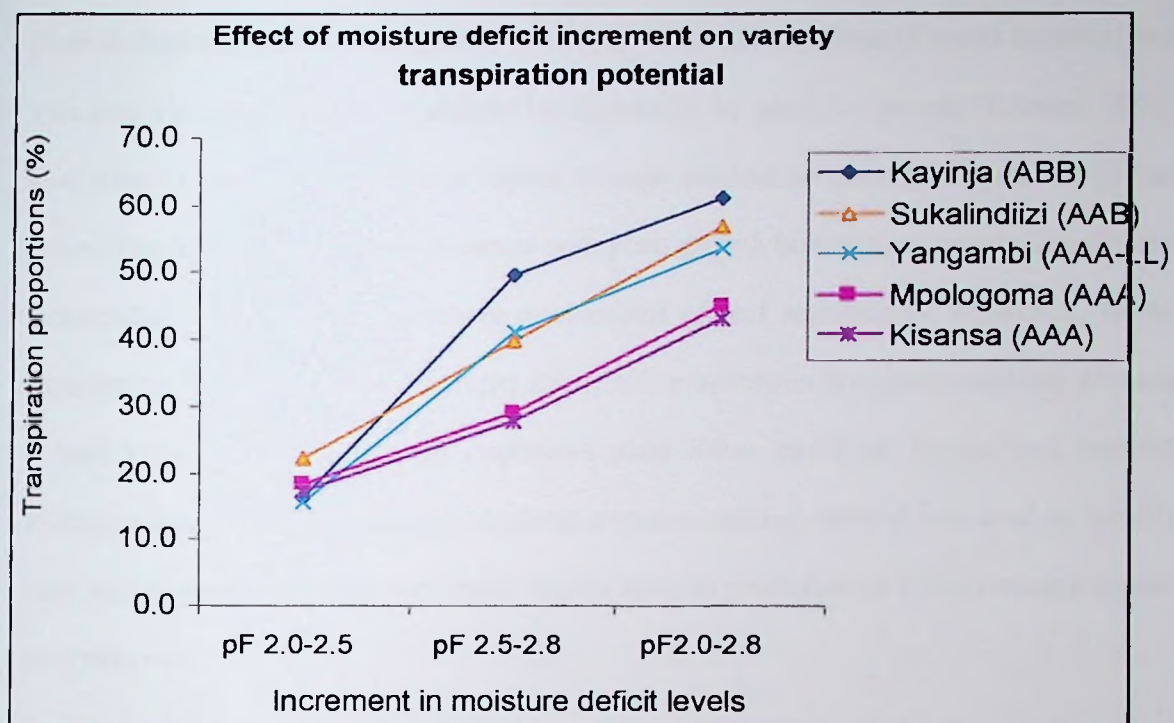


Figure 19. Effect of moisture deficit increment on variety transpiration potential

The reaction of leaf water content with CO_2 intake in the plant is an important assimilatory power in determining the plant growth. However, of the total volume of water absorbed, not more than 5% is reported to be utilized biochemically by plant for growth (Kramer, 1983). Most water is lost in form of water vapour through stomata on plant parts particularly leaf tissues. The rate of transpiration increases with plant growth however, excessive dehydration is controlled by the plants expressive mechanisms of leaf architectural behaviour. In the characterization of cultivars for drought stress, soil evaporation was controlled and allowed at least 95% transpiration through responsive plant tissue based on weight loss method. Multiple linear regression analysis subject to stepwise ranking method was used to identify plant growth parameters that contributed significantly to prediction of transpiration potential per genotype.

The need to identify variable that significantly determined transpiration rate were conducted by creating a model through regression analysis. A stepwise regression analysis and correlation coefficient enhanced the elimination of variables that were not strongly contributing significantly to transpiration. The regression coefficient variables identified were used to determine the rate transpiration per unit change in variable development.

Therefore, results from regression analysis were generated based on genotype potential than per moisture deficit levels. At very stressful conditions (pF 2.5 and pF 2.8), there were no significant differences among responsive variables to predict transpiration potential. The non significance among variables was attributed to low transpiration rate due to expressed mechanisms of drought stress avoidance. The significance was obtained from regression of plant parameters across moisture deficit levels hence the identification of the most important predictive variables. A constant parameter enhanced the identification of responsive variables

based on their grand mean while t-statistic showed the level of transpiration compared to the degrees of freedom and also indicated the significant relationship between the regression parameters and transpiration. A correlation coefficient was determined to indicate the strength of predictive variables to transpiration.

Parameters that predicted the transpiration potential of cv. *Kayinja* (ABB) were leaf potential to remain unfolded and the constant estimated value during 2008_A season, while the addition of healthy number of leaves enhanced the prediction of transpiration potential for cv *Kayinja* during the 2008_B season (Table 14).

In the first season (2008_A) only leaf folding parameter significantly predicted transpiration potential for cv *Kayinja*. The cultivar transpiration prediction model was determined as $Y = [a (0.517) + \beta_1 * b_1 (0.024)] + [T_K + T_0 + M_0]$, and showed that plant water transpiration increased by 0.024 liters with each degree of leaf unfolding. The predicted parameter exhibited a strong correlation coefficient relationship of -89.1%, indicating the cultivar reliability on unfolded leaves for high transpiration.

However, in second season (2008_b), there was an additional parameter of number of healthy leaves, enhancing the expansion of model to $Y = [a (-3.68) + \beta_1 * b_1 (0.020) + \beta_2 * b_2 (0.338)] + [T_K + T_0 + M_0]$. The model showed that transpiration increased by 0.338 liters for each developed healthy leaf. The observed strength between predicted parameters and transpiration showed a strongly inverse relationship (-81.3%), indicating that transpiration decreases with leaf folding. However, the variability in transpiration sets of observations were accounted for by 52.2% and 31.4% for 2008_a and 2008_b seasons respectively (Table 14). The variability could increase with addition of more exploratory variables like time (T_k),

Temperature (T_0) and available Moisture (M_0) in the model. The few predictive variables to transpiration were attributed to the cultivar potential in exhibiting the drought stress avoiding mechanisms to control excessive dehydration for plant survival.

Cultivar *Sukali Ndiizi* (AAB) exhibited more responsive parameters in predicting transpiration in 2008b than 2008a seasons (Table 14). In the first season (2008a), only leaf area parameter significantly predicted the potential for transpiration and determined the model as $Y = [a (0.217) + \beta_1 * b_1 (6.76)] + [T_K + T_0 + M_0]$. The regression coefficient in the model indicated that transpiration of cv. *Sukali Ndiizi* increased by 6.76 liters of water for every fortnightly expansion in leaf area. The strength of relationship between responsive parameter and transpiration was observed at 93.0%.

Contrary, in the second season, the significant responsive parameters included in the model were leaf folding, healthy number of leaves and plant height in predicting transpiration. The results indicated that transpiration increased by 0.012L, 0.207L and 0.013L for leaf opening potential, healthy number of leaves and plant height respectively for every degree in leaf opening per week, for every developed healthy leaf and for successive plant height per centimeter, and therefore developing the model as $Y = [a (-2.408) + \beta_1 * b_1 (0.012) + \beta_2 * b_2 (0.207) + \beta_3 * b_3 (0.013)] + [T_K + T_0 + M_0]$ (Table 14). The relationships between responsive parameters and transpiration were strong for leaf area (93.0%) in 2008a season, and relatively weak at leaf folding (-43.4%), healthy number of leaves (-11.5%) and plant height (32.8%) in 2008b season (Table 14). The weaker correlation was attributed to many non specific prediction parameters. The variance (adjusted R^2) in transpiration sets were observed at 62.9% and 69.2% in 2008a and 2008b seasons respectively (Table 14).

The cooking type of cultivars though sharing similar genomic composition differed in the responsive parameters in the model for predicting transpiration. The significant responsive parameters that

predicted transpiration for cv. *Mpologoma* were leaf area for 2008a season, and leaf folding and fresh leaf biomass for 2008b season (Table 14). The developed models were $Y = [a (0.418) + \beta_1 * b_5 (0.001) + (T_K + T_0 + M_0)]$ and $Y = [a (-0.890) + \beta_1 * b_1 (0.016) + \beta_2 * b_6 (0.001) + (T_K + T_0 + M_0)]$ for the 2008a and 2008b seasons respectively. The determined regression coefficient for leaf area in the first model led to the prediction that transpiration increased by 0.001 grams of water by cm² expansion in leaf area. The correlation showed a strong relationship of -90.1% between transpiration (Y) and leaf area. The negativity of relationship indicated reduced variables but with better relationship.

Contrary to 2008a model, the significant regression coefficient in the 2008b model predicted that transpiration increased by 0.016gms and 0.001gms per degree of leaf unfolding and gram increase of fresh leaf biomass respectively. A strong relationship was observed between transpiration and leaf folding (-98.0%) and very weak for fresh biomass (-2.1%). The variability in both sets observations as explained by the fitted model were 80.2% and 42.9% for 2008a and 2008b transpiration models respectively. The low variance percentage could increase with incorporating more exploratory constant variables.

Similar prediction models were observed among cv. *Kayinja* and cv. *Mpologoma* in the 2008b season. The related performance was attributed to similar genome composition. The significant responsive parameters for cv *Kisansa* in prediction of transpiration were leaf area and folding for 2008a season, and fresh leaf biomass and leaf folding for 2008b season. The models developed were $Y = [a (-0.160) + \beta_1 * b_3 (9.00) + \beta_2 * b_1 (0.010) + (T_K + T_0 + M_0)]$ for 2008a season and $Y = [a (-0.139) + \beta_1 * b_1 (0.009) + \beta_2 * b_6 (0.001) + T_K + T_0 + M_0]$ for 2008b season (Table 14). The variation in model development was due to seasonal variations. The regression coefficient in the first model predicted that transpiration significantly increased by 9.00gms with increment in leaf area (cm²) per

month and 0.009gms per degree of leaf unfolding. However, the coefficients in 2008b model predicted that transpiration increased by 0.009g and 0.001g with additional degree of leaf opening and gram of fresh leaf biomass development. The variability in both sets observations that was explained by the fitted model were 81.3% and 44.2% for 2008a and 2008b transpiration models respectively.

Table 14. Transpiration prediction models for selected banana cultivars

2008 _a Season												2008 _b Season											
Variety	Genome	Parameter	DF	Est.	t (14)	t pr	Corr ⁿ	DF	Est.	t (Value)	t pr	Corr ⁿ											
<i>Kayinja</i>	ABB	Constant (a)	2	0.517	2.58	0.022	1.0	2	-3.68	-3.17	0.003	1.0											
		Leaf Folding (b ₁)	2	0.024	4.17	<.001	-0.891	2	0.020	3.13	0.004	0.42											
		No. of healthy Leaves	2	(b ₂)	-			2	0.338	3.92	<.001	-0.813											
		S.E. of observation		0.364					0.576														
		% Variance accounted		52.2					31.4														
Transpiration Prediction Equation:																							
2008 _a Season: = [a (0.517) + β ₁ * b ₁ (0.024) + T _K + T ₀ + M ₀]																							
2008 _b Season: =[a (-3.68) + β ₁ * b ₁ (0.020)+ β ₂ *b ₂ (0.338) + T _K +T ₀ + M ₀]																							
Variety	Genome	Parameter	DF	Est.	t (Value)	t pr	Corr ⁿ	DF	Est.	t (Value)	t pr	Corr ⁿ											
<i>Sukali Ndiizi</i>	AAB	Constant (a)	4	0.217	0.92	0.371	1.0	3	-2.408	-5.67	<.001	1.0											
		Leaf Area (b ₃)	4	6.76	5.14	<.001	0.930		-														
		Leaf Folding (b ₁)	4	-				3	0.012	3.64	<.001	-0.434											
		No. of healthy Leaves	4	(b ₂)	-			3	0.207	3.66	<.001	-0.115											
		Plant Height (b ₄)	4	-				3	0.013	2.20	0.036	0.328											
		S.E. of observation		0.345					0.407														
		% Variance accounted		62.9					69.2														
Transpiration Prediction Equation: 2008 _a Season: = [a (0.217) + β ₁ * b ₃ (6.76) + T _K + T ₀ + M ₀]																							
2008 _b Season: =[a (-2.408) + β ₁ * b ₁ (0.012) + β ₂ * b ₂ (0.207) + β ₃ * b ₄ (0.013) + T _K + T ₀ + M ₀]																							
Variety	Genome	Parameter	DF	Est.	t (Value)	t pr	Corr ⁿ	DF	Est.	t (Value)	t pr	Corr ⁿ											
<i>Mpologoma</i>	AAA	Constant (a)	3	0.418	3.43	0.004	1.0	2	-0.890	-1.61	0.118	1.0											
		Plant Volume (b ₅)	3	0.001	8.20	<.001	-0.901		-														
		Leaf Folding (b ₁)	3	-				2	0.016	3.09	0.004	-0.980											
		Fresh Leaf Biomass (b ₆)	3	-				2	0.001	3.59	0.001	-0.21											
		S.E. of observation		0.219					0.414														
		% Variance accounted		80.2					42.9														
Transpiration Prediction Equation:																							
2008 _a Season: = [a (0.418) + β ₁ * b ₅ (0.001) + T _K + T ₀ + M ₀]																							
2008 _b Season: = [a (-0.890) + β ₁ * b ₁ (0.016) + β ₂ * b ₆ (0.001) + T _K + T ₀ + M ₀]																							

Variety	Genome	Parameter	DF	Est.	t (Value)	t pr	Corr ⁿ	DF	Est.	t (32)	t pr	Corr ⁿ
Yangambi	AAA-LL	Constant (a)	4	-0.134	-0.31	0.685	1.0	3	0.397	0.77	0.446	1.0
		Leaf Area (b ₃)	4	11.54	4.22	<.001	-0.969	-				
		No. of healthy Leaves	4	(b ₂)	-			3	0.232	2.48	0.018	-0.751
		Fresh Leaf Biomass (b ₆)	4	-				3	0.002	4.13	<.001	-0.052
		Plant Height (b ₄)	4	-				3	-0.04	-3.07	0.004	-0.788
		S.E. of observation		0.339				0.496				
		% Variance accounted		49.7				46.6				
Transpiration Prediction Equation:												
				2008 _a season: = [a (-0.134) + β ₁ * b ₃ (11.54) + T _K + T ₀ + M ₀]								
				2008 _b season: = [a (3.97) + β ₁ * b ₂ (0.232)+ β ₂ * b ₆ (0.002) + β ₃ *b ₄ (-0.04) +T _K + T ₀ + M ₀]								

Variety	Genome	Parameter	DF	Est.	t (Value)	t pr	Corr ⁿ	DF	Est.	t (13)	t pr	Corr ⁿ
Kisansa	AAA	Constant (a)	2	-0.160	-0.63	0.541	1.0	2	-0.139	-0.28	0.778	1.0
		Leaf Area (b ₃)	2	9.00	3.47	0.004	-0.92	-				
		Leaf Folding (b ₁)	2	0.010	3.18	0.007	-0.670	2	0.009	1.96	0.059	-0.969
		Fresh Leaf Biomass (b ₆)		-				2	0.001	4.84	<.001	-0.112
		S.E. of observation		0.203					0.444			
		% Variance accounted		81.3					44.2			

NB values that showed significant different (P<0.05) were stayed to be used in regression model construction and also based on variance ratio
β Regression coefficient; T_K = Transpiration at given time K; T₀ = Transpiration at given ambient temperature; M₀ = Transpiration based on available soil moisture

Despite *Yangambi Km5* constituting similar genome (AAA) with cooking type of cultivars, it is a lowland cultivar with different morphological traits. The significant responsive parameters included in the model were leaf area for 2008a season, and healthy number of leaves, fresh leaf biomass and plant height for 2008b season. The models developed were $Y = [a (-0.134) + \beta_1 * b_1 (11.54) + T_K + T_0 + M_0]$ for 2008a season and $Y = [a (3.97) + \beta_1 * b_2 (0.232) + \beta_2 * b_6 (0.002) + \beta_3 * b_4 (-0.04) + (T_K + T_0 + M_0)]$ for 2008b season (Table 14). Based on regression coefficients, the first model predicted that transpiration increased by 11.54 gms per unit expansion in leaf area (cm^2) per month. However, the corresponding model for 2008b season, predicted that transpiration increased by 0.232 gms, 0.002 gms and -0.04 gms for healthy number of leaves, fresh leaf biomass and plant height respectively. The relationship (96.9%) between leaf area parameter and the dependent variable were very strong for 2008a transpiration model, indicating the importance of the parameter. In the second transpiration model (2008b), the strength of relationships were -75.1% (for healthy number of leaves), -78.8% (for plant height) and -5.2% (for fresh leaf biomass), indicating the most vital contributing parameters.

Despite strong relationships between dependent and independent variables, the variability of the sets of observations as explained by the fitted models were relatively low at 49.7% and 46.6% for both models respectively. The variance therefore suggested increasing the exploratory variable such a time and temperature for a higher variance in the model.

Generally the most observed predicting parameter with strong correlation coefficients in the models were leaf unfolding potential, healthy number of leaves and leaf area. The observation is valid based on leaf architectural behaviour in for of development, expansion of surface area and remaining un folded. A leaf therefore contributes over $pF\ 2.0$ of transpiration rate.

4.4.2 Chlorophyll (a + b) response of selected banana cultivars across moisture regimes

The results presented in (Table 15 & 16) indicate the rate of chlorophyll progress in plant leaves across moisture deficits treatments (pF 2.0, pF 2.5 & pF 2.8). The response of chlorophyll was determined based on absorption on the specific wavelength of light recorded by the SPAD meter. All plants expressed high chlorophyll mean values ($39.5 - 56.4 \text{ mg g}^{-1}$; $48.4 - 64.9 \text{ mg g}^{-1}$) in 2008a and b season for highly contrasted cv *Kayinja* and *Mpologoma* respectively. Elucidated significant differences of chlorophyll content in leaves were observed among cooking type of cultivars (*Kisansa* and *Mpologoma*) across seasons. However, the desert and plantain cultivars showed a non significant difference in chlorophyll content in the first season (2008a), and improved significantly in 2008b season.

Chlorophyll concentration in leaves progressed cumulatively over time in 2008a than in 2008b seasons (Table 15 & 16). However, across moisture deficit levels, chlorophyll concentration in leaves were significantly higher in plants subjected to field capacity (pF 2.0) and progressively decreased upon increased moisture deficit levels (pF 2.5 and pF 2.8) particularly among the cooking type of cultivars (*Mpologoma* and *Kisansa*). Similarly, Lavah (1995) observed critical concentrations of nutrients within the banana germplasm with A-genome genotypes requiring high levels of nutrients. The lower chlorophyll concentrations were partly attributed to weak distribution of nutrients to the development of young leaves hence disappearing of the green colour and appearance of photochemical damage on leaves in the study.

Generally, across moisture deficit levels, cv *Mpologoma* exhibited the highest concentrations of chlorophyll in leaves at rates of 56.6 , 50.7 and 48.2 mg g^{-1} for pF 2.0, pF 2.5 and pF 2.8 respectively in the 2008a season. Similar chlorophyll levels of 60.5 , 64.9 and 61.4 mg g^{-1} for pF

2.0, pF 2.5 and pF 2.8 were observed in 2008b season. Cultivar *Kisansa* exhibited slightly lower chlorophyll levels than rates of cv. *Mpologoma* in 2008a and b seasons (Table 15), but increased chlorophyll levels were observed over time in 2008b season (Table 16). The difference in chlorophyll rates particularly at pF 2.0 indicated that chlorophyll in the leaves of cooking types of cultivars were affected by increased moisture deficit (Table 15). However, high chlorophyll rates were later observed in upper leaves (young shoots), suggesting the potential for remobilization over time (Table 16). Cultivar *Yangambi Km5* (AAA-lowland) exhibited non differing rates of chlorophyll across moisture deficit levels over seasons suggesting that the reduction in available soil water did not affect chlorophyll progress in leaves.

Cultivar *Sukali Ndiizi* (AAB) exhibited lower rates of nitrogen content (49, 46.2 and 45.3 mg g⁻¹ for pF 2.0, pF 2.5 and pF 2.8 respectively) in leaves in the 2008a season and increased significantly at rates of 54 mg g⁻¹, 57.4 mg g⁻¹ and 58.7 mg g⁻¹ for pF 2.0, pF 2.5 and pF 2.8 respectively in 2008b season though (Table 15 & 16). The rates of nitrogen progress were not affected by increased moisture deficit over seasons. In the most stressful condition nitrogen rates remained low suggesting weak potential for nutrient remobilization and development of young leaves. Cultivar *Kayinja* exhibited the lowest rates on nitrogen content (39.5 – 42.1 mg g⁻¹; 48.8 - 51.5 mg g⁻¹) in leaves across seasons (Table 15 & 16). The non significance in rates of chlorophyll progress suggested little effect of increased moisture deficit hence cultivar ability to survive during drought stress. Strong nutrient redistribution to the development of young leaves may have been observed over time in 2008b season as judged by senescence of older leaves and chlorophyll content of young leaves.

Table 15. Variety leaf chlorophyll development across different moisture regimes

		Season1 (2008 _a) Sampling intervals (Fortnightly)						
Variety	Moisture Regime (M.A)	SPAD						Mean
		Wk ₉	Wk ₁₁	Wk ₁₃	Wk ₁₅	Wk ₁₇	Wk ₁₉	
<i>Kayinja</i>	<i>pF</i> 2.0	39.2	39.0	42.8	43.3	43.2	45.0	42.1 ^{a**}
(ABB)	<i>pF</i> 2.5	36.3	35.2	37.4	40.0	44.9	43.3	39.5 ^a
	<i>pF</i> 2.8	39.3	38.8	38.4	38.7	44.7	47.6	42.0 ^a
<i>Mpologoma</i>	<i>pF</i> 2.0	56.3	54.3	55.6	56.7	57.3	58.0	56.4 ^a
(AAA)	<i>pF</i> 2.5	48.0	49.8	44.2	50.0	55.4	56.8	50.7 ^b
	<i>pF</i> 2.8	47.7	43.7	45.8	45.0	49.4	52.7	48.2 ^b
<i>Sukali Ndizi</i>	<i>pF</i> 2.0	46.5	50.1	47.8	51.8	48.1	49.7	49.0 ^a
(AAB)	<i>pF</i> 2.5	42.0	38.3	45.7	48.9	50.1	52.4	46.2 ^a
	<i>pF</i> 2.8	37.9	38.2	49.0	50.2	41.1	50.8	45.3 ^a
<i>Yangambi Km5</i>	<i>pF</i> 2.0	50.7	50.9	53.2	53.8	52.2	52.7	52.3 ^a
(AAA)	<i>pF</i> 2.5	50.7	50.5	49.7	53.1	53.0	51.8	51.5 ^a
	<i>pF</i> 2.8	46.6	46.6	78.8	47.0	50.9	50.8	53.4 ^a
<i>Kisansa</i>	<i>pF</i> 2.0	45.6	51.2	47.6	54.7	55.0	55.6	51.6 ^a
(AAA)	<i>pF</i> 2.5	39.9	33.7	45.4	45.7	52.1	53.9	45.1 ^b
	<i>pF</i> 2.8	50.3	45.6	38.9	44.2	49.1	50.8	47.3 ^{ab}
LSD (M.A.)		3.264	4.41	11.87	2.40	3.16	2.63	
LSD (M.A.*V)		7.298	9.87	26.55	5.38	7.07	5.89	
CV%		9.6	13	33.1	6.6	8.4	6.8	

M.A= Moisture Availability, *means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test.

Table 16. Chlorophyll progress for selected banana cultivars across moisture deficit regimes

Sampling intervals (Fortnightly) Season2 (2008 _b)															
Variety	Moisture Regimes (M.A.)	Third leaf (-3leaf from plant apex)						Fifth leaf (-5leaf from plant apex)							
		Wk ₉	Wk ₁₁	Wk ₁₃	Wk ₁₅	Wk ₁₇	Wk ₁₉	Means	Wk ₉	Wk ₁₁	Wk ₁₃	Wk ₁₅	Wk ₁₇	Wk ₁₉	Means
		SPAD						Means	SPAD						
Kayinja (ABB)	pF 2.0	51.6	51.5	47.0	50.8	46.2	45.7	48.8 ^b	55.1	53.3	52.9	47.6	49.0	47.3	50.9 ^{a**}
	pF 2.5	52.2	48.6	47.7	48.4	46.7	47.0	48.4 ^b	58.3	54.5	50.7	54.1	50.4	48.7	52.9 ^a
	pF 2.8	51.5	51.7	51.1	52.1	51.8	50.6	51.5 ^a	56.9	56.4	53.3	55.5	53.7	52.7	54.8 ^a
Mpologoma (AAA)	pF 2.0	64.1	61.9	59.6	59.7	61.0	56.7	60.5 ^b	66.2	64.5	108.3	56.3	55.3	54.4	67.5 ^a
	pF 2.5	67.2	65.3	66.9	64.1	63.9	61.8	64.9 ^a	61.5	68.2	65.2	64.5	62.5	61.9	64.6 ^a
	pF 2.8	64.1	62.8	61.2	63.3	59.3	57.8	61.4 ^b	65.6	63.2	65.4	61.8	60.5	61.9	63.1 ^a
Sukali Ndiizi (AAB)	pF 2.0	61.5	59.8	58.8	55.4	51.5	51.8	56.5 ^a	66.0	59.7	59.3	60.2	56.9	53.0	59.2 ^{ab}
	pF 2.5	62.9	60.1	58.9	56.4	56.1	54.6	58.2 ^a	67.3	64.8	62.5	60.8	58.8	54.3	61.4 ^a
	pF 2.8	56.8	55.8	57.9	57.9	55.6	51.1	55.9 ^a	67.0	54.3	52.2	51.1	54.1	57.4	56.0 ^b
Yangambi Km5pF 2.0 (AAA)	pF 2.0	54.7	50.2	58.1	57.8	55.2	54.1	55.0 ^a	55.3	55.5	57.4	55.8	55.1	54.8	55.7 ^a
	pF 2.5	53.9	57.5	56.5	56.5	57.3	56.4	56.3 ^a	53.2	57.4	57.8	56.9	59.7	58.9	57.3 ^a
	pF 2.8	53.2	55.6	54.3	56.5	57.8	55.4	55.5 ^a	54.8	55.5	56.5	56.2	57.0	55.4	55.9 ^a
Kisansa (AAA)	pF 2.0	59.1	52.7	55.9	54.4	51.3	52.5	54.3 ^b	60.6	56.7	57.8	56.0	55.1	52.3	56.4 ^a
	pF 2.5	63.4	58.8	56.6	54.2	57.2	54.0	57.4 ^a	65.5	63.1	61.6	52.1	54.9	55.7	58.7 ^a
	pF 2.8	59.9	58.5	58.7	59.3	57.3	58.6	58.7 ^a	60.1	63.4	59.1	52.1	58.6	59.1	58.8 ^a
LSD (M.A.)		2.48	2.88	2.30	2.10	2.43	2.85		13.88	2.94	16.66	4.09	2.46	3.30	
LSD (M.A.*V)		5.55	6.45	5.14	4.69	5.43	6.37		31.05	6.57	37.26	9.14	5.51	7.37	
CV%		5.7	6.8	5.4	5.0	5.9	7.1		28.9	6.6	36.3	9.7	5.9	8.0	

MA= Moisture Availability, * means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test.

MA = Moisture Availability. * means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test.

4.3 Banana Crop survival Mechanisms

4.3.1 Leaf angle architectural behavior

The results obtained showed the effect of seasonal variation with the varieties showing no significant difference over the weekly sampled data (Table 9.). Plant angle between axial and the third fully developed leaf were found to be drooping at pF 2.0, and relatively erect at pF 2.5 and pF 2.8 moisture deficit levels across varieties. Leaf angle standing interactions were observed with fluctuating angles and this was attributed in particular due to the diurnal period differences.

On average, across both seasons, cv. *Kisansa* oriented its leaves at a larger drooping angle of 51.4° , 45° and 43.2° at pF 2.0, pF 2.5 and pF 2.8 levels than other varieties (Fig. 12A-C). The orientation of leaves for cultivars followed a similar trend with cv. *Kayinja* drooping at 49.9° , 42.2° and 44.3° , cv. *sukalindiiz* at 48.1° , 46.3° and 42.6° , cv. *Mpologoma* at 47.6° , 42.4° and 42.8° , cv. *Yangambi Km5* at 46.5° , 43.7° and 44.1° for pF 2.0, pF 2.5 and pF 2.8. levels respectively. The leaf orientation trend across genotypes showed cv. *Yangambi Km5* with most erect leaves and therefore had less potential for drought avoiding mechanism. The drooping potential meant the ability to expose a larger surface area that enhanced the high transpiration rate. A larger leaf drooping angle at pF 2.0 was potentially attributed to leaf weight and turgidity relative to the plant height but rather not a mechanism for drought avoidance. The argument based on observation was supported by findings of variety leaf orientation (Fig 11 A-E) across moisture deficit for fifteen weeks of crop growth.

Table 9 Leaf angle of selected banana cultivars across moisture deficit regimes

Season1 (2008 _a)															Season2 (2008 _b)				
Sampling intervals (Weekly)															Sampling intervals (Weekly)				
Moisture Regimes																			
Variety	(M.A.)	Wk ₉	Wk ₁₀	Wk ₁₁	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Mean	Wk ₉	Wk ₁₀	Wk ₁₁	Wk ₁₂	Wk ₁₃	Wk ₁₄	Wk ₁₅	Mean		
<i>Kayinja</i>	<i>pF</i> 2.0	33.8	25.5	30.7	23.8	22.2	50.3	52.9	34.2 ^{a*}	61.3	63.7	75.0	81.3	85.0	49.0	43.3	65.5 ^a		
(ABB)	<i>pF</i> 2.5	31.7	32.3	22.0	21.5	21.1	37.5	45.2	30.2 ^a	60.3	63.3	50.0	56.3	61.0	45.0	43.0	54.1 ^b		
	<i>pF</i> 2.8	24.4	33.4	31.9	28.3	30.8	42.3	40.4	32.4 ^a	57.0	59.3	53.0	60.3	62.7	53.7	47.0	56.1 ^b		
<i>Mpologoma</i>	<i>pF</i> 2.0	24.5	18.1	36.2	33.6	28.6	44.5	47.4	33.3 ^a	63.3	64.3	66.0	71.7	76.7	51.0	40.0	61.9 ^a		
(AAA)	<i>pF</i> 2.5	13.7	13.5	25.3	24.1	21.2	34.9	41.8	24.9 ^b	69.3	70.3	57.3	63.0	64.0	48.7	46.0	59.8 ^a		
	<i>pF</i> 2.8	7.6	13.8	24.4	10.9	13.6	34.6	43.3	20.6 ^b	74.0	76.3	70.3	64.0	66.7	54.7	49.0	65.0 ^a		
<i>Sukali Ndiizi</i>	<i>pF</i> 2.0	34.8	27.2	37.4	32.9	32.3	48.6	53.6	38.1 ^a	43.0	45.3	75.3	81.3	84.3	34.7	42.7	58.1 ^a		
(AAB)	<i>pF</i> 2.5	32.9	34.1	30.2	32.4	32.9	46.1	49.5	36.9 ^a	51.3	54.7	64.3	71.3	77.7	35.7	34.7	55.7 ^a		
	<i>pF</i> 2.8	45.1	16.3	34.8	33.8	39.1	40.6	55.6	37.4 ^a	49.7	52.0	44.0	51.0	55.3	44.3	37.7	47.7 ^a		
<i>Yangambi km5</i>	<i>pF</i> 2.0	37.3	35.9	43.3	43.0	42.8	56.6	57.0	45.1 ^a	43.0	44.7	52.3	58.0	60.7	40.0	36.7	47.9 ^a		
(AAA-LL)	<i>pF</i> 2.5	26.2	35.4	43.8	45.6	43.4	49.6	56.1	42.9 ^a	47.3	49.3	41.0	46.0	51.0	40.7	36.0	44.5 ^a		
	<i>pF</i> 2.8	25.4	32.6	38.1	29.2	33.2	53.9	58.3	39.6 ^a	61.0	63.0	43.3	50.0	52.3	40.3	32.7	48.5 ^a		
<i>Kisansa</i>	<i>pF</i> 2.0	40.2	38.4	39.1	35.3	36.8	46.5	41.7	39.7 ^a	56.0	58.7	72.0	76.3	78.3	53.7	45.7	63.0 ^a		
(AAA)	<i>pF</i> 2.5	22.9	20.0	24.7	31.3	31.2	39.3	43.1	30.4 ^b	60.0	61.7	64.7	69.3	67.0	50.0	44.7	59.6 ^a		
	<i>pF</i> 2.8	17.4	12.7	34.7	18.6	29.1	36.5	34.3	25.6 ^b	64.3	66.0	56.0	62.7	64.7	58.7	52.3	60.7 ^a		
LSD (M.A.)		6.54	4.25	5.52	5.73	5.01	4.15	2.45		6.48	6.35	9.10	8.36	8.98	4.40	3.58			
LSD (M.A.*V)		14.62	9.51	12.34	25.6	11.19	9.28	5.47		14.49	14.21	20.34	18.69	20.07	9.83	8.00			
CV%		31.1	21.9	21.6	25.6	21.6	12.6	6.8		15.1	14.3	20.6	17.4	17.9	12.6	11.4			

FA = Moisture Availability. *means followed by the same letter within a column are not significantly different according to student-newman-keuls (S-N-K) test

MA = Moisture Availability *means followed by the same letter within a column are not significantly different according to student-newman-Keuls (S-N-K) test

Cultivar *Sukali Ndiizi* initially exhibited significantly increased chlorophyll in pF 2.8 moisture deficit levels during the 9th-12 WAP (Fig x4) but dropped again by 17WAP. Contrary to cv. *Sukali Ndiizi*, cv. *Kayinja* despite possessing lower rates of nitrogen content, the most stress level of moisture deficit (pF 2.8) exhibited clear traits of nutrient redistribution (table 16) for the development and growth of young leaves hence the survival of plant growth.

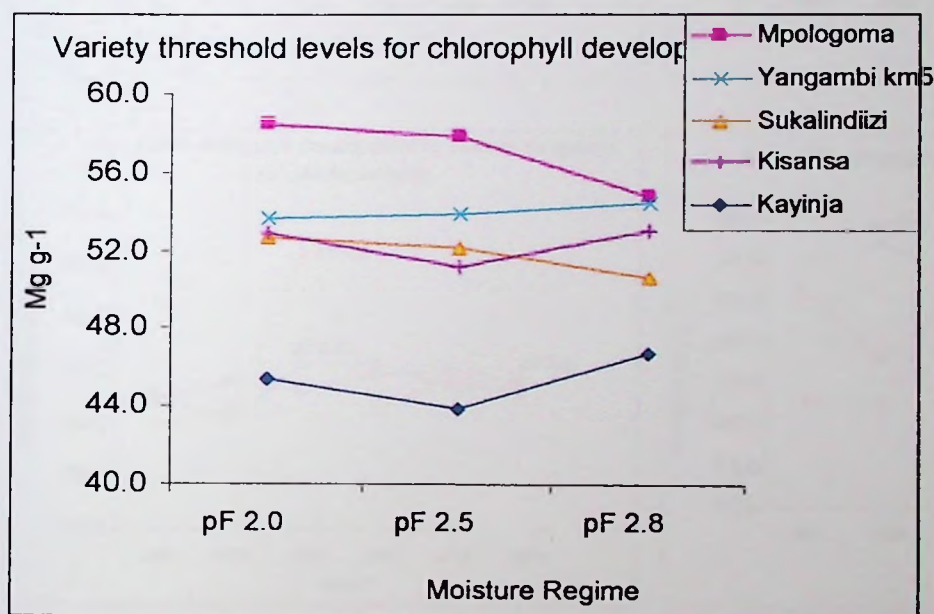
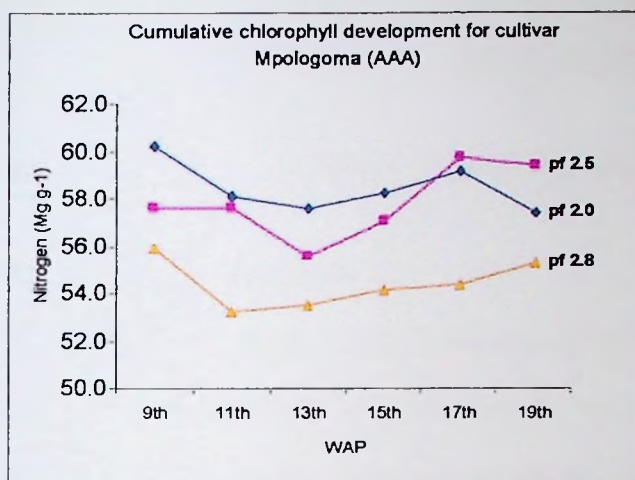
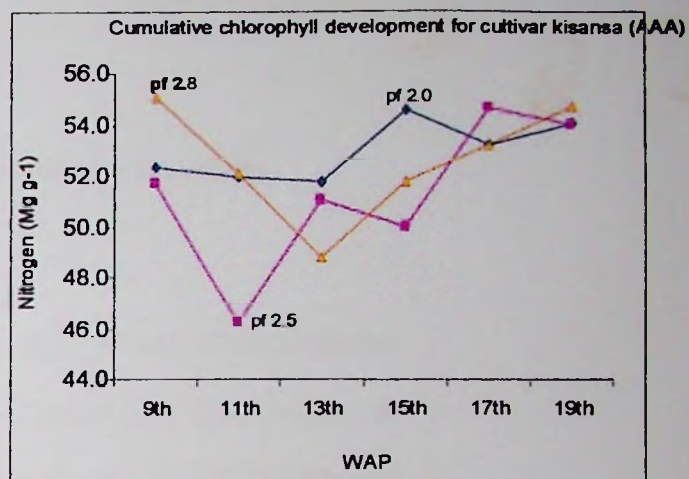


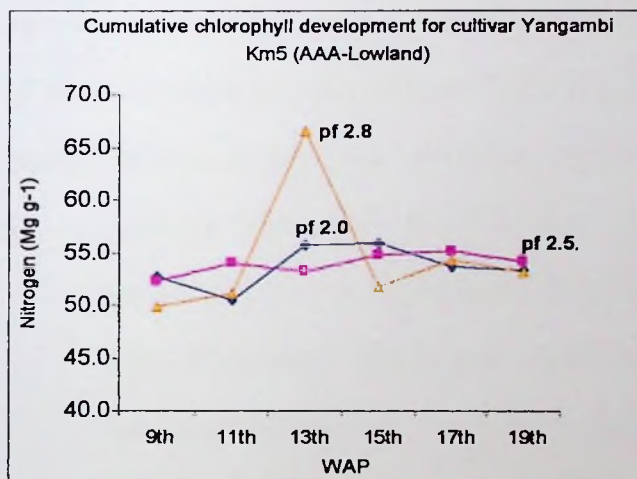
Figure 20. Chlorophyll development for the selected banana cultivars across different moisture regimes



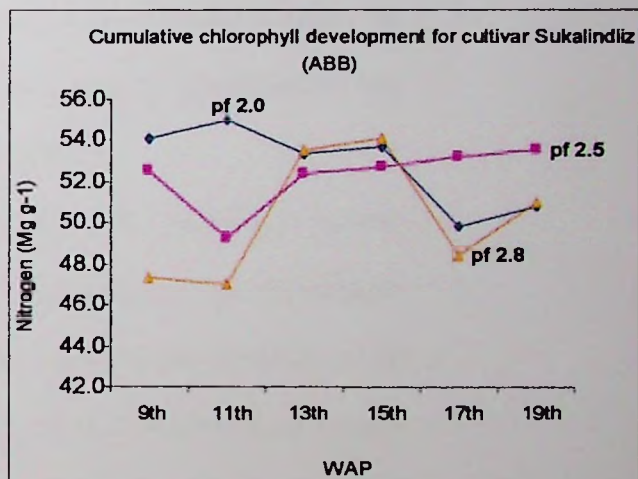
21_A



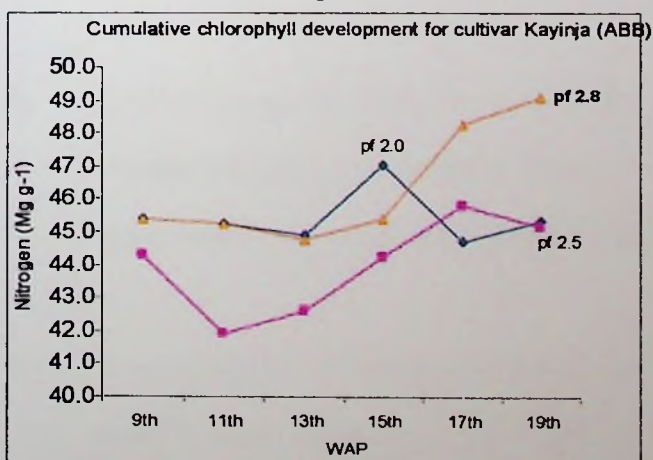
21_B



21_C



21_d



21_E

Figure 21_{A-E}

Chlorophyll (a+b) per selected cultivar across different moisture regimes

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 General conclusion

The major aim of study was to characterizing the response of East African Banana cultivars to drought stress effect. Specifically identify /quantify threshold values for drought avoiding mechanisms, and determining the influence of drought stress on selected physiological processes for plant growth. The study enhanced identifying of the most important trait affected by drought stress hence limited potential for higher yields. In terms of beneficial traits, it was found that:

- 1- Cultivars comprising of the similar genome (B) expressed crucial mechanisms of avoiding excessive effect of drought stress. This observation is in confirmation with earlier studies that cultivars compositing to *M balbisiana* (B) genome conferred hardness, disease resistance and acid starchy fruit quality.
- 2- In the environment of high moisture deficits, both the dessert cultivars expressed drought avoidance mechanisms through leaf folding. Leaf folding was found a good trait for expression mechanisms of drought avoidance.
- 3- The exploration of both below ground (rooting system) and above ground (shoot system) ratio relationship was found to be necessary with mechanisms for avoiding drought stress. The cooking type of cultivars; *Kisansa* and *Mpologoma*

(AAA) which are most predominantly cultivated bananas cultivars were found to develop both extensive rooting system important in search for moisture and large leaf surface area characterized with high rate of transpiration for water spending. Similarly cv. *Sukali Ndiizi* (AAB) expressed high potential for plant growth at free drainage and succumbed to drought stress upon increased moisture deficit (pF 2.8). The poor expression of drought avoiding mechanisms by highland cultivars comprised under *M. acuminata* species was poor an indication of susceptibility to drought stresses. However, the lowland cultivar *Yangambi Km5*, (AAA) despite being a hybrid of *M. acuminata*, it developed few roots with narrow leaves but expressed more drought tolerance than the highland cooking cultivars. But given its narrow shoots, the potential for carbohydrates partitioning were limited and therefore the cultivar can not be ideally relied on for improving the cooking cultivars where yield (>60 t/ha) is the interest to feed the persistently growing population. The significance for a higher yield is therefore suited to increasing yield per unit area through managing drought stress mechanisms.

Cultivar *Kayinja* (ABB) developed extensive roots, optimum leaf area and expressed traits of drought avoidance. The cultivar sensitivity to increased levels of moisture deficit triggered the avoidance mechanism through leaf canopy orientation to reduce the dehydration hence water saving. Therefore cv. *Kayinja* can be ideally a reliable source of important genes for improving the drought susceptible cooking type of cultivars. Incorporation of expressive genes of drought avoidance mechanisms will be important in enhancing plant growth and

production especially in areas of central, southern and southwestern Uganda which are characterized by a bimodal rainfall pattern.

Therefore in areas where bananas are grown, there is need to practice moisture conservation methods in order to potentially realize high yields.

5.2 Recommendations

Based on the results of this study, the following have been recommended:

1. Based on the obtained results, it is evidenced that cooking AAA genomic type of banana cultivars (Mpologoma, Kisansa) requires field capacity conditions for better plant growth. To achieve high yield during times of moisture stress, soil moisture conservation methods should be conducted to provide an ideal environment for the banana plant growth.
2. In areas that are persistently drought prone, cultivars such as Kayinja, sukalindiizi can be grown given their potential for expression of mechanisms for drought avoidance.
3. Given the study concentrated on determining the response of EAHB cultivars to drought stress, the results showed that the mechanisms for avoiding persistent stress require expression of methods for reducing the high rate of dehydration. It's therefore recommended for future research to ascertain the genes that influence the expression leaf folding mechanism.

REFERENCES

- Abele, S. 2007. IITA-Uganda, Bacterial wilt and drought stresses in banana production and their impact on economic welfare in Uganda: implications for banana research in East African Highlands
- Adupa, R. and Ngambeki, D.S. 1994. Demand and consumption of bananas in Uganda; *African Crop Science Conference Proceedings*, Vol. 1.
- Ali, M., Jensen, C.R., Mogensen V.O., Bahrin A. 1999. Drought adaptation of field grown wheat in relation to soil physical conditions. *Plant Soil*, 208, 149-159.
- Alves, A.A.C., Setter, T.L. 2004. Absciscic acid accumulation and osmotic adjustment in cassava under water deficit. *Environmental and Experimental Botany* 51: 259-271.
- Ashizawa, M., Wariishi, T. and Manabe K. 1983. Leaf transpiration rate as an indicator of irrigation timing for Satsuma mandarin trees in summer. *Tech. Bull. Fac. Agric. Kagawa Univ.*, 35: 5-12.
- Araya, M. 2005 Stratification and spatial distribution of the banana *Musa* AAA, Cavendish subgroup, cvs 'Valery' and Grande naine' root system. In: Turner DW, Rosales FE eds. *Banana Root System: Towards a Better Understanding for its Productive Management*, pp.83-103. INIBAP, Montpellier.
- Aries, F., Prevot L., Monestiez P. 1993. Geometrical canopy modelling in radiation simulation studies. In: Varlet-Grancher C, Bonhomme R, Sinoquet H, eds. *Crop structure and light microclimate*. Paris: INRA, 159-173.
- Azam-Ali, S.N. 1983. Seasonal estimates of transpiration from a millet crop using a porometer. *Agric. Meteorol.*, 30: 13-24.
- Bagamba, F. 1994. Resource allocation efficiency in a banana based cropping system in Uganda. MSc, Thesis. Makerere University, Kampala
- Bajji, M., Lutts S., Kinet J.M. 2001. Water deficits effects on solute contribution to osmotic adjustment as a function of leaf aging in three durum wheat *Triticum durum* Desf. cultivars performing differently in arid conditions. *Plant Sci* 160:669-681.
- Bananuka, J.A, Rubaihayo P.R., Tenywa M.M. 1999. Reactions of *Musa* genotypes to drought stress. *Afr. Crop Sci. J.* 7:333-339.
- Barber S.A., 1992. Roots- past, present and future. Pp. 19-29 in *Proceedings of plant nutrition conference. Addressing the physical / chemical / biological / environmental interactions*

relating to root growth and plant nutrition. July 8-12, 1992 H.F. Reetz, ed.. Champaign, Illinois, USA.

- Barrs, H.D., Weatherley P.E. 1962.** A re-examination of the relative turgidity technique for estimating water deficit in leaves. *Australian journal of biological science* 15, 413-428.
- Bekunda, B. and Woomer, 1996.** Organic resource management in banana based cropping systems of the Lake Victoria basin, Uganda. *Agriculture Ecosystems and Environment* 59
- Blomme, G. 2000.** The interdependence of root and shoot development in banana *Musa* spp. under field conditions and the influence of different biophysical factors on this relationship. PhD thesis No. 421. KULeuven. Faculty of Agriculture and Applied Biological Sciences. Belgium. 183pp.
- Blomme, G., Swennen R. and Tenkouano A. 2003.** Assessment of genotypic variation in the root architecture of *Musa* spp. under field conditions. *InfoMusa* 121:24-29.
- Blomme, G., Swennen R. and Tenkouano A., 2002.** The effect of soil bulk density on root and overall plant development in six banana varieties. *InfoMusa* 112:38-40.
- Blomme, G., Swennen R., Tenkouano A., and Ortiz R. 2001.** Estimation of root development from shoot traits in plantain and banana *Musa* spp.. *InfoMusa* 101:15-17.
- Blomme, G., Swennen R. and Tenkouano A., 2000.** Assessment of variability in the root system characteristics of banana *Musa* spp. according to genome group and ploidy level. *InfoMusa* 92:4-7.
- Blomme, G., Draye X., Rufyikiri G., Declerck S., De Waele D., Tenkouano A. and Swennen R. 2000.** Progress in understanding the roots of *Musa* spp. Pp. 14-19 in INIBAP Annual Report 1999. INIBAP, Montpellier, France.
- Blomme, G. and Ortiz R. 1996.** Preliminary assessment of root systems. *Musa*. First International Conference on Banana and Plantains for Africa. *MusAfrica* 10:16 abstract.
- Boyer, J.S. 1996:** Advances in drought tolerance in plants. *Adv. Agron.* 57, 187-218
- Boyer, J.S., Armand P., and Sharp R.E. 1987.** Light stress and leaf water retentions. In: Photoinhibition. Kyle, D.J., Osmound C.B., Arntzen C.J., (Eds.), Elsevier science publishers B.V., Amsterdam, pp: 111-122.
- Broadly, R., Rigden, P., Chay-Prove, P., Daniells, J. 2004.** *Subtropical Banana Growers Handbook*. Queensland department of primary industries, pp 1-206.

- Brun, W. A., 1960. Photosynthesis and transpiration from upper and lower surfaces of intact banana leaves. *Plant Physiol.*, 36: 399-405.
- Cheung, F., Town, C.D. 2007. A BAC end view of *musa acuminata* genome.
- Condon, Richards, G.J. Rebetzke, and G.D. Farquhar, 2004. Breeding for high water use efficiency. *J. Exp. Bot.* 55, 2447-2460.
- Correia, M.J., Chaves M.M., Pereira J.S. 1990. Afternoon depression in photosynthesis in grape vine leaves-evidence for a high light stress effect. *J. Exp. Bot.* 41, 417-426.
- Dale, I.R. (1955) The Indian origins of some African plants and African cattle. *Uganda journal* 19:68-72
- Deckmyn, G., Nijs I. and Ceulemans R. 2000. Laboratory of Plant and Vegetation Ecology, Department of Biology, University of Antwerp UIA, Universiteitsplein 1, 2610 Wilrijk, Belgium
- De Langhe E., R. Swennen and Wilson G.F. 1983. Aspects hormonaux du rejetonnage des bananiers plantains. *Fruits* 38:318-325.
- Do F., Winkel T., Cournac L., Louguet P. 1966. Impact of late-season drought on water relations in a sparse canopy of millet (*Pennisetum glaucum* L. R.Br.). *Field Crops Res* 48:103-113
- Dorel, M., (2002). Physical properties of the volcanic soils of Guadeloupe used for banana growing: influence of cultural practices and their effects on rooting. *InfoMusa* 11(2):48.
- DweUe, R.B., Hurley P. J. and Pavék J.J., 1983. Photosynthesis and stomatal conductance of potato clones (*Solanum tuberosum* L.). *Plant Physiol.*, 72: 172-176.
- Edmeades, S., Smale M., and Karamura D. 2005. Demand for cultivar attributes & biodiversity of Banana on-farm in Uganda. Chapter 7 in valuing crop biodiversity: On-farm genetic resources and econ change, M. Smale, ed Wallingford, U.K.; CAB International.
- Egberts, T. 1977. Ecophysiology of tropical crops, printed by Academic Press, Inc. Library congress cataloging in publication data, Chapter 16, Pg441-459.
- Eissenstat, D.M., Yanai R.D. 1997. The ecology of root lifespan. *Adv Ecol Res* 27:1-62.
- Embrechts, J., Bananuka, J.A. Couveur, Y., Bagamba F. and Lallemand D. 1996. *Banana subsector review*, Republic of Uganda. Commissioned by the European Union (STABEX), Service Contract No. SC/26/96. October, 1996.

- Escalant, J.V., Sharrock, S., and Frison, E. 2002. The genetic improvement of Musa using conventional breeding and modern tools of molecular and cellular biology.
- Ferreira, F.J. and Kieber, J.J. 2005. Cytokinin signaling.
- Food and Agricultural Organization (FAO), 2008. Banana war makes best practice.
- Food and Agricultural Organization (FAO), 2006. Special Report FAO/GIEWS Review of crop and food situation in Uganda. Global information and early warning systems on Food and Agriculture.
- Food and Agricultural Organization (FAO), 2006. Special Report FAO/GIEWS Review of crop and food situation in Uganda. Global information and early warning systems on Food And Agriculture. World Food Program
- Food and Agricultural Organization (FAO), 1987. Production year book for 1986. Vol. 30. FAO, Rome
- Frison, E.A. and Putter, C.A.J., 1989. FAO/IBPR. *Technical Guidelines for the Safe Movement of Musa Germplasm* FAO/IBPGR
- Gammon, J.A., Field C.B., Bilger W., Bjorkman O., Fredeen A.L., Penuelas J. 1990. Remote sensing of the xanthophyll cycle and chlorophyll fluorescence in sunflower leaves and canopies. *Oecologia* 85: 1-7.
- Gold, C.S. Kagezi, G.H.; Night, G. Ragama, P.E. 2004. The effects of banana weevil, *Cosmopolites sordidus*, damage on highland banana growth, yield and stand duration in Uganda
- Gold, C.S. 1999. Integrated pest management of banana weevil with emphasis on East Africa. In: Rosales, F., Tripon, S.C. & Cerna, J. (Eds.), *Proceedings of an international workshop of the International Network for the Improvement of Banana and plantain – INIBAP*, held in EARTH, Guacino, Costa Rica, July 27-29, 1998. IPGRI, Rome, Italy
- Gold, C.S., 1995. Banana weevil: Ecology, pests status and prospects of integrated control with emphasis on East Africa. In: *Proceedings of a Symposium on Biological Control in Tropical Crop Habitat*. Third International Conference on Tropical Entomology. 30 Oct-4 Nov., 1994. Nairobi, Kenya
- Gousseland, J., 1983. Etude de l'enracinement et de l'émission racinaire du bananier 'Giant Cavendish' (*Musa acuminata* AAA, sous-groupe Cavendish) dans les andosols de la Guadeloupe. *Fruits* 38:611-623.

- Gowen, S. and Quénéhervé P. 1990. Nematode parasites of bananas, plantains and abaca. Pp. 431-460 *in* Plant parasitic nematodes in subtropical and tropical agriculture (M. Luc, R. Sikora & J. Bridge, eds). CAB International, Wallingford, UK.
- Gowen, S.R. 1995. Pests. Pp. 382-402 *in* Bananas and Plantains (S. Gowen, ed.). Chapman & Hall, London, UK.
- Harper, G., Hart, D., Moulton, S., Hull, R. 2004. Banana streak virus is very diverse in Uganda. *In* : -Virus Research (USA), 100, (1), p. 51-56
- Holder, G.D., Gumbs F.A. 1983. Effects of irrigation on the growth and yield of banana. *Tropical Agriculture, Trinidad* 60:25-30.
- Hörtensteiner S., Pružinská, A., Tanner, G., Aubry S., Anders I., Moser S., Müller T., Ongania K., Kräutler B., Youn J. and Liljegren S.J. 2005. Chlorophyll Breakdown in Senescent Arabidopsis Leaves. Characterization of Chlorophyll Catabolites and of Chlorophyll Catabolic Enzymes Involved in the Degreening Reaction.
- IITA, 2005. Biotechnology for improvement of banana production in Africa. (9th International Conference on Agricultural Biotechnology
- Indira and Kabeerathuma. 1988. Sweetpotato yield reduction as a result of water stress at different growth rate
- INIBAP, (2000). Banana international Network for the improvement of banana and plantain. International Plant genetic resources institute.
- IPCC (Intergovernmental Panel on Climate Change), 2001: Climate Change Available at <http://www.ipcc.ch>, accessed on September 1, 2005.
- Itai, C. and Birnbaum H. 1996. Synthesis of plant growth regulators by roots. Pp. 273-284. *in* Plant roots: The hidden half. (Y. Waisel, A. Eshel, & U. Kafkafi, eds). Marcel Dekker, Inc. New York, USA.
- Jones, H.G. 1983. Estimation of an effective soil water potential at the root surface of transpiring plants. *Plant Cell Environ.*, 6: 671-674.
- Kahl, G. 2007. The banana genome in focus. A technical perspective. Chapter 22. *In*: SM Jain, R Swennen, eds. Cellular, molecular Biology and Induced mutations. Science publishers inc., Enfield, USA.
- Kalyebala, R., Woods, S., Abodi, P. 2005. The potential of economic benefits of improved banana productivity in Uganda: An industry scale analysis. IFRI BRIEF 9

- Karamura, D. A. and Karamura, E.B. 1994.** A provisional check list of banana cultivars in Uganda. Pages 1-28. National Agricultural Research Organisation (NARO)/ International Network for Improvement of Banana and Plantain (INIBAP), Montpellier
- Karamura, E.B. and Karamura D. A. 1995.** Banana morphology-part II; the aerial shoot. In: S. Gowen (Editor). *Bananas and Plantains*. Chapman and Hall
- Ke, L.S., (1979).** Studies on the physiological characteristics of bananas in Taiwan. II. Effects of soil moisture on some physiological functions and yield of the banana plant. J. Agric. Assoc. China, 108: 11-23.
- Kempton, R.A., 1984.** The use of biplots in interpreting variety by environment interactions. J. Agric. Sci., 103: 123-135.
- Koning, Ross E., 1994;** Leaves and plant hysiology information
- Kramer P.J. 1983.** Water relations of the whole plant. Introduction to plant physiology, 2e/William G. Hopkins. Copyright 1995, 1999 John Willey & sons inc. ISBN 0-471-19281-3 USA
- Krishnan B.M. and Shanmugavelu K.G. 1979.** Studies on water requirements of banana cv. 'Robusta'. Effect on morphological characters, crop duration, yield and quality of fruits. Mysore J. Agric. Sci., 13: 433-441.
- Kumar, C.P. and Mittal S. 2010.** Soil moisture retention characteristics and hydraulic conductivity for different areas in India in selected states
- Kusaka, M., Ohta M., Fugimura T. 2005.** Contribution of inorganic components to osmotic adjustment and leaf folding for drought tolerance in pearly millet. Appropriate technology & sci. for sustainable dev't, life & environmental sci.
- Lahav, E. 1995.** Banana nutrition. In: Gowen S (ed), *Bananas and Plantains*. pp.258-316. Chapman and Hall, London.
- Lahav, E. and Turner, D.W. 1989.** Banana Nutrition. International Potash Institute, Bern, Switzerland
- Lauer, M.J., Boyer J.S. 1992.** Internal CO₂ measures directly in leaves. Abssic Acid and low leaf water potential cause opposing effects. Plant physiol., 98: 1010-1016.
- Lejju, B.J., Robertshaw P, Tayler D. 2006** Africa's earliest bananas? J. Archaeol. Sci. 33:102-113.

- Lockhart, B.E.L., Olszewski N.E. 1993.** Serological and genomic heterogeneity of banana streak badnavirus: implications for virus detection in *Musa* gerplasm. Pp. 105-114 in *Breeding bananas and plantain for resistance to diseases and pests* (J. Ganry, Ed.). CIRAD/INIBAP, Montpellier, France.
- Lu, P., Woo K.C., Liu Z-T. 2002.** Estimation of whole-plant transpiration of bananas using sap flow measurements. *J. Exp. Bot.* 53:1771-1779.
- Milburn, J.A., Kallarackal J., Baker D.A. 1990.** Water relations of the banana. I. Predicting Plant Physiol. 17:57-68.
- Mindzie, C.M., Doutrelepont H., Vrydaghs L., Swennen R., Swennen R.J., Beekman H., DeLanghe E., De Maret P. 2001.** First archaeological evidence of banana cultivation in central Africa during the third millennium before present. *Veg. Hist. Archaeobot.* 10:1-6.
- Ministry of Agriculture Animal Industry and Fisheries, 2005** Summary of the National Agricultural Statistics 2005/06, (Rain fall pattern).
- Mugisha, J. and Ngambeki D.S. 1993.** Marketing system of the Uganda banana industry. In: Adipala, E. Bekunda, M.A., Tenywa, J.S., Ogenga-Latigo. M.W. & Mugah, J.O. (Eds.) *African Crop Science Proceedings*, Kampala, Uganda. 1, 384-387.
- Munne, B., and Algere, 2004.** The induction of senescence as a result of drought stress having interaction with ABA.
- Nankinga, C.K., Magara E., Gold C.S. Kawuki R.S., Erima R., Ragama P., Gowen S.R. and Tushemereirwe W. 2005.** Response of East African Highland Bananas to plant densities in Uganda
- Nankinga C.M. and Ogenga-Latigo M.W. 1996.** Effect of method of application on effectiveness of *Beauveria bassiana* against the banana weevil, *Cosmopolites sordidus*. *Afr. J.Pl.Prot.* 6:12-21
- Nankinga, C.M. 1994.** Potential of indigenous fungal pathogens for the biological control of the banana weevil, *Cosmopolites sordidus* (Germar) in Uganda. MSc. Thesis, Makerere University
- Nelson, S.C., Ploetz, R.C. Kepler, A.K. 2006.** *Musa* species (banana and plantains) In: C.R Elevitch, ed. *Species profiles for Pacific Island Agroforestry*.

- Niinemets, Ü., D.S. Ellsworth, A. Lukjanova and M. Tobias. 2002. Dependence of needle architecture and chemical composition on canopy light availability in three North American *Pinus* species with contrasting needle length. *Tree Physiol.* 22:747-761.
- Okech, S.H.O., Gold, C.S., Speijer, P.R., Karamura, E., Ssali H. & McIntyre, B. 1996. Relationship between soil fertility, banana weevil, nematodes and agronomic practices in southwestern Uganda. *MusAfrica* 10,31
- Oppenheimer, H.R. 1960 Adaptation to drought: Xerophytism. *Plant-Water relationships in Arid and semi-Arid conditions: Reviews of research.* UNESCO, Paris, pp 1-105.
- Ostonen, I., Puttsepp U., Biel C., Alberton O., Bakker M.R., Lohmus K., Madji H., Metcalfe D., Olsthoorn A.F.M., Pronk A., Vanguelova E., Weith M., Brunner I. 2007. Specific root length as an indicator of environmental Change. *Plant Biosystems*, Vol. 141, No.3 November 2007, pp. 426-442.
- Paknejad F., Nasri M., Reza H., Moghadam T., Zahedi H., Alahmadi M.J. 2007. Effects of drought stress on chlorophyll fluorescence parameters, chlorophyll content & grain yield of wheat cultivars.
- Patakas A., Nikolaou N., Ziozio E., Radoglou K., Noitsakis B. (2002) The role of organic solute an ion accumulation in osmotic adjustment in drought stressed grapevines. *Plant Sci* 163: 361-367.
- Pattison, T. and Lindsay, S. 2006. Banana soil health users manual. Queensland department of primary industries
- Phillips, D.L., Johnson, M.G., Tingey D.T., Storm, M. J., Ball J.T., Dale W. J., 2006. CO₂ and N-fertilization effects on fine-root length, production, and mortality: a 4-year ponderosa pine study
- Pilar B., Miguel P., Centeno A., Junquera P., Linares R., Lissarrague J.R. 2007. Water relations between leaf water potential, photosynthesis and agronomic vine response as a tool for establishing thresholds in irrigation scheduling.
- Pillay, M. and Tripathi L. 2007. Banana chapter 15. In C Kole, Ed. *Genome mapping and molecular breeding in plants, volume 4 fruits and nuts.* Springer-verlag, Berlin. Pp 281-301.

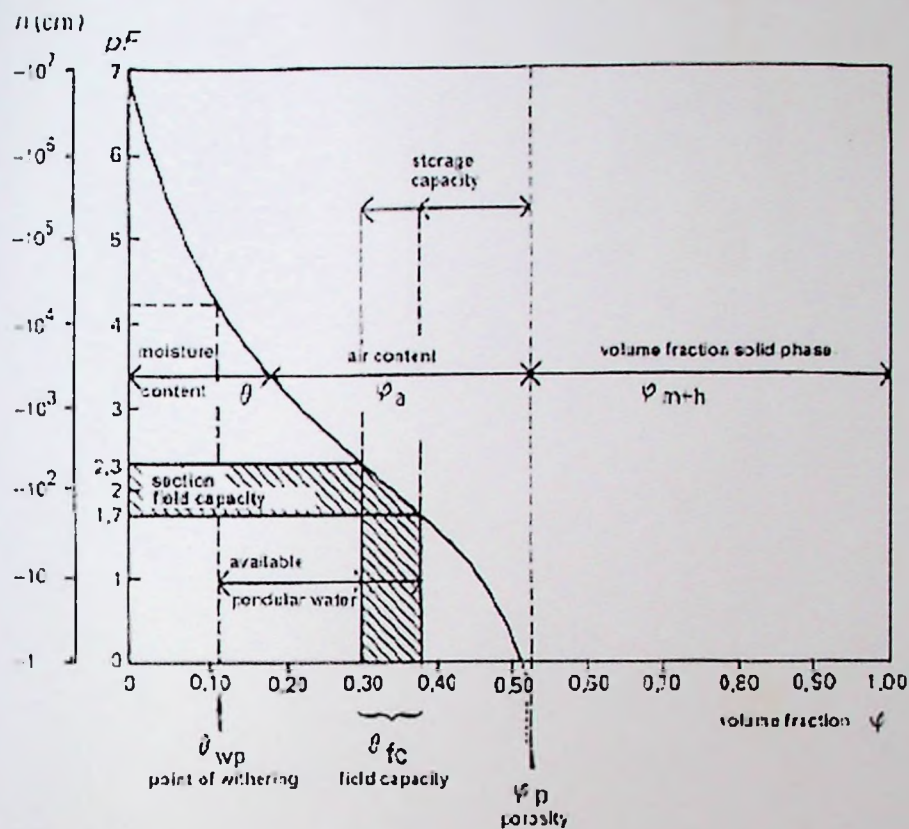
- Price, N.S. 1995. Banana morphology 1: roots and rhizomes. Pp.190-205 in Bananas and Plantains (S. Gowen, ed.). Chapman and Hall, London
- Purseglove J.W. 1972. Tropical crops. Monocotyledons. Vol. 2. Rosetta Ed., Longman Group Ltd., London. 633 pp.
- Rampino P., Pataleo S., Carmela G., Mita G., Perrotta C. 2006. Drought stress response in Wheat: physiological and molecular analysis of resistant and sensitive genotypes.
- Robinson J.C. 1995. Systems of cultivation and management In: S. Gowen (Edu.) Bananas and Plantain. Chapman and Hall, London, pp. 15-65.
- Robinson, J.C. 1996. Bananas and plantains. CAB international. Wallingford, UK. 283pp.
- Robinson, J.C. and bower J.P., 1986. Transpiration characteristics of banana leaves (Cultivar 'Williams') in response to progressive depletion of available soil moisture
- Rubaihayo, P.R. & Gold C.S. 1993. Rapid rural appraisal of highland banana production in Uganda. InfoMusa2, 15-16
- Rukazambuga, N.D., 1996. The effect of banana weevil (*Cosmopolites sordidus Germar*) on the growth and productivity of bananas (Musa AAA) and the influence of the host vigour on weevil attack. Ph.D. Thesis. University of Reading
- Sebuwufu G., Rubaihayo P.R. and Blomme G., (2004). Variability in the root system of East African banana genotypes in Conservation through utilization of banana and plantain in the Great Lakes Region of East Africa (E. Karamura, D.A. Karamura, S. Sharrock and E. Frison, eds). African Crops Science Journal (Special issue) 12(1):85-93.
- Sengoba, T. 1986. Survey of banana pests problems complex in Rakai and Masaka districts of Uganda
- Shmueli, E. 1953. Irrigation studies in the Jordan Valley. 1. Physiological activity of the banana in relation to soil moisture. Bull. Res. Council. Isr. 3:228-247.
- Simmonds, N. W., 1960. Megasporogenesis and female fertility in three edible triploid bananas. *Journal of Genetics* 57
- Simmonds, N.W. 1959. Bananas. Longmans, Green and Co.Ltd., London.
- Smithson, P.C., McIntyre, B.D, Gold, C.S., Ssali, H., Night, G. and Okech, S. 2001. Potassium and magnesium fertilizers on banana in Uganda: yields, weevil damage, foliar nutrient status and DRIS analysis

- Smith, M.K., Hamill, S.D., Becker, D.K., Dale, J.L. 2005. Musa spp. Banana and Plantain. Chapter 13.1. In: RE Litz, ed. Biotechnology of fruits and nut crops. CAB international Wallingford, UK. Pp366-391.
- Sinoquet, H., Rivet P.1997. Measurements and visualisation of the architecture of an adult tree based on a three-dimensional digitising device. *Trees* **11**, 265-270.
- Sinoquet, H., Valmorin M., Cabo X, Bonhomme R. 1993. DALI: an automated laser distance system for measuring profiles of vegetation. *Agricultural and Forest Meteorology* **67**, 43-64.
- Small Group Meeting (SGM) report, 2003. Improved Production of Bananas and Simmonds, N. W., 1960. Megasporogenesis and female fertility in three edible triploid bananas. *Journal of Genetics* **57**
- Ssebuliba, R, Vuylsteke D, Hartman J, Makumbi D, Talengera D, Rubaihayo P, Magambo S, Nuwagala L, Nahamya P, Karamura E. 2000. Towards improving high land bananas. *Uganda J. Agric. Sci.* **5**(1): 36-38.
- Speijer, P.R., Gold, C.S., Karamura E.B. and Kashaia I.N. 1994. Banana weevil and nematode distribution patterns in Highland banana systems in Uganda: preliminary results from a diagnostic survey. In: *African Crop Science Conference Proceedings*. 14-18 June, 1993 Kampala (Eds Adipala, E. Bekunda M.A., Tenywa J.S., Ogenga-Latigo, M.W. and Mugah, J.O.), African Crop Science Society, Kampala
- Speijer, P.R., Rukazambuga N.D. and Karamura E.B. 1994. Assessment of banana weevils in East African highland banana systems and strategies for control In: *Proceedings of a conference-workshop on nematodes and weevil borer affecting bananas in Asia and the Pacific*. Serdang, Selangor, Malaysia 18-22 April 1994. (Eds Valmayor, Davide, Stanton, Treverrow, and Roa.), INIBAP
- Stover R.H. Simmonds N.W. 1987. Bananas, 3rd ed. Longman, Harlow. 468pp.
- Supranova T., Krugman T., Fahima T., Chen G., Shams I., Korol A., & Nevo E. 2004. Differential expression of dehydrin genes in wild barley, *Hordeum spontaneum*, associated with resistance to water deficit. *Plant, cell & Environment* **27**, 1297-1308.
- Sys, C., Van Ranst E., Debaveye J., Beernaert F. 1993. Crop requirements. Land evaluation part III. Agricultural publications No.7, Brussels-Belgium.

- Tardieu, F, Reymond M, Hamard P, Granier C, Muller B. 2000.** Spatial distributions of expansion rate, cell division rate and cell size in maize leaves: a synthesis of the effects of soil water status, evaporative demand and temperature. *Journal of Experimental Botany* 51: 1505–1514.
- Thornley, J.H.M, Johnson IR. 1990..** Plant and crop modelling. Oxford: Clarendon Press.
- Tosserams, M, Magendans E, Rozema J. 1997.** Differential effects of elevated ultraviolet-B radiation on plant species of a dune grassland ecosystem. *Plant Ecology* 128, 266–281.
- Turner, D.W., Fortescue J.A., Thomas D.S. 2008.** Environmental physiology of the banana (*Musa* spp). *Braz. J. Plant Physiol.* 19, 463-484.
- Turner, D.W and Lavav, E. 1983.** The growth of bananas in relation to temperature *Aust. J. Plant Physiol.*, 10, 43-53
- Turner, N.C., Jones M.M. 1980.** Turgor maintenance by osmotic adjustment: A review and evaluation. In: Turner N.C., Kramer P.J. (eds) *Adaptation of Plants to Water and High Temperatures Stress*. Wiley-Interscience, New York, pp 87-103
- Tushemereirwe, W. 1996.** Factors influencing expression of leaf spot disease of highland bananas in Uganda. Ph.D. Thesis, Reading University
- Van Asten, P.J.A., Gold C.S., Wendt J., Dewaele D., Okech S.H.O., Ssali H & Tushemereirwe W.K. 2004.** The contribution of soil quality to banana yield problems and its relationship with other banana yield loss factors in Uganda. In: Blomme, G., Gold, C.S., Karamura, E. (Eds.) *Proceedings of a workshop held on farmer participatory testing of IPM options for sustainable banana production in Eastern Uganda*, Seeta, Uganda, December 8-9, 2003.
- Van Asten, P.J.A., Taulya, G., Okech, S.H., Gold, C.S., Mugaga, T.K.W. 2007.** Drought is a major yield loss factor for East African Highland banana (cv. *Enyeru*)
- Vazan S. 2002.** Effects of chlorophyll parameters & photosynthesis efficiency in different beet. *Assay Ph.D Islamic azad University sci.& research Tehran-Branch*, pp:285.
- Vendeland, JS, Sinclair TR, Spaeth SC, Cortes PM. 1982.** Assumptions of plastochron index evaluation with soybean *Glycine max* cultivar Wilkin under field drought conditions. *Annals of Botany* 50: 673–680.
- Vos, J. and Bom M. 1993.** Hand-held chlorophyll meter: A promising tool to assess the nitrogen status of potato foliage. *Potato Res.* 36: 301–308.

- Vuylsteke, D. 2000. Breeding bananas and plantains: from intractability to feasibility. *Acta Horticulturae* 540: 149-156
- Wairegi L.W.I., Van Asten P.J.A., Kiwanuka C., Tenywa M., Bekunda M. 2007. Assessment of soil management practices in East African Highland cooking banana (*Musa* spp. AAA-EA) systems in Uganda. In: Paper presented at the AFNET International Symposium, Arusha, Tanzania, September 17-21, 2007
- Warren-Wilson J. 1963. Estimation of foliage denseness and foliage angle by inclined point quadrats. *Australian Journal of Botany* 11, 95-105.
- Zake, J.Y.K, Nkwine, C., Okwakol, M., Sessanga, S., Bwamiki, D.P. Tumuhairwe, J.K., Najjuma, C. and Kagole, H. 1994. Identification of suitable soils and soil management practices for banana productivity. In Rubaihayo P. R. (Editor) *Banana-Based Cropping Systems Research Report*. Department of Crop Science. Makerere University

Appendix 1



***** The ANOVA table for AMMI model *****

Source	df	SS	MS	F	F_prob
Total	539	236.75	0.44	*	*
Treatments	14	164.93	11.78	85.90	0.00000
Genotypes	4	1.37	0.34	2.49	0.04215
Environments	2	160.42	80.21	754.29	0.00000
Block	6	0.64	0.11	0.78	0.58953
Interactions	8	3.15	0.39	2.87	0.00396
IPCA	5	2.61	0.52	3.80	0.00216
IPCA	3	0.54	0.18	1.31	0.27170
Residuals	0	0.00	*	*	*
Error	519	71.18	0.14	*	*