

**CHARACTERIZATION, WATER STRESS AND NUTRIENT MANAGEMENT
OF YELLOW PASSION FRUITS (*PASSIFLORA EDULIS*, var *F. FLAVICARPA*.
deg) IN KIAMBU AND EMBU COUNTIES, KENYA**

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**Thesis Submitted in Partial Fulfillment of the Requirements for the Award of the
Degree of Doctor of Philosophy in Agronomy in the School of Agriculture and
Enterprise Development, Kenyatta University**

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DECLARATION

I declare that this thesis is my original work and has not been presented for the award of a degree in any other university or any other award.

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DEDICATION

This work is dedicated to the peasant farmers of the world.

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ACRONYMS

ASL	Above sea level
ANOVA	Analysis of Variance
CAN	Calcium Ammonium Nitrogen
DAP	Diammonium Phosphate
HCDA	Horticulture Crops Development Authority
KALRO	Kenya Agriculture Livestock Research Organization
KPF4	Kenya Passion Fruit Number 4
KPF11	Kenya Passion Fruit Number 11
KPF12	Kenya Passion Fruit Number 12
MOP	Muriate of Potash
MT	Metric Ton
TSP	Triple Superphosphate

ABSTRACT

Passion fruit has gained significant importance as a horticultural crop of choice among farmers in Kenya. The yellow passion has been recently commercialized in Embu County due to its adaptation to the hot arid conditions and potential for high yields. Currently, the production levels of the fruit are low due to poor agronomic practices, declining soil fertility levels and changing climate leading to reduced rainfall. To further understand these challenges, there is need for careful investigation of plant-soil-water relations which requires careful in-depth analysis of the soil's nutrients of any area. This is because each nutrient has a specific role to play in the development of the plant and deficiency symptoms will manifest specific to each nutrient. Further, to establish and manage nutritional and water stress related disorders, their causes requires knowledge of the symptoms. The primary objective of this study was to carry out socioeconomic survey of passion fruit farmers and determine the correct water and nutrient management of yellow passion fruit in Embu County. The study also carried out morphological characterization of the cultivated populations to identify hybrids with favorable characteristics such as drought tolerance. The study involved a mixture of field survey, on-farm experiments with selected farmers and controlled experiments at Kenyatta University research farm. Results of the survey established that majority of the farmers grow passion on small acreages of less than 2 acres and have a common source of planting materials. Further, major agronomic practices including fertilizer and water application were also not correctly followed. The results on morphological characterization indicate the presence of two main groups of cultivars. Further, for fertilizer application, the study established that the treatments 100g DAP+20kg Manure+50g CAN and 20kgManure+50gNitrabor had the best impact on flowering ($p \leq 0.05$) and fruit development while results on determination of water uptake established the treatment of 10 liters of water per day giving the longest primary vine and highest number of secondary vines ($p \leq 0.05$). In conclusion, field survey and on-farm experimental results indicate the need for increased availing of new knowledge to farmers in the management of the crop while results from controlled experiments at the university farm indicate a need for correct application of fertilizers and efficient monitoring of irrigation regimes. All these factors will lead to improved quality and quantity in yield of yellow passion fruit. The study recommends provision of updated agronomic management practices to yellow passion farmers in Embu County, the use of either 100gDAP+10kgManure+50gNitrabor, 100gDAP+20kgManure+50gNitrabor or 50gDAP+10kgManure+50gNitrabor and the application of 10 liters of water per day per plant for optimum yield of passion fruits. Future studies on nutrient partitioning and water use efficiency can also be conducted to have a clear understanding of the nutrient and water relations in yellow passion fruit.

CHAPTER ONE: INTRODUCTION

1.1 Background information

Yellow and purple passion fruits are important cash crops in Kenya and are the third most important fruit crops after mango and avocado (Kahinga *et al.*, 2006). However, the yellow variety faces major challenges including pests, diseases, low soil fertility and poor agronomic practices. The impacts of these constraints are most evident especially among small-scale farmers (Wasilwa, 2007). Yellow passion fruit (*Passiflora edulis f. flavicarpa* Deg.) is native to tropical America and is grown in many countries. There are two main cultivars, the sweet and sour which are best suited for lowlands. The variety also thrives in mid altitudes of up to 1500m above sea level and lately there has been increased production in semi-arid regions of Embu, Meru, Tharaka Nithi and Kirinyaga counties under irrigation (HCDA, 2013). The yellow passion is thought to be tolerant to *Fusarium* wilt caused by *Fusarium oxysporum* and Brown spot disease caused by *Alternaria passiflora*. *Fusarium* disease is one of the key challenges to passion fruit and can reduce the average orchard life from 6 to 3 years (Amata *et al.*, 2009). However, using the yellow variety as a rootstock in grafting can help to reduce the disease severity (KARLO, 2014).

Due to the vulnerability of the purple variety to diseases, the Kenya Agricultural & Livestock Research Organization (KALRO) opted to develop new varieties and hence introduced the yellow passion cultivar. Breeding of this new cultivar started with support

from the World Bank and the United States Agency for International Development (USAID). The breeding program which took more than 20 years eventually produced the KPF4, KPF11 and KPF12 varieties which are both adapted to drought and are high yielding (Joseph, 2014). The initials KPF represent Kenya Passion Fruit while the numbers represent the series variety. Variety KPF4 has higher yields and the fruits also have a higher juice content hence it's more preferred. To ensure the varieties were widely disseminated to farmers, KALRO partnered with TechnoServe, a private agribusiness firm to establish a mother block for seed extraction and nurseries propagation. The mother block has also been used for conserving germplasm to facilitate continuous research. The yellow passion is mainly consumed locally and exported by some Kenyan companies (HCDA, 2013). Currently this fruit is widely grown in Mbeere Sub County of Embu, an initiative promoted by Kenyatta University, KALRO and Kamurugu Agricultural Development Initiatives (KADI), among others.

1.2 Morphological characterization

The genetic structure of the yellow passion has not been adequately studied through morphological characterization yet this can lead to identification of superior materials that can be used for developing better varieties (Tamiru *et al.*, 2008). These studies involve the classification of different morpho-variables that are present in certain populations. The data from these studies can be analyzed with several methods including Principal Component Analysis and Cluster Analyses (Dansiet *al.*, 1999). These then can be used to predict the genetic diversity of the materials.

In morphological characterization, the classification of a range of variability among accessions is pivotal to the maintenance of germ-plasm resources. Different techniques of taxonomy have been successfully used at both intra and inter-specific levels (Sneath and Soka, 1973; Chheda and Fatokun, 1982; Ariyo, 1991). Several multivariate methods, such as the Principal Components, Canonical Variables and Cluster Analyses can be used to predict genetic divergence. The choice of the method depends on the precision the breeder desires, as well as the ease of analysis and data management.

1.3 Statement of the problem

In Kenya, yellow passion fruit has emerged as an important high market value horticultural crop over the last decade following the establishment and expansion of large-scale processors of fruit juice and increasing population of health-conscious consumers. This has led to increasing interest in the enterprise among farmers. Yellow passion being a relatively new variety is constrained by abiotic and biotic factors in the Mbeere region of Kenya (Joseph, 2014). Preliminary studies on selected farms has identified emergence of diseases, pests and physiological challenges that need detailed research. These and other factors are making many farmers to withdraw from passion fruit farming, citing low productivity of their orchards. There has not been much work conducted on characterization to determine varietal diversity with most studies focusing on pests and diseases (Wangungu *et al.*, 2010). In addition, in depth studies on nutrient and water stress management for yellow passion are scanty. These issues require detailed studies to determine the best management practices.

1.4 Justification

Farmers in Embu and other yellow passion growing regions are addressing agronomic, water stress and nutrient management challenges based mainly on informal knowledge from their fellow farmers and selected private companies. Nevertheless, KALRO and other agricultural agencies periodically provide formal knowledge. Private companies are the main buyers of the fruits and provide extension services. To safeguard the smallholder farmer and improve production of this crop, there is need to carry out detailed studies under controlled environments. Characterization results will be crucial in breeding programs for varietal improvement while results on water stress and nutrient management will be important in advising farmers on the correct management practices. Yellow passion fruit being a relatively new crop under commercialization has not been adequately studied hence there is no updated information for farmers and even consumers. This study will generate empirical results that will help nutrient and water stress management of the yellow passion.

1.5 Objectives

1.5.1 Main objective

To morphologically characterize and assess water and nutrient management of yellow passion fruit grown by farmers in Kiambu and Embu Counties.

1.5.2 Specific objectives

1. To assess the socio-economic status of yellow passion fruits farmers in Mbeere, Embu County.

2. To characterize yellow passion fruit varieties grown in Mbeere Sub County through morphological indices.
3. To determine plant morphological and physiological aspects as affected by different fertilizer regimes.
4. To assess the effect of different irrigation regimes on plant growth.

1.6 Hypothesis

- i) There are no differences in the socio-economic status of yellow passion fruit grown in Mbeere Sub County.
- ii) There is no diversity in the varieties of yellow passion fruit grown.
- iii) Plant growth aspects of the passion fruits are not affected by different fertilization regimes.
- iv) Different watering scheduling have no effect on the growth and yield of yellow passion fruits.

1.7 Significance of the study

The introduction of yellow passion fruit farming in Mbeere Sub County provides an alternative source of income to the farmers in the region. Despite these opportunities, farmers are experiencing new challenges including nutrient and water management that are impacting negatively on the potential utilization of the crop. This study has been important in determining the best nutrient and water stress management for yellow passion fruits in Mbeere. In addition, presence of diversity among the cultivars grown by farmers has provided crucial information that can be used in future breeding programs, for example in

selecting the most suitable cultivar for Mbeere. In addition, advice including orchard management, input application and water management will be communicated to the stakeholders through various channels. It is expected that farmers will utilize the recommendations to sustainably improve their yields and profitability through increased quality fruit supply.

1.8 Conceptual framework

The conceptual framework was based on production theory (Figure 1.1) where, $y = f(x_s)$, y being the output (yield) and x_s are production factors (Cobb and Douglas, 1928). The conceptual framework was organized in terms of influence and feedback mechanisms of farm level production methods and efficiency. Production factors (seedlings variety diversity, fertilizer application, irrigation regimes and general agronomy) were used as inputs in the yellow passion fruit production process. It is anticipated that as inputs are used more efficiently by the farmer, fruit yields will increase and hence translate to improved incomes. Therefore, optimization in the method and level of inputs to be applied by farmers will be of crucial consideration. This perspective is supported by the notion that for a production process to be efficient, the manner of utilization of the available resources is important in realization of maximum output from a given set of inputs (its technical efficiency).

The production function is presented as : $y = \beta_0 + \sum \beta_i X_i + v - \mu \dots (1)$ Where: y is the yellow passion fruit output, x are inputs applied, β are the unknown parameters, μ is the

non-negative random variable which is assumed to account for technical inefficiency in production (one-sided), and v being a random variable (which is symmetric in nature).

Agronomic management practices by farmers are hypothesized to play an important role in the conceptualized efficiency model. Updated management practices across the study areas are expected to influence future policy recommendations particularly on yellow passion fruit agronomy.

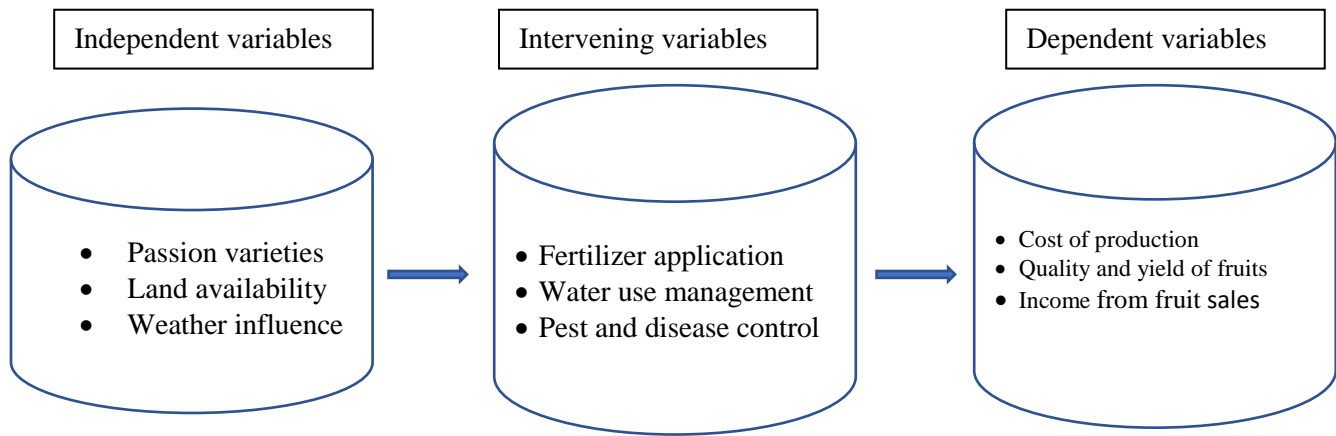


Figure 1.1: Conceptual framework

Source: Modified from Cobb and Douglas (1928) and Sibiko (2012)

CHAPTER TWO: LITERATURE REVIEW

2.1 Origin of passion fruit

The family Passifloraceae includes 550 species in 12 genera. The major species and varieties include *Passiflora edulis* (Purple or violet passion fruit), *Passiflora edulis* (var) *Flavicarpa* (Yellow passion fruit), *Passiflora ligularis* (Violet red passion fruit) and *Passiflora caerulea* (Blue Crow) (Morton, 1987). Passion fruits are thought to have originated in South American rain forests of Brazil. Other probable regions could include Argentina and Paraguay (Morton, 1987). The fruits have been commercially adopted in California, Florida, South Africa and Hawaii. Other regions growing passion fruits include Sri Lanka and Fiji while Kenya adopted the crop in the middle of the 20th Century.

2.2 Botanical description

The passion fruit plant is a vine with leaves evergreen, 3-lobed and finely toothed. The fruit is best suited to tropical zones. The leaves are long approx. 7.6-20 cm and have deep green glossy leaves. However, some varieties may have reddish or purplish colour on their leaves with single fragrant flowers borne on the nodes.

2.3 World production

Brazil is the world's foremost producer of passion-fruit, with about 90% of the production, followed by Peru, Venezuela, South Africa, Sri Lanka and Australia (Janick and Paull, 2008). Brazilian production is around 478,000 MT with a yield of about 13.8 MT/ha. The

northern and north-eastern regions of the country are responsible for more than 80% of the national production (Gamarra and Medina, 1995). In Brazil, the passion-fruit is used primarily for fresh consumption and the production of juice, which is also exported. For Brazilian exporters, the principal market is Europe, which imports more than 90% of the juice. However, there are very good prospects in the American, Canadian and Japanese markets.

2.4 Production in Kenya

Yellow passion fruit has great commercial potential in Kenya. The yellow and purple passion fruit contributed Kshs 2.25 billion under a cultivated area of 4,377.2 Ha and production of 62,207 MT (HCDA, 2013). The area and production of Passion fruit increased by 16.9% and 57.2% respectively from 2011-2013 (Table 2.1). The increase that has been recorded could be due to collaborative work between the government and other partners where more than 100,000 smallholder farmers accessed clean planting materials from certified commercial nurseries which reduced pests and disease incidences while improving yields (HCDA, 2013). The leading counties in 2013 in terms of production were Kwale (22.7%), Embu (20.9%), and Migori (16.8%) (HCDA, 2013) (Table 2.1).

Table 2.1: Production of yellow passion fruit in Kenya (2011-2013)

	2011			2012			2013		
County	Area (Ha)	Quantity (MT)	Value (Ksh- million)	Area (Ha)	Quantity (MT)	Value (Ksh- million)	Area (Ha)	Quantity (MT)	Value (Ksh- million)
Embu	102	1,661	109.58	127	1,539	95.9	89	12,981	757.64
Kwale	115	1,309	39.28	306	3,441	103.2	886	14,108	282.34
Migori	1,073	10,037	238.75	1,103	10,309	253.27	1,121	10,462	222.18
Meru	207	6,658	216.38	208	4,155	152.73	205	5,569	191.48
Elgeyo marakwet	220	2,899	113.99	270	3,248	129.82	346	4,565	180.26
Uasin- gishu	230	2,000	120.7	351	5,779	209.14	222	3,190	119.6
Others	1,219	10,368	415.65	1,378	11,096	442.13	1,508	11,332	501.2
National Total	3,166	34,932	1,254.33	3,743	39,567	1,386.1	4,377	62,207	2,254.6

The high production from Embu and Kwale could be attributed to the introduction of high yielding yellow passion fruits that do well in low altitudes and warm areas by KALRO. In addition, TechnoServe has further opened the markets to neighbouring countries such as Uganda. This company has promised to consume most of the fruits where they sell them to processors as concentrates for making soft drinks. These offer opportunity for the processing industry to grow and create employment in the fruit industry (HCDA, 2013).

2.5 Challenges of yellow passion fruit farming in Embu

2.5.1 Water stress

Mbeere Sub County falls within the semi-arid zones of Kenya and has been classified as a low potential zone (Herlocker, 1999). The region is characterized by annual erratic low rainfall levels of average 700 to 900 mm (Moscar, 2014). Hence most of the crops grown in the region suffer water stress during the growth and development. In the case of yellow passion fruit, water deficit during the reproduction phase may lead to a decrease in fruit weight and pulp volume, wilt, flower abortion and finally fruit fall (Teixeira *et al.*, 1990), hence affecting the mean weight, length and diameter of the fruit (Cavichioli *et al.*, 2008), (Plate A and B).

Mbeere region face salinity, usually due to the high evapotranspiration demand, reduced precipitation and poor management of tillage (Doneen and Westcot, 1988). Salinity is further exacerbated through intensive and continuous tillage operations (Niu & Wang, 2002). Li *et al.*, 2006 further argues that high concentrations of salts in the soil hamper agricultural crop production through impeding plant nutrient uptake, increased physiological stress and predisposing plants to diseases and pests. Poor use of organic fertilizers by farmers further aggravates the problem of water stress. According to Ayers and Westcot (1999), yellow passion fruit is highly sensitive to the action of salts hence irrigation with saline water which is common in the region may produce undesirable effects in the physicochemical quality of the fruit (Costa *et al.*, 2001; Freire *et al.*, 2010; Dias *et al.*, 2011).



Plate A



Plate B

Plate A & B: Symptoms of water stress (shedding of leaves) on passion fruits in the study area.

Source: Maina, 2015 (unpublished)

2.5.2 Fertilization and nutrient management

The yellow passion grows well in the tropics especially between altitudes 650-1300m above sea level and temperatures of 15 to 28°C. The fruit performs well within well distributed rainfall range of 1000 to 2500mm (Matheri *et al.*, 2017). Rainfall is particularly important and should be minimal during flowering to avoid bursting of the pollen. Uneven and inadequately distributed rain promotes insect pest, poor pollination and low fruit yield (Nakasone and Paull, 1998).

For growth and production, passion-fruit requires adequate nutrient supply at all stages of growth. The macro-nutrients N, K and Ca are taken up in the greatest quantities, followed by S, P and Mg. Of the micro-nutrients, Mn and Fe are absorbed in the greatest quantities, followed by Zn, B and Cu (Haag *et al.*, 1973). From the start of fruit formation, there is a strong translocation of nutrients from the leaves to the developing fruits and this reduces the vegetative growth of the plant (Joy, 2010). Although farmers in Mbeere have made

effort to apply both organic and inorganic fertilizers, plants have been noted to show nutrient deficiency symptoms (Matheri, *et al.*, 2017).

2.5.3 Abnormalities in fruits in relation to nutrient management and water stress

Various undetermined abnormalities were observed on the fruits during a prefeasibility study (Matheri, *et al.*, 2017). These included distortions in shape, abnormal textures, spotting and coloration (plate C). Some of the abnormalities have been attributed to genetic, physiological factors such as nutrient and water stress, poor pollination, cultural practices or a combination of all (Matheri, *et al.*, 2017).



Plate C

Plate C: Fruit abnormalities in the study area

Source: Matheri *et al.*, 2017

2.5.4 Diseases and pests

Yellow passion fruit varieties are recommended to farmers on the strength that they are tolerant to most common diseases and pests of the purple passion (Aline *et al.*, 2013). However, a preliminary study on selected farms has confirmed that several diseases are attacking the yellow passion fruit (Matheri *et al.*, 2016). The diseases and pest attack

severely affect the quality of fruits and marketability. There is need for identification of these diseases and their management. In addition, farmers reported a condition that is causing fruits to shrivel, wither and drop off prematurely. To mitigate this problem, farmers with the advice of Agrochemical companies spray fungicides to minimize losses with mixed results. This makes the farmers to spray continuously for them to achieve good results hence exposing the plant to excess chemicals. High pesticide concentrations in plants may leave residues in farm produce hence reaching toxic levels which are unsafe for consumption (Kahinga *et al.*, 2006). High levels of pesticides may also lead to plant stress, in addition to increased cost of production. The intensive spraying is likely to lead to rejection of produce in markets due to exceeded pesticide maximum residue levels (HCDA, 2013).

2.6 Water and nutrient management

Drought which is common in the growing zone is a major stress in yellow passion fruit production and is mainly caused by erratic rainfall, water shortage, high temperatures and high light intensities (Cornic, 1994; Lawlor, 1995). In passion fruit which is a C3 plant, high light intensities lead to a reduction in photosynthesis and especially CO₂ uptake in chloroplasts (Nunes *et. al.*, 2017; Öpik and Rolfe, 2005). Therefore, to maintain favorable photosynthesis under drought conditions, there is need to have optimal light intensity by maintaining correct pruning (Osmond, 1994).

Reduction in soil moisture content has been demonstrated to affect crop productivity hence for maximum yields, it is important to apply water before soil moisture is reduced beyond the wilting point (Dooren and Westcot, 1988). A favorable water irrigation regime can be determined by several factors including water holding capacity of the soil, depth of the root zone, volumes of water to be applied among other factors. Various methods of irrigation including use of motorized pumps to deliver water to the root zone and hand watering by use of watering cans can be used for an irrigation regime (Martin *et al.*, 2014). Ensuring the root zone is continuously wet keeps a vine flowering and fruiting almost continuously. Water requirement is high when fruits are approaching maturity. If soil is dry, fruits may shrivel and fall prematurely (Morton, 1987). Destructive effects of drought similarly apply in all passion fruits, necessitating establishment of remedial measures.

Accumulation of Dry Matter (DM) in a plant depends on several factors including correct synthesizing of carbohydrates and efficient photosynthesis pathways. These processes can be stimulated and accentuated by the availability of enough moisture in the soil. Further, increase or decrease in photosynthate partitioning as a result of insufficient soil moisture can lead to increased or reduced DM accumulation (Norero and Pilatti, 2002). DM accumulation is also dependent on the stage of growth of a crop. For example, Montenegro (1991) has shown that DM accumulation in bananas peaks just at the onset of ripening hence the need to provide enough moisture at this stage.

Leaves are the main organs involved in photosynthesis process hence their interception of photosynthetically active radiation is important in determining the total amount of DM accumulated in a plant (Coombs and Hall, 1982). Specific leaf area becomes therefore

critical. The leaf area ratio (LAR) also becomes important in determining the amount of DM since it also affects the evapotranspiration and the capture of active radiation that is used in photosynthesis (Hunt, 2003). As for the driving variables of plant growth, Lambers *et al.*, (1998) designated leaf area and net assimilation rate, as well as the plant's nutrient concentration and nutrient productivity. When mineral nutrients are limiting, plants reduce growth and change their morphology, as well as uptake and utilization of minerals to maximize acquisition of these scarce resources (Schachtman and Shin, 2007). Thus, the visualization of plant deficiency symptoms is a valuable tool for morphological characterization (Lizarazo *et al.*, 2013), basic to identifying nutrients as limiting the factors in plant growth and production, and is also useful to differentiate physiological disorders caused by abiotic factors such as climate or toxicities induced by fertilization, among other factors (Gómez, 2012).

2.7 Morphological characterization

Falconer (1987) demonstrated that when different varieties are studied in more than one environment, differences in performance can mean different clusters of a particular accession. Based on their environment responses, accessions developed in varying ecological systems can then be differentiated. Interactions between genotypes and different ecosystems pose challenges to breeders especially in selecting the most suitable variety. Important genotypic interactions are therefore determined by the strength of the genetic diversity in any environment (Borém, 1997). This therefore means a critical assessment of the genetic potential in several environments can be used to determine the selection of a

potential genotype or cultivar for use in a breeding program. Notwithstanding this importance, evaluation studies using techniques of multivariate studies have demonstrated the importance of heterotic crosses as a potential tool for improving the yellow passion genotype (Viana *et al.*, 2004). Further correlation studies between different passion genotype traits by Viana *et al.*, (2003) and studies on passion reproductive traits by Meletti *et al.*, (2003) and Souza *et al.*, (2004) have showed the importance of these techniques for use in future breeding improvement programs.

This study aimed to quantify the genetic diversity by use of morphological traits in yellow passion fruit accessions collected in Mbeere Sub County to identify superior genotypes that can be used in a regional improvement program for the crop. The research will use techniques of principal component and cluster analysis.

CHAPTER THREE: MATERIALS AND METHODS

3.1 Objective 1: To assess the socio-economic status of yellow passion fruits farmers in Mbeere, Embu County

3.1.1 Study site description

Mbeere Sub County is in Embu County and lies between Latitudes 0° 20' and 0°50' South and Longitude 37° 16' and 37° 56' East (Fig 3.1). The Sub County has a gentle slope in a North West to South East direction. Its altitude ranges from 500 m asl to about 1200 m asl on the Tana River basin. The Sub County is served by five rivers namely Tana, Rupingazi, Thuci, Thiba and Ena. The Sub County is covered by three main agro-ecological zones namely: Lower Midlands LM4, the Lower midland, Lower Midlands LM5 and Lowland Lowlands (Jaetzold *et al.*, 2006). The soils of the region are variable in structure and texture and are generally low in fertility. The study focused on the following administrative Wards; Evurore, Kiambere, Mavuria, Muminji, Mbeti South and Nthawa. The region receives a bimodal pattern of rainfall with the long rains falling between April and June while the short rains fall between October and December. The short rains are more reliable. The annual rainfall averages between 640 mm and 1,100 mm with most parts receiving 550 mm of rainfall per year hence making Mbeere a semi-arid region. The altitudinal variation influences temperatures that range from 15°C and 30°C annually (Jaetzold *et al.*, 2006). The predominant land use type in Mbeere is livestock keeping, crop production and agroforestry.

3.1.2 Sampling and data collection

A farm level survey covering Mbeere Sub County was conducted from December 2014 to January 2015. The study followed a stratified sampling procedure which was used to identify best sampling units. Data was collected through personal interviews with farmers directly responsible for management of the passion orchards using structured and semi-structured questionnaires (Appendix 1). Sixty households were sampled representing a proportion of 40% estimated farmers that were growing yellow passion fruits from a total population of 170,950. The required sample size was determined by sample size calculation according to Anderson *et al.*, (2007) as shown below:

$$n = \frac{pqZ^2}{E^2}$$

Where; n = Sample size; Z= confidence level ($\alpha=0.05$); p = proportion of the population containing the major attribute (purple passion fruit farmers) and q = 1-p, E= allowable error. The proportion of the population is assumed to be 10% of the total population (this was arrived at from pre-feasibility study).

$$p=0.1 \quad q=1-0.1=0.9, \quad E=0.09 \quad Z(\alpha=0.05)=1.96.$$

$$n = \frac{0.1*0.9*1.96^2}{0.09^2}=42$$

This presented a minimum sample of approximately 42 respondents although this was increased to a total sample size of 60 to cater for any likely incomplete data.

3.2 Objective 2: To characterize yellow passion fruit varieties grown in Mbeere, Embu County through morphological indices

3.2.1 Plant material

A total of 59 accessions of the yellow passion fruits were obtained from Embu County during the month of January 2015.

3.2.2 Morphological data recording

Farms were sampled based on the number of plants established and the level of knowledge and management by the farmers. The characterization was based on descriptors developed for passion and other tropical fruits by Bioversity International (IBPGRI, 1980). Variables measured included leaf colour which was determined using a standard colour chart, leaf arrangement, stem colour, days to flowering, twinning direction and number of fruits per vine. Fruit indices measured included fruit weight, length and equatorial diameter.

A total of 8 morphological traits were assessed on plants growing in the field (Table 3.1). Data recording was by visual observation and direct measurement which was then converted into binary recording (1=present and 0=absent). This was then subjected to Principal Component Analysis and Agglomerative Cluster Analysis to generate a similarity Dendrogram.

Table 3.1: Morphological characters recorded on yellow passion fruit

Code	Characters	Score Code-Descriptor State
1	Twinning direction	0-Anticlockwise, 1-Clockwise
2	Leaf colour	1-Dark green, 2-Green, 3-Yellow green, 4-Purple green
3	Leaf density	1-Heavy 2-Medium 3-Low
4	Stem colour	1-Green brown, 2-Purple green, 3-Normal green 4-Dark green, 5-Light grey
5	Number of secondary vines	1-1 2-2 3-3, 4-4, 5-5
6	Unripe fruit colour	1-Light green 2-Green with brown spots, 3-Normal green
7	Fruit shape	1-Round, 2-Oval
8	Maturity period	1-8 months 2-Over 1 year

3.2.3 Principal component analysis

Principal component analysis (PCA) is a statistical technique using descriptive characters to identify variation in accessions and differences in their patterns. The technique further segregates data into different components hence revealing the amount of variation in set

populations (Jeffers, 1967). PCA can further be combined with canonical analysis to study variables that are highly correlated hence getting a clearer understanding of the variation within and between groups (Lawley and Maxwell, 1971). In this study, PCA was performed using XLSTAT software, a program that interlinks with the Microsoft Office Excel program. In the analysis, data collected in the field generated Eigen values which are associated with a linear system of specific characters and together with Eigen vectors are important in understanding the distribution of characters under study. The analysis further generated accumulated variation in percentages and the load coefficient values between the original characters and respective PCA. The results were used to determine the first five principal components that had more than 50% variance.

3.2.4 Cluster analysis

In cluster analysis, the number of variable units used in grouping variation is decreased into individual units which are then used to generate a similarity Dendrogram (Sneath and Sokal, 1973; Tatineni *et al.*, 1996). Together with the Dendrogram, a similarity matrix is then used to plot distances of the different accessions following Euclidean coefficients and unweighted pair-group method average (UPGMA). The analysis helps in further identifying relationships between variables and classifying them into significant clusters.

3.3 Objective 3: To determine plant growth aspects as affected by different fertilizer regimes

3.3.1 Soil sampling and analysis

Soil was sampled from selected farms in Mbeere, Embu at the beginning of the experiment and analyzed for macro and micro elements and pH levels. The soil was sampled by marking the field into different homogenous units based on farm topography and visual soil fertility. This was followed by removing the surface litter at the sampling spot using a hoe then collecting 500g of 10 soil samples up to a depth of 15cm using a soil auger. The samples were then transported to the laboratory in buckets and analysis was carried out using Atomic Absorption Spectrophotometer following the method of Agilent Technologies (1989) whereby a sample is aspirated and atomized in a flame. In this method, the ground state atoms absorb light of a specific wavelength supplied by a hollow cathode lamp, progressing to an excited state. To determine the sample concentration, the amount of absorbed wavelength is then measured by a photomultiplier tube and compared to known calibration standards (Agilent Technologies, 1989). The pH levels in the soil were determined using a pH meter.

Sixty-four plants belonging to KPF4 variety were grown in two sites at Kenyatta University (KU) Farm and Ugweri farmer's orchard in Embu (Plate E and D).



Plate E: Passion fruits growing at KU study site



Plate F: Selected passion fruits growing at Embu study site

Pruning of lateral vegetative growth and training of vines along trellis was carried out throughout the experiment period.

3.3.2 Experimental design

The experiment was laid out in a Factorial Complete Randomized Block Design with planting and top-dressing fertilizers as the main factors. Farmyard manure and

Diammonium phosphate (DAP) fertilizer were used for planting while for top dressing was with Calcium ammonium nitrate (CAN) and Nitrabor®. The treatments are as shown in Table 3.2.

Table 3.2: Treatment coding

Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

Planting fertilizers are indicated in brackets

3.4 Objective 4: To determine the effect of watering scheduling on plant growth under different irrigation regimes

3.4.1 Experimental design

The experiment was set up in a Complete Randomized Design in a greenhouse at Kenyatta University experimental farm from July 2017 to March 2018. Plants were planted in 40-liter plastic pots consisting of top soil mixed with farmyard manure. DAP fertilizer was applied at the rate of 100g per seedling at planting. The water treatments were 2.5 liters/day, 5 liters/day, 10 liters/day and control (water was applied based on visual assessment of how dry the soil was. This was to replicate what farmers do). Each treatment had one plant per pot replicated five times per treatment.

3.4.2 Soil water infiltration rate

Soil moisture contents was determined by gravimetric method (Black, 1965). Fresh soil samples were taken in china dishes and weights were recorded. The soil samples were dried in the oven at 105⁰C overnight. Samples were removed from the oven and after 24 hours, weights were recorded. Soil moisture was determined by using the following formula:

$$\text{Moisture content(\%)} = \frac{\text{Weight of fresh soil} - \text{Weight of oven dry soil}}{\text{Weight of oven dry soil}} \times 100$$

Soil particle analysis was done using hydrometer method (Gee and Bauder, 1986) and the soil texture classification was determined using USDA texture triangle (Rubén and Susan, 2015).

3.4.3 Data analysis

Descriptive data analysis for objective 1 on socioeconomics was performed using SPSS version 18 with results being presented in tables and figures in percentage form. A Pearson correlation between the farm size and the proportion under passion cultivation was also performed. The analysis used a confidence probability level of 95%.

For objective 2 on morphological characterization of yellow passion fruits, data was collected on direction of twinning, leaf colour, leaf density, stem colour, fruit colour, fruit shape and maturity period. Cluster analysis was performed used XLSTAT statistical program.

For objective 3 on determination of plant growth and yield as influenced by different fertilizers, data recording begun at the onset of the first flower bud and the number of unopened flower buds, open flowers and young unripe fruits was recorded on a weekly basis for two consecutive seasons of December 2016 and April 2017. The data collection was continued until approximately 80% of the flowers had formed fruits. Analysis of variance using SAS software version 9.1 was performed on the data.

Data for objective 4 on effect of watering scheduling on yellow passion growth included primary vine length, number of vines per plant and secondary vine length and was collected on a weekly basis. The experiment was terminated after the plants attained a minimum of four secondary vines lengths. Analysis of variance was performed using SAS ver. 9.4 and presented in tables and figures.

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Objective 1: Socio-economic status of yellow passion fruit growers

4.1.1 Farm size

The sizes of the farm under yellow passion cultivation ranged from <1 acre to > 8 ha. Majority of the farmers (52.5%) cultivate small pieces of land ranging <1-2 ha, 22% cultivating 3-4 and 11.9% cultivating from 5-8. Few farmers (14%) had slightly over 8 acres (Table 4.1).

Table 4.1: Farm size in the study area

Size of the farm (ha)	Respondents (%)
<1-2	52.5
3-4	22
5-8	11.9
>8	13.6

n=60

The sizes of the farms confirm similar findings by John *et al.*, (2013) in his baseline report on Mbeere North. This further agrees with findings by Guy *et al.*, (2001) that established that typical small-holder farm ownership in Kenya is less than 5 acres.

4.1.2 Proportion of land allocated to yellow passion

Majority of the farmers (50.8%) allocated less than 10% of their land to yellow passion while a smaller proportion (6.8%) allocated more than 30% (Table 4.2). The yellow passion being recently introduced, it is still finding acceptance among the farmers hence the probable reason why few farmers have allocated substantial space for its growth.

Nevertheless, this trend is true for any new product with early and later adopters (Nicholas et al., 2018).

Table 4.2: Proportion of land allocated to yellow passion

Proportion of land under passion (%)	Respondents (%)
>30	6.8
<10	50.8
11-20	30.5
21-30	11.9

n=60

4.1.3 Household demographics

Household sizes varied between one to 11 persons, with a majority size of three persons per household (Table 4.3). Gender distribution among the respondents was more skewed towards the males (75%) with females (25%) among the farmers. The number of hired workers for passion fruit farming among the households varied from zero to 8 with majority (54%) hiring only one worker at a time. Most of the work in the passion orchards was carried out by family members or occasional help from friends and neighbours. The lack of extensive engagement of hired labourers can also be attributed to low purchasing power among the farmers in Mbeere, a region that is traditionally economically disadvantaged. Urban migration and lethargy from youth engagement in agricultural activities could also be reasons for low labour engagement in Mbeere.

Table 4.3: Household size

No of children per household	Percentage respondents
0	10.2
1	3.4
2	16.9
3	22
4	13.6
5	13.6
6	8.5
7	6.8
8-11	5.1

n=60

4.1.4 Main crops preferred by farmers in Embu County

In this study, intercropping and mixed farming were the main forms of farming systems in Mbeere. Passion was frequently intercropped with several other crops. Maize (*Zea mays*) and Khat/Miraa (*Catha edulis*) (34%; 31%, respectively) were the most preferred crops. Passion was the preferred crop by 15% of the farmers (Figure 4.1). Other common crops included watermelon (*Citrullus lanatus*), green grams (*Vigna radiata*) and tomatoes (*Solanum lycopersicum*). The preference for maize was probably due to its short maturity period and use for direct consumption as food by the household while Khat was preferred for its readily available local market and good prices. While this study focused on one county only, the results are similar to a horticulture validation by HCDA, (2016) which shows passion fruits contributing around 2% to all the fruits grown in Kenya.

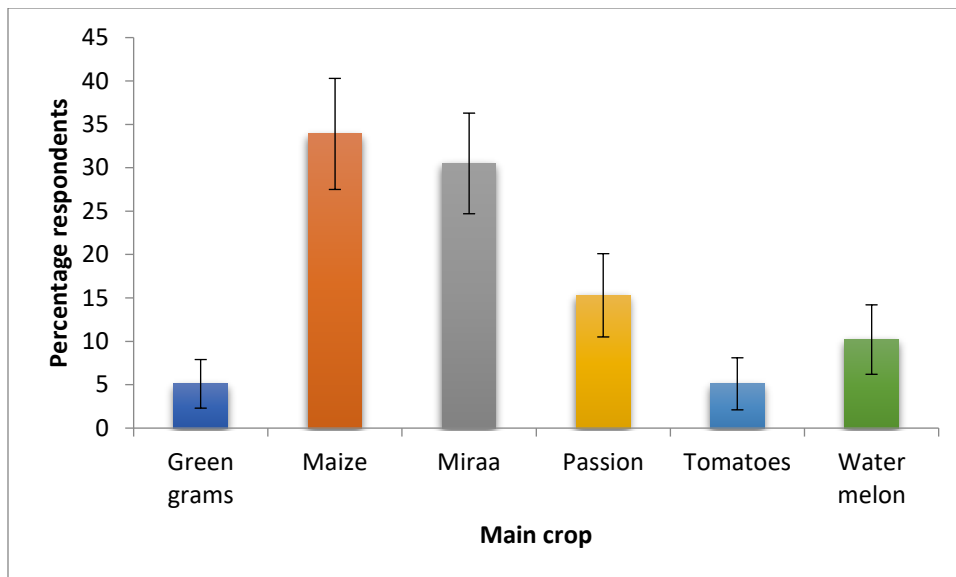


Figure 4.1: Preferred crops by farmers in Embu County

Error bars indicate $\pm SE$, $n=60$

There was no significant correlation between the size of the farm and the proportion allocated to yellow passion grown indicating that farmers did not accord any special preference to the passion fruit due to the size of the land. This is probably as a result of this crop being newly commercialized by majority of the farmers hence, they have not yet fully adopted it over their traditional crops. This was especially due to the availability of only one main buyer of the fruit. Moreover, farmers take time to adopt a new crop since they are not very sure about the potential returns (Dibba *et al.*, 2012).

Major farming systems reported in the study was mixed farming which involved food crops including maize, beans, cow peas and indigenous vegetables. Mixed farming has the advantage of cushioning the farmer against natural disasters for example extreme weather

events that can lead to the loss of one crop (Muui *et al.*, 2013). This type of farming also benefits the soil and the ecology through nutrient cycling and offering refuge to beneficial micro-organisms (Steduto *et al.*, 2012).

4.1.5 Planting materials

The source of the planting material varied with majority (44%) sourcing their materials from KALRO in Thika and 33% from their neighbours (Fig 4.2). Other sources included purchase from agro-veterinary shops and local NGO's.

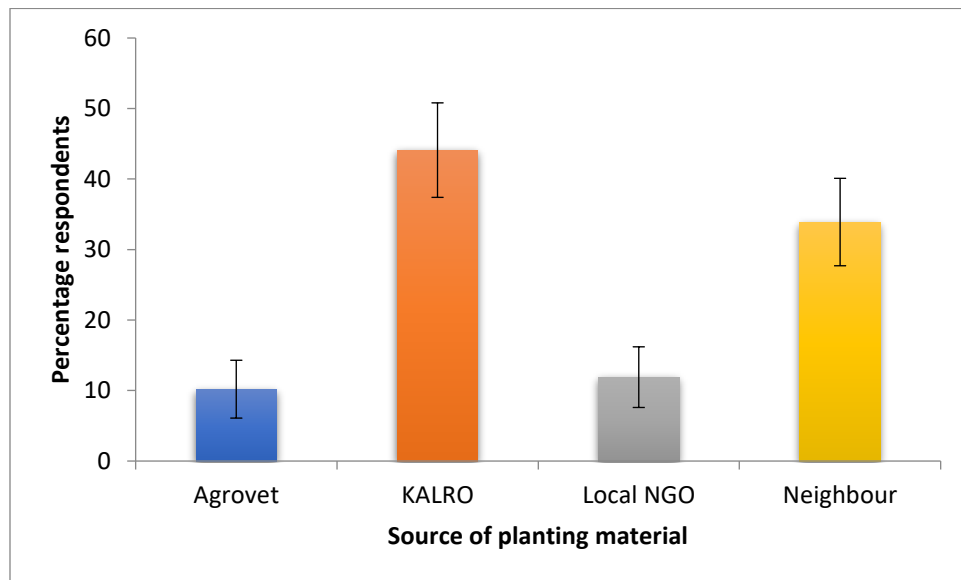


Figure 4.2: Source of yellow passion planting material

Error bars indicate $\pm SE$, $n=60$

The most common type of planting material were seedlings. This might have impacts on the yield and quality in the long term since passion being a cross pollinated plant is likely to be contaminated with other less desirable varieties.

4.1.6 Plant nutrition management

At planting, majority (44%) of the farmers used Yaramillar winner® (15%N: 9%P: 20K), a NPK (Nitrogen Phosphorus and Potassium) brand recommended by one of the private buyers of passion in the region. This was always used in combination with farmyard manure. In addition, 27% of farmers used manure only while 20% used DAP (Diammonium Phosphate). Other fertilizers used by farmers for planting included top dressing fertilizers Nitrabor®, (25.6 % CaO, 15.4 % Nitrogen, 14.1 % Nitrate, 1.3 % Ammonium and 0.3 % Boron) and TSP (Triple Super Phosphate) (Fig 4.3). The use of these top-dressing fertilizers for planting can be probably attributed to lack of knowledge or their ready availability. The common rate of application among the farmers was 100g/plant of Yaramillar winner fertilizer for majority of the farmers (44%). Few farmers (3.4%) used Nitrable. Other farmers used different rates per plant.

The method of measuring the quantity of fertilizer to be applied differed with some using their hand palms, teaspoon, empty tin cans and spades. These application of varying rates of fertilizers likely leads either to low or excessive supply of nutrients which affect the yield and quality of passion.

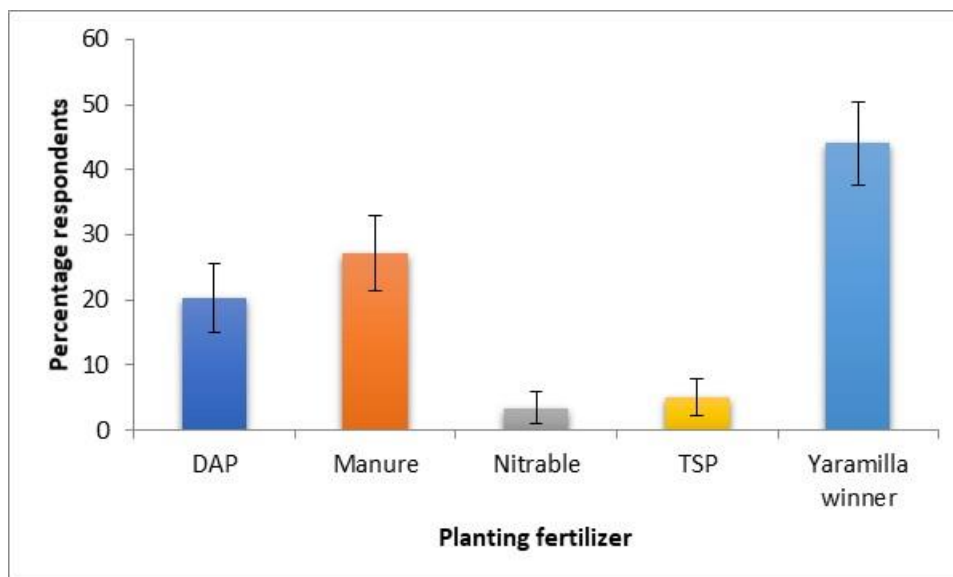


Figure 4.3: Type of planting fertilizers used in yellow passion fruit farming

Error bars indicate $\pm SE$, $n=60$

Key: DAP (Diammonium Phosphate); TSP (Triple Superphosphate)

Top dressing fertilizers commonly used by the farmers included Nitrabor®, CAN (Calcium Ammonium Nitrate), Easygrow®, farm yard manure, NPK (Nitrogen Phosphorus and Potassium) and MOP (Muriate of Potash) with majority (41%) of the farmers preferring Nitrabor (Table 4.4, Fig 4.4). The rates of application varied from 40g to 100g/plant with most farmers (44%) applying 100g/plant. The choice of the fertilizers was probably made by the knowledge that fertilizers influence the growth and yield of yellow passion fruits. This is concurrent with studies by Ferrara and Brunetti (2008) that has shown positive effect on chemical, physical and biological soil properties and consequently in root growth, higher nutrient availability and chlorophyll biosynthesis in yellow passion fruits orchards.

The use of inorganic fertilizers can also further improve crop yields, soil pH, total nutrient content and nutrient availability (Akande *et al.*, 2010).

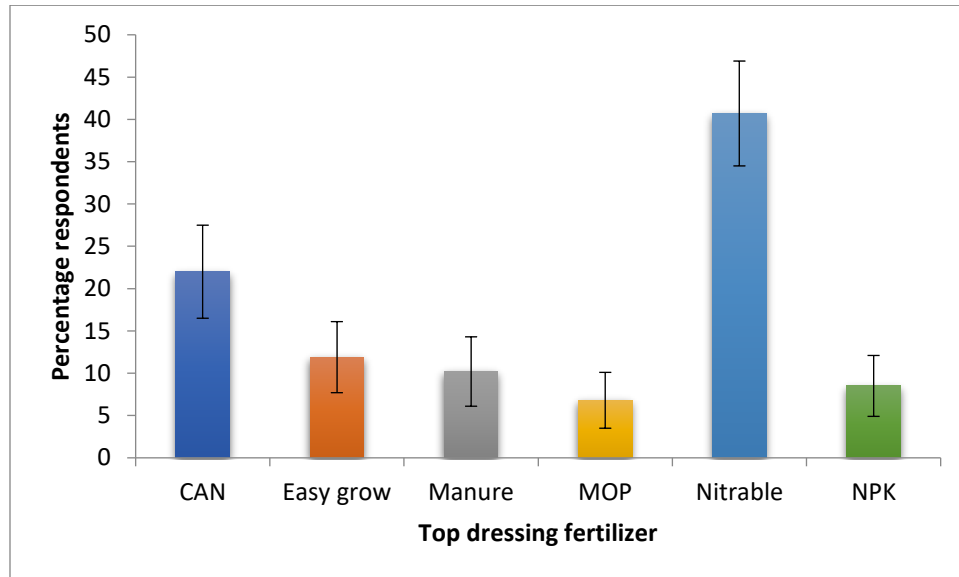


Figure 4.4: Type of top-dressing fertilizers used in yellow passion fruit farming

Error bars indicate $\pm SE$, $n=60$

Key: CAP (Calcium Ammonium Nitrate); MOP (Muriate of Potash); NPK (Nitrogen, Phosphorous and Potash)

4.1.7 Rates of fertilizer application

There were different rates of fertilizer application with majority (44%) preferring Yaramillar fertilizer at the rate of 100g for planting. For top dressing, 54% of farmers preferred Nitrabor at a rate of 100g (Table 4.4). This brand was recommended mainly by a private company that was purchasing the fruits due to its enhanced Calcium content. Calcium has been demonstrated in studies to improve fruit quality of many plants including passion fruit (Borges *et al.*, 2017). In addition to Yaramillar, farmers used other fertilizer brands with the rates of applications differing. The variance in the application rates can be

attributed to several factors including lack of knowledge among farmers, saving on resources to be able to apply a larger area, influence by other farmers and influence by sellers of the products who tended to recommend the higher rates.

Table 4.4: Rates of application of different fertilizers applied

Fertilizer type	Rate/plant	Respondents (%)
Planting fertilizer		
Manure	0.5 debe*	3.4
Manure	1 debe	3.4
Manure	1 spade**	5.2
Manure	20kg	1.9
Manure	2kg	1.6
Yaramillar winner	100g	44.1
DAP	10g	1.8
DAP	1kg	1.6
DAP	200g	1.5
DAP	20g	3.5
DAP	25g	3.4
DAP	40g	1.7
DAP	50g	23.7
Top dressing		
Nitrabor	100g	54.3
MOP	40g	6.8
TSP	500g	1.6
NPK	50g	37.3

N=63

*debe: a full tin weigh approx. 15kg of fertilizer

** spade: approx. 1.5kg of fertilizer

Note: DAP (Diammonium Phosphate), MOP (Muriate of Potash), TSP (Triple Super Phosphate) and NPK (Nitrogen Phosphate and Potassium).

Incorrect and inconsistent fertilizer applications can have detrimental effects on the soil and general plant development. For example, excess application of fertilizers can lead to scorching effect on the plant and can lead to death of micro-organisms while low application can lead to poor crop performance (Boman *et al.*, 2002; Steinman *et al.*, 2007).

Studies by Kihanda and Warren, (1998) in Eastern Kenya and especially in Mbeere region have demonstrated significant decline in the soil fertility attributed to poor agronomic practices. Other studies have further shown that this decline in soil fertility is directly related to low or incorrect application of fertilizers (Warren, *et al.*, 1996). To mitigate this trend, it is important to adopt efficient agronomic management practices of the farms including correct use of fertilizer and other farm resources and the exploration of novel nutrient management techniques (Hilhorst and Muchena, 2000). The reduced fertility can further be attributed to lack of updated information on correct nutrient management which is further compounded by socio and economic constraints including low farm input purchasing power (Michael *et al.*, 2007).

In Mbeere, it has been observed that nutrient removal far exceeds replenishment. For example, studies by Gitari *et al.*, (1999) and Kihanda and Gichuru, (1999) have shown 26 to 46 kg/ha/yr of nitrogen being removed. Karyotis *et al.*, (2005) also working in semi-arid areas of Kenya has reported rates of 53 to 56 kg/ha/yr of nitrogen loss. This therefore calls for frequent fertilization of these soils with Nitrogenous fertilizers to ensure optimum crop performance.

Balanced fertilizer application must be based on the concept of integrated nutrient management for a crop/cropping system with balanced adoption of organic manure and biofertilizers so that productivity is maintained.

4.1.8 Irrigation

Mbeere being a semi-arid zone presents great challenges in water availability especially for irrigation. Majority of the farmers (44%) irrigated their passion fruits once per week while 34% irrigated 2 days per week. Other irrigation frequencies included 3 days and 4 days per week (Fig 4.5). The method of irrigation varied from using buckets, flooding by pumping from rivers and streams and the use of overhead sprinklers. Water pans are also a common source of irrigation water in the area. The common rates of application were 10, 20 and 40 liters with majority of the farmers (46%) applying 20lts per plant at each watering time. Water in Mbeere is also slightly saline with high pH. This has a negative effect on the yield and growth of passion. Studies on pH have indicated that plants growing in a high pH substrate are subject to nutrient imbalances because of changes in nutrient availability as pH increases in the substrate (Jensen, 2010). This effect may be related to low availability of micronutrients for vegetative growth, such as Copper which has an important role in photosynthesis, respiration, fixation and reduction of nitrogen (Cácio *et al.*, 2013).

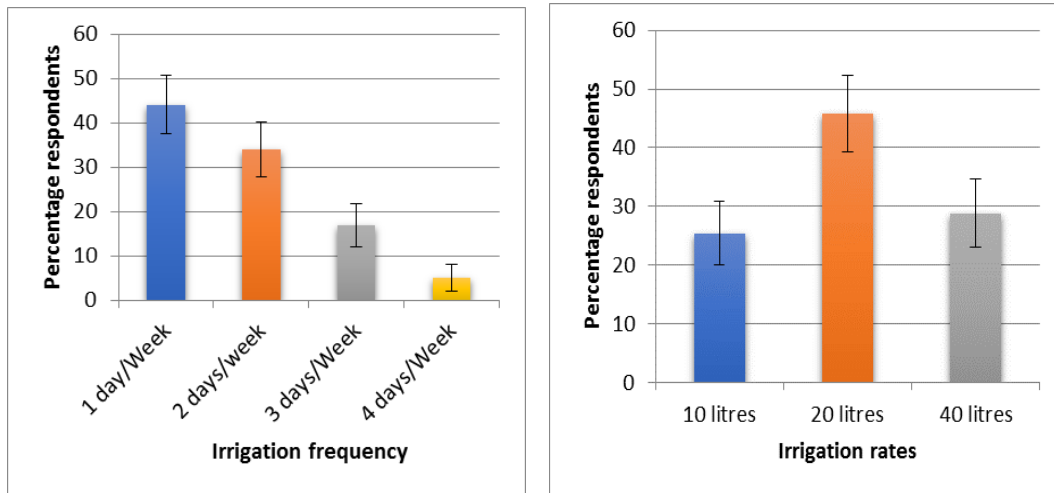


Figure 4.5: Yellow passion irrigation frequency and rates per plant

Error bars indicate $\pm SE$, $n=60$

Flooding which was a common method of irrigation exposes different nutrients to increased leaching. The leaching risk for a nutrient increase with its potential mobility in the soil. Nitrate through its ionic form is particularly liable to leaching due to its slow interaction with the negatively charged particles of the topsoil. This therefore increases its mobility in the soil. Studies by Robertson (1989); Schroth *et al.*, (1999a) have shown that nitrification rates are variable in tropical soils but can nevertheless make nitrate to dominate in acidic soils. This is particularly of concern to soils at KU site that were found to be of medium acidity (Appendix 2). High leaching can have negative consequences on the growth and yield of passion fruits due to imbalances of the nitrogen in the soil (Smaling *et al.*, 1993). The problem of nitrogen leaching is further aggravated during flash floods or occasional heavy rains. This is due to mineralization flush of organic nitrogen which leads to release of high quantities of nitrate when dry soil is wetted suddenly and especially when

crops have just been sown but have not germinated hence not ready to utilize it (Birch, 1960).

Other nutrients liable to leaching include Sulphur where Havlin *et al.*, (1999) demonstrated its mineralization immediately after wetting of soil that has been dry for extended period. The leaching of sulphate is highest in soils dominated by monovalent cations especially sodium and potassium.

In contrast to nitrate and sulphate, phosphate is of less concern due to its known immobility in most soils hence the effects of its leaching maybe negligible. However, Havlin *et al.*, (1999) has demonstrated phosphate leaching to have significant effect on crop production for very sandy soils hence this maybe a factor especially for farmers in Embu who cultivate soils close to riverbanks and on dry riverbeds that are sandy. Eroding of the surface soil particles through overcultivation, wind erosion and other soil disturbances can further accelerate phosphorus loss.

Daily irrigation was necessitated by the fact that Mbeere is a dry region with highly weathered soils that have high permeability. This is also confounded by the fact that yellow passion despite being relatively drought tolerant requires large amounts of water and water stress especially during the early vegetative growth can lead to low yields. Controlled experiments in glass houses in Australia have further shown that mild water stress can reduce all aspects of passion growth (Menzel *et al.*, 1986). Similar studies have reported corresponding results in South Africa (Staveley and Wolstenholme, 1990).

4.2 Objective 2: Characterization of yellow passion fruit varieties grown in Mbeere Sub County using morphological indices

4.2.1 Principal component analysis

Results showed that 67.8% of the total variation was explained by the first five PCs or Factor Components. These are the ones that had coefficient values greater than 1.0 (Table 4.5). This is similar to the criterion by Clifford and Stephenson (1975) and corroborated by Guei *et al.*, (2005), which suggested that, the first five principal components are often the most important in reflecting the variation patterns among accessions, and the characters associated with these are more useful in differentiating accessions.

Table 4.5: Eigen values of the principal component analysis

	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9	PC10
Eigenvalue	1.99	1.36	1.30	1.07	1.04	0.94	0.85	0.63	0.49	0.29
Variability (%)	19.90	13.65	13.07	10.78	10.41	9.42	8.56	6.32	4.91	2.94
Cumulative %	19.90	33.56	46.63	57.41	67.83	77.25	85.82	92.14	97.05	100

Eigen values indicate the characteristic values or the direction of variance of the principal components

The first PC (PC-1) which accounted for 19.9% of the total variation had scores highly correlated (correlation coefficient >0.3) to characters related to leaf colour and leaf density (Table 4.6). The second principal component (PC-2) explained 13.7% of the total variation and was highly associated with twinning direction, colour of the immature fruit and maturity period (Table 4.6). The third component (PC-3) which explained 13.1% of the

variation was associated with the maturity period of the fruits. The fifth component (PC-5) was stem and fruit colour and accounted for 10.4% of the total variability. Principal component six (PC-6) was correlated to shape of the fruit and explained 9.4%. PC-7, PC-8 and PC-9 explained an additional 8.6, 6.3 and 4.9% of the total variation and were correlated to source of the planting material, leaf density and maturity period; twinning direction, leaf colour, maturity period and leaf colour and immature fruit colour respectively. PC-10 had variations of less than 3% and was considered of less significance to the overall variability (Table 4.6). Similar results to these have demonstrated on rice genotypes in West Bengal (Vishnu *et al.*, 2014; Ravi Kumar *et al.*, 2015 and Gour *et al.*, 2017).

Table 4.6: Correlations between variables and factors

	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10
Twinning direction	0.234	0.526	-0.343	0.223	-0.135	-0.019	-0.235	0.538	-0.274	-0.249
Leaf colour	0.494	-0.168	-0.039	0.385	0.036	-0.166	0.271	0.306	0.514	0.344
Leaf density	0.478	-0.175	0.087	0.322	0.263	0.170	0.314	-0.307	-0.448	-0.373
Stem colour	-0.155	-0.254	-0.259	-0.184	0.709	-0.390	-0.025	0.275	0.044	-0.277
No of vines per plant	-0.316	-0.526	-0.047	0.432	-0.086	0.047	-0.189	0.264	-0.456	0.335
Fruit colour (immature)	-0.236	0.454	-0.363	0.341	0.371	-0.038	0.112	-0.402	-0.045	0.418
Shape of the fruit	-0.401	0.069	0.130	0.297	0.175	0.626	0.192	0.249	0.340	-0.304
Maturity period of passion	-0.071	0.316	0.625	-0.136	0.214	-0.149	0.356	0.345	-0.316	0.269

Values in bold indicate the most relevant characters (>0.3) that contributed positively to the variation of the component/factor (F).

Note: In PCA, values between 0 and 0.3 indicate a weak positive linear relationship while between 0.3 and 0.7 indicate a moderate positive linear relationship and between 0.7 and 1.0 indicate a strong positive linear relationship. Negative values indicate a negative correlation.

The correlation among the different characters helps in revealing the level of genetic variation that exists in a population and explains, which characters contribute most for genetic diversity among the genotypes in the population. Further, Important characters coming together in different principal components and contributing towards explaining the variability have the tendency to stay together hence making it easier to identify features that can be incorporated in breeding programs. This has been also been demonstrated rice breeding programs in West Bengal (Mahendran *et al.*, 2013).

4.2.2 Distribution and dispersal of variation

Significant variation in the phenotypic characters and their dispersal in x and y axis among the passion accessions is indicated by PC1- and PC-2 (Fig 4.6). The two components explain a cumulative variability of 33.56%. Based on this distribution, the cultivars found in Nunguni, Ngigeri, Gatirari and Gachoka1 are most distantly related to each other while the many cultivars congregating around the central axis are most likely similar and belong to the same group. The further the cultivar is from the center of the axis, the least related it is to the group (Fig 4.6).

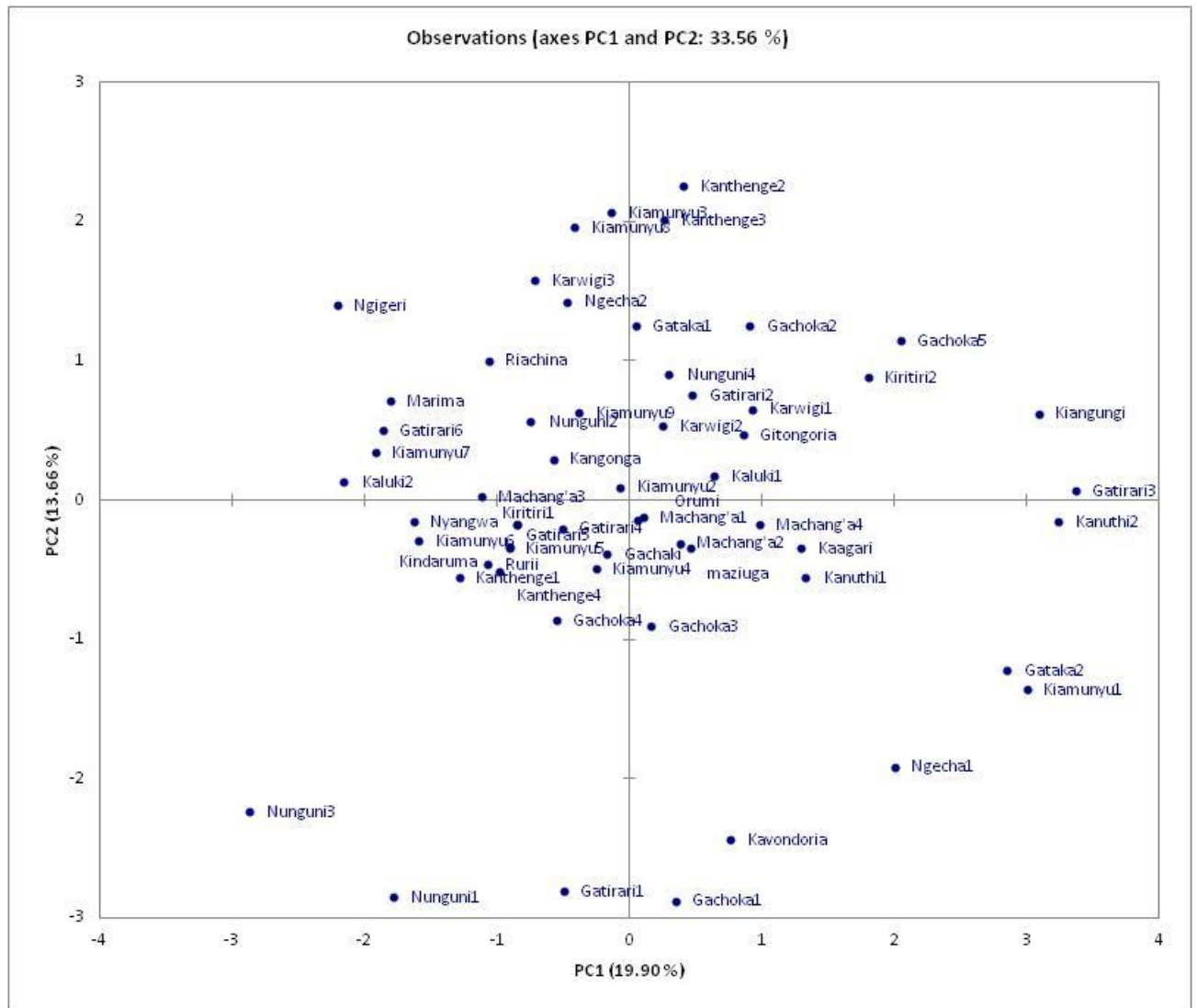


Figure 4.6: Distribution of morphological variates among accessions in PC1 and PC2

4.2.3 Correlation among characters

The correlation among characters for the first two principal components shows four main groups of characters that are distinct (Fig 4.7). In a clockwise direction, the first

group comprise of traits associated with fruit colour, maturity period, shape of the fruit and the source of the planting material; the second group comprise of traits associated with the twinning direction only; the third group comprise of those related to leaf density and leaf colour while the last group shows traits associated with yield per plant, stem colour and number of vines per plant (Fig 4.7).

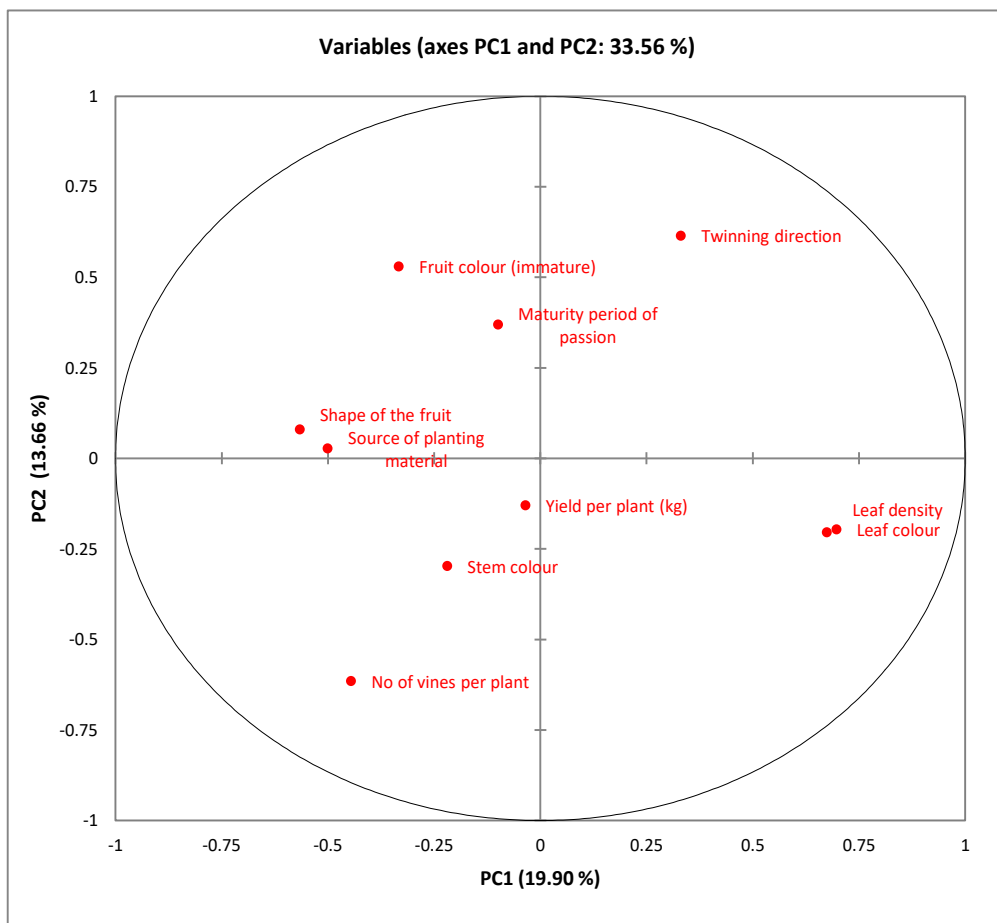


Figure 4.7: Correlation among characters associated with the first and second principal components

4.2.4 Principal components and cluster analysis

A Dendrogram illustrates the relationship among the accessions (Fig 4.8). At 0.88 level of similarity, almost all the 59 accessions were distinct from each other while at 0.05 levels, they are separated into major groups. This indicates that majority of the materials probably belong to two varieties and this confirms the fact that only two main varieties have been released by KALRO. However, the pruned Dendrogram indicates the presence of four closely related clusters (1, 2, 3, and 4) according to the villages in which they occur (Fig 4.8). This indicates close similarity with the little differences probably being attributed to agronomic management practices and changes in edaphic factors. At higher similarity levels, the above clusters can further be separated into smaller less significant sub-clusters. In addition, characters with high variability are expected to provide high level of gene transfer (Gana, 2006; Aliyu *et al.*, 2000) hence this is useful information for consideration in a breeding program.

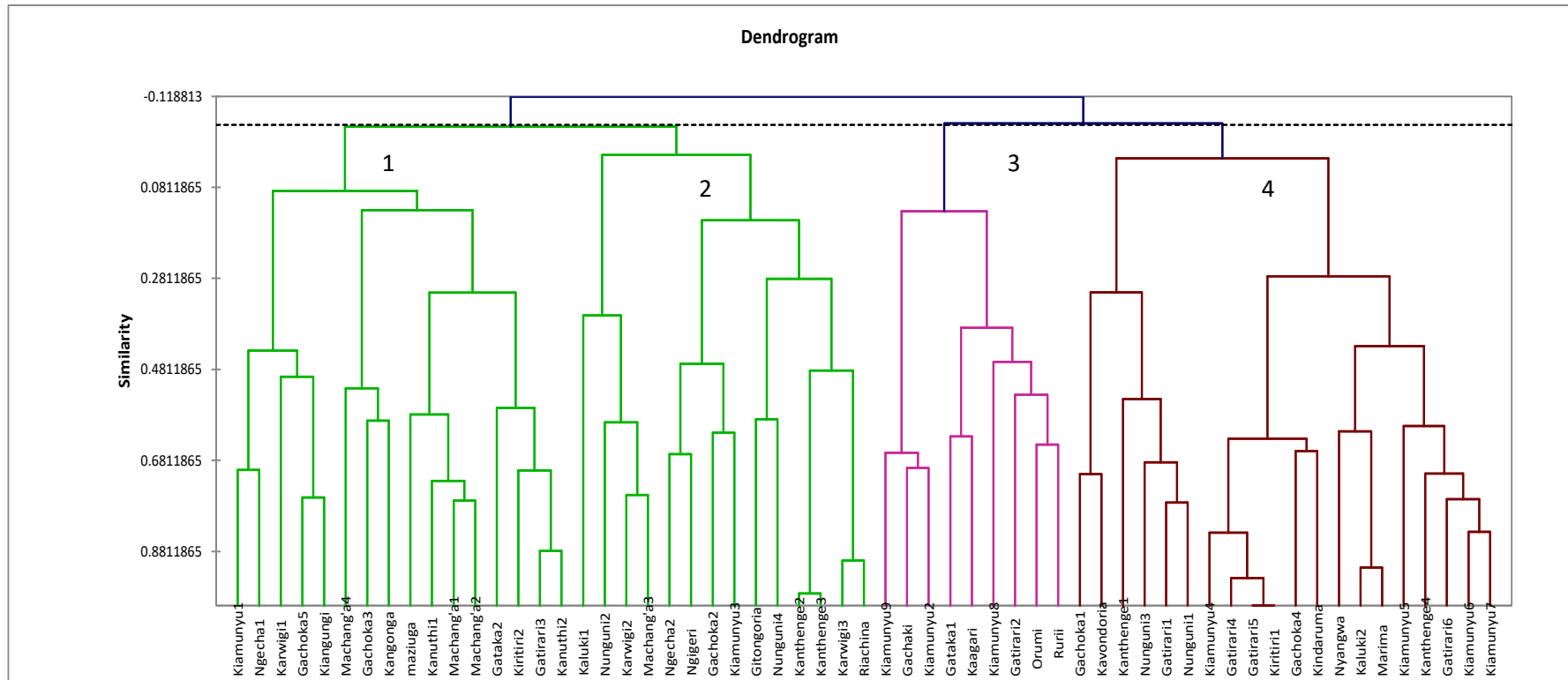


Figure 4.8: Dendrogram constructed based on morphological traits of yellow passion fruit in Embu County

The Principal Component Analysis was also able to identify specific characters and morphological components that can be relied upon when identifying different varieties and cultivars in the field. Morpho-agronomic descriptors play an important role in the characterization and selection of plant species for purposes of use in breeding programs. This can then be combined with multivariate analysis which assumes the presence of maximum genetic divergence within species (Bhatt, 1970; Amurrio *et al.*, 1995). Presence of variability was obtained in the measured characters with the four classes obtained indicating a high degree of morphological polymorphism among the cultivars. These classes could further be separated into much closer related relatives. This could be explained by the fact that majority of the farmers reported sourcing their planting materials mainly from KALRO who have commercialized mainly the KPF4 variety but have also recommended KPF11 and KPF12. The other variety could probably be as a result of cross pollination with purple varieties, one of the other recommended varieties or through gene flow in the environment. These results are further validated by Matheri *et al.*, (2016) who reported the presence of two major clusters in the same area through genotypic analysis.

This degree of polymorphism could probably be attributed to differences in management, for example irrigation and fertilization regimes. The observed divergence also can further be attributed to differences in the agronomic conditions of the study area since the locations of the study area are widely distributed and far apart. The significant morphological variation within and between the various accessions could also be further attributed to

cross-pollination and sexual recombination (Marta *et al.*, 2003). Whereas self-pollination helps maintain the genetic purity, cross pollination may introduce new characteristics to the pure lines. Mutation during seed development combined with intensive selection could be other factors contributing to these observed physical differences (Martin, 1976).

The information obtained from this study can be important in informing farmers and researchers of this crop as to the best selection to make (Gana, 2006). This is especially for breeders who may be specifically interested in a specific cultivar.

From the Dendrogram, it was not possible to group all the cultivars from the different villages into their specific groups but it can be seen clearly that majority were related. Many of the groups in the different clusters were evenly distributed indicating the possibility of frequent exchange of planting materials among and between farmers or the use of the same materials to generate new seedlings for subsequent crop (Mahendran *et al.*, 2015). This confirms the finding that majority of the farmers sourced their materials from the same source, KALRO.

Despite the analysis showing significant phenotypic variation among the groups, the study has also found traits that can be useful as indicators for classifying and identifying specific cultivars. The results demonstrate that traits that best discriminate between the accessions include shape of the fruit, leaf density and leaf colour. This finding agrees with Cerqueira-Silva *et al.*, (2014), who demonstrated that fruit characteristics are useful determinants for the differentiation of accessions of passion species.

4.3 Objective 3: Determination of plant growth aspects as affected by different fertilizer regimes

4.3.1 Number of flower buds

Results indicate that with regard to flower formation, there were significant differences ($p \leq 0.05$) among the treatments (100gDAP+20kgManure)+50gNitrabor, (20kgManure)+50gCAN. The treatment (20kgManure)+50gNitrabor had the highest number of flower buds in Embu while a combination of (10kgManure)+50gNitrabor and (100g DAP+20kg Manure)+50g CAN were the best in KU (Fig 4.9).

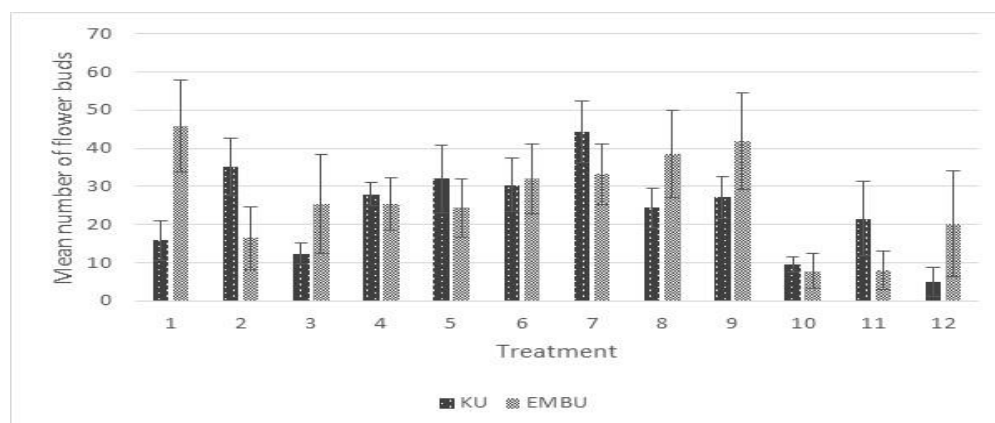


Figure 4.9: Number of flower buds formed at KU and Embu sites

Error bars indicate \pm SE

Treatments coding

Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

Additionally, for the flower bud initiation and open flowers, there were differences for the two sites with Embu having the highest average number of flower buds and open flowers (Fig 4.9). The application of fertilizer had been reported to influence the nutritional and biochemical properties of passion fruits in different studies (Ani and Baiyeri, 2008; Freire *et al.*, 2014; Ndukwe and Baiyeri, 2016a).

4.3.2 Number of unripe fruits

The number of fruits formed increased over the season and had differences in the seasons but there were no major observed differences between the two sites. The treatment (100g DAP+20kg Manure)+50g CAN had the highest number of fruits formed at Embu site while (100gDAP+10kgManure)+50gNitrabor and (10kgManure)+50gNitrabor were the best for KU site (Fig 4.10).

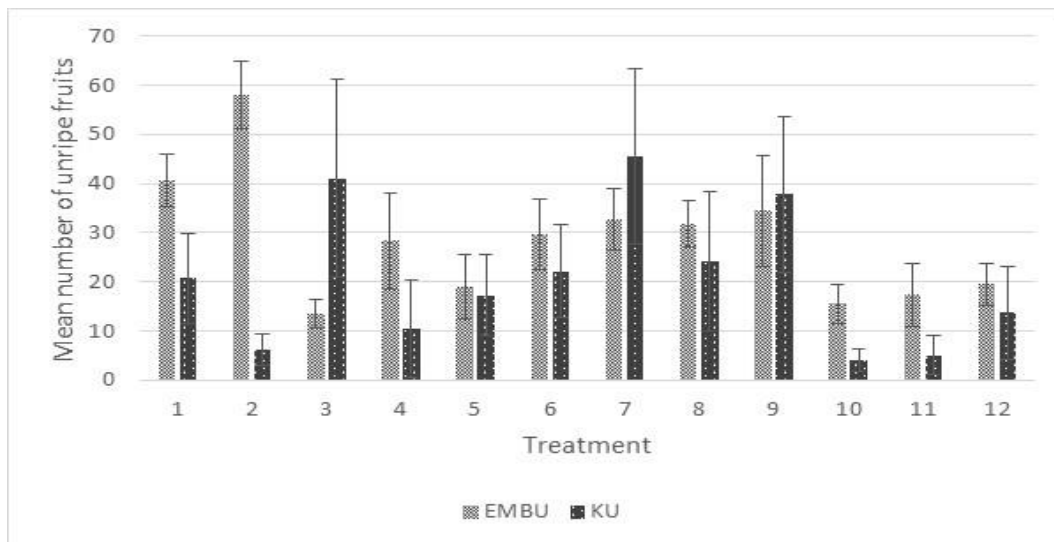


Figure 4.10: Number of unripe fruits formed at Embu and KU sites

Error bars indicate \pm SE

Treatments coding			
Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

The commercial Nitrabor fertilizer (15.4% N + 25.9% CaO + 0.3% B) appears to have influenced earlier flowering possibly due to its enhanced boron content and the improved solubility of calcium. On the other hand, treatments 9, 10 and 11 which were lacking the Nitrabor showed significantly less number of opened flowers and fruits formed. This study further agrees with findings by Freitas *et al.*, (2006) which demonstrated that nitrogen deficit negatively influences flowering, reducing fruit number per plant and affecting fruit weight. The results are also similar to studies in Nigeria where application of fertilizers rich in Nitrogen and Calcium has been demonstrated to contribute to distinct aroma and visual characteristics of passion fruit juice which are important for the marketing of the fruits (Abreu *et al.*, 2009; da Silva *et al.*, 2015). Experiments by Ani and Baiyeri (2008) have further revealed that potassium concentration of passion fruit juice increased with increase in poultry manure rate which is known to have high concentrations of Nitrogen, Calcium and Magnesium (Ndukwe and Baiyeri, 2018).

4.3.3 Correlation of flower buds and open flowers

Results of correlation analysis of flower buds and open flowers indicate a positive correlation where an increase in the flower buds led to an increase in open flowers. However, the strength of the correlation is weak (0.218) indicating less flowers opening as compared to the number of buds (Fig 4.11).

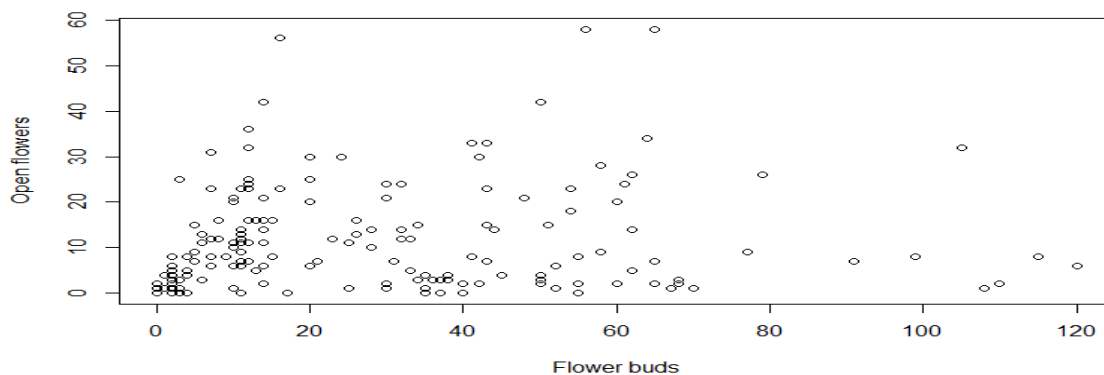


Figure 4.11: Correlation relationship of flower buds and open flowers

```
> cor (`Flower buds`,`Open flowers`) [1] 0.218
```

Flower bud formation and opening are highly influenced by the presence of macro elements especially potassium (Joy, 2010) hence the increased levels of potassium in Nitrabor fertilizer could have led to an increase in bud formation. However, the results demonstrate less number of flower opening as compared to the buds formed. This is likely due to poor pollination or reduction in the amount of potassium uptake during flower opening which could have been attributed to water stress. Similar to passion fruit, stress due to drought has been demonstrated to induce sharp decreases in total Potassium and Phosphorus uptake of maize organs at different developmental stages (Ge tida *et al.*, 2012). Farming of passion

fruits with no irrigation during a dry season is also likely to cause a reduction in bloom (Gachanja and Gurnah, 1980).

4.3.4 Correlation between open flowers and young unripe fruits

Analysis on correlation relationships for open flowers and young unripe fruits indicate a negative relationship (Fig 4.12). This is probably due to more flowers aborting and failing to form fruits, an observation that more pronounced during the dry season. Noam *et al.*, has also demonstrated that although passion fruit vines initiate flowers all year round, flower primordia abort during warm summers. Further, heat stress has been shown to be more serious threat at further stages in reproductive development (pollen viability, stigma receptivity) [Barnabas *et al.*, 2008; Sato *et al.*, 2000] or during fruitlet initial development (Racsko *et al.*, 2007).

Passion is also sensitive to cross pollination hence lack of pollinators could also have led to high number of flower abortions. Poor pollination of passion fruits by bees in India has been shown to lead to flower bud abortion and immature fruit drop (Akali and Maiti, 2006). In addition, it is further hypothesized that exposure to different light intensities can contribute to flower abortion. Differences in light intensities at the experimental sites could be attributed to shading effects and changes in weather patterns. Similarly, Nave *et al.*, (2010) has shown that flower primordia of most varieties abort at an early stage of development if exposed to photoperiods shorter than 11 h (Nave *et al.*, 2010). In many species, photoperiod influences flower induction (Samach and Coupland, 2000) with long

days being necessary for intact flower development. An additional restraint seems to be low irradiance (Menzel and Simpson, 1988).

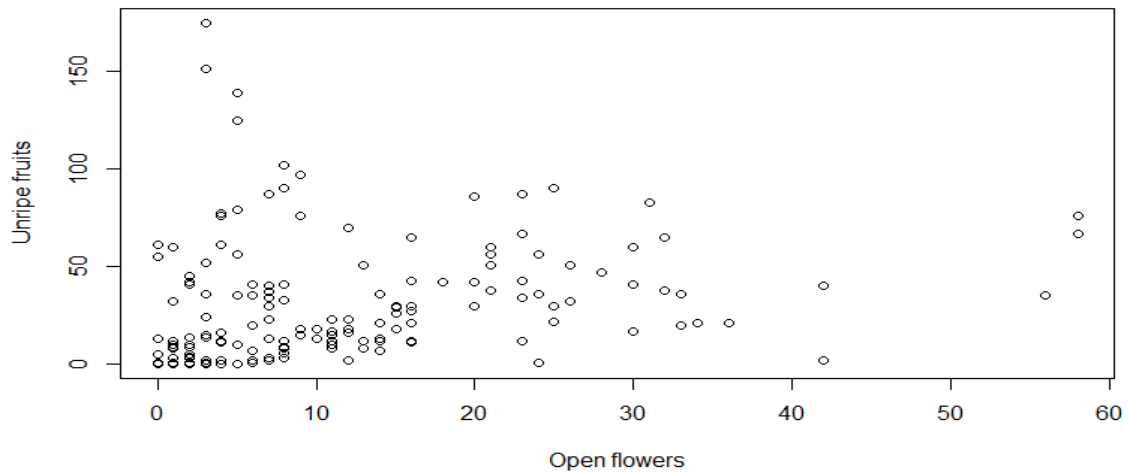


Figure 4.12: Correlation relationship for open flowers and unripe fruits

```
> cor (`Open flowers, Unripe fruits`). [1] -0.08431008
```

4.3.5 Number of fruits harvested per plant

Comparing the two sites, there were significant differences ($p \leq 0.05$) for the number of fruits harvested. Embu site had more fruits than KU across all treatments except for 100gDAP+10kgManure+50gNitrabor, which had a slightly higher number of fruits for KU, site (Fig 4.13). This is because the soils in Embu are deep and well drained and of higher fertility as compared to KU which is mainly composed of clay friable soils that are poor in nutrients (Appendix 2).

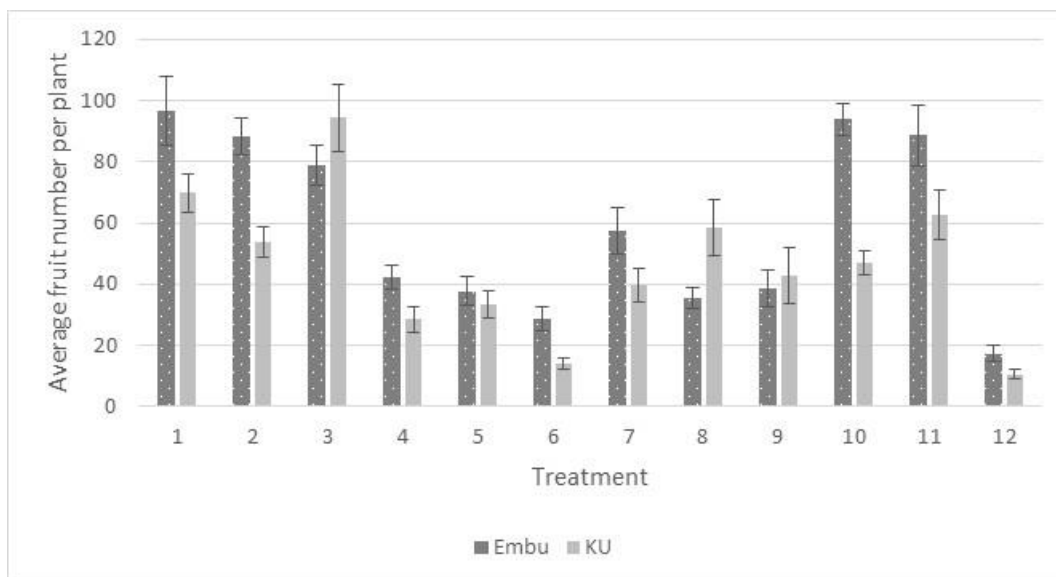


Figure 4.13: Mean number of fruits harvested per plant at Embu and KU sites

Error bars indicate \pm SE

Treatments coding

Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

4.3.6 Fruit weight

There were significant differences ($p \leq 0.05$) in the weight of the fruits harvested at the two sites. Generally, Embu site had fruits with higher mean weight as compared to KU (Fig

4.14) except for treatments 100g DAP+20kg Manure+50g CAN, 10kgManure+50gNitrabor and 50gDAP+10kgManure+50gNitrabor.

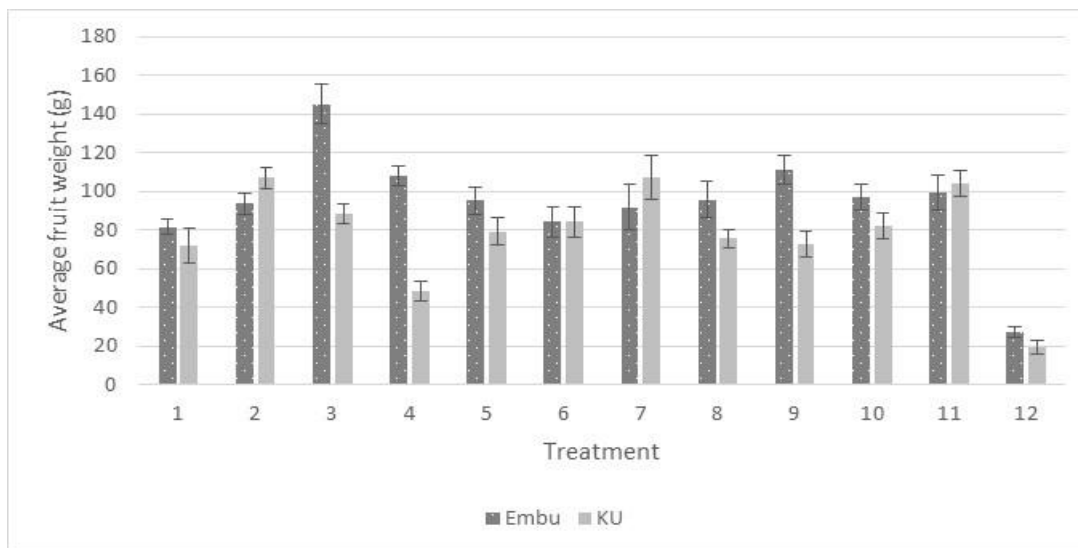


Figure 4.14: Mean fruit weight of Embu and KU sites

Error bars indicate $\pm SE$

Treatments coding

Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

Passion fruit weight is highly influenced by correct balance of nutrients especially with nitrogen and potassium, since these nutrients are the most up taken by the crop (Daniel *et al.*, 2016) hence the increase in weight of fruits treated with higher levels of Nitrabor and CAN which are rich in Nitrogen and Potassium. Balanced fertilization with nitrogen and potassium also implies improvement of physical and chemical characteristics of fruits especially increase in weight which is highly preferred by fresh fruit consumers. Fruit weight is also a key characteristic for the juice agro-industry (Rodrigues *et al.*, 2009).

4.3.7 Fruit length

For all treatments except 10kgManure+50gNitrabor and control, there were no significant differences ($p \leq 0.05$) in the fruit length for the two sites. However, fruits at Embu generally showed higher length compared to fruits at KU (Fig. 4.15). This is probably due to the organic manure content which may have enhanced general fruit setting. The influence of fruit formation on other crops has been extensively demonstrated. For example, high fruit yield due to compost application were reported on tomatoes while compost application was observed to have positive effects which aid crop growth and development thereby improving the crop phyto-nutritional components (Togun *et al.*, 2003). Further in apricots (cv Bergeron), it has been demonstrated that increased fertilization especially with fertilizers rich in Nitrogen, Phosphorus and Potassium enhances vegetative growth, yield average fruit weight and length (Bussi *et al.*, 2003).

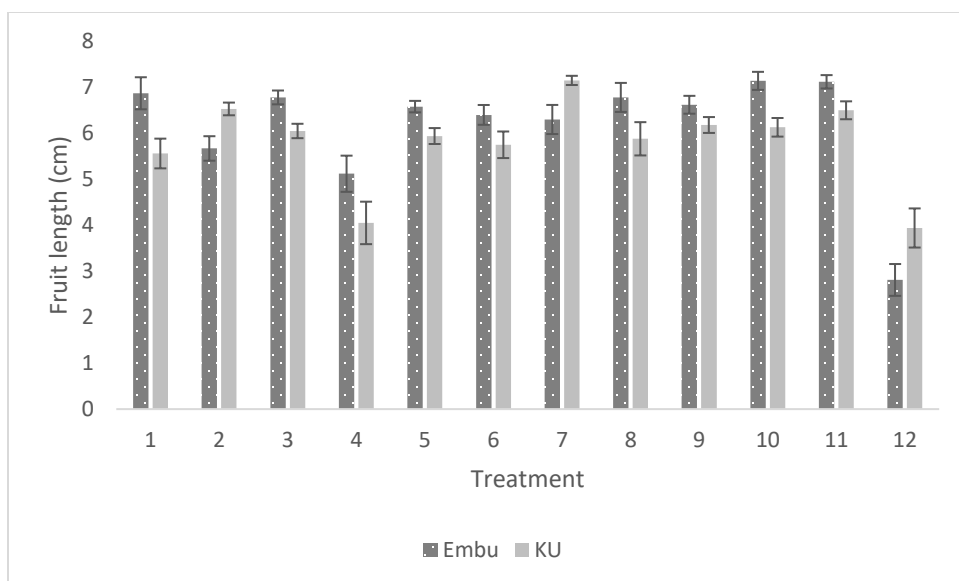


Figure 4.15: Fruit length in Embu and KU sites

Error bars indicate \pm SE

Treatments coding

Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

4.3.8 Fruit circumference

There were significant differences ($p \leq 0.05$) in fruit circumference of the two sites with KU generally indicating a bigger circumference compared to Embu (Fig 4.16). This compares well with data on fruit weight where KU had a higher weight. This could be attributed to sufficient availability of moisture throughout the growing season due to supplemental irrigation at the KU site.

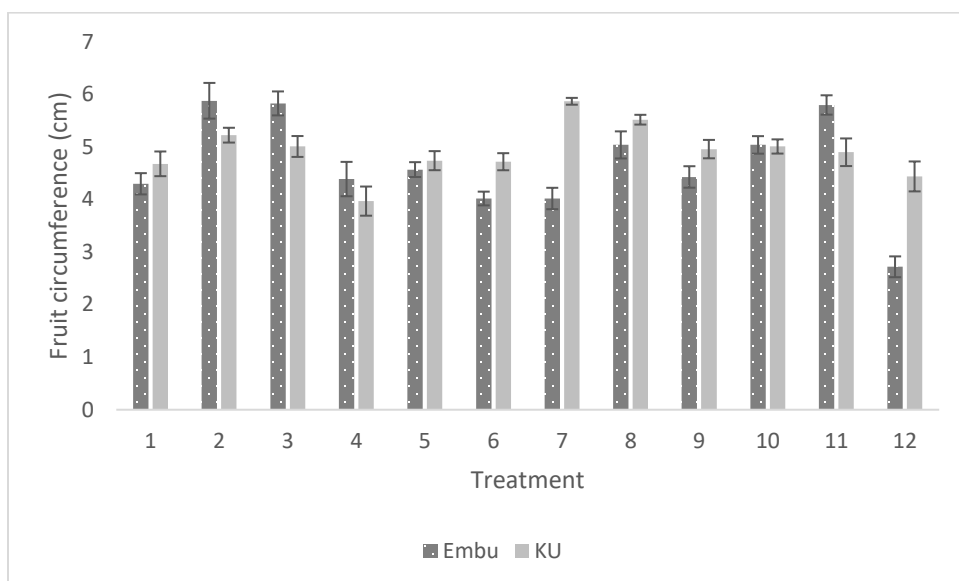


Figure 4.16: Fruit circumference of the harvested fruits at Embu and KU sites

Error bars indicate \pm SE

Treatments coding

Treatment	Code	Treatment	Code
(100gDAP+20kgManure)+50gNitrabor	1	(10kgManure)+50gNitrabor	7
(100g DAP+20kg Manure)+50g CAN	2	(20kgManure)+50gCAN	8
(100gDAP+10kgManure)+50gNitrabor	3	(20kgManure)+50gNitrabor	9
(100gDAP)+50gCAN	4	(50gDAP+10kgManure)+50gCAN	10
(100gDAP)+50gNitrabor	5	(50gDAP+10kgManure)+50gNitrabor	11
(10kgManure)+50gCAN	6	Control	12

Environmental stress including nutritional stress affect the reproductive organs of passion fruits especially flower and fruit formation. An increase in these stresses during early stage of plants' developmental cycle can lead to poor flower formation and hence poor yields (Menzel *et al.*, 1986). Even though passion fruit flowers throughout the year, flower

primordia abortion will occur under conditions of water and nutrition stress. On the other hand, improved nutrition and water availability will likely boost flower formation through initiation of strong flower buds that open fully. This will eventually lead to healthy fruit formation. Flower initiation and opening was found to be influenced by a combination of planting and top-dressing fertilizers that were supplemented with manure. These results are similar to the findings by Campos *et al.*, (2007) where the study found an increase in flowering due to the application of bovine fertilizers. The increase in flower and fruiting formation can also be attributed to Nitrabor® fertilizer (15.4% N + 25.9% CaO + 0.3% B) which is a field grade calcium nitrate fertilizer, with added boron. The mechanism of Calcium ions on stimulating flowering has been studied and confirmed that calcium not only stimulates flowering but also plays a critical role in the entire process of flower development (Andrzej, *et al.*, 1994). Boron could probably also have contributed to the flower formation through its role of improving calcium mobility and the transport of sugars and plant growth regulators. Additionally, studies on Boron in other crops including Brinjals (Suganiya *et al.*, 2015) have further shown that it plays a key role in flower pollination, fruit formation and in maintaining the integrity of the fruit skin.

The control treatment which had no organic or inorganic fertilizers demonstrated poor flower and fruit formation probably due to lacking essential nutrients. Several studies have shown that flower production and seed quality are highly correlated to nutrient availability which can have impacts on the embryo formation, chemical composition and general metabolism of the plant (Carvalho and Nakagawa, 2000). This influence was observed in

other agricultural crops such as corn (Bono *et al.*, 2008) and millet (Abrantes *et al.*, 2010). Panaytov (2006) also noted this trend of improvement of the physiological quality of seeds when pepper plants were fertilized with NPK. The cultivation of passion fruits in saline soils which are common in the study area especially in Mbeere has been shown to affect flower and fruit formation (Mesquita *et al.*, 2012) and the final quality of the fruit (Freire *et al.*, 2014).

The different fertilizer treatments had also significant differences on the number of fruits formed. Specifically, the presence of enhanced nitrogen and calcium salts in Nitrabor could have contributed to increase in the number of fruits observed. The importance of calcium for fruit development has further been demonstrated with studies by Shear (1975) showing deficiencies in calcium lead to several disorders and hence leading to low quality fruits. This is probably through its enhanced role of plant signaling, water relations and interactions of the cell wall. It is also known that with low supply of calcium, there is disruption in the transport of ions resulting to local calcium deficiencies. This can lead to breakdown of cell membrane and cell wall failure hence leading to weak and shriveled fruits (de Freitas and Mitcham, 2012).

The elevated content of calcium in the Nitrabor fertilizer (15.4% N + 25.9% CaO + 0.3% B) could possibly also have played additional role in fruit development. Studies have for example demonstrated the effect of calcium on chemical changes of the fruit wall including pectin chain modifications, depolymerization of pectins and hemicellulose degradation (Hepler and Winship, 2010). Calcium also affects the activity of non-catalytic proteins and

arabinogalactan-proteins (AGPs) (Dodd *et al.*, 2010). Studies by Konrad *et al.*, (2011) have further shown that calcium maybe involved in cell turgor pressure changes and differences in cell expansion observed during fruit ripening. All these changes affect fruit characteristics and textural changes including in fruit size and ripening processes that are important consideration by the consumer (Negreiros *et al.*, 2008).

The nitrogen (15.4%) in the Nitrabor though not as elevated as the calcium could also have played a significant role in fruit development since it is a major component in photosynthesis especially in mobility of the chlorophyll molecule and its involvement in nucleic acid synthesis which are important for division of cells and growth of tissues including leaves and fruits (Gomes *et al.*, 2012).

4.4 Objective 4: Effect of water scheduling on passion fruit growth under different irrigation regimes

4.4.1 Soil water infiltration rate

The friable clay soils used for the experiment were found to have a high-water infiltration rates of 78% at a maximum depth of 30 cm (Table 4.7).

Table 4.7: Soil water infiltration rate

Soil sample origin	Infiltration rate
Embu samples	78%

High infiltration capacity in soils can lead to nutrient leaching hence requiring frequent nutrient replenishment. However, in some instances, high infiltration rate of soils has been demonstrated to lead to the higher water availability for crops, which is desirable in semi-arid environments which are characterized by chronic water shortage (Giuseppe *et al.*, 2019).

4.4.2 Primary vine length

The analysis of variance shows significant difference ($p \leq 0.05$) between the four treatments. A box plot analysis for the distribution of mean vine length indicate significant differences among the treatments with 10 liters per day having the highest mean length of 57 cm. The control (irrigated based on visual dryness of the soil) had the least mean length of 33 cm (Fig 4.17).

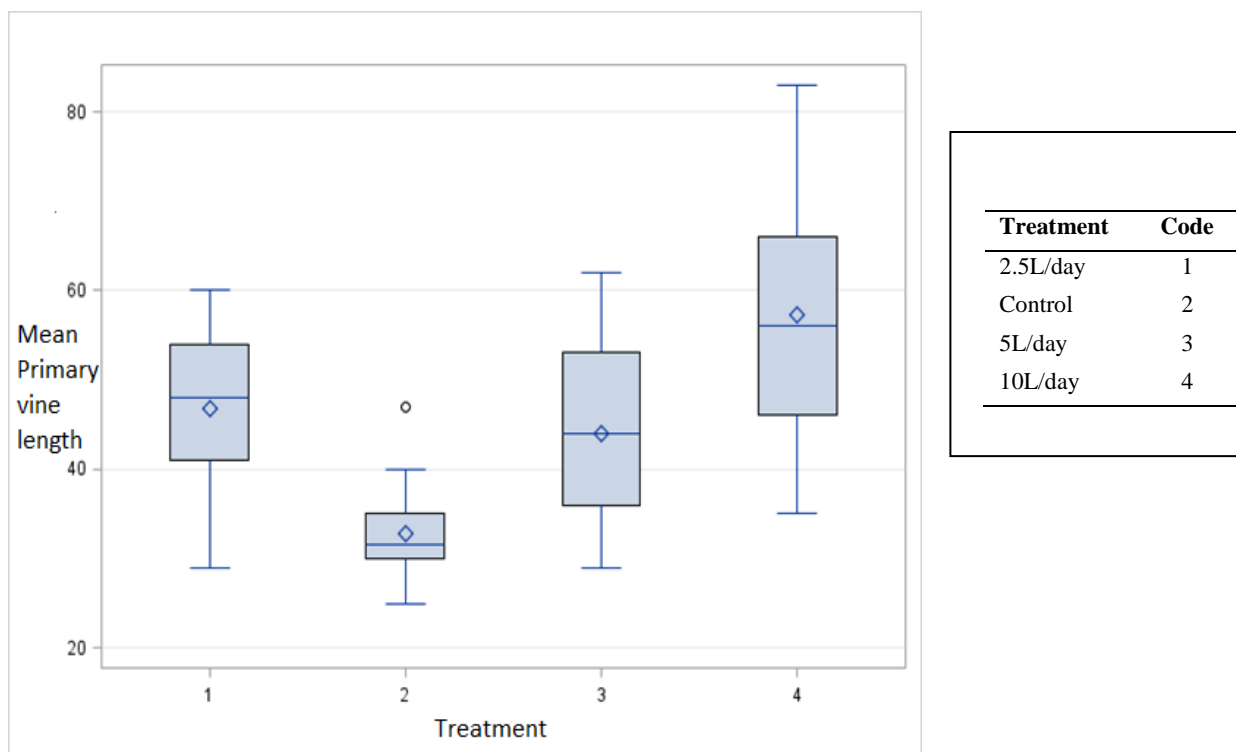


Figure 4.17: Distribution of mean plant length among passion fruits treated with varying amounts of water

The box plot indicates the distribution of the mean vine length with Median represented by the line in the box, the interquartile range box representing the middle 50% of the data while whiskers that extend from either side of the box representing the ranges for the bottom 25% and the top 25% of the data values, excluding outliers.

Similar to the box plot above, a comparison of the different treatments through a diffogram indicates significant differences among the treatments with 10 liters per day having the highest mean. The diffogram enables multiple comparisons of means to determine whether the pairwise differences between means of groups are statistically significant (Fig 4.18). Further analysis of the diffogram indicates there were no significant differences between

treatment 2.5L/day and irrigation of 5 liters per day. Probably there was not sufficient time for the two treatments to make difference on the plant growth. The control treatment was based on the visual assessment of the soil conditions to determine the need for irrigation.

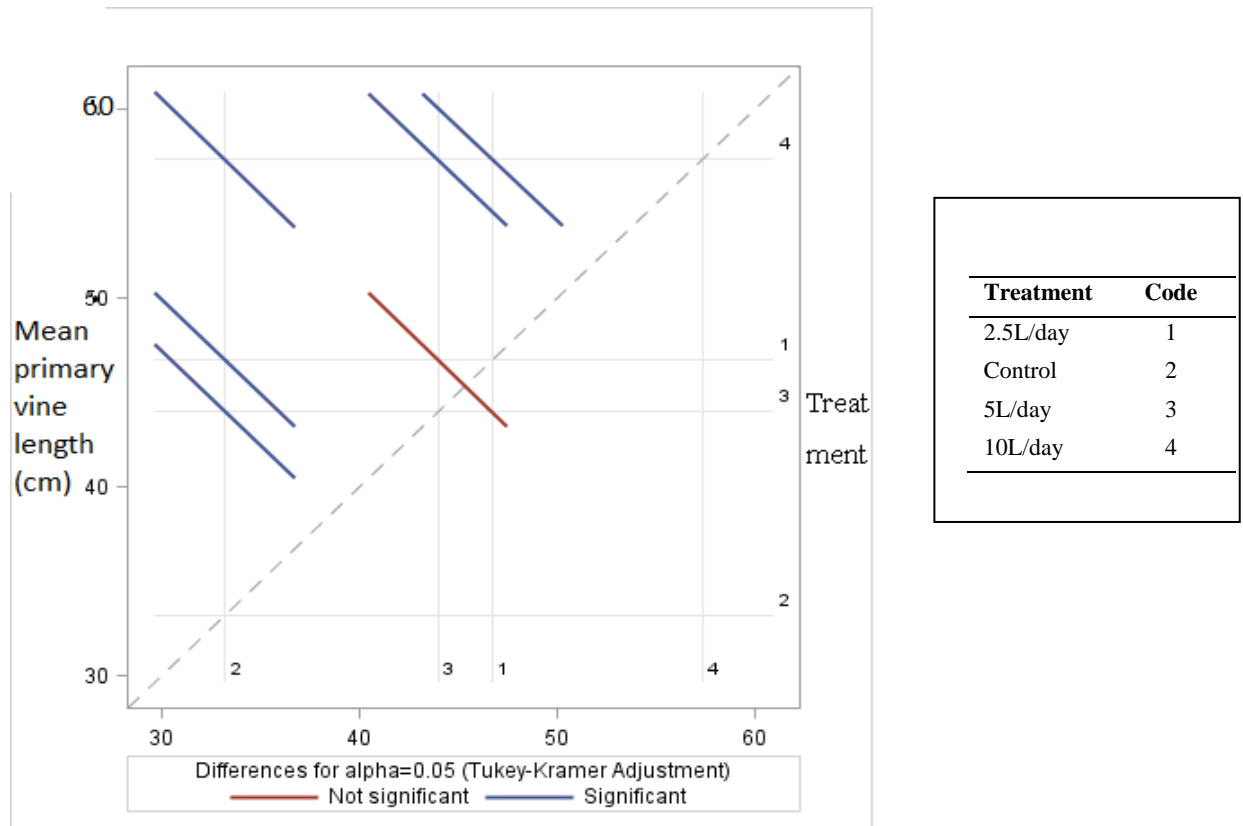


Figure 4.18: Diffogram of plant length means comparison for the different treatments

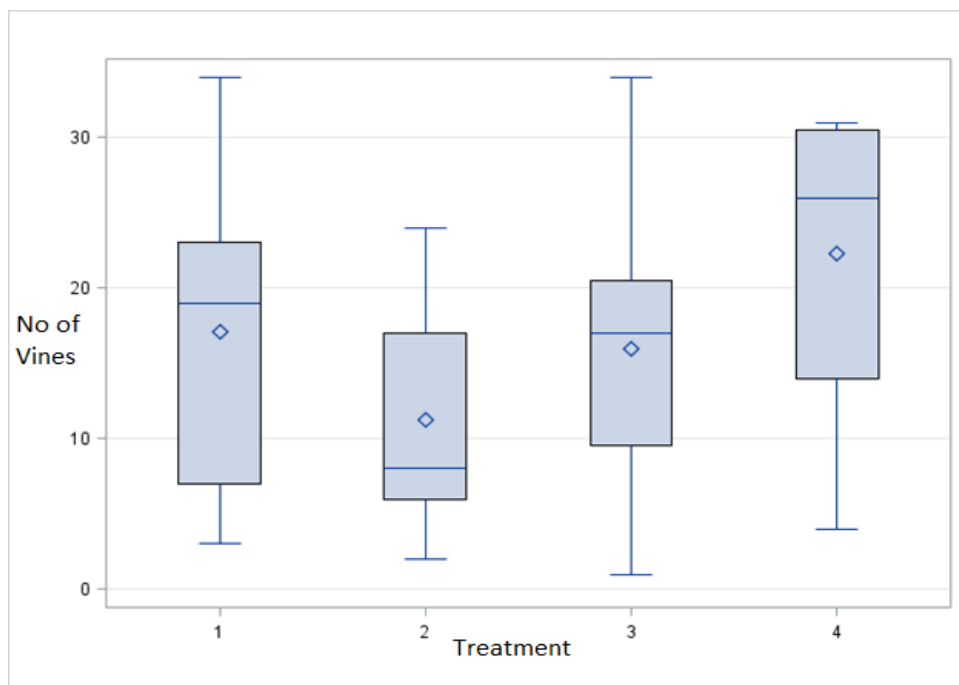
In diffogram, the confidence interval is interpreted as being perpendicular to the diagonal (45°) dashed line. In particular, confidence intervals that crosses the diagonal line indicates a pair of means is not significantly different from each other (e.g. treatment 1 and 3) while a confidence interval that does not cross the diagonal line indicates a pair of means that are

significantly different from one another (treatment 2 and 4). The vertical and horizontal grid lines are the reference lines that show values of least-square means.

Different levels of watering invariably affected the primary vine length with the treatment of 10 liters per week having the longest vine. Treatments with less water especially the control and 2.5liters per day had less length of primary vine. Similar studies on peach trees have also demonstrated that water stress significantly reduces trunk growth and shoot extension growth (Berman and Dejong, 1996) Reduction or halting of lateral branching and new leaf production soon after water stress is the major factor that contributes to differences in passion fruit and other fruit trees production (Steinberg *et al.*, 1990). Similarly, Sotiropoulos *et al.*, (2010) has shown that regulated deficit irrigation applied at stage II as well as combined regulated irrigation at stage II and postharvest stage reduced length of the shoots (>75 cm) inside the canopy in clingstone peaches.

4.4.3 Number of secondary vines

The distribution of means for number of vines indicate significant differences among the means with the treatment of 10 liters per day having the highest number of vines (18) and the control treatment the lowest, 7 vines (Fig 4.19). Number of vines is a key indicator of plant vigor hence the more the vines the higher the yield (Sangeeta, 2016). Nevertheless, an excess in the number of vines can reduce yield due to excessive vegetative growth at the expense of fruiting. The vines for passion fruits therefore were managed through pruning. For this experiment, data on number of vines was collected only up to the first pruning.



Treatment	Code
2.5L/day	1
Control	2
5L/day	3
10L/day	4

Figure 4.19: Distribution of mean number of secondary vines on passion fruit treated with varying amounts of irrigation water

4.4.4 Secondary vine length (cm)

The result indicate there were significant differences at ($p \leq 0.05$) with the treatment of 10 liters per day having the largest mean while control had the least vine length (Fig 4.20).

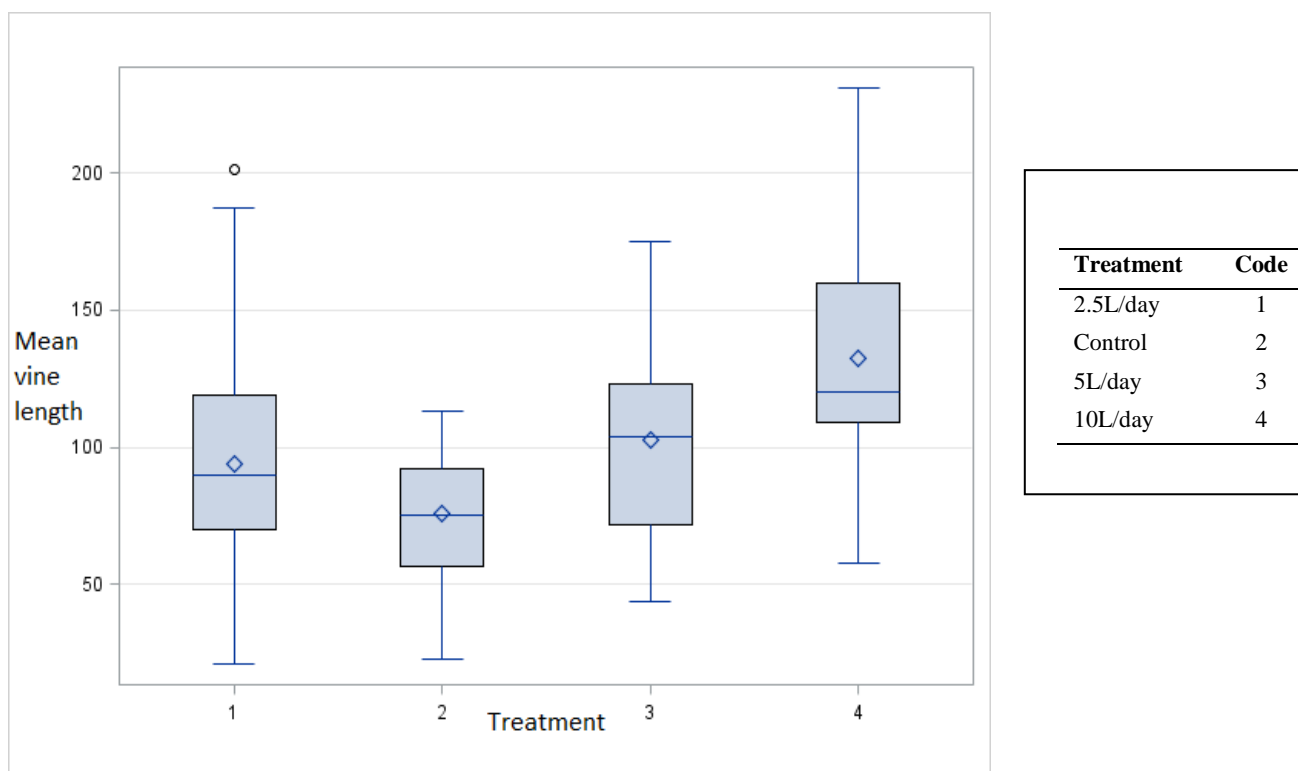


Figure 4.20: Distribution of mean secondary vine length on passion fruit treated with varying amounts of irrigation water

A further comparison of the means through a diffogram indicates no significant differences between treatments 2.5 liters per day, 5 liters per day and the control over the period of data collection (Fig 4.21). The differences in the treatment 10L/day can possibly be due to adequate uptake of moisture for the plant.

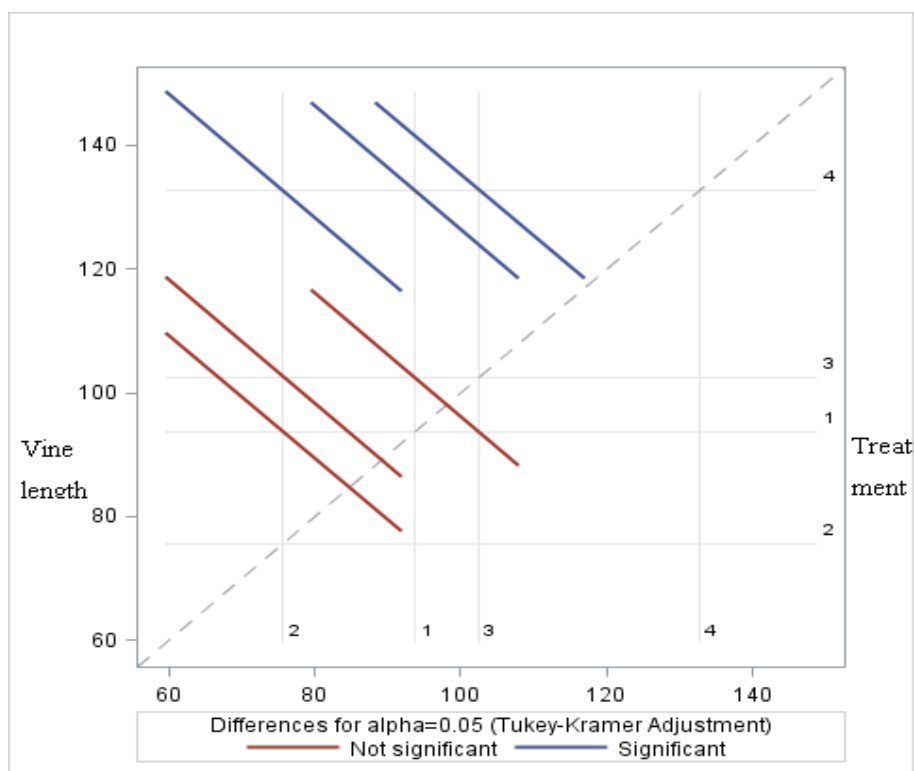


Figure 4.21: Diffogram of mean secondary vine length comparisons for the treatments

Secondary vine lengths are important since they are the fruit bearing vines. The longer the vines the higher the likelihood of getting more fruits. The treatment 10L/day had the highest vine length of 144 cm and this is probably due to the sufficient moisture available to the plant during the vegetative growth stage.

Fruit yield in passionfruit depends on vegetative growth, since flowers are initiated in the axils of new shoots. Any factor which reduces node production inevitably limits future yields (Menzel *et al.*, 1986b) hence it is important for provision of sufficient water to plants. On similar studies on passion fruits grown in a glasshouse in Brazil under soil moisture

stress, plants suffered reduced vegetative growth and fewer flowering/fruiting sites (Gomes *et al.*, 2012). Severe water stress essentially prevents plant development.

4.4.5 Correlation for primary vine length and secondary vine lengths

Correlation analysis for primary vine length and secondary vine length indicate positive correlation for all treatments except the control treatment which had a negative correlation (Table 4.8).

Table 4.8: Correlation for secondary vine length

Treatment	Correlation
2.5L/day	0.16878
5L/day	0.49168
10L/day	0.68468
Control	-0.05683

Pearson correlation coefficient; n=5

The treatment 2.5L/day had a weak positive correlation (0.16878) indicating the secondary vines were growing slowly. This is probably due to insufficient moisture available to the plant. On the other hand, treatment 10L/day which had higher rate of water content had a stronger positive correlation (0.68468), an indication of vines growing at a faster rate. The negative correlation for secondary vine length in the control treatment is probably because the plant had started wilting due to insufficient moisture.

The study has demonstrated that prolonged periods of water stress can lead to poor yields in yellow passion fruits and has further shown the development of large number of flower abortions and shriveled small fruits in conditions of water stress. Similar studies in Brazil by de Sousa *et al.*, (2003) have shown the development of fewer flower buds in plants exposed to water stress. In Kenya, Gaturuku and Isutsa (2011) on an experiment on different irrigation regimes of weekly rates have further shown differences in the number of fruits for plants grown using less water.

The study has established that among the four treatments, 10 liters of water per day gave the best results of plant growth. This implies that yellow passion is a relatively heavy user of water. These results compare well with studies by Oliveira *et al.*, (2012) that have shown that in areas with poorly distributed rainfall, it is only through supplemental irrigation that passion fruit can yield optimally. Water stress has further been shown to compromise photosynthesis through decreased stomatal opening and reduced carbon dioxide flow (Cornic, 1994; Lawlor, 1995). Insufficient water is also known to lead to retardation of the plant development and hence leading to poor yield. On the other hand, provision of enough water especially during the vegetative growth and reproductive phase will lead to a vigorously and strong growing plant that will have higher yield. Water also plays a crucial role in the transport of assimilates and the cooling of the plant (Srinivas *et al.*, (2010). Studies by Boutraa and Sanders (2001) further demonstrates water scarcity affects plant growth and development through inhibition of the photosynthetic process.

CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

In conclusion, 1) the key socio-economic aspects that affect the production of yellow passion in Embu County are small land sizes & poor agronomic management practices; 2) morphological characterization identified only two major clusters of passion fruits which confirms that majority of the planting materials were sourced from KARLO which avails only the KPF4 and KPF11 varieties; 3) studies on nutrient management have identified the combination of either 100gDAP+ 10kgManure+ 50gNitrabor, 100gDAP+ 20kgManure+ 50gNitrabor or 50gDAP+ 10kgManure+ 50gNitrabor as the best for optimum yield while 4) experiments on irrigation regimes have demonstrated and shown 10L per week as the best rates of supplemental irrigation for passion fruits.

5.2 Recommendations

The following recommendations are proposed:

1. Provision of updated agronomic management practices to yellow passion farmers in Embu County.
2. For the farmers to be assured of seed quality, it is important for them to source their planting materials directly from KALRO and avoid using seedlings from own fruit extractions. KALRO also needs to be more involved in extension work of advising the farmers on seed selection and make the materials much more readily. This will lead to assured quality of the fruits and hence a market confident in the product.

3. A combination of either 100gDAP+ 10kgManure+ 50gNitrabor, 100gDAP+ 20kgManure+ 50gNitrabor or 50gDAP+ 10kgManure+ 50gNitrabor should be used in passion growing to give the best yields.
4. For irrigation, the study recommends the application of 10 liters of water per day per plant. However, there is need to carry out further detailed studies on this treatment to determine its impact on overall yield.
5. Future studies on nutrient partitioning and water use efficiency to have a clear understanding of the nutrient and water relations in yellow passion fruit.

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APPENDICES

Appendix 1: Survey questionnaire

GPS.....

Date.....

AREA

Sub county..... County.....

Village.....

HOUSE HOLD

Age of the farmer..... Gender.....

Marital status..... Number of children.....

Persons working full time on the farm: No. in family..... No. Hired.....

PASSION PRODUCTION

Main crop grown by the farmer.....

Farm production: Subsistence ☐ Subsist+Market ☐ Market only ☐

What proportion do you sell? 0-25% ☐ 25-50% ☐ 50-75% ☐ >75% ☐

FARM DESCRIPTION

Size (Acreage) of the farm: 0-2 ☐ 2-4 ☐ 4-8 ☐ >8 ☐

Proportion of the farm under yellow passion: 0-2% ☐ 2-4% ☐ 4-8% ☐ >8% ☐

Nature of passion production: Intercrop ☐ Main crop ☐ Abandoned ☐

How is land preparation done? By hand ☐ Animal power ☐ Machine ☐

What is the main source of planting material?.....

What is the normal planting time in the year?.....

What is the type of planting material? Seedlings ☐ Direct sowing of seeds ☐ (specify).....

If direct sowing, how long do they take to sprout? <1 week ☐ 1-2wk ☐ 1-4wks ☐
>3M ☐ ☐

Spacing of the passion.....

What planting fertilizer do you use?.....

What are the rates?.....

What top dressing fertilizer do you use?.....

What are the rates?.....

At what stage do you apply the top dressing?.....

How often do you irrigate your plants?.....

What are the rates?.....

How long does passion take to mature? <6Months ☐ 6-12M ☐ 1-2Yrs ☐ >2Yrs ☐

What are the maturity indices?.....

No of harvests per week: Once ☐ 1-2 ☐ Continuous ☐

Yields per plant: >10kg ☐ 10-20 ☐ 20-30 ☐ >30 ☐

What are the causes of the changes in the yield? Soil fertility ☐ Pest and Diseases ☐ Mar ☐

Water ☐ Source ☐ planting material ☐

SCIENTIST OBSERVATION

Position within the slope: Crest/ Upper slope/ Middle slope/Lower slope/Valley bottom

Slope: Flat/ Gentle / Moderate/ Steep/ Very steep

Texture: Sand/ Sandy loam/ Loam/Sandy clay/ Clay loam/ Clay (cracking soil)

Surface coarse fragments (gravel, rock fragments): None (>2%)/ Few (2-5%)/ Common (5-15%)/ Many (>15%)

Erosion: None/ Some (rill)/ Moderate (Small gully)/Severe (large gull

CHARACTERIZATION DESCRIPTORS-stem/leaf

Farm no.	County	Sub county	Village	Cultivar	Local name	Twinning direction	Leaf colour	Leaf density	Leaf shape	Stem colour	No of vines per plant

PASSPORT DESCRIPTORS-fruit

Farm no.	County	Sub county	Village	Cultivar	Local name	Fruit colour (mature/immature)	Shape of the fruit	Banding of flower (corona)	Flower density	Fruit density/plant	Yield per Ha

Appendix 2: Soil analysis results

KU site



Kenya Agricultural & Livestock Research Organization
National Agricultural Research Laboratories
P. O. Box 14733, 00800 NAIROBI
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SOIL TEST REPORT

Name	Justine Mwambi Michoma
Address	P. O. Box 880 - 40202, Keroka
Location of farm	Kenyatta University, Ruiru, Kiambu
Crop(s) to be grown	Passion fruits
Date sample received	18-01-18
Date sample reported	13-02-18
Reporting officer (through Director NARL)	A. Chek

Soil Analytical Data								
Field	KB2 P3 U		KB3 P1 U		KB3 P2 U		KB3 P3 U	
Lab. No/2018	152		156		157		158	
Soil depth cm	top		top		top		top	
Fertility results	value	class	value	class	value	class	value	class
* Soil pH	5.30	medium acid	5.21	medium acid	5.31	medium acid	5.30	medium acid
Exch. Acidity me%	0.2	adequate	0.2	adequate	0.2	adequate	0.2	adequate
* Total Nitrogen %	0.13	low	0.12	low	0.12	low	0.13	low
* Total Org. Carbon %	1.09	low	1.02	low	1.00	low	1.11	low
Phosphorus ppm	20	low	20	low	20	low	20	low
Potassium me%	0.97	adequate	0.74	adequate	0.82	adequate	0.88	adequate
Calcium me%	2.2	adequate	2.0	adequate	2.0	adequate	3.0	adequate
Magnesium me%	2.50	adequate	2.14	adequate	2.89	adequate	2.21	adequate

* ISO/IEC 17025 accredited

Interpretation and Fertilizer Recommendation

All fields have similar soil fertility status. The soil reaction (pH) is acidic for plants' growth. Hence, acidifying fertilizer like DAP should be avoided. Nitrogen and phosphorus are deficient. Soil organic matter content is low. **Passion fruits:** The optimum soil pH is 5.5-7.0. To stimulate the plants' growth apply 10 kg/plant of well decomposed manure or compost and 100 gm/plant of N:P:K 23:23:0. Mix well with the soil. The fertilizer quantity should be split and applied 1-2 weeks after the onset of the rains.

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

Embu site



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SOIL TEST REPORT

Name	Abasi Edna Andeyo
Address	Kenyatta University
Location of farm	Ugweri, Runyenjes, Embu
Crop(s) to be grown	Passion fruits
Date sample received	12-05-17
Date sample reported	5-07-17
Reporting officer (through Director NARL)	A. Chek

Soil Analytical Data								
Ugweri								
Location								
Field	R1 Control		4M Block1		3M Block 2 double		3M Block 3 double	
Date of sampling	29-04-17		12-01-17		12-01-17		12-01-17	
Lab. No/2017	2865		2868		2870		2874	
Soil depth	top		top		top		top	
Fertility results	value	class	value	class	value	class	value	class
* Soil pH	6.12	slight acid	6.03	slight acid	6.43	slight acid	5.71	medium acid
* Total Nitrogen %	0.21	adequate	0.24	adequate	0.22	adequate	0.23	adequate
Phosphorus ppm	150	high	230	high	150	high	95	high
Potassium me%	0.56	adequate	0.66	adequate	0.88	adequate	0.84	adequate

* ISO/IEC 17025 accredited

Interpretation and Fertilizer Recommendations

All fields have similar soil fertility status. The soil reaction (pH) is satisfactory for plants' growth. **Passion fruits:** Mix top soil with 10 kg of well decomposed manure or compost per planting hole. Fill the planting hole with this mixture using extra top soil if necessary. This should be done at least three weeks before transplanting. To stimulate the plants' growth top dress with 100 gm/plant of CAN. The fertilizer quantity should be split and applied 1-2 weeks after the onset of the rains.

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

Methods used: Information is given out on client's request.

Appendix 3: ANOVA tables

Flowering and fruiting of yellow passion fruits in response to varying fertilizer treatment

Dependent Variable: Flower bud initiation

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	16	68076.8636	4254.804	15.61	<.0001
Error	278	75782.133	272.5976		
Corrected Total	294	143858.9966			

Dependent Variable: Open flower

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	16	19701.77955	1231.36122	17.06	<.0001
Error	278	20062.54588	72.16743		
Corrected Total	294	39764.32542			

Dependent Variable: Fruits formed

Source	DF	Sum of Squares	Mean Square	F Value	Pr>F
Model	16	116328.2391	7270.5149	12.57	<.0001
Error	278	160753.0965	578.2485		
Corrected Total	294	277081.3356			

Analysis of variance for the number of fruits harvested in Embu and KU sites

Dependent variable: Number of fruits					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	160195.1256	12322.7020	30.09	<.0001
Error	226	92556.8077	409.5434		
Corrected Total	239	252751.9333			

Analysis of variance for fruit weight in Embu and KU sites

Dependent variable: Fruit weight (g)					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	13	130201.6936	10015.5149	15.27	<.0001
Error	226	148213.2714	655.8109		
Corrected Total	239	278414.9650			

Analysis of variance for water uptake under different irrigation regimes

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	6757.512597	1351.502519	25.82	<.0001
Error	53	2774.724691	52.353296		
Corrected Total	58	9532.237288			