PRODUCTIVITY AND WATER USE BY RAIN-FED EARLY MATURING CASSAVA (*Manihot esculenta* Crantz) VARIETIES GROWN AT DIFFERENT PLANT DENSITIES IN A COASTAL SAVANNAH ENVIRONMENT

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DECLARATION

This thesis is the result of the research work undertaken by Mr. Amanor, Emmanuel Nartey in the Department of Nuclear Agriculture and Radiation Processing, School of Nuclear and Allied Sciences, University of Ghana, under the supervision of Dr. Daniel Kwasi Asare.

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DEDICATION

I dedicate this thesis to the memory of my late Grandmother, Madam Patience Oboshie Schandorf.

Finally, to my son (John Nartey-Amanor) and wife (Mary Amanor) for their support.

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CPN	Campbell Pacific Nuclear
DM	Dry matter
DOY	Days of the year
ESRB	Early storage root bulking
FAO	Food and Agriculture Organization
FAOSTAT	Food and Agriculture Organization Statistics
GDP	Gross Domestic Product
LAI	Leaf area index
LDM	Leaf dry matter
LSRB	Late storage root bulking
MSRB	Medium storage root bulking
PVC	Poly Vinyl Chloride
RDM	Root dry matter
RY	Root yield
SDM	Stem dry matter
SRID	Statistics, Research and Information Directorate
TDM	Total dry matter
TUE	Transpiration use efficiency
WUE	Water use efficiency

ABSTRACT

The production of cassava (*Manihot esculenta* Crantz) under rain-fed conditions at the Kwabenya-Atomic area in the coastal savannah environment is constrained by low and erratic rainfall events. Improving cassava production in the area requires the use of cassava varieties which are efficient in the use of limited soil moisture. The objective of the study was to evaluate the response of two early maturing cassava varieties to three (3) planting densities to TDM, RY, and WUE. The actual evapotranspiration was also partitioned into crop transpiration and soil evaporation using LAI data. The field experiment was conducted at Biotechnology and Nuclear Agriculture Research Institute (BNARI) research farm, Atomic Energy Commission (GAEC), Kwabenya-Atomic in 2015. The split plot design in three replicates was used. The two (2) cassava varieties, Bankye Hemaa and Capevars Bankye, were assigned to the main plots and three (3) planting densities: 10,000, 13,333 and 20,000 plants ha^{-1} to the subplots. Plants were sampled each month and moisture in the 120 cm soil profile monitored every two weeks using the neutron probe (CPN 503 Hydroprobe). Soil moisture data were used to estimate actual evapotranspiration (AET) using the water balance approach. Root yield (RY) for Bankye Hemaa and Capevars Bankye, ranged from 2.8 to 15.1 t/ha^{-1} for the 10,000 plants ha^{-1}, 4.2 to 18.1 t/ha^{-1} for the 13,333 plants ha^{-1} and 5.1 to 21.3 t/ha^{-1} for the 20,000 plants ha^{-1}. Additionally, water use efficiency in term of total dry matter (WUE$_{TDM}$) for the two cassava varieties ranged from 1.7 to 11.6, 2.3 to 12.8 and 3.7 to 12.4 kg ha^{-1} mm^{-1} for the 10,000, 13,333 and 20,000 plants ha^{-1} planting density, respectively. Bankye Hemaa grown at 20,000 plants ha^{-1} produced the highest root yield of 21.3 t/ha^{-1} and WUE$_{TDM}$ of 12.4 kg ha^{-1} mm^{-1}, because of the comparatively lower soil evaporation which led to increased available soil water for crop use and higher crop transpiration, leading to enhanced yield and water use efficiency. A good positive correlation existed between TUE_{RY} and RY for both cassava varieties grown at the planting density of 20,000 plants ha $^{-1}$ with Bankye Hemaa producing a near perfect linear relation (TUE_{RY} = 0.0011RY + 13.492, r^2 = 0.97; $P \leq 0.01$**). Additionally, a linear model sufficiently describes the relation between the combined total dry matter (TDM) and its associated water use efficiency for Bankye Hemaa and Capevars Bankye grown at all three planting densities: 10,000 plants ha^{-1} (WUE_{TDM} = 0.0011TDM + 1.4628, r^2 = 0.90; $P \leq 0.01$**) , 13,333 plants ha^{-1} (WUE_{TDM} = 0.0012TDM + 2.8, r^2 = 0.90; $P \leq 0.01$**) and 20,000 plants ha^{-1} (WUE_{TDM} = 0.0001TDM + 2.6754, r^2 = 0.90; $P \leq 0.01$**) . Furthermore, a strong and positive correlation existed between WUE_{RY} and RY for both cassava varieties grown at all three planting densities: 10,000 plants ha $^{-1}$ (WUE_{RY} = 0.0012RY + 3.1252, r^2 = 0.94; $P \leq 0.01$**), 13,333 plants ha $^{-1}$ (WUE_{RY} = 0.001RY + 4.052, r^2 = 0.92; $P \leq 0.01$**) and 20,000 plants ha $^{-1}$ (WUE_{RY} = 0.001RY + 4.7749, r^2 = 0.97; $P \leq 0.01$**).

CHAPTER ONE

1.0 Introduction

1.1 Background

Cassava (*Manihot esculenta* Crantz) is a perennial plant, but commercially the crop cycle may range from six (6) to twenty four (24) months depending on the conditions of the growing region (Alves, 2006). Brazil is the second largest producer, behind Nigeria (FAO, 2014).

Cassava is well known as a resistant crop, especially to climate and soil conditions. It can grow in places where cereals and other crops do not grow well (IFAD, 2000; FAO 2000). It can tolerate drought and can grow in low-nutrient soils. Also, it is grown in the arid and semiarid tropics where it accounts for approximately 10% of the total caloric value of staple crops (de Figueroa *et al*., 2001).

In Ghana, cassava is a major source of food for human consumption as well as a raw material for industrial starch production (Asare *et al*., 2009).The low rainfall, less than 1000 mm per year (Morris *et al*., 1999), in the coastal savannah agro ecological environment, coupled with its erratic nature is a major constraint to cassava production and other field crops. Cassava can be cultivated in areas receiving less than 300 mm rainfall per year with a dry season of four to six months (El-Sharkawy, 1993), but much higher yields can be obtained with higher levels of soil moisture, good management and agronomic practices. With better planting materials, better improved input management, the productivity of cassava could be doubled (IFAD, 2000). Cassava is grown in most of the agro ecological zones of Ghana (Asare *et al*., 2009) mostly under rain-fed conditions. Consequently, the amount of rainfall and its distribution could influence the production of rain-fed cassava.

Although cassava can withstand extreme periods of drought. The crop is very sensitive to soil water deficit during the first three (3) months after planting (Pardales and Esquibel, 1996; Agili and Pardales, 1997).Water stress during the early growth period reduces significantly the growth of cassava and impairs subsequently the development of the storage roots (FAO, 2013). Cassava is one crop known to contribute immensely to Ghana's agriculture example, food security and gross domestic product (GDP). Early maturing cultivars have gained importance in Ghana because of erratic and reducing rainfall in the growing areas, particularly the coastal savannah environment.

Cassava has many remarkable characteristics including physiological, biological, commercial and industrial application which makes it a suitable crop to solve Africa's food security problems and a potential cash crop in the future. There are different cassava cultivars adopted by farmers in Ghana these are: The early storage root bulking (ESRB), medium storage root bulking (MSRB) and late storage root bulking (LSRB). The early storage root bulking type is improved cultivar that yields between 43-49 tonnes per hectare as compared to the local cultivars that yield between 10-15 tonnes per hectare. Early storage root bulking cultivars are suitable for fufu, gari and cassava dough, early harvest (six months maturity), good planting material (tall and non-branching or less branching), good stake quality (germination and storage duration), good root shape, white flesh and tolerant to major pest and diseases (SRID, 2009). Some examples include Bankye Hemaa, Capevars Bankye, Dokuduade and Essam Bankye.

Water use efficiency (WUE) is the relationship between the amount of water used by a crop per unit weight of dry matter produced (Jones, 2004).WUE is influenced by environmental factors such as leaf temperature, wind speed, air temperature and relative humidity (Liu *et al*, 2002)**.** Under mild temperature conditions, cassava plants are usually very efficient in using water, that is, they lose less water than many other species, for the fixation of the same amount of carbon dioxide (El-Sharkawy, 2003).

WUE is an important determinant of yield under water stress conditions and even as a component of crop drought resistance (Blum, 2005). This suggests that rain-fed crop production can be increased per unit water used, resulting in "more crop per drop" (Kijne *et al.*, 2003).

Studies have indicated that, when water is available, cassava maintains a high stomata conductance and can keep the internal carbon dioxide concentration high, but when water becomes scarce, it closes stomata in response to even a small decrease in soil water potential (Alves and Setter, 2000; El-Sharkawy and Cock 1984). The rapid closure of cassava stomata and the resulting decline in transpiration lessens the decrease in leaf water potential and soil water depletion, thus protecting leaf tissues from turgor loss and desiccation (Cock *et al.* 1985; El-Sharkawy and Cock 1984; Palta 1984).

Cassava is renowned for its drought tolerance and hardiness in stressful environments (El-Sharkawy, 2004). This drought tolerance mechanism leads to high crop water use efficiency and positions the crop as an efficient crop that can take advantage of global climate change.

Plant density or plant spacing influences all crops. In cassava (*Manihot esculenta* Crantz), the distance between plant rows has influenced plant height, stem and canopy diameter, number of leaves, and root yield (Rojas *et al.*, 2007). Thus, plant spacing (planting density) has the potential to affect soil water use and productivity of cassava, particularly in areas with low and erratic rainfall patterns.

In addition, planting density maintains a relation with other components of the crop's production system, including cultivar, applied nutrients, competition with weeds, and incidence of diseases and pests (Opara-Nadi and Lal, 2008; Ayoola and Makinde, 2007; López-bellido *et al.*, 2005;).

1.2 Problem Statement

Agricultural production under rain-fed conditions is largely dependent on the availability of water stored in the soil during rainfall events. This raises the question of the effectiveness and efficient use of rainfall to guarantee sustainable crop production.

Under conditions of low, inadequate and erratic rainfall conditions, as experienced in the coastal savannah environment of Ghana, the productivity of cassava grown under rain-fed conditions is low. This is as results of poor and retarded growth and development of the crop during some periods of the crop growth cycle. Thus, water stored in the soil after rainfall events during the cropping season is usually not adequate to support, enhanced and sustainable cassava production

It is, therefore, imperative to adopt management strategies that will promote effective and efficient use of inadequate soil water by cassava grown under low and erratic rainfall environment. This will ensure enhanced and sustainable rain-fed cassava grown under this environment. Management strategies such as the adoption of early maturing cassava varieties and appropriate planting densities have the potential to impact on weed growth and efficient use of soil water for enhanced productivity of cassava grown under low and erratic rainfall conditions in coastal savannah environment.

1.3 Justification

Poor and erratic rainfall experienced in the coastal savannah environment of Ghana is a major constraint to rain-fed cassava production. The adoption of strategies to ensure effective and efficient use of stored soil water by rain-fed cassava in the coastal savannah environment is paramount for ensuring enhanced and sustainable production of the crop.

Such management strategies must include the use of early maturing cassava grown at appropriate plant densities to match low, inadequate and erratic rainfall conditions experienced in the coastal savannah environment.

Studies done to assess the effect of planting density on cassava have concentrated on root yield and biomass production. Reports on water use efficiency in relation to planting density are lacking. Therefore information on the consequence of planting density on water use and water use efficiency is necessary for designing management strategies to enhance productivity of cassava in coastal savannah environment of Ghana.

1.4 Objectives

The main objective of the study is to evaluate the effect of plant spacing (plant densities) on the productivity and soil moisture use by early maturing cassava varieties grown under rain-fed conditions in a coastal savannah environment of Ghana.

1.5 Specific Objectives

The specific objectives of the study were to:

1. Determine the effect of different plant spacing on leaf area index (LAI) of two early maturing cassava (*Manihot esculenta* Crantz) varieties under rain-fed conditions in the Atomic area.
2. Estimate crop water use (evapotranspiration) of two early maturing cassava varieties grown under three plant densities in the Atomic area.

3. Partition the evapotranspiration into soil evaporation and crop transpiration for two early maturing rain-fed cassava varieties grown under three plant densities.
4. Estimate water use efficiency and transpiration use efficiency of two early maturing cassava varieties grown under rain-fed conditions in atomic area at three different plant densities.

CHAPTER TWO

2.0 Literature Review

2.1 Introduction

Most studies in the literature have quantified the effect of planting density on the production of tuberous roots (Aguiar *et al.*, 2011). There is significant literature on climatic, soil, nutrient, rainfall, soil moisture, biomass, tuber yield, plant density, evapotranspiration, soil water use efficiency by cassava (*Manihot esculenta* Crantz). However limited studies have been done in subtropical ecological regions to investigate the effect of different spacing on growth, development and productivity of cassava **(**Aguiar *et al.*, 2011). Such studies are important as they provide data on growth and development needed for validating models including the GUMCAS model (Gabriel *et al.*, 2014; Matthews and Hunt, 1994).

2.2 Cassava

Cassava (*Manihot esculenta* Crantz) is a perennial woody shrub 2–4 m in height of the class Dicotyledoneae, family Euphorbiaceae, genera Manihot Tournefort and species Manihot esculenta Crantz (Alves, 2002), with edible roots. It is a typical tropical crop which is drought resilient or tolerant to extreme weather conditions. The genus *Manihot* comprises 98 species of which *M. esculenta* is the most widely cultivated member (Nassar, 2005; Mkumbira, 2002; Rogers and Appan, 1973). There are three (3) main types of cultivars cultivated namely early storage root bulking (ESRB), medium storage root bulking (MSRD) and late storage root bulking (LSRD).

Cassava is a major crop in Ghana and it is grown extensively in the coastal savannah agro-ecological zone.

2.2.1 Climatic requirement of cassava

Cassava requires a warm, humid climate at favourable temperature range of 25 - 29ºC (Conceicao, 1979) but it can tolerate a temperature range of 16 - 36 ºC (Cock, 1984). Its cultivation is restricted to regions between the latitudes of 30° north and 30° south. It is most widespread near the equator between 15° north and south. The crop produces best when rainfall is fairly abundant, but it can be grown where annual rainfall is as low as 500 mm in semi-arid or where it is as high as 5,000 mm in sub-humid tropics (Akinpelu *et al.*, 2011). Cassava can grow in the semi-arid tropics with an annual rainfall less than 600 mm, but the ideal rainfall ranges 1000 and 1500 mm per year (Alves, 2002). The crop can withstand periodic and extended period of drought (Hillocks *et al.*, 2003). Thus, cassava is a valuable crop where seasonal annual rainfall distribution is erratic.

2.2.2 Soil requirement

Generally, cassava is grown on a wide range of soils, provided the soil texture is friable enough to allow the development of the tubers. Soils with a pH range of 6-7 are best suited for optimum growth of the crop (Onwueme and Sinha, 1991). Poorly drained soils, gravelly or saline soils, or soils with a hardpan are not suitable for cassava production (Onwueme and Sinha, 1991). Also, stony soils inhibit the formation of root tubers (Florchinger *et al.*, 2000).

2.2.3 Nutrient requirement

Cassava is a high carbohydrate producer; it requires a large amount of potassium (K) which has a special role in carbohydrate synthesis and translocation (Imas and John, 2013). Abundant K supply favours the primary processes of photosynthesis. It also regulates the balance between assimilation and respiration in a way that improves net assimilation. This is a prerequisite for vigorous growth and the formation of reserve assimilates (Jansson, 1980).

The crop also requires nitrogen (N) to stimulate leaf formation and photosynthesis and relatively a smaller amount of phosphorus (P) (Imas and John, 2013). Cassava is well adapted to acid soils with high levels of exchangeable Al (Hillocks *et al.*, 2002). Although the plant is well adapted to low levels of available P, it requires fairly high quantities of K, especially when grown continuously for many years on the same land (IFA, 1992). The crop is susceptible to zinc (Zn) deficiency and often shows Zn deficiency symptoms at early stages of growth (Nasaar and Ortiz 2007).

2.2.4 Rainfall and soil moisture requirement

Cassava is also very sensitive to soil water deficit during the first three (3) months of planting (Agili and Pardales, 1997). Water stress at this period reduces growth and productivity of the crop significantly, particularly the growth of roots and shoots which subsequently affect the storage of roots. However if soil moisture availability is low, crop will cease to grow and shed some older leaves, reducing the transpiration surface (El-Sharkawy, 1993).

Planting early in the rainy season will generally produce the highest yields because the plants have adequate soil moisture during the most critical stage of their growth cycle (FAO, 2013).

However, yields may vary according to the variety or cultivar used, the soil type, the crop's age at harvest, and the amount of rainfall and distribution during the planting season (FAO, 2013).

2.3 Importance of cassava

Cassava is the most important tropical root crop (Mkumbira, 2002; Roa *et al.*, 1997). Its starchy tuber roots are a major source of dietary energy (Nassar, 2005; Lynam, 1993;Cock *et al.*, 1985). Cassava is known to be the highest producer of carbohydrates among staple crops (FAO, 2002). According to Amaner (2011), the world annual production of cassava is over 158 billion tonnes. According to the United Nations Food and Agriculture Organization (FAO), cassava ranks fourth as a food crop in the developing countries, after rice, maize and wheat. Cassava leaves are relatively rich in protein, minerals and vitamins and can be consumed (Benesi *et al.*, 2001; Fregene *et al.*, 2000; Chiwona-Karltun *et al.*, 1998; Nweke, 1994; FAO, 1993). Cassava can be stored in the ground for a long period, thereby serving as a reserve food when other crops fail.

According to FAO (2000), Africa accounts for 54%, Asia for 28%, and Latin America and the Caribbean for 19% of the total world production. Nigeria is the leading producer of cassava in the world while Ghana is rank sixth. Cassava accounts for approximately one-third of the total staples produced in Sub Saharan Africa (SSA) and is grown exclusively as food in 39 African countries stretching through a wide environment from Madagascar in the south-east to Senegal in the north-west (Raji *et al.*, 2001). Cassava therefore has all indicators to be a food security crop for Africa (Shore, 2002), particularly in Ghana where the mean root yield level is about 18.58 t/ha^{-1} (FAO, 2014). According to SRID (2013), more than 90 per cent of Ghana's small-holder farmers are engaged in cassava production, suggesting that the crop presents good fortunes, therefore there is the need to develop the cassava value chain to become lucrative to all stakeholders particularly farmers. There are about eighteen (18) improved varieties so far developed awaiting utilization and marketing in the value chain. They include Ampong, Sika, Otuhia, Broni Bankye, Afisiafi, Agbelifia, Doku Duade, Esam Bankye, Tek Bankye, Nkabom, Bankye Hemaa, Capevars Bankye and Abasafitaa

In Ghana cassava is a potential crop for commercialization, with several uses such as processed for food, feed for animals, ethanol and other industrial uses including pharmaceuticals, brewery and ethanol for fuel. Currently, Ghanaian companies like Guinness Ghana Brewery Limited, Accra Brewery Limited and indigenous pharmaceutical companies in Ghana urgently require cassava flour and starch as a product substitute to manufacture their products. Companies like Olam Ghana Limited, Irani Flours Limited, Takoradi Flour Mills and Flour Mills Ghana, also import wheat to mill in Ghana, whilst up to 10 % well refined cassava flour can be substituted to make bread without any change in taste and flavor (MOFA, 2013). Bread made from imported wheat is almost eaten by everyone on daily basis. Wheat imported into the economy and milled into wheat flour annually is over US$700 million. GIHOC Distilleries Company Limited, Kasapreko Company Limited and Agya Appiah Bitters Limited also import ethanol for their distilleries. These companies rely on imports for their raw materials.

Cassava very rich in carbohydrates compare to other root crops cultivated globally (FAO, 2013). It is very low in fats and has more protein than other root crops. It contains vitamins and minerals in significant amounts example, vitamins B, C, calcium, iron etc. The leaves particularly the young ones are very rich in proteins and vitamins K which have the potential function to support bone development which is critical for the promotion of osteotrophic activity. Cassava is also a unique source of vitamins B-complex group. Cassava is a notable source of mineral such as, zinc, magnesium, copper, iron, and manganese etc. It is also a good source of potassium .The leaves and root serves a good source for dietary element that supports and provides nutrients for the development and function of the body (FAO, 2013). Also about 100g of cassava root significantly gives 160g of calories mainly from carbohydrates

It is interesting to note that even egg trays, candles, mosquito coils, maggie cubes, tomato paste, confectionery products, cartons, sausages, akpeteshie, sugar, textile, livestock feed, etc., are all produced with major cassava component. In fact, cassava has over 2000 derivatives (MOFA, 2013).

The country's unemployment rate is 4.6 per cent and this is likely to get worse with the projection of Ghana's population (26.98 million) to double in the next 30 years (SRID, 2013).

According to Parkes *et al.* (2012), cassava occupies an important position in Ghana's agricultural economy and contributes about 46% of the agricultural Gross Domestic Product (GDP). Cassava produces a maximum output yield of up to 24.0 tonnes per acre (MOFA, 2013). Interestingly, the Ghanaian economy alone requires more than 200,000 metric tonnes of starch (SRID, 2013). Specifically, cassava accounts for a daily calorie intake of 30% in Ghana and is grown in nearly all agro ecological zones (Stone, 2002 and MOFA, 2003).

Therefore, Ghana can take advantage of cassava production and its allied industry for commercialization purposes to generate income, create employment and reduces poverty. In view of the enormous potential of cassava, it is necessary to adopt management practices to ensure maximization in production root yields.

2.4 Planting density

In cassava, the distance between plant rows influences plant height, stem and canopy diameter, number of leaves, and root yield. However the distance between plants within rows does not influence plant height and stem diameter (Rojas, 2007). Studies by Guerra (2003) and Rojas (2007) have demonstrated that the planting density effect on root yield varies with cassava variety. An increased planting density may increase, reduce, or maintain cassava root yield, depending on the variety that is evaluated. Due to the importance of planting density, several studies have been conducted with cassava, at planting densities that ranged from 6,666 plants ha^{-1} (Rojas, 2007) to 27,777 plants ha^{-1} (Guerra, 2003). Larger populations (of up to 50,000 plants ha^{-1}) have been tested to determine their effects on the above-ground biomass (Lima, 2002).

2.5 Evapotranspiration (ET)

Evapotranspiration (ET) is the loss of water from a vegetated surface through the combined process of soil evaporation and plant transpiration by a crop for growth and cooling purposes.

Apart from the water availability in the topsoil, the evaporation from a cropped soil is mainly determined by the fraction of the solar radiation reaching the soil surface. This fraction decreases over the growing period as the crop develops and the crop canopy shades more and more of the ground area. When the crop is small, water is predominately lost by soil evaporation, but once the crop is well developed and completely covers the soil, transpiration becomes the main process. Evapotranspiration (ET) is an essential factor to estimate crop water use. It is also one of the major elements in soil water storage and water resource in a region.

2.5.1 Estimation of evapotranspiration

Estimation of evapotranspiration (ET) is important for multiple purposes such as regional water studies, field irrigation practice, description of atmospheric boundary layer and weather forecasting (Amarakoon *et al*., 2000). To better predict actual or potential crop production, it is quite necessary to evaluate ET hence; vegetative productivity is closely related to ET (Watanabe *et al*., 2004).Potential evapotranspiration (PET) is the maximum amount of water lost to the atmosphere via evaporation and transpiration from vegetation (Jensen *et al*., 1990). Estimates of PET are necessary in many of the rainfall-runoff and ecosystem models that are used in global change studies (Band *et al*., 1996; Hay and McCabe, 2002). Actual evapotranspiration (AET) is the quantity of water that is actually removed from a surface due to the processes of evaporation and transpiration. Actual evapotranspiration is often estimated as a fraction of potential evapotranspiration (PET) (Federer *et al*., 1996).

2.5.2 Models for estimating evapotranspiration

Some of the models generally used to estimate potential evapotranspiration (PET), using weather data as inputs, are described as follows:

(a) Penman-Monteith (PM) Model

The PM model (Allen *et al*., 1998) is a combination method and estimates the flux of energy and moisture between the atmosphere, land and water surfaces (Lee *et al*., 2004). The model is complex and requires daily weather variables such as air temperature, humidity, wind speed and solar radiation. The model is expressed as:

$$\mathrm{PET} = \frac{0.408\,\Delta(\mathrm{Rn}-\mathrm{G})+\Upsilon\frac{900}{\mathrm{Ta}+273}\,\mathrm{u}\,(\mathrm{es}-\mathrm{ea})}{\Delta+\Upsilon(1+0.34\mathrm{u})} \qquad [1]$$

Where PET is the potential evapotranspiration (mm day^{-1}), Δ is the slope of the vapour pressure temperature curve (kPa °C^{-1}), Rn is the net radiation (MJ m^{-2} day $^{-1}$), G is the soil heat flux density (MJ m^{-2} day $^{-1}$), ϒ is the psychometric constant (KPa °C^{-1}), Ta is the daily mean air temperature (°C), *u* is the wind speed (m s^{-1}), e_s is the saturated vapour pressure (kPa) and e_a is the actual vapour pressure (kPa).

(b) Hargreaves-Samani (HS) Model

The HS model (Hargreaves and Samani, 1985) requires daily maximum and minimum air temperatures and the extra-terrestrial solar radiation computed using latitude and day of the year (Allen *et al.*, 1998; London and Frohlich, 1982; Duffie and Beckman, 1980). Therefore, air temperature is the only measured weather input required. The HS model (Hargreaves and Samani, 1985) estimated PET as:

$$\mathrm{PET} = \frac{(0.0023\ \mathrm{X}\ \mathrm{Ra})(\mathrm{Tmax}-\mathrm{Tmin})^{0.5}\,(\mathrm{Ta}+17.8)}{\lambda} \qquad [2]$$

Where λ is the latent heat of evaporation (MJ kg^{-1}), Tmax and Tmin are the maximum and minimum daily air temperature (°C) respectively, Ta is the daily mean air temperature (°C) and Ra is the extra-terrestrial solar radiation (MJ m^{-2} day^{-1}) and computed based on the procedure outlined by Campbell (1985). The latent heat of vapourization (λ) is estimated as

$$\lambda = 2.501 - 0.002361\ \mathrm{Ta} \qquad [3]$$

Where Ta is the daily mean air temperature (°C).

(c) Priestly-Taylor (PT) Model

Priestly-Taylor (1972) developed this model for estimating daily PET using the mean air temperature and net solar radiation as inputs. This is a simplified combination equation with an empirical coefficient to account for mass transfer effects (Lee *et al.*, 2004). According to the model,

$$\mathrm{PET} = 1.26\,\frac{\Delta}{\lambda(\Delta+\lambda)}\,(\mathrm{Rn} - \mathrm{G}) \qquad [4]$$

PET is the potential evapotranspiration (mm d^{-1}), Rn is the net radiation (MJ m^{-2} d^{-1}), G is the soil heat flux density (MJ m^{-2} d^{-1}), λ is the latent heat of evaporation (MJ kg^{-1}), Δ is the slope of the saturation vapour pressure temperature curve (kPa), ϒ is the psychometric constant (KPa $°C^{-1}$). The psychometric constant is estimated as:

$$\Upsilon = \frac{\mathrm{CpP}}{0.622\lambda} \qquad [5]$$

Where Cp is the specific heat of moist air at constant pressure (0.001013 MJ kg^{-1} $°C^{-1}$). P is the atmospheric pressure (kpa) computed as:

$$\mathrm{P} = 101.3 - 0.01055\ \mathrm{H} \qquad [6]$$

Where H is the elevation (m) of the site.

(d) IRMAK1 Model

This PET model is basically multi-linear regression models developed by Irmak *et al.*, 2003 for humid environments using as inputs the daily solar shortwaves radiation and daily mean air temperature data. The daily potential evapotranspiration (PET) is estimated as:

$$\text{PET} = -0.611 + 0.146\,Rs + 0.079\,\text{Tmean} \qquad [7]$$

Where PET is evapotranspiration (mm d^{-1}), Rs is the solar shortwave radiation (MJ m^{-2} d^{-1}) and Tmean is the daily mean temperature (°C).

(e) IRMAK2 Model

Irmak *et al.*, (2003) developed this PET model for humid environment using inputs the daily net solar radiation and mean daily air temperature data. The daily potential evapotranspiration (PET) is estimated as:

$$\text{PET} = 0.489 + 0.289\,Rn + 0.023\,\text{Tmean} \qquad [8]$$

Where PET is evapotranspiration (mm d^{-1}), Rn is the net radiation (MJ m^{-2} d^{-1}) and Tmean is the daily mean temperature (°C).

Once PET is known, the actual evapotranspiration (ETa) is predicted, as shown in figure 2.1, as:

$$\text{ETa} = K_c * \text{PET} \qquad [9]$$

Where K_c is the crop coefficient.

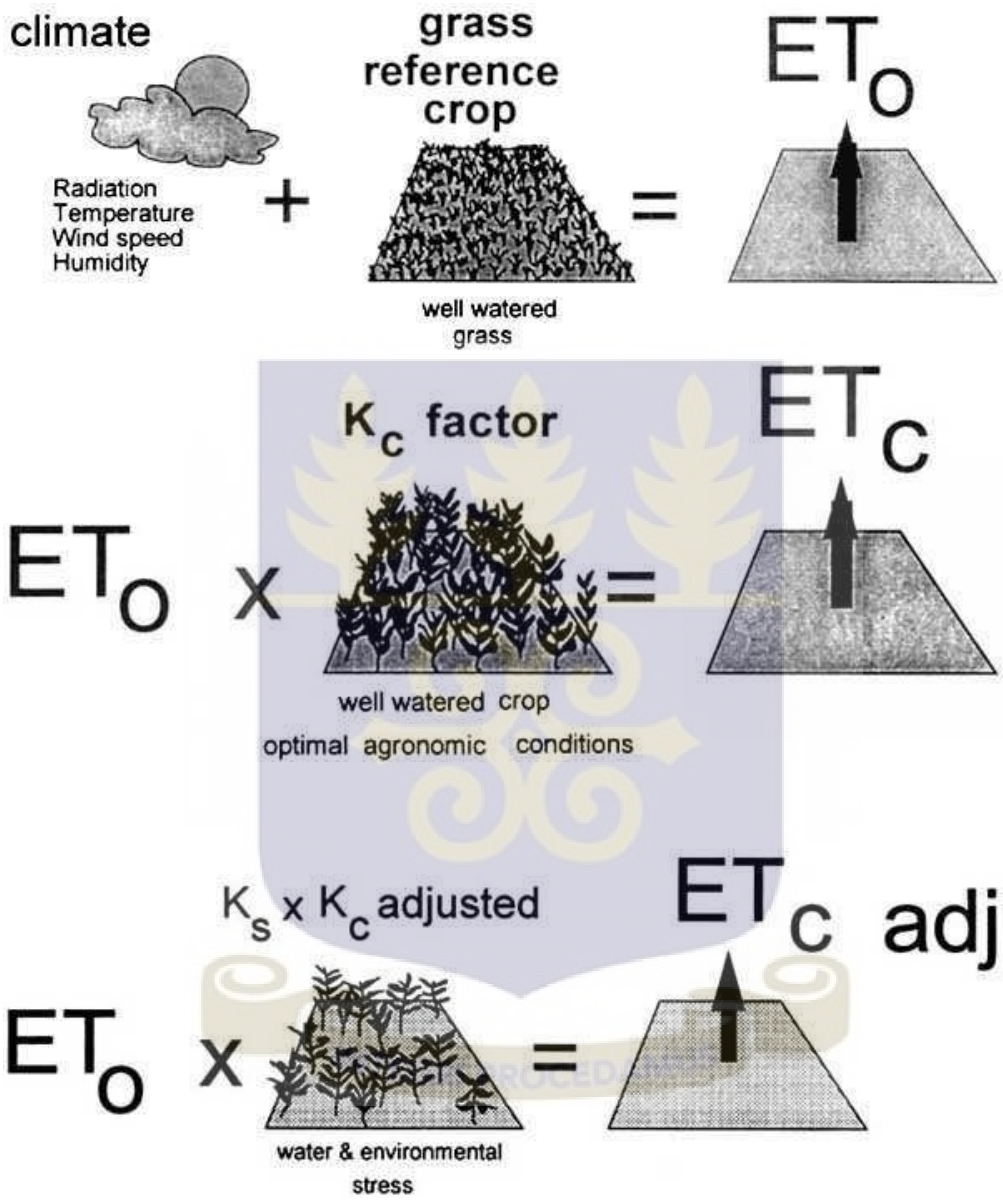


Figure 2.1 Reference (ET_o), crop evapotranspiration under standard (ET_c) and non-standard conditions ($ET_{c\ adj}$), (Source: FAO Irrigation and Drainage paper NO 56, Crop Evapotranspiration).

2.6 Field measurement of actual evapotranspiration (ETa)

2.6.1 Soil water balance

The flow of water in and out of the soil profile can be estimated and quantified by the water balance model. Water balance is a statement of law of conservation of matter, meaning matter is neither created nor destroyed but only changes from one state, form or location to another. The water content of a given volume of soil cannot increase without addition outside, nor can it diminish unless transported to the atmosphere by evaporation or deeper zone by drainage (Hillel, 1971).

Basically, the water balance is the amount of water held in a root zone at a given time, t (day), expressed as the difference in water input (W_{in}) and water loss (W_{out}) at a given time in the soil profile. The terms of water balance are usually expressed in units of volume per area, mm.

$$\Delta W = (P + I) - (ETa + RO + D) \qquad [10]$$

Where ΔW is change in water stored in known soil profile at a time step, P is precipitation, I is irrigation, ETa is evapotranspiration, RO is run-on/runoff and D is deep drainage.

Therefore water balance is a computation of gains and losses to and from an agro-ecosystem over time interval Δt and for a selected soil layer thickness.

2.7 Partitioning of evapotranspiration

Partitioning of evapotranspiration (ET) into evaporation from the soil (E) and transpiration through the stomata of plants (T) is challenging but important in order to assess biomass production and the allocation of increasingly scarce water resources (Kool *et al.*, 2014).

As water limited environments currently comprise about half of the earth's land surface and are expected to continue to expand (Newman *et al.*, 2006), the issue of accurately assessing ET and its components has become more crucial for enhancing crop production in water limiting environments. In addition, rising world population and associated food demand is expected to further increase the need for productive use of traditionally marginal areas (Yermiyahu *et al.*, 2007). Better understanding of ET components can help investigate water management strategies to ensure that available water is used more productively (Zhao *et al.*, 2013; Kite, 2000).

2.7.1 Isotope mass balance

Stable oxygen and hydrogen isotopes are used in isotope mass balance studies for partitioning evapotranspiration (ET) into crop transpiration (T) and soil evaporation (E). The isotopic mass balance method for ET partitioning is based on a difference in the isotopic signature of water vapor as a result of E and T. Under natural conditions, two stable hydrogen isotopes occur: ^{1}H (99.9844%) and ^{2}H (0.0156%). Oxygen has three forms of stable isotopes: 99.762% of ^{16}O, 0.038% ^{17}O and 0.200% ^{18}O. Combinations yield nine different possible isotopic water molecules (Horita *et al.*, 2008). The isotopic composition of E and T are distinctly different and can be used to partition between the fluxes. A comparison between the sample composition and measured of estimated isotopic compositions of E, T and ET subsequently allows partitioning

(Wang *et al.*, 2012, 2010). The method is costly, laborious, and has a low time resolution (Griffis, 2013). The method has been widely used to determine sources of water used by plants (Brunel *et al.*, 1997; Ehleringen and Dawson, 1992), including olives (Williams *et al.*, 2004) and wheat (Zhang *et al.*, 2011). Isotopic methods are mostly applicable in dry areas with significant (>10%) evaporation.

2.7.2 Keeling plot

Keeling plot is very important in evapotranspiration studies due to the unique nature of portraying photosynthetic separation of CO_2 as oxygen isotopes and the impact of the trading of oxygen with leaf water. Leaf water determination is very advanced in ^{18}O because of balance fractionation. Water in other crop parts, example, leaves, stems and roots is not enhanced; rather it has the same isotopic piece of water. The CO_2 that is breathed from these plant parts will equilibrate with water, furthermore have the same isotope structure and signature as the water source, which is exhausted in ^{18}O.Soil water is by and large drained in ^{18}O because of the isotopic structure of precipitation. Keeling plots interpret carbon isotope ratios of ambient CO_2 and to identify the sources that contribute to atmospheric CO_2 concentrations on a regional basis (Yakir *et al.*, 2000). Keeling plot is used to analyze the isotopic composition of atmospheric CO_2 to determine carbon sources and sinks (Stenberg *et al.*, 1998). Works pertaining to soils, such as work by Liu *et al.*, (2006) who studied the $\delta^{13}C$ and $\Delta^{14}C$ in natural soils and used the Keeling plot to determine at what depths in the soil atmospheric CO_2 had an effect and what depths it was no longer present. Yepez *et al.*, (2005, 2003) separated the evaporation flux into soil evaporation and transpiration and estimated the ratio of transpiration from total evaporation using Keeling plot of water vapour under transient conditions. Xu *et al.* (2008) partitioned soil evaporation and transpiration using a combination of Keeling plots and stable isotopes. Wang *et al. (*2010) partitioned evaporation based on a combination of newly developed laser-based isotope analyzer and Keeling plot approach.

2.7.3 Correlation-based ET partitioning method

A relatively new approach to measure evapotranspiration (ET) partitioning makes use of the fact that transpiration (T) and carbon uptake by plants occur simultaneously. The relation between ET and CO_2 is a function of stomatal fluxes (T and photosynthesis) and non-stomatal fluxes (direct evaporation and respiration). Scanlon and Sahu (2008) proposed a carbon-water vapor correlation method using high frequency eddy correlation (EC) measurements. The value of this method lies in its relative simplicity and the fact that EC systems are already used quite widely. Scanlon and Kustas (2012) found reasonable values using carbon-water vapor correlations over a corn field, but did not verify E and T with independent measurements.

2.7.4 Partitioning of ET using leaf area index (LAI)

Leaf area index is an important structural variable descriptive of vegetation, is directly related to evapotranspiration and productivity. A model developed by Norman and Campbell (1983), which assumes that the ratio of transpiration to evapotranspiration is the same as the ratio of radiation intercepted by the crop total incidence radiation. This is determined by leaf area index of the crop and averaged over a day as:

$$T/ET = 1 - \exp(-0.82F) \quad [11]$$

Where T is transpiration (mm^{-1}), ET is evapotranspiration (mm) and F is leaf area index of the crop.

Another LAI based ET partitioning method has been proposed by Leuning *et al. (*1994) as:

$$Es/E = e^{-0.61L} \quad [12]$$

Where E_s is soil evaporation (mm^{-1}), E is total canopy evaporation or crop transpiration and L is leaf area index.

2.7.5 Evapotranspiration partitioning models

Numerous models and variations of models for evapotranspiration (ET) partitioning are described in literature. The following models were found to have been validated for ET partitioning and are briefly described: Shuttleworth–Wallace, FAO dual K_c model, and two source energy balance model (TSEB).

2.7.5.1 Shuttleworth–Wallace (S-W) model

Shuttleworth and Wallace (1985) suggested an analytical approach to ET partitioning based on two Penman–Monteith equations (Penman, 1948; Monteith, 1965): one for the crop (PM_C) and one for the soil surface (PM_S):

$$\lambda ET = CcPMc + CsPMs \quad [13]$$

λ is latent heat of vapourization (Jkg^{-1}) , ET is evapotranspiration,C_c and C_s are respective canopy and soil rate of change of saturated vapor pressure with air temperature (kPa $^{\circ}C^{-1}$).

Analytical models such as the S-W model are used sporadically but form the foundation for many other ET partitioning models. Efforts to parameterize the resistances required for simulations were reported by Brisson *et al*. (1998), Lund and Soegaard (2003) and Ortega-Farias *et al*. (2007). Many authors (Iritz *et al.*, 2001, Lagos *et al.*, 2009) have suggested modifications to the S-W model. Li *et al*. (2010) proposed and validated a simplification of the model by using the Priestley–Taylor formula (Priestley and Taylor, 1972) to compute E, which requires more easily obtainable parameters. Validations for partitioning of ET using variations of the S-W model were reported for soybean (Brisson *et al.*, 1998), cherry (Li *et al.*, 2010), and millet (Lund and Soegaard, 2003). The S-W model is generally considered accurate.

2.7.5.2 FAO dual-K_c model

The FAO dual-Kc model (Allen *et al.*, 1998) computes ET of a well-watered crop using an empirically defined crop specific multiplication factor (K_c) in combination with a reference evapotranspiration (ET_0). Reference evapotranspiration (ET_0) takes into account plant response to atmospheric conditions by solving the Penman–Monteith equation (Penman, 1948; Monteith, 1965) for a reference crop (short grass or alfalfa). The dual-K_c approach divides the K_c factor into a plant component K_{cb} and a soil component K_e. The model is defined as:

$$ET = (Kcb + Ke)ET0 \qquad [14]$$

Where ET and ET_0 are in mm d^{-1} and K_{cb} and K_e are dimensionless. Reference evapotranspiration (ET_0) can be calculated from atmospheric data at 2 m height that are measured at most weather stations (Allen *et al.*, 1998).

The FAO-dual K_c model is the most common model used to partition ET, as it requires relatively few parameters and the results are generally accurate enough to be applied as an irrigation scheduling tool. However the model is empirical and pre-defined crop factors are not always applicable to sites in different contexts (Ferreira *et al.*, 2012). Evapotranspiration (ET) partitioning using the FAO-dual K_c model has been tested for olives (Er-Raki *et al.*, 2010; Rousseaux *et al.*, 2009), vineyards (Ferreira *et al.*, 2012), coffee (Flumignan *et al.*, 2011), and peach (Paço *et al.*, 2011).

2.7.5.3 Two Source Energy Balance (TSEB)

The two source energy balance (TSEB) model was developed to compute ET using surface temperature data that could potentially be acquired using remote sensing (Norman *et al.*, 1995; Anderson *et al.*, 1997; Kustas and Norman, 1999). The required inputs for the model include directional radiometric temperature of the surface, standard meteorological data, and canopy characteristics including LAI. The model is based on separate equations for soil and canopy energy balances. The respective energy balances are solved by partitioning measured R_n between soil and canopy based on LAI, a clumping factor (characterizing the canopy structure), and extinction coefficients, where G is defined as a fraction of R_n at the soil surface.

The TSEB model has been tested for ET partitioning in a cotton field (Colaizzi *et al.*, 2012).

2.8 Water use efficiency (WUE)

Plant biomass accumulation, and consequently yield is inextricably linked to transpiration (Sinclair *et al.*, 1984). The ratio of plant productivity to water loss, water-use efficiency is very conservative. The prime concern in cultivating crops has always been water availability in several agro ecological environment severely effecting crop growth and economic yield (Araus *et al.*, 2002). Water use efficiency (WUE) is defined as the ratio of economic yield to total water use or evapotranspiration (Copeland *et al.*, 1993). Generally, water use efficiency is stated as:

$$\text{WUE (kg ha}^{-1}\text{)} = \frac{\text{yield (kg ha}-1\text{)}}{\text{Actual Evapotranspiration (mm)}} \qquad [15]$$

Yield in the above equation [15] is either the total dry matter or economic crop yield. An understanding of water use efficiency is essential for evaluating the field crops in dry regions where water is a limiting factor (Johnson and Henderson, 2002). Water use efficiency (WUE) is often considered an important determinant of yield under stress and crop production can be increased per unit water used, resulting in “more crop per drop” (Kijne *et al.*, 2003).

2.9 Transpiration use efficiency (TUE)

Transpiration use efficiency (TUE) is defined as the ratio of biomass produced per unit of water transpired, and it is well established that the cumulative transpiration of a crop is linearly related to total dry matter production at a given site and season (Tanner and Sinclair, 1983). Soil water availability is considered to be the main factor limiting crop production. Crop production depends mainly on the amount of water available to the crop and the amount of water transpired by the crops. The amount of water transpired by a crop may be increased either by reducing soil evaporation or by supplemental irrigation. Estimates of soil evaporation range from 20% to 70% of total water used and can be reduced by crop structure (Siddique *et al.*, 1990) and agronomic practices that stimulate early ground cover, such as application of fertilizers, early sowing (Oweis *et al.*, 1998) and increased plant density (Van den Boogaard *et al.*, 1996).

Transpiration use efficiency (TUE) has been widely investigated at the leaf and individual plant scales (Condon *et al.*, 1990). Improvement of TUE means maximization of crop production per unit of water use (Turner *et al.*, 2001). Transpiration use efficiency can be calculated from biomass accumulation and water use by transpiration over period, generally, transpiration use efficiency is stated as:

$$\text{TUE} = \frac{\text{Total biomass}}{\text{Cumulative transpiration}} \qquad [16]$$

Transpiration use efficiency varies with crop type and atmospheric humidity, with higher efficiencies in more humid environments. In principle, therefore, more biomass could be produced using the same amount of water by selecting species with high transpiration efficiencies or by growing plants in more humid air.

Transpiration use efficiency (TUE) is a suitable parameter to rapidly screen for drought tolerance because it is directly influenced by both growth and transpiration (Condon *et al.* 2004 and Wallace, 2000). According to Jones (2013), TUE tends to rise when stomata close. A higher TUE is thereby correlated with higher stomatal closure, which is mainly seen as a survival strategy and is inversely related to productivity.

CHAPTER THREE

3.0 Materials and methods

3.1 Study area

The study area was the Biotechnology and Nuclear Agriculture Research Institute (BNARI) research farm, Atomic Energy Commission (GAEC), Kwabenya-Atomic. The study area is situated on latitude 05º 40′ N and longitude 0º13′ W in the coastal savannah environment of Ghana in the Greater Accra region. The site is 76.0 m above sea level and 20 km north of Accra (Ghana).The site receives an average annual rainfall of less than 1000 mm (Morris *et al.*, 1999). The soil at the experimental site is the Haatso series, a well-drained savannah ochrosol described as Ferric Acrisol, (FAO/UNESCO, 1994). Selected physical and chemical properties of the soil at the experimental site are presented in Table 3.1.

3.2 Land preparation and field layout

The experimental plot was ploughed and harrowed before planting commenced. The size of the experimental plot was 50.5 m by 33.0 m giving a total area of 1666.5 m^2. A split plot experimental design was used with three replicates.

Two cassava varieties, Bankye Hemaa and Capevars Bankye, were in the main plot (factor A) and three planting densities in the subplots (factor B). Plant densities used were 10,000, 13,333 and 20,000 plants ha^{-1}. Each subplot measured 10.0 m by 50.0 m. A distance of 2.0 m and 1.5 m were left between blocks and sub-plots, respectively.

Table 3.1 Physical and chemical properties of soil sampled at experimental site.

	Soil profile depth (cm)					
Soil property	**0-20**	**20-40**	**40-60**	**60-80**	**80-100**	**100-120**
[a]pH (H_2O(1:2)	7.33	7.39	7.83	7.99	7.79	7.85
[b]Org. C (%)	1.06	0.50	0.50	0.39	0.36	0.23
[c]Total N (%)	0.36	0.34	0.31	1.26	0.42	1.13
[d]Avai P (p.p.m)	11.07	6.79	4.28	3.89	2.40	2.10
[e]K ($cmol_c\ kg^{-1}$)	0.41	0.30	0.25	0.19	0.21	0.22
[f] ρ_b ($kg\ m^{-3}$)	1.34	1.22	1.41	1.33	1.47	1.38
Sand (%)	41.41	40.43	45.31	47.99	46.31	55.82
Silt (%)	43.17	44.68	43.75	41.06	42.95	36.39
Clay (%)	15.42	14.89	10.94	10.95	10.75	7.79
Textural class	**SL**	**SL**	**SL**	**SL**	**SL**	**SL**

Source: Asare *et al.* (2011)

[a]=Electrometrical method

[b]=Walkley and Black (Allison *et al.*, 1965)

[c]=Kjeldahl procedure (Jackson, 1958)

[d]=(Olsen *et al.*, 1954, Bray and Kurtz, 1945)

[e]=Flame photometric method

[f]=Core sampler method

[g]=Bouyoucos method (Day, 1965)

SL= Sandy loam

3.2.1 Experimental material

The two cassava varieties used for the experiment were Bankye Hemaa and Capevars Bankye. Bankye Hemaa and Capevars Bankye are improved cassava varieties which are early maturing (matures as early as six (6) months after planting) and have good cooking qualities, good stake quality material (germination and storage duration), good root shape with white flesh and tolerant to diseases.

3.2.2 Planting

Bankye Hemaa and Capevars Bankye were planted on May 4th, 2015. The planting was done at the following planting densities: 10,000, 13,333 and 20, 000 plants ha^{-1}. Plots were weeded using a hoe whenever necessary.

3.2.3 Access tube installation

Access tubes were installed in each of the subplots to 120 cm soil depth before 50% sprouting. Access tubes were made of polyvinyl chloride (PVC) pipe of 38.1 mm internal diameter with the bottom capped with same PVC material to prevent soil water entering the tube. The tubes were installed in between two central rows within each sub-plot to facilitate in situ moisture monitoring at 20 cm stepwise to 120 cm soil profile depth using the CPN (Campbell Pacific Nuclear) 503DR Hydro (neutron) probe. The open end above the soil surface of each access tube was covered with an empty plastic bottle to prevent water and debris from entering the access tube.

3.3 Soil moisture monitoring

The soil moisture was monitored using the neutron probe in each subplot at an interval of fourteen (14) days throughout the duration of the experiment. Soil moisture data were used to estimate the depth of water stored in the root zone (100 cm soil profile depth) and actual evapotranspiration (AET) and based on the water balance approach.

3.3.1 Estimation of actual evapotranspiration (AET)

The actual evapotranspiration (AET) was estimated by soil water balance approach of the root zone (Hartman, 1998). The AET for Bankye Hemaa and Capevars Bankye was estimated from sprouting to 28 DAE, 56 DAE, 84 DAE, 112 DAE, 140 DAE, 168 DAE and 196 DAE at the following planting densities: 10,000, 13,333 and 20,000 plants ha^{-1} in each subplot for the period of the experiment. The water balance equation is:

$$P+I-ET\pm RO\pm Q_L = \pm\Delta S_L \qquad [17]$$

Where

P is the rainfall (mm),I is the irrigation (mm), ET is the evapotranspiration (mm), RO is the runoff (mm),Q_L is the water drainage or capillary rise of water from soil profile at a depth L integrated over time Δt (mm),ΔS_L is the change in soil-water storage in layer during time Δt (mm).Runoff (RO), was assumed to be zero since the slope of the experimental field is less than 1%. Irrigation I (mm), is zero since crops were grown under rain-fed conditions. Therefore equation [17] becomes:

$$ET= P\pm\Delta S\pm Q_L \qquad [18]$$

3.4 Plant sampling

Plants were sampled in each sub-plot and separated into leaves, stems and roots when necessary. Subsamples were taken for dry matter determination after drying in the oven at 65°C for three (3) days or to a constant weight.

The plant sampling was done at 28 DAE, 56 DAE, 84 DAE, 112 DAE, 140 DAE, 168 DAE and 196 DAE. The actual evapotranspiration (AET) values for sampling time steps were summed up over the growing season to obtain the seasonal AET for Bankye Hemaa and Capevars Bankye for each planting density.

3.5 Estimation of leaf area index (LAI)

Leaf area index (LAI) was determined using the leaf meter. (AM300 model manufactured by ADC Bio-scientific Limited) at 28 DAE, 56 DAE, 84 DAE, 112 DAE, 140 DAE, 168 DAE and 196 DAE for the cassava varieties at the following planting densities: 10,000, 13,333 and 20, 000 plants ha^{-1}.

3.6 Estimation of evapotranspiration partitioning

The partitioning of evapotranspiration for Bankye Hemaa and Capevars Bankye grown at the following planting densities: 10,000 , 13,333 and 20, 000 plants ha^{-1} was also estimated at 28 DAE, 56 DAE, 84 DAE, 112 DAE, 140 DAE, 168 DAE and 196 DAE based on the following relationship (Campbell, 1985):

$$T/ET = 1 - \exp(-0.82\ LAI) \quad [19a]$$

and

$$T = ET\ [(1 - \exp(-0.82)\ LAI] \quad [19b]$$

Where

T is the transpiration (mm^{-1}), ET is the actual evapotranspiration (mm), and LAI is the leaf area index.

3.7 Estimation of water use efficiency

The water use efficiencies of Bankye Hemaa and Capevars Bankye grown at three (3) different planting densities were estimated in terms of total biomass yield and root tuber yield relations below.

$$WUE_{DM} = \frac{TDM}{AET} \quad [20]$$

$$WUE_{RY} = \frac{RY}{AET} \quad [21]$$

Where

WUE_{DM} is the WUE in terms of dry matter yield (kg ha^{-1} mm^{-1}),WUE_{TY} is the WUE in terms of root tuber yield (kg ha^{-1} mm^{-1}), TDM is the total biomass production (kg ha^{-1}),RY is the root yield (Kg ha^{-1}) and AET is the actual evapotranspiration (mm).

3.8 Estimation of transpiration use efficiency

Transpiration use efficiencies for Bankye Hemaa and Capevars Bankye grown at three (3) different planting densities were estimated in terms of total biomass yield and root yield as follows:

$$\mathrm{TUE_{TDM}} = \frac{\mathrm{TDM}}{\mathrm{T}} \qquad [22]$$

$$\mathrm{TUE_{RY}} = \frac{\mathrm{RY}}{\mathrm{T}} \qquad [23]$$

Where

$\mathrm{TUE_{TDM}}$ is the TUE in terms of total dry matter yield (kg $\mathrm{ha^{-1}}$ $\mathrm{mm^{-1}}$), T is the Cumulative transpiration (kg $\mathrm{ha^{-1}}$ $\mathrm{mm^{-1}}$), $\mathrm{TUE_{RY}}$ is the TUE in terms of root tuber yield (kg $\mathrm{ha^{-1}}$ $\mathrm{mm^{-1}}$), TDM is the total biomass (kg $\mathrm{ha^{-1}}$) and RY is the root yield (kg $\mathrm{ha^{-1}}$).

3.9 Computations and statistical analysis

The total biomass, root yield, actual evapotranspiration, crop transpiration, leaf area index (LAI), $\mathrm{WUE_{TDM}}$, $\mathrm{WUE_{RY}}$, $\mathrm{TUE_{TDM}}$ and $\mathrm{TUE_{RY}}$ data were subjected to analysis of variance (ANOVA) based on the split plot experimental design. Means were separated using the least significance difference (LSD) when F-test indicated significance difference among the treatment means. The GENSTATS statistical package (9th edition) was used for the data analysis.

CHAPTER FOUR

4.0 Results

4.1 Weather Conditions at the Experimental site

Nineteen rainfall events were observed during the study period (Figure 4.1), giving a total of 861.1 mm of rainfall. There was no rainfall in August, September and December (Figure 4.1). June had the highest amount of rainfall (350.9 mm) over six (6) rainfall events. Generally, a total of 668.7 mm of rain occurred during the major rainy season (May-July) while the minor rainy season (September – December) had a total of 192.4 mm of rainfall (Figure 4.1). Air temperatures recorded were generally higher during the minor crop growing season (September-December) compared to air temperatures observed during the major cropping season (May-July). The average maximum and minimum air temperatures were 30.7 and 22.5°C for the major cropping season (May-July). Similarly, maximum and minimum air temperatures were 31.6 and 23.7°C for minor cropping season (September- December). The average solar radiation for major and minor cropping season was 217.7 and 230.6 W m^{-2}, respectively. The average value of relatively humidity was 81.4% and 78.2% for major and minor cropping season, respectively.

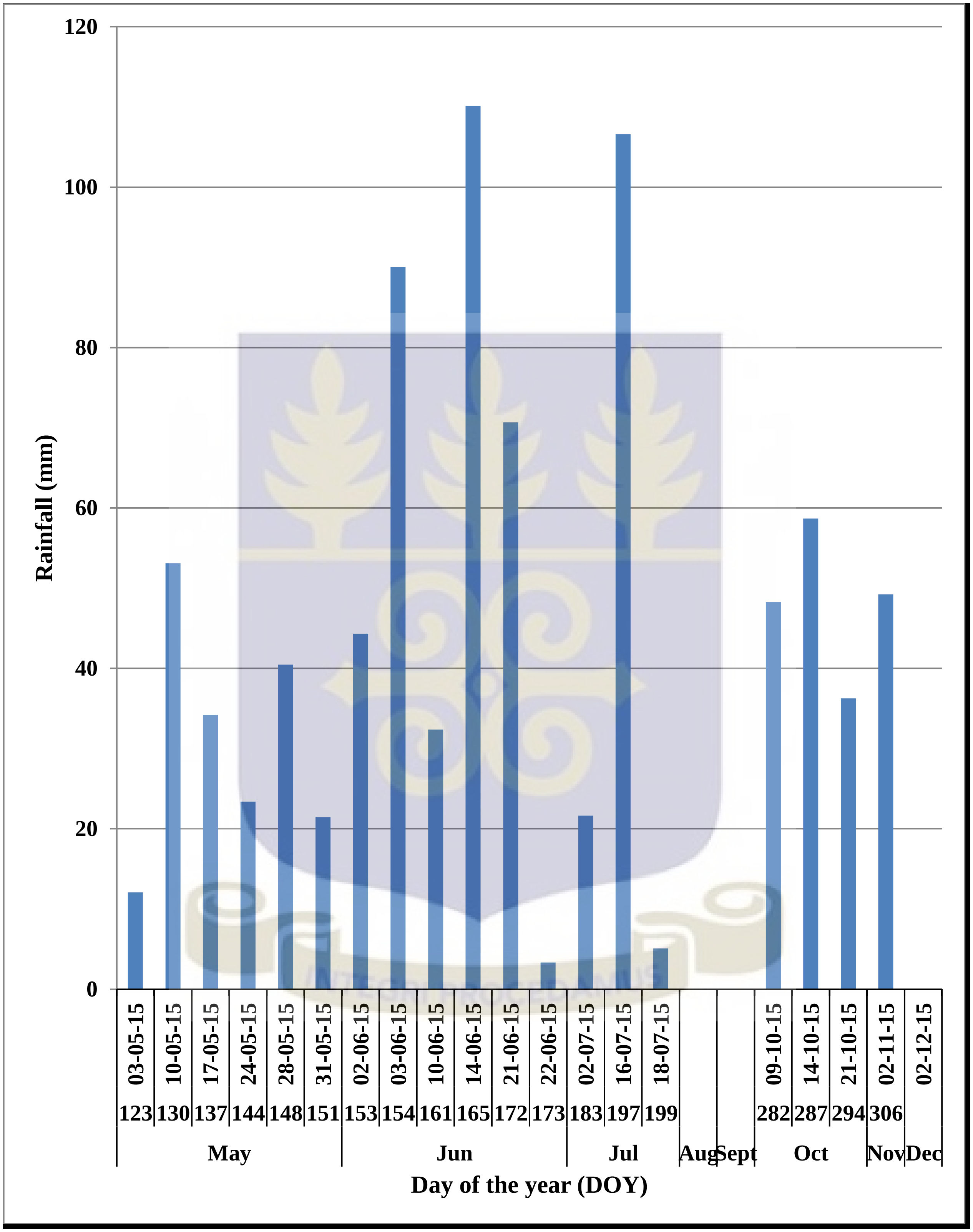


Figure 4.1: Daily rainfall events for the period of studies in 2015 at the experimental site, Atomic-Kwabenya.

4.2 Leaf area index (LAI)

4.2.1 Leaf area index for Bankye Hemaa

For the cassava variety Bankye Hemaa grown at 10, 000 plants ha $^{-1}$, the observed LAI was 0.7 on 28 DAE, 1.1 on 56 DAE, 3.1 DAE on 84 DAE, 5.2 on 112 DAE, 5.3 on 140 DAE, 6.2 on 168 DAE and declined to 5.4 on 196 DAE (Figure 4.2A).

The cassava variety Bankye Hemaa grown at 13,333 plant ha^{-1} had LAI of 0.8 on 28 DAE, 1.2 on 56 DAE, 3.4 on 84 DAE, 5.2 on 112 DAE, 5.4 on 140 DAE, 6.2 on 168 DAE and declined to 5.4 on 196 DAE (Figure 4.2A).

Similarly, the LAI for the cassava variety Bankye Hemaa grown at 20,000 plants ha^{-1} was 0.9 on 28 DAE, 1.3 on 56 DAE, 3.7 on 84 DAE, 5.2 on 112 DAE, 5.5 on 140 DAE, 6.8 on 168 DAE and declined to 6.5 on 196 DAE (Figure 4.2A).

The highest LAI for Bankye Hemaa was observed on 168 DAE for all the planting densities at which the crop was grown (Figure 4.2A).

The LAI values for Bankye Hemaa at plant density of 20,000 plants ha^{-1} on 168 and 196 DAE were significantly different ($P < 0.05$) from LAI values for 13,333 and 10,000 plants ha^{-1} (Figure 4.2A).

4.2.2 Leaf area index for Capevars Bankye

The leaf area index (LAI) for the cassava variety Capevars Bankye grown at 10,000 plants ha^{-1} was 0.5 on 28 DAE, 1.7 on 56 DAE, 3.0 on 84 DAE, 4.4 on 112 DAE, 4.6 on 140 DAE, at 5.3 on 168 DAE and remain same on 196 DAE (Figure 4.2B).

For the 13,333 plants ha^{-1} the observed LAI for Capevars Bankye was 0.9 on 28 DAE, 1.8 on 56 DAE, 3.1 on 84 DAE, 4.5 on 112 DAE, 4.7 on 140 DAE, peaked at 5.4 on 168 DAE and decreased to 5.3 on 196 DAE (Figure 4.2B).

Also for the 20,000 plants $ha^{-1,}$ planting density LAI for Capevars Bankye was 1.5 on 28 DAE, 1.8 on 56 DAE, 5.4 on 84 DAE, 5.7 on 112 DAE, peaked at 6.0 on 140 DAE, 5.4 on 168 DAE and 5.4 on 196 DAE (Figure 4.2B).

Additionally, significant differences ($P < 0.05$) in LAI of the Capevars Bankye grown at the three (3) different plant densities were observed on 28 DAE, 84 DAE, 112 DAE and 140 DAE (Figure 4.2B).

However, interactive effects of cassava varieties and plant densities on LAI were not significantly different ($p > 0.05$).

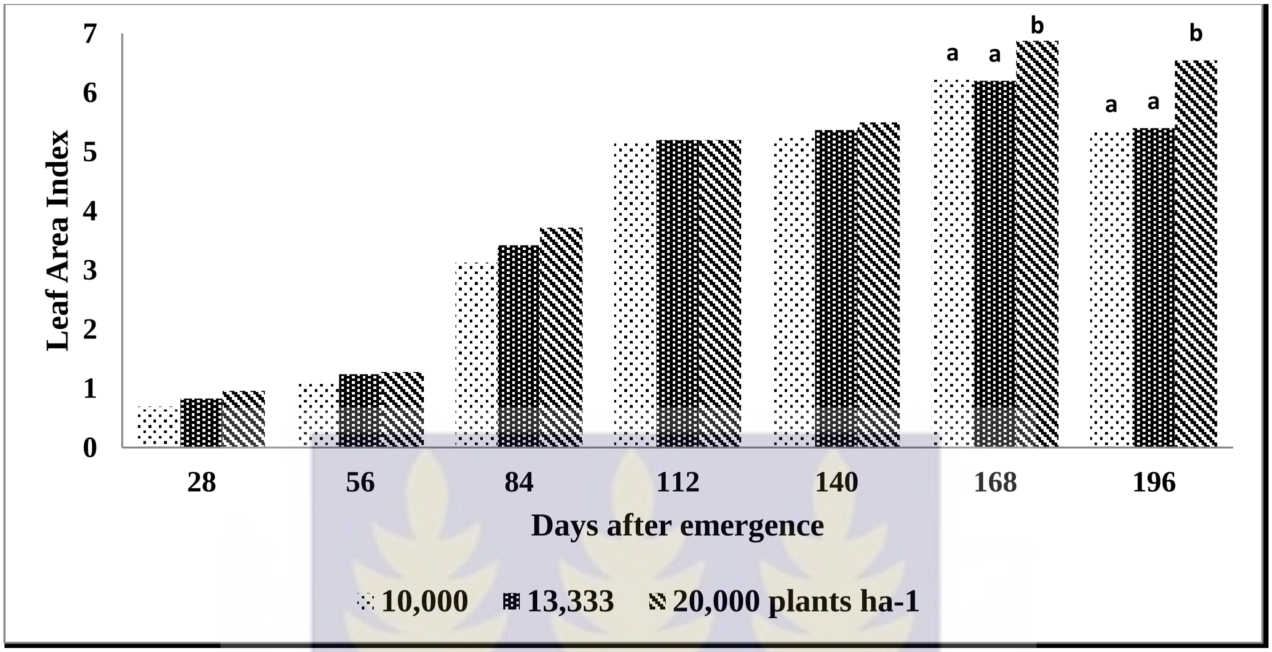


Figure 4.2A. Leaf area index of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

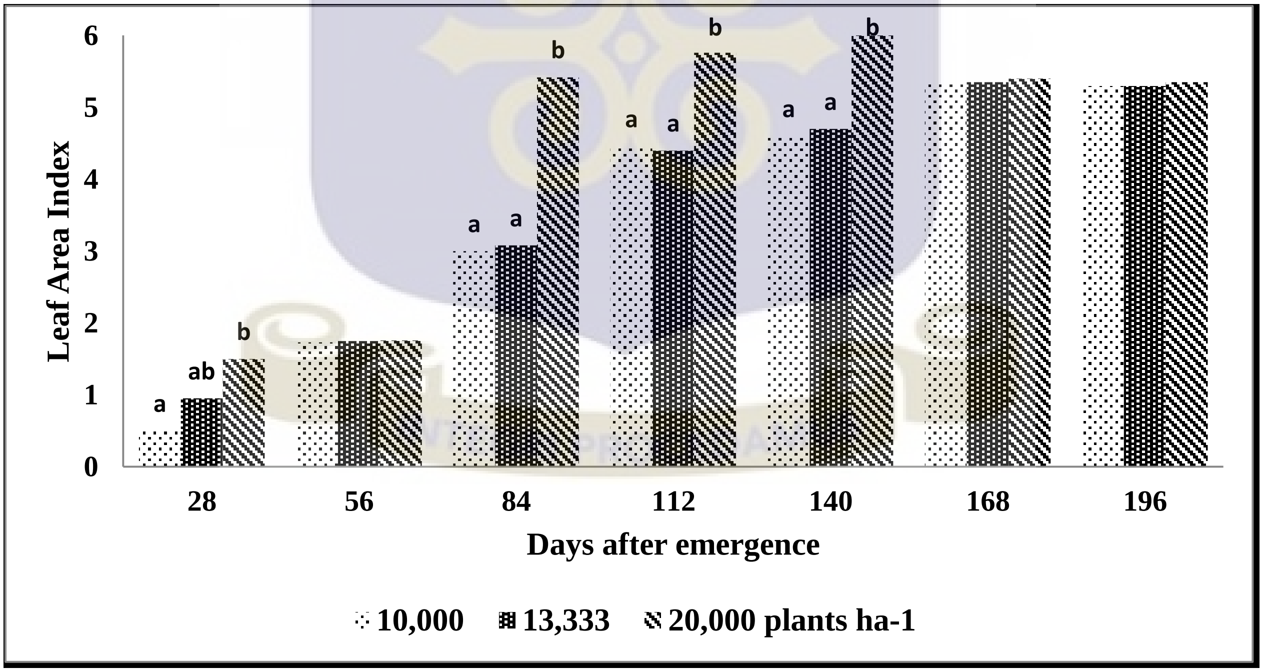


Figure 4.2B. Leaf area index of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.3 Total dry biomass accumulation

4.3.1 Total dry biomass accumulation for Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, produced total dry matter (TDM) of 587.1 kg ha^{-1}on 28 DAE, 1,192.9 kg ha^{-1} on 56 DAE, 2,750.0 kg ha^{-1} DAE on 84 DAE, 4,102.6 kg ha^{-1} on 112 DAE, 5,085.0 kg ha^{-1} on 140 DAE, 7,265.0 kg ha^{-1} on 168 DAE and TDM peaked at 9,194.3 kg ha^{-1} on 196 DAE (Figure 4.3A).

Also, Bankye Hemaa, grown at 13,333 plants ha $^{-1}$, produced TDM of 749.3 kg ha^{-1}on 28 DAE, 1,652.3 kg ha^{-1} on 56 DAE, 3,065.5 kg ha^{-1} DAE on 84 DAE, 4,748.0 kg ha^{-1} on 112 DAE, 5,696.5 kg ha^{-1} on 140 DAE, 7,386.5 kg ha^{-1} on 168 DAE and TDM peaked at 9,746.3 kg ha^{-1} on 196 DAE (Figure 4.3A).

Furthermore, Bankye Hemaa, grown at 20, 000 plants ha $^{-1}$, produced TDM of 1,306.7 kg ha^{-1}on 28 DAE, 1,788.7 kg ha^{-1} on 56 DAE, 3,620.0 kg ha^{-1} on 84 DAE, 5,425.7 kg ha^{-1} on 112 DAE, 6,347.8 kg ha^{-1} on 140 DAE, 7,850.5 kg ha^{-1} on 168 DAE and TDM peaked at 10,002.00 kg ha^{-1} on 196 DAE (Figure 4.3A).

Generally, there was no statistical difference in TDM values produced by Bankye Hemaa among the planting densities. However plant density of 20,000 plants ha $^{-1}$ produced the highest TDM value of 10,002.0 kg ha^{-1} with no significant interaction between the variety and plant density (Figure 4.3A).

4.3.2 Total dry biomass accumulation for Capevars Bankye

The Capevars Bankye grown at 10, 000 plants ha $^{-1}$ produced TDM of 784.0 kg ha^{-1}on 28 DAE, 860.0 kg ha^{-1} on 56 DAE, 3,806.0 kg ha^{-1} on 84 DAE, 3,500.0 kg ha^{-1} on 112 DAE, 4,000.9 kg ha^{-1} on 140 DAE, 4,950.0 kg ha^{-1} on 168 DAE and TDM peaked to 5,912.40 kg ha^{-1} on 196 DAE (Figure 4.3B).

Also, Capevars Bankye, grown at 13,333 plants ha $^{-1}$, produced TDM of 1,240.7 kg ha^{-1}on 28 DAE, 1,761.4 kg ha^{-1} on 56 DAE, 4,288.8 kg ha^{-1} on 84 DAE, 4,695.3 kg ha^{-1} on 112 DAE, 5,186.5 kg ha^{-1} on 140 DAE, 6,255.5 kg ha^{-1} on 168 DAE and TDM peaked at 7,200.0 kg ha^{-1} on 196 DAE (Figure 4.3.B).

Furthermore, Capevars Bankye, grown at 20,000 plants ha $^{-1}$, produced TDM of 1,337.3 kg ha^{-1}on 28 DAE, 1,889.5 kg ha^{-1} on 56 DAE, 5,309.5 kg ha^{-1} on 84 DAE, 5,865.1 kg ha^{-1} on 112 DAE, 5,468.7 kg ha^{-1} on 140 DAE, 7,288.9 kg ha^{-1} on 168 DAE and TDM peaked at 8,200.0 kg ha^{-1} on 196 DAE (Figure 4.3.B).

Generally, there was no statistical difference in TDM values produced by Capevars Bankye among the planting densities. However plant density of 20,000 plants ha $^{-1}$ produced the highest TDM value of 8,200.0 kg ha^{-1} with no significant interaction between the variety and plant density (Figure 4.3B).

Similarly, there were no statistically differences in TDM values produced by Bankye Hemaa and Capevars Bankye and among the planting densities. However Bankye Hemaa under 20,000 plants ha^{-1} produced the highest TDM value of 10,002.0 kg ha^{-1} (Figure 4.3B).

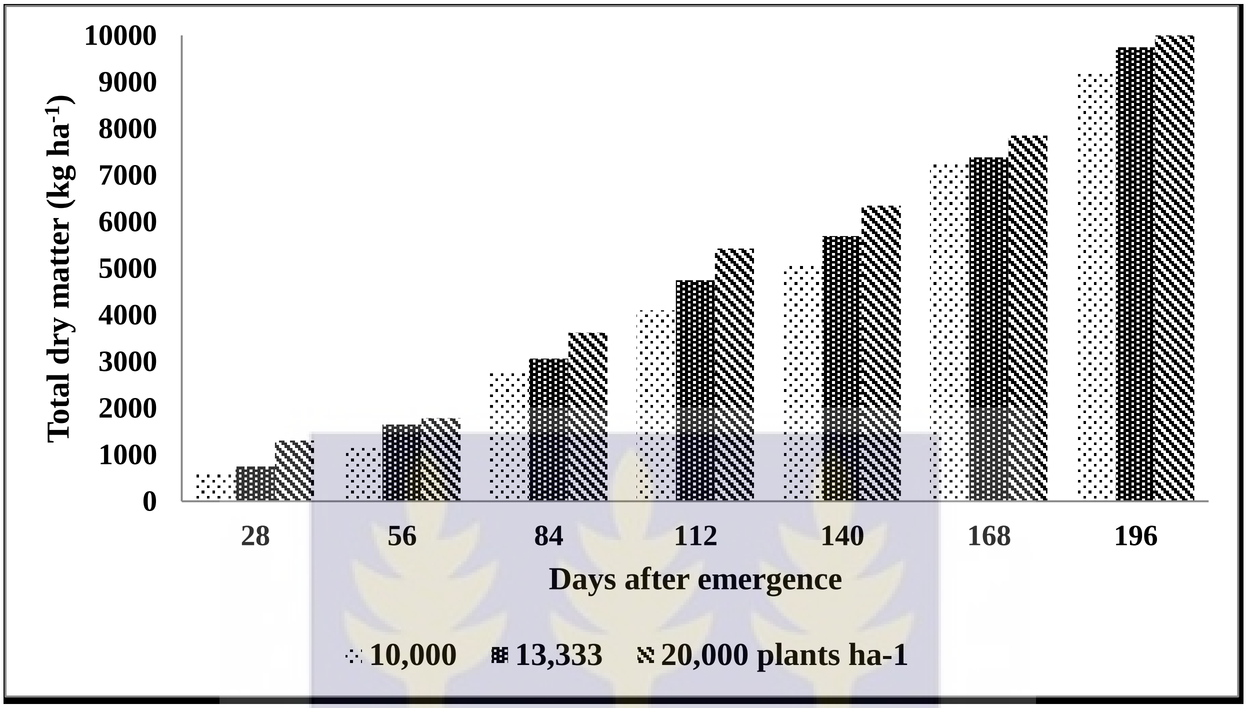


Figure 4.3A. Total biomass yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

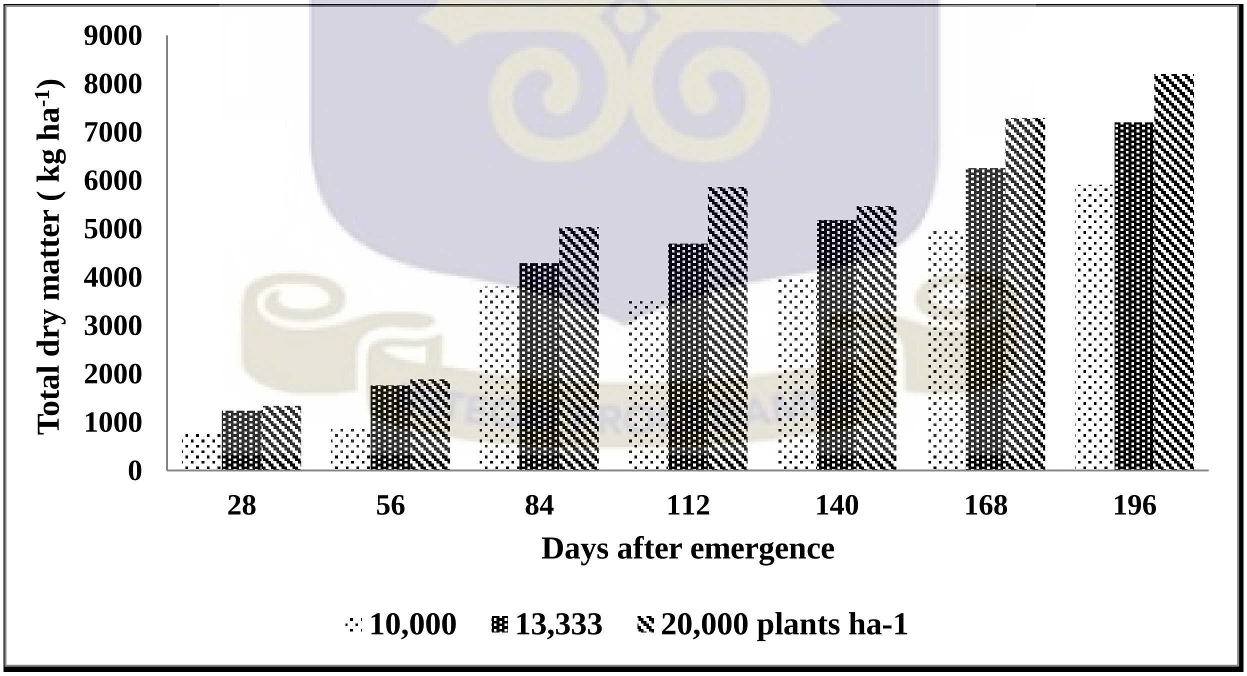


Figure 4.3B. Total biomass yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.4 Biomass partitioning

4.4.1 Leaf dry matter

4.4.1.1 Leaf dry matter for Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, produced leaf dry matter (LDM) of 411.1 kg ha^{-1} on 28 DAE, 715.1 kg ha^{-1} on 56 DAE, 550.0 kg ha^{-1} on 84 DAE, 205.1 kg ha^{-1} on 112 DAE, 178.0 kg ha^{-1} on 140 DAE, 108.8 kg ha^{-1} on 168 DAE and 69.0 kg ha^{-1} on 196 DAE (Figure 4.4.1A).

Also, Bankye Hemaa, grown at 13,333 plants ha $^{-1}$, produced LDM of 524.5 kg ha^{-1} on 28 DAE, 1,103.6 kg ha^{-1} on 56 DAE, 551.8 kg ha^{-1} on 84 DAE, 474.8 on 112 DAE, 398.8 kg ha^{-1} on 140 DAE, 369.3 kg ha^{-1} on 168 DAE, and 292.4 kg ha^{-1} on 196 DAE (Figure 4.4.1A).

Furthermore, Bankye Hemaa, grown at 20,000 plants ha $^{-1}$, produced LDM of 914.7 kg ha^{-1} on 28 DAE, 1,448.0 kg ha^{-1} on 56 DAE, dropped to 724.0 kg ha^{-1}, 542.6 on 112 DAE, 317.4 kg ha^{-1} on 140 DAE, 314.0 kg ha^{-1} on 168 DAE and 300.0 kg ha^{-1} on 196 DAE (Figure 4.4.1A).

For Bankye Hemaa, significant differences ($P < 0.05$) in LDM were observed among the different planting densities for all sampling dates except on 112 DAE (Figure 4.4.1A). However significant interactive effects ($P < 0.003$-0.001) of the cassava variety and plant densities on LDM were observed on 140 DAE, 168 DAE and 196 DAE (Figure 4.4.1A).

4.4.1.2 Leaf dry matter for Capevars Bankye

Capevars Bankye, grown at 10, 000 plants ha $^{-1}$, produced LDM of 548.8 kg ha^{-1} on 28 DAE, 602.0 kg ha^{-1} on 56 DAE, 1,063.8 kg ha^{-1} on 84 DAE, 350.0 kg ha^{-1} on 112 DAE, 120.0 kg ha^{-1} on 140 DAE, 100.0 kg ha^{-1} on 168 DAE and 88.7 kg ha^{-1} on 196 DAE (Figure 4.4.1B).

Also Bankye Hemaa, grown at 13,333 plants ha $^{-1}$, produced LDM of 868.5 kg ha^{-1} on 28 DAE, 1,056.8 kg ha^{-1} on 56 DAE, 1,072.2 kg ha^{-1} on 84 DAE, 375.6 on 112 DAE, 129.7 kg ha^{-1} on 140 DAE, 125.1 kg ha^{-1} on 168 DAE and 108.0 kg ha^{-1} on 196 DAE (Figure 4.4.1B).

Furthermore, Capevars Bankye, grown at 20,000 plants ha $^{-1}$, produced LDM of 936.1 kg ha^{-1} on 28 DAE, 1,133.0 kg ha^{-1} on 56 DAE, peaked to 1,259.9 kg ha^{-1}, dropped to 439.9 on 112 DAE, 54.7 kg ha^{-1} on 140 DAE, 51.0 kg ha^{-1} on 168 DAE, and 49.2 kg ha^{-1} on 196 DAE (Figure 4.4.1B).

Additionally, Capevars Bankye, produced LDM values which were significantly different among the different planting densities ($P<0.05$) on 28 DAE, 56 DAE, 84 DAE and 140 DAE (Figure 4.4.1B).

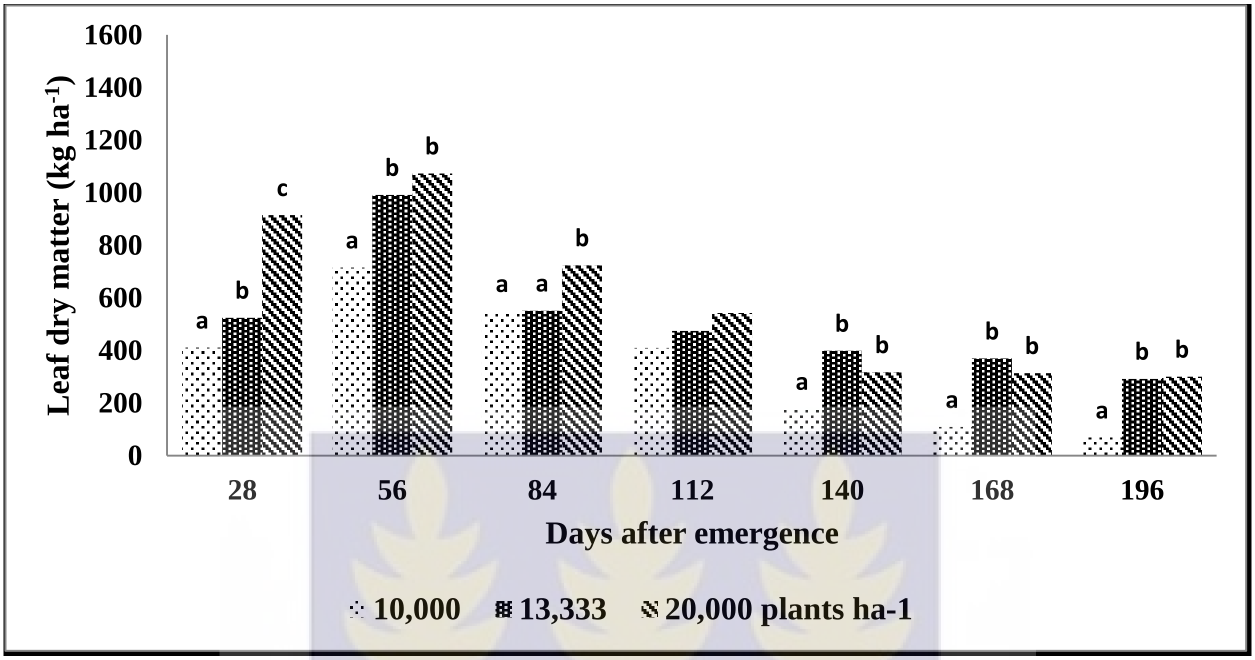


Figure 4.4.1A. Leaf dry matter yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

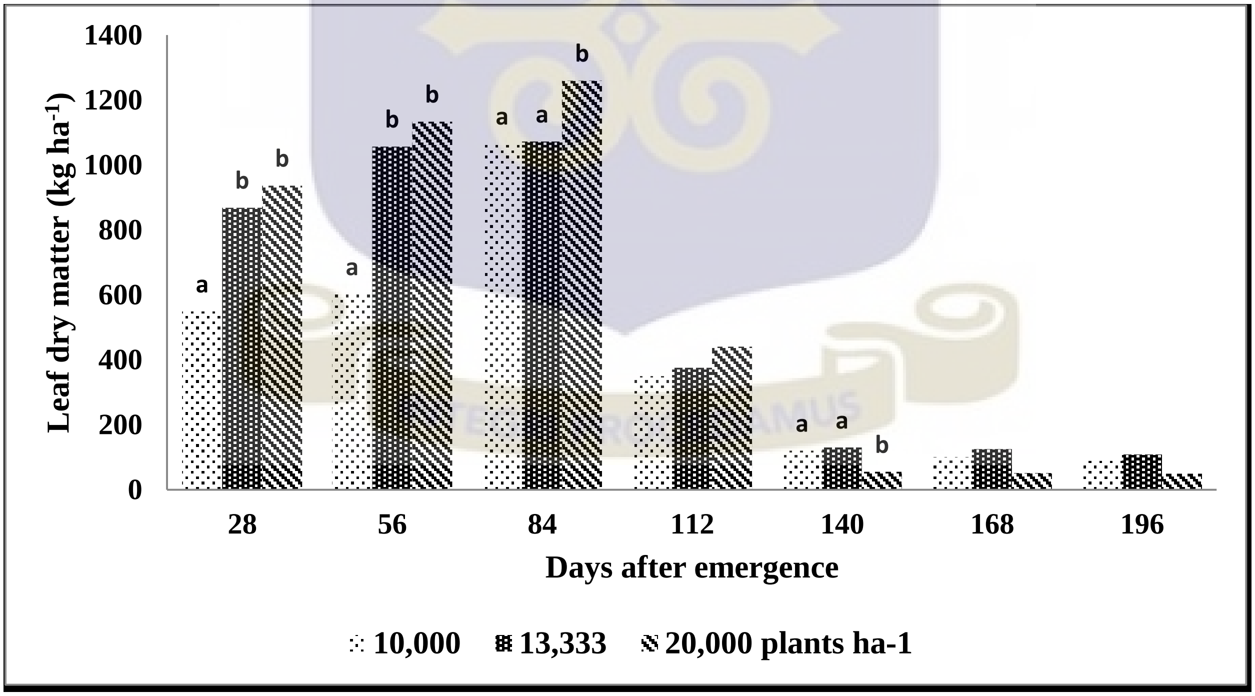


Figure 4.4.1B. Leaf dry matter yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.4.2 Stem dry matter yield

4.4.2.1 Stem dry matter yield for Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, produced stem dry matter (SDM) of 176.1 kg ha^{-1} on 28 DAE, 477.2 kg ha^{-1} on 56 DAE, 495.0 kg ha^{-1} on 84 DAE, 1025.7 kg ha^{-1} on 112 DAE, 1,525.5 kg ha^{-1} on 140 DAE, 2,321.9 kg ha^{-1} on 168 DAE and 2,758.3 kg ha^{-1} on 196 DAE (Figure 4.4.2A).

Also Bankye Hemaa, grown at 13,333 plants ha $^{-1}$, produced SDM of 224.8 kg ha^{-1} on 28 DAE, 660.9 kg ha^{-1} on 56 DAE, 613.3 kg ha^{-1} on 84 DAE, 1,471.9 on 112 DAE, 1,879.3 kg ha^{-1} on 140 DAE, 2,437.5 kg ha^{-1} on 168 DAE, and 2,923.90 kg ha^{-1} on 196 DAE (Figure 4.4.2A).

Furthermore, Bankye Hemaa, grown at 20,000 plants ha $^{-1}$, produced SDM of 392.0 kg ha^{-1} on 28 DAE, 715.5 kg ha^{-1} on 56 DAE, 742.0 kg ha^{-1} on 84 DAE, 1,627.7 on 112 DAE, 1,904.3 kg ha^{-1} on 140 DAE, 2,590.7 kg ha^{-1} on 168 DAE, and 3,000.0 kg ha^{-1} on 196 DAE (Figure 4.4.2A).

Additionally, Bankye Hemaa produced significantly different ($P < 0.05$) SDM among the different planting densities on 112 DAE (Figure 4.4.2A). However the planting density of 20,000 plants ha $^{-1}$ produced the highest SDM of 3,000.0 kg ha^{-1} on 196 DAE (Figure 4.4.2A).

4.4.2.2 Stem dry matter yield for Capevars Bankye

Capevars Bankye, grown at 10, 000 plants ha $^{-1}$, produced SDM of 235.2 kg ha^{-1} on 28 DAE, 258.0 kg ha^{-1} on 56 DAE, 837.5 kg ha^{-1} on 84 DAE, 1,050.0 kg ha^{-1} on 112 DAE, 1,040.2 kg ha^{-1} on 140 DAE, 1,600.0 kg ha^{-1} on 168 DAE and 2,246.7 kg ha^{-1} on 196 DAE (Figure 4.4.2B).

Also, Capevars Bankye, grown at 13,333 plants ha $^{-1}$, produced SDM of 372.2 kg ha^{-1} on 28 DAE, 704.6 kg ha^{-1} on 56 DAE, 1,310.2 kg ha^{-1} on 84 DAE, 1,408.6 on 112 DAE, 1,763.4 kg ha^{-1} on 140 DAE, 1,876.7 kg ha^{-1} on 168 DAE, and 2,556.00 kg ha^{-1} on 196 DAE (Figure 4.4.2B).

Furthermore, Capevars Bankye, grown at 20,000 plants ha $^{-1}$, produced SDM of 401.2 kg ha^{-1} on 28 DAE, 755.8 kg ha^{-1} on 56 DAE, 1,511.9 kg ha^{-1} on 84 DAE, 1,847.50 on 112 DAE, 1,859.40 kg ha^{-1} on 140 DAE, 2,186.70 kg ha^{-1} on 168 DAE, and 2,714.2 kg ha^{-1} on 196 DAE (Figure 4.4.2B).

Additionally, Capevars Bankye produced significantly different ($P < 0.05$) SDM among the different planting densities on 28 DAE, 56 DAE, 84 DAE, 112 DAE and 140 DAE. Also, significant difference ($P<0.002$) in SDM was observed for the interactive effects of cassava variety plant densities on 56 DAE. The highest SDM of 2714.2 kg ha^{-1} was observed for Capevars Bankye at 20,000 plants ha $^{-1}$ on 196 DAE (Figure 4.4.2B).

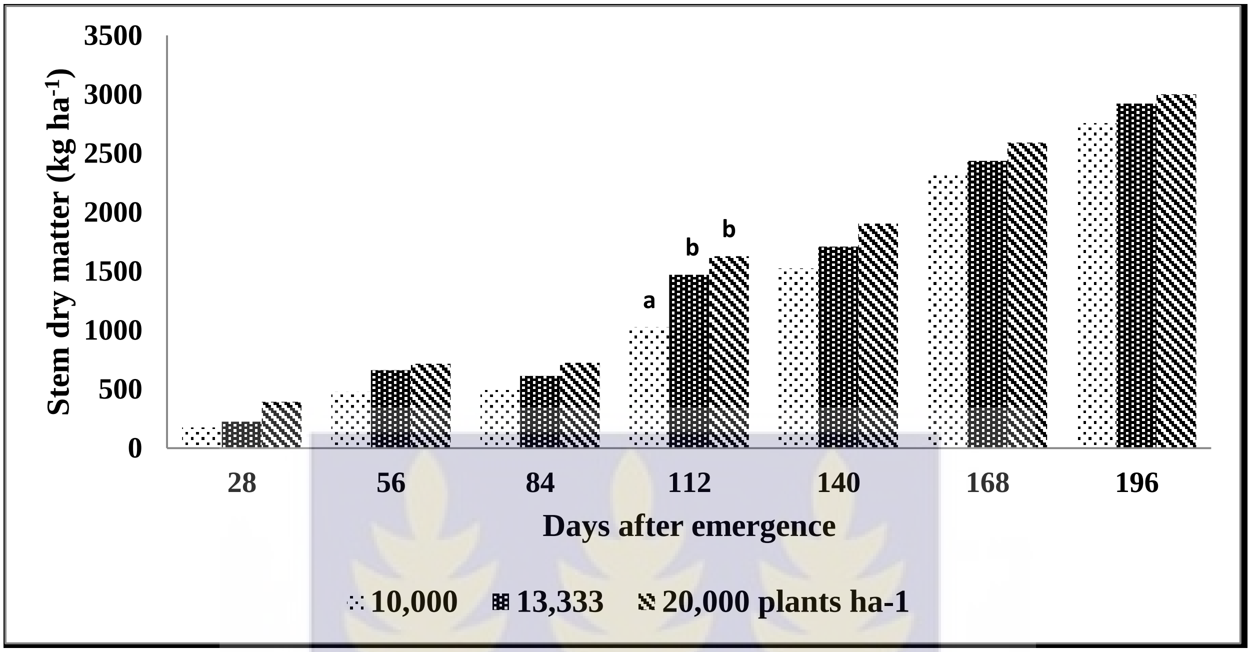


Figure 4.4.2A. Stem dry matter yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

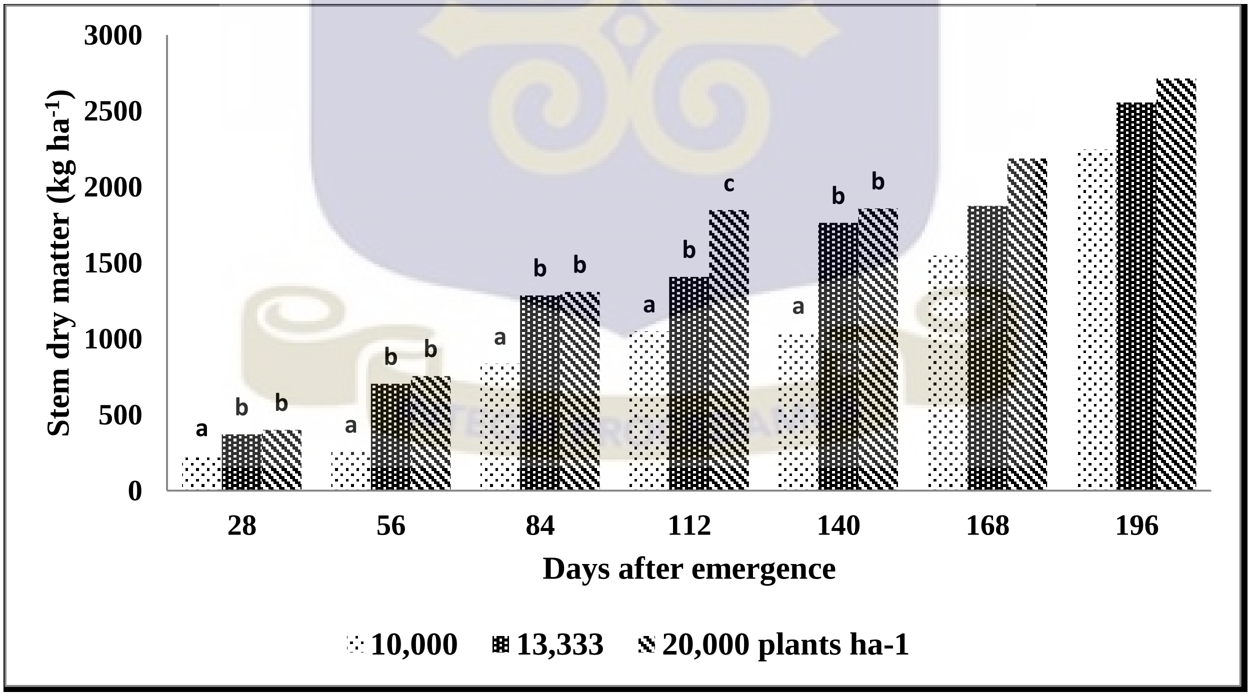


Figure 4.4.2B. Stem dry matter yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.4.3 Root dry matter yield

4.4.3.1 Root dry matter yield for Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, produced no root dry matter (RDM) on 28 DAE and 56 DAE but RDM of 1,705.0 kg ha^{-1} on 84 DAE, 2,666.7 kg ha^{-1} on 112 DAE and increased to 3,881.5 kg ha^{-1} on 140 DAE, 4,825.2 kg ha^{-1} on 168 DAE and 6,367.1 kg ha^{-1} on 196 DAE (Figure 4.4.3A).

Also, Bankye Hemaa, grown at 13,333 plants ha $^{-1}$, produced no RDM on 28 DAE and 56 DAE but RDM of 3,801.2 kg ha^{-1} on 84 DAE, 2,801.3 kg ha^{-1} on 112 DAE 3,588.8 kg ha^{-1} on 140 DAE, 4,579.6 kg ha^{-1} on 168 DAE and 6,530.0 kg ha^{-1} on 196 DAE (Figure 4.4.3A).

Furthermore, Bankye Hemaa, grown at 20,000 plants ha $^{-1}$, produced no RDM on 28 DAE and 56 DAE but RDM of 4,343.9 kg ha^{-1} on 84 DAE, 3,255.4 kg ha^{-1} on 112 DAE and 4,126.1 kg ha^{-1} on 140 DAE, 4,945.8 kg ha^{-1} on 168 DAE and peaked to 6,701.3 kg ha^{-1} on 196 DAE (Figure 4.4.3A).

4.4.3.2 Root dry matter yield for Capevars Bankye

Capevars Bankye, grown at 10, 000 plants ha $^{-1}$, produced no RDM on 28 DAE and 56 DAE, but produced RDM of 1,903.30 kg ha^{-1} on 84 DAE, 2,100.0 kg ha^{-1} on 112 DAE, 2,840.6 kg ha^{-1} on 140 DAE, 3,350.0 kg ha^{-1} on 168 DAE and 3,517.0 kg ha^{-1} on 196 DAE (Figure 4.4.3B).

Also, Capevars Bankye, grown at 13,333 plants ha $^{-1}$, had no RDM on 28 DAE and 56 DAE, but produced RDM of 1,929.96 kg ha^{-1} on 84 DAE, 2,911.1 kg ha^{-1} on 112 DAE, 3,293.4 kg ha^{-1} on 140 DAE, 4,253.7 kg ha^{-1} on 168 DAE and 4,536.00 kg ha^{-1} on 196 DAE (Figure 4.4.3B).

Furthermore, Capevars Bankye grown at 20,000 plants ha $^{-1}$, had no RDM on 28 DAE and 56 DAE, but produced RDM of peaked 2,469.4 kg ha^{-1} on 84 DAE, 3,577.7 kg ha^{-1} on 112 DAE, 3,554.7 kg ha^{-1} on 140 DAE, 4,759.7 kg ha^{-1} on 168 DAE and peaked at 5,436.6 kg ha^{-1} on 196 DAE (Figure 4.4.3B).

Also, RDM values produced by Capevars Bankye were significantly different ($P < 0.05$) among the different planting densities on 84 DAE, 112 DAE, and 196 DAE (Figure 4.4.3B). However interactive effects of the cassava variety and plant densities on RDM were significantly different on 84 DAE ($P=0.022$), 112 DAE ($P<0.001$), and 196 DAE ($P=0.016$),

Generally both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1} produced the highest root dry matter, but Bankye Hemaa produced the higher RDM value of 6,701.3 kg ha^{-1} on 196 DAE (Figure 4.4.3A).

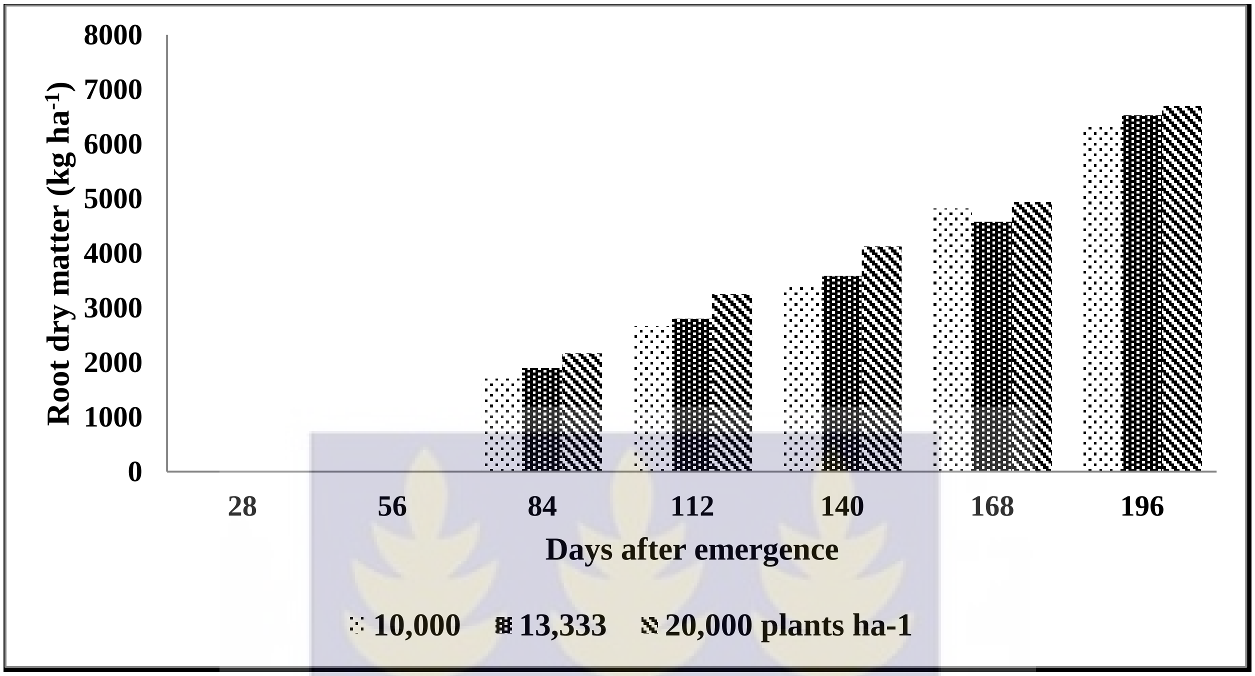


Figure 4.4.3A. Root dry matter yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

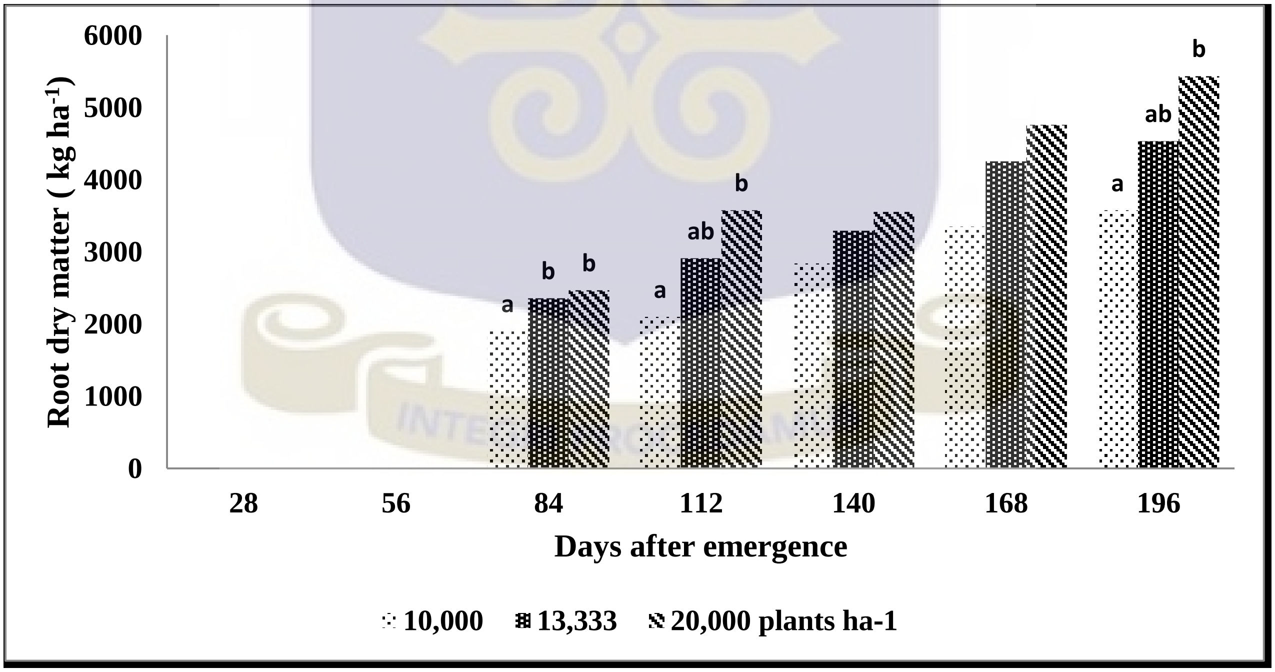


Figure 4.4.3B. Root dry matter yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.5 Yield and harvest Index

4.5.1 Root Yield of Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, had no root yield (RY) on 28 DAE and 56 DAE but produced RY of 2.8 t ha^{-1} on 84 DAE, 4.7 t ha^{-1} on 112 DAE, 7.7 t ha^{-1} on 140 DAE, 10.0 t ha^{-1} on 168 DAE and RY and 15.1 t ha^{-1} on 196 DAE (Figure 4.5.1A).

Also, Bankye Hemaa, grown at 13,333 plants ha $^{-1}$ had no RY on 28 DAE and 56 DAE 4.20 t ha^{-1} on 84 DAE, 5.5 t ha^{-1} on 112 DAE 7.9 t ha^{-1} on 140 DAE, 12.40 t ha^{-1} on 168 DAE and RY peaked to 18.10 t ha^{-1} on 196 DAE (Figure 4.5.1A).

Furthermore, Bankye Hemaa, grown at 20,000 plants ha $^{-1}$, had no RY on 28 DAE and 56 DAE but produced RY of 5.4 t ha^{-1} on 84 DAE, 6.8 t ha^{-1} on 112 DAE 8.2 t ha^{-1} on 140 DAE, 15.2 t ha^{-1} on 168 DAE and 21.3 t ha^{-1} on 196 DAE (Figure 4.5.1A).

On the other hand, RY on 196 DAE for Bankye Hemaa grown at 20,000 plants ha^{-1} was not significantly ($P > 0.05$) different from those from the 13,333 and 10,000 plants ha^{-1}.

4.5.2 Root Yield of Capevars

Capevars Bankye, grown at 10, 000 plants ha $^{-1}$, had no RY on 28 DAE and 56 DAE but produced RY of 2.9 t ha^{-1} on 84 DAE, 5.2 t ha^{-1} on 112 DAE ,5.7 t ha^{-1} on 140 DAE, 7.7 t ha^{-1} on 168 DAE and 8.7 t ha^{-1} on 196 DAE (Figure 4.5.2B).

Also, Capevars Bankye, grown at 13,333 plants ha $^{-1}$, had no RY on 28 DAE and 56 DAE but produced RY of 3.6 t ha^{-1} on 84 DAE, 6.2 t ha^{-1} on 112 , 7.9 t ha^{-1} on 140 DAE, 8.7 t ha^{-1} on 168 DAE and 15.5 t ha^{-1} on 196 DAE (Figure 4.5.2B).

Furthermore, Capevars Bankye, grown at 20,000 plants ha $^{-1}$, had no RY on 28 DAE and 56 DAE but produced RY of 5.1 t ha^{-1} on 84 DAE, 7.2 t ha^{-1} on 112 DAE ,10.2 t ha^{-1} on 140 DAE, 10.5 t ha^{-1} on 168 DAE and 18.1 t ha^{-1} on 196 DAE (Figure 4.5.2B).

A significant difference ($P< 0.05$) was observed in RY on 196 DAE among the different plant densities, with 20,000 plants ha^{-1} producing the highest root yield (t ha^{-1}) value of 18.1 t ha^{-1} (Figure 4.5.2B).

Generally, Capevars Bankye grown at 20,000 plants ha^{-1} produced the highest RY value of 18.1 t ha^{-1} followed by 15.5 t ha^{-1} for 13,333 plants ha^{-1} and 8.7 t ha^{-1} for 10,000 plants ha^{-1} on 196 DAE (Figure 4.5.2B).

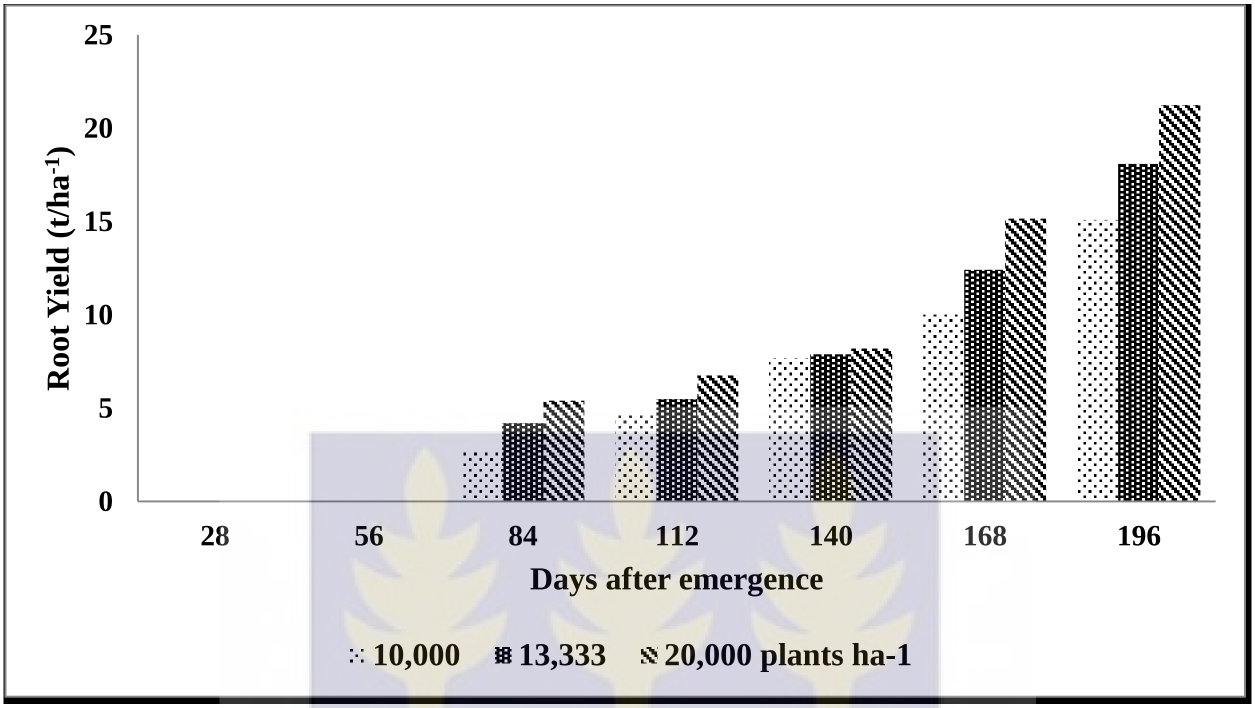


Figure 4.5.1A. Root yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

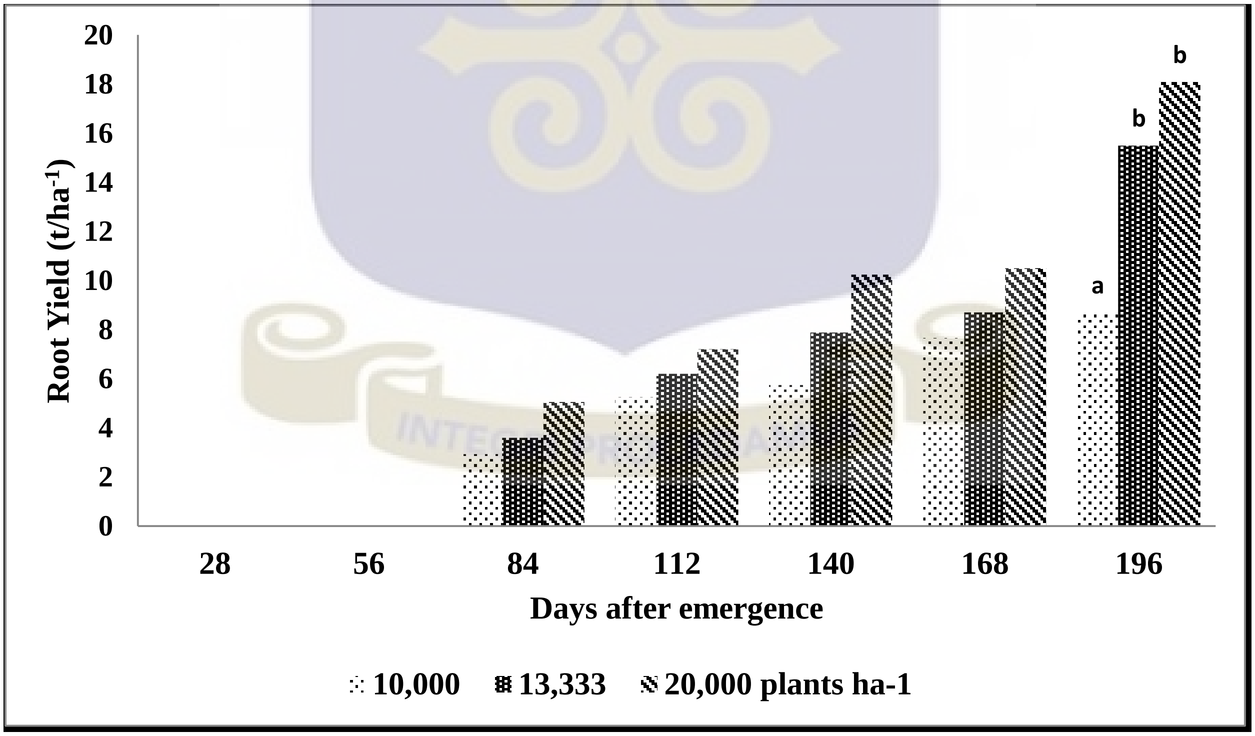


Figure 4.5.2B. Root yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.5.3 Harvest Index (%)

4.5.3.1 Harvest index for Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, had no harvest index (HI) on 28 and 56 DAE, but had HI of 50% on 84 DAE, 53.9% on 112 DAE , 56.6% on 140 DAE, 58.8% on 168 DAE and 61.2% on 196 DAE (Figure 4.5.3A).

Also, Bankye Hemaa grown at 13,333 plants ha $^{-1}$, had no harvest index (HI) on 28 and 56 DAE, but had HI of 52.9% on 84 DAE, 57.9% on 112 DAE 60.2% on 140 DAE, 60.5% on 168 DAE and 63.6% on 196 DAE (Figure 4.5.3A).

Furthermore, Bankye Hemaa grown at 20,000 plants ha $^{-1}$, had no harvest index (HI) on 28 and 56 DAE, but had HI of 55.5% on 84 DAE, 57.1% on 112 DAE , 58.7% on 140 DAE, 61.8% on 168 DAE and 68.5% on 196 DAE (Figure 4.5.3A).

Additionally, the HI value of 68.5% for Bankye Hemaa grown at 20,000 plants ha^{-1} was highest and significantly different ($P<0.05$) from HI values for the 10,000 and 13,333 plants ha^{-1} on 196 DAE (Figure 4.5.3A).

4.5.3.1 Harvest index for Capevars Bankye

Capevars Bankye, grown at 10,000 plants ha $^{-1}$, had no harvest index (HI) on 28 and 56 DAE, but had HI of 46.9% on 84 DAE, 48.0% on 112 DAE , 50.0% on 140 DAE, 54.0% on 168 DAE and 59.0% on 196 DAE (Figure 4.5.3B).

Also, Capevars Bankye, grown at 13,333 plants ha $^{-1}$, had no harvest index (HI) on 28 and 56 DAE, but had HI of 49.6% on 84 DAE, 51.7% on 112 DAE ,54.6% on 140 DAE, 56.5% on 168 DAE and 59.5% on 196 DAE (Figure 4.5.3B).

Furthermore, Capevars Bankye grown at 20,000 plants ha $^{-1}$, had no harvest index (HI) on 28 and 56 DAE, but had HI of 51.5% on 84 DAE, 53.0% on 112 DAE ,57.0% on 140 DAE, 60.0% on 168 DAE and peaked to 66.0% on 196 DAE (Figure 4.5.3B).

The HI value of 66.0% for Capevars Bankye grown at 20,000 plants ha^{-1} was highest and significantly different ($P< 0.05$) from HI values for 10,000 and 13,333 plants ha^{-1}on 196 DAE (Figure 4.5.3B).

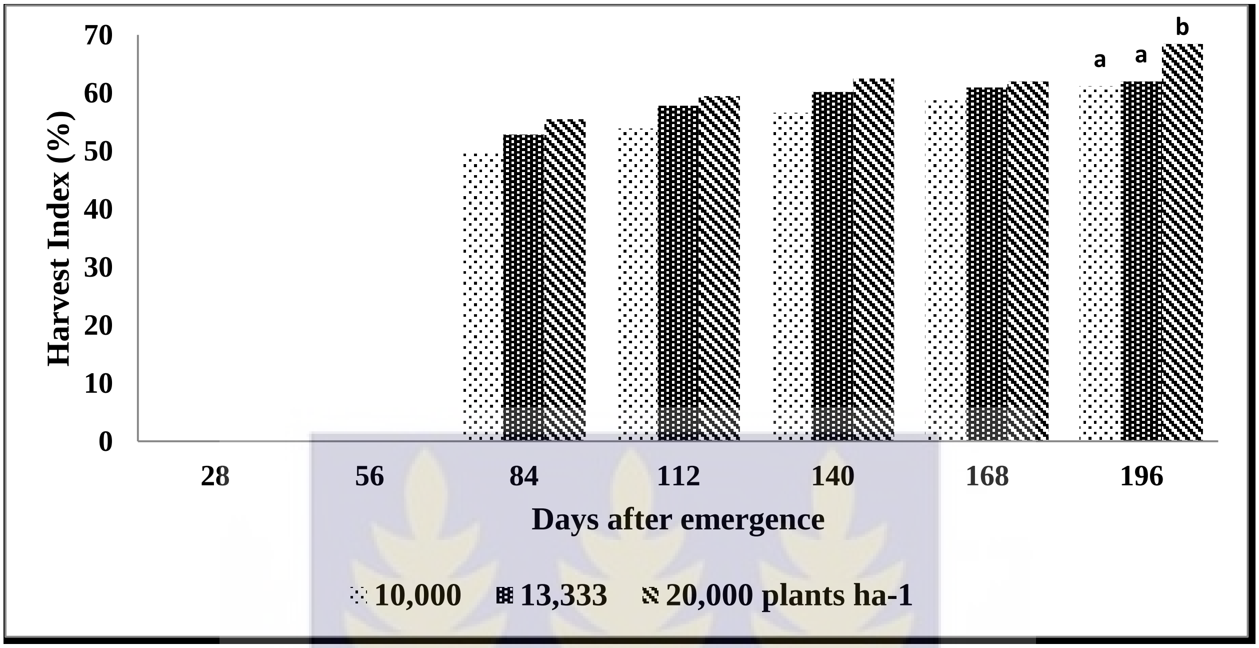


Figure 4.5.3A. Harvest index of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

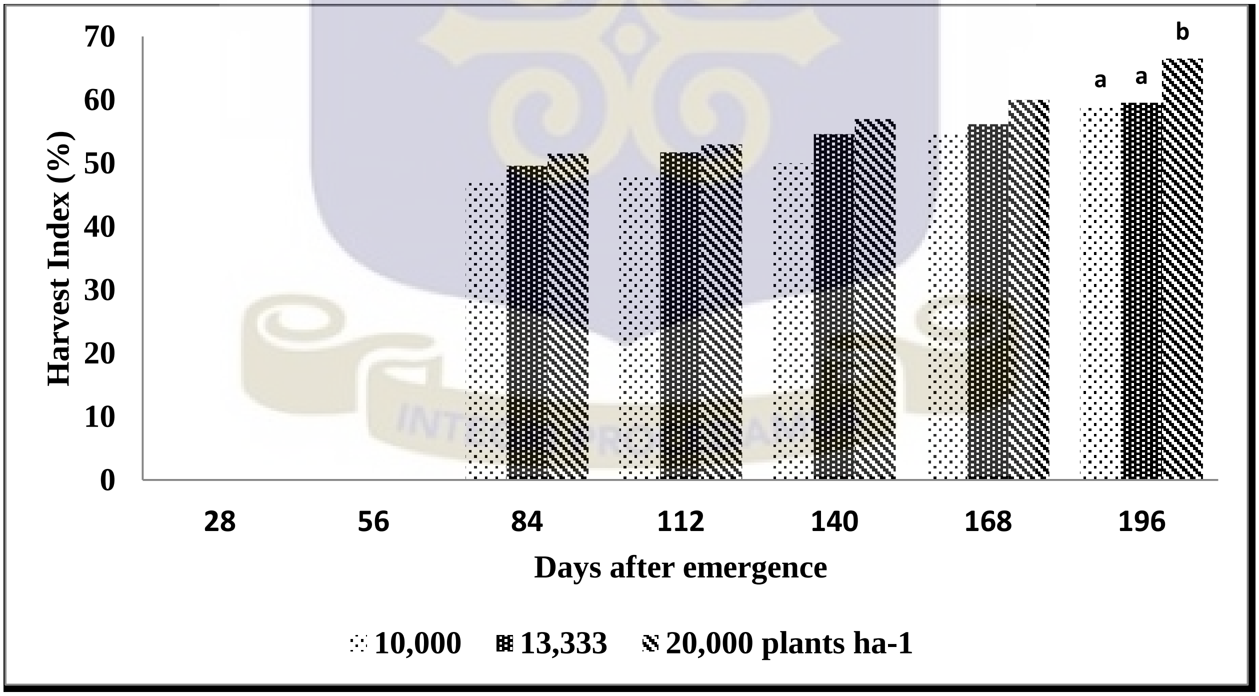


Figure 4.5.2B. Harvest index of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.6 Actual Evapotranspiration (AET)

4.6.1 Actual Evapotranspiration (AET) for Bankye Hemaa

Bankye Hemaa, grown at of 10, 000 plants ha $^{-1}$ had cumulative AET value that ranged from, 346.6 mm on 28 DAE, 474.2 mm on 56 DAE, 516.4 mm on 84 DAE, 561.4 mm on 112 DAE, 617.2 mm on 140 DAE, 758.2 mm on 168 DAE to 794.0 mm on 196 DAE (Figure 4.6.A) .

Also, Bankye Hemaa, grown at 13,333 plants ha $^{-1}$ had cumulative AET of 325.3 mm on 28 DAE, 448.7 mm on 56 DAE, 512.8 mm on 84 DAE, 543.6 mm on 112 DAE, 602.7 mm on 140 DAE, 753.5 mm on 168 DAE and 764.0 mm on 196 DAE (Figure 4.6 A).

Furthermore, Bankye Hemaa, grown at 20, 000 plants ha $^{-1}$ had cumulative AET of 357.1 mm on 28 DAE, 495.1 mm on 56 DAE, 539.0 mm on 84 DAE, 563.4 mm on 112 DAE, 631.4 mm on 140 DAE, 791.8 mm on 168 DAE and 809.2 mm on 196 DAE (Figure 4.6 A).

Though, seasonal AET values for the different plant densities were not statistically different the highest seasonal AET of 809.2 mm occurred under 20,000 plants ha $^{-1}$ on 196 DAE respectively. Similarly, interactive effect of plant densities and cassava varieties was not significantly different ($P< 0.05$).

4.6.2 Actual Evapotranspiration (AET) for Capevars Bankye

Capevars Bankye, grown at 10, 000 plants ha $^{-1}$ had cumulative AET of 390.3 mm on 28 DAE, 514.4 mm on 56 DAE, 570.9 mm on 84 DAE, 592.3 mm on 112 DAE, 616.6 mm on 140 DAE, 787.6 mm on 168 DAE and 814.6 mm on 196 DAE (Figure 4.6 B).

Also Capevars Bankye, grown at 13,333 plants ha $^{-1}$ had cumulative AET of 383.4 mm on 28 DAE, 513.2 mm on 56 DAE, 548.9 mm on 84 DAE, 567.7 mm on 112 DAE, 613.3 mm on 140 DAE, 760.4 mm on 168 DAE and 791.2 mm on 196 DAE (Figure 4.6.B).

Furthermore, Capevars Bankye, grown at 20, 000 plants ha $^{-1}$ had cumulative AET of 361.0 mm on 28 DAE, 495.6 mm on 56 DAE, 555.5 mm on 84 DAE, 582.5 mm on 112 DAE, 632.3 mm on 140 DAE, 799.9 mm on 168 DAE and 827.6 mm on 196 DAE (Figure 4.6 B).

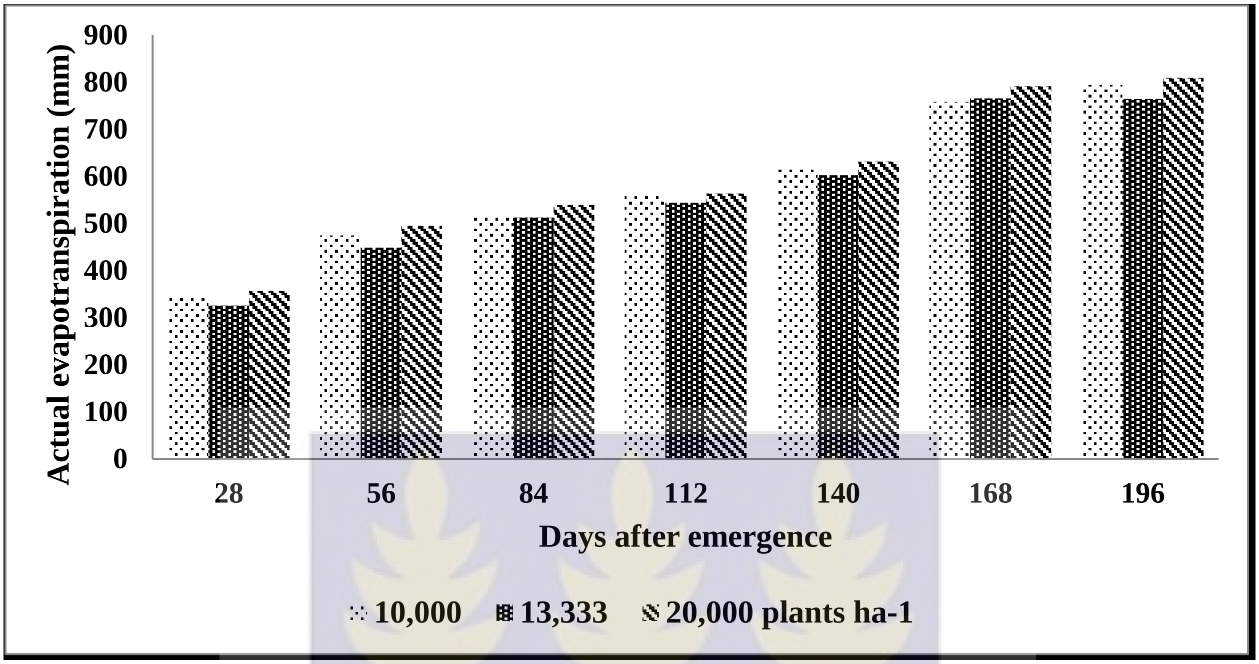


Figure 4.6A Actual evapotranspiration for Bankye Hemaa at different growth stages grown at different plant densities. Bars with the same letters or without letters are not significantly different.

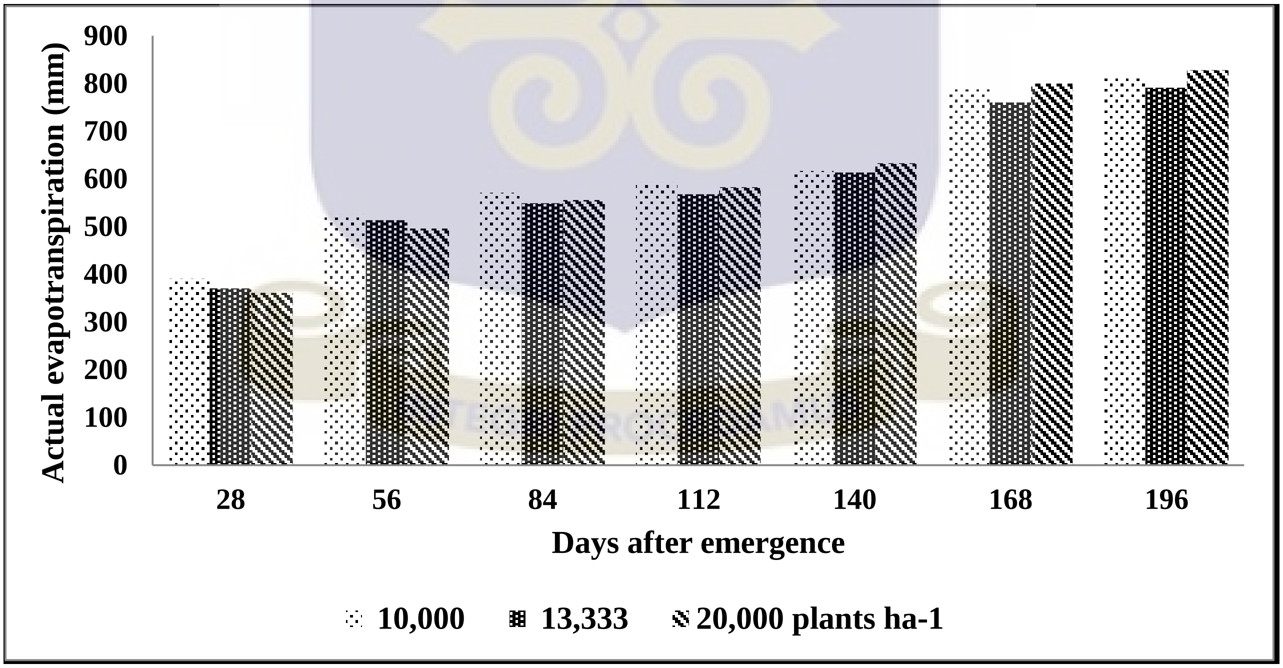


Figure 4.6B. Actual evapotranspiration for Capevars Bankye at different growth stages grown at different plant densities. Bars with the same letters or without letters are not significantly different.

4.7 Evapotranspiration partitioning

4.7.1 Crop transpiration

4.7.1.1 Crop transpiration for Bankye Hemaa

Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$ had crop transpiration value that increased progressively from 152.4 mm^{-1} on 28 DAE to 227.2 mm^{-1} on 56 DAE, 266.3 mm^{-1} on 84 DAE, 310.7 mm^{-1} on 112 DAE, 365.7 mm^{-1} on 140 DAE, 505.8 mm^{-1} on 168 DAE and 540.8 mm^{-1} on 196 DAE (Figure 4.7.1A).

Also, Bankye Hemaa, grown at 13, 333 plants ha $^{-1}$ had crop transpiration value that increased progressively from 159.0 mm^{-1} on 28 DAE to 234.4 mm^{-1} on 56 DAE, 293.2 mm^{-1} on 84 DAE, 323.4 mm^{-1} on 112 DAE, 381.4 mm^{-1} on 140 DAE, 531.2 mm^{-1} on 168 DAE and 541.5 mm^{-1} on 196 DAE (Figure 4.7.1A).

Furthermore, Bankye Hemaa, grown at 20,000 plants ha $^{-1}$ had crop transpiration value that increased progressively from 193.3 mm^{-1} on 28 DAE to 278.5 mm^{-1} on 56 DAE, 320.2 mm^{-1} on 84 DAE, 344.2 mm^{-1} on 112 DAE, 411.5 mm^{-1} on 140 DAE, 571.2 mm^{-1} on 168 DAE and 588.5 mm^{-1} on 196 DAE (Figure 4.7.1A).

Significant difference ($P < 0.05$) was observed on 28 DAE, 84 DAE, 140 DAE, 168 DAE and 196 DAE respectively for crop transpiration for the different plant densities.

4.7.1.2 Crop transpiration for Capevars Bankye

Capevars Bankye, grown at 10, 000 plants ha $^{-1}$had crop transpiration value that increased progressively from 128.2 mm^{-1} on 28 DAE to 203.7 mm^{-1} on 56 DAE, 255.8 mm^{-1} on 84 DAE, 276.6 mm^{-1} on 112 DAE, 300.5 mm^{-1} on 140 DAE, 468.8 mm^{-1} on 168 DAE and 495.5 mm^{-1} on 196 DAE (Figure 4.7.1B).

Also Capevars Bankye, grown at 13, 333 plants ha^{-1}, had crop transpiration value that increased progressively from 207.6 mm^{-1} on 28 DAE to 302.6 mm^{-1} on 56 DAE, 334.8 mm^{-1} on 84 DAE, 353.1 mm^{-1} on 112 DAE, 397.9 mm^{-1} on 140 DAE, 543.1 mm^{-1} on 168 DAE and 573.1 mm^{-1} on 196 DAE (Figure 4.7.1B).

Furthermore, Capevars Bankye, grown at 20,000 plants ha^{-1}, had crop transpiration value that increased progressively from 256.1 mm^{-1} on 28 DAE to 350.7 mm^{-1} on 56 DAE, 409.9 mm^{-1} on 84 DAE, 436.6 mm^{-1} on 112 DAE, 485.0 mm^{-1} on 140 DAE, 650.5 mm^{-1} on 168 DAE and 677.9 mm^{-1} on 196 DAE (Figure 4.7.1B).

Significant difference ($P < 0.05$) was observed in crop transpiration on 112 DAE among the planting densities (Figure 4.7.1B).

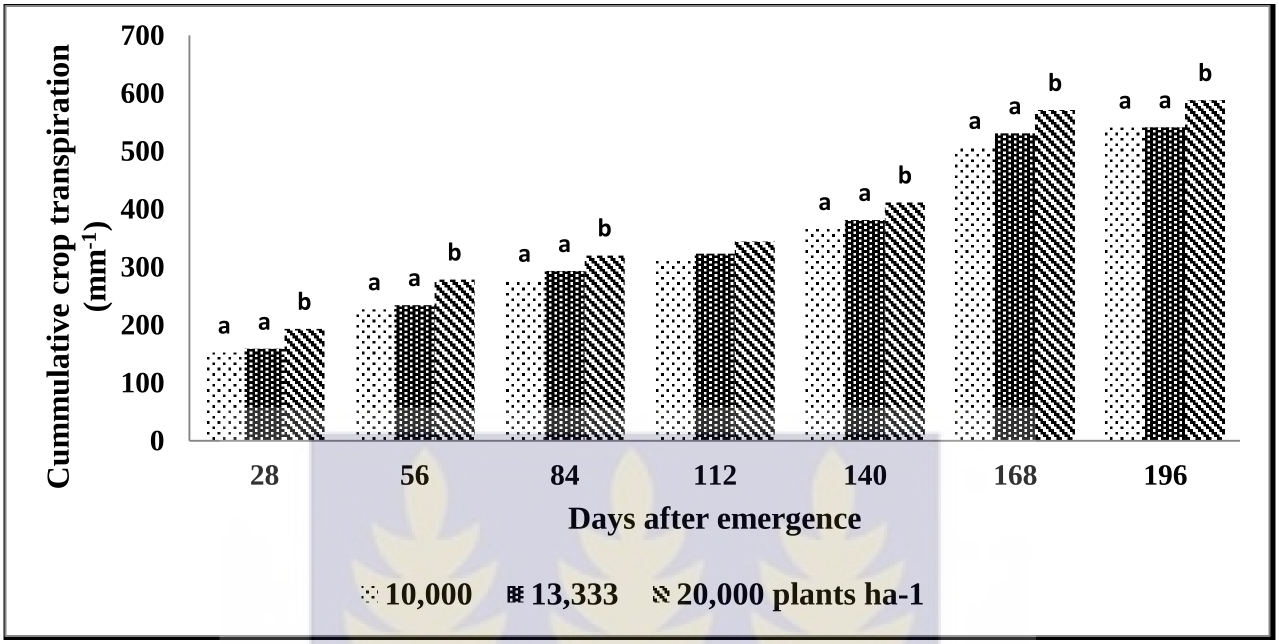


Figure 4.7.1A. Crop transpiration of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

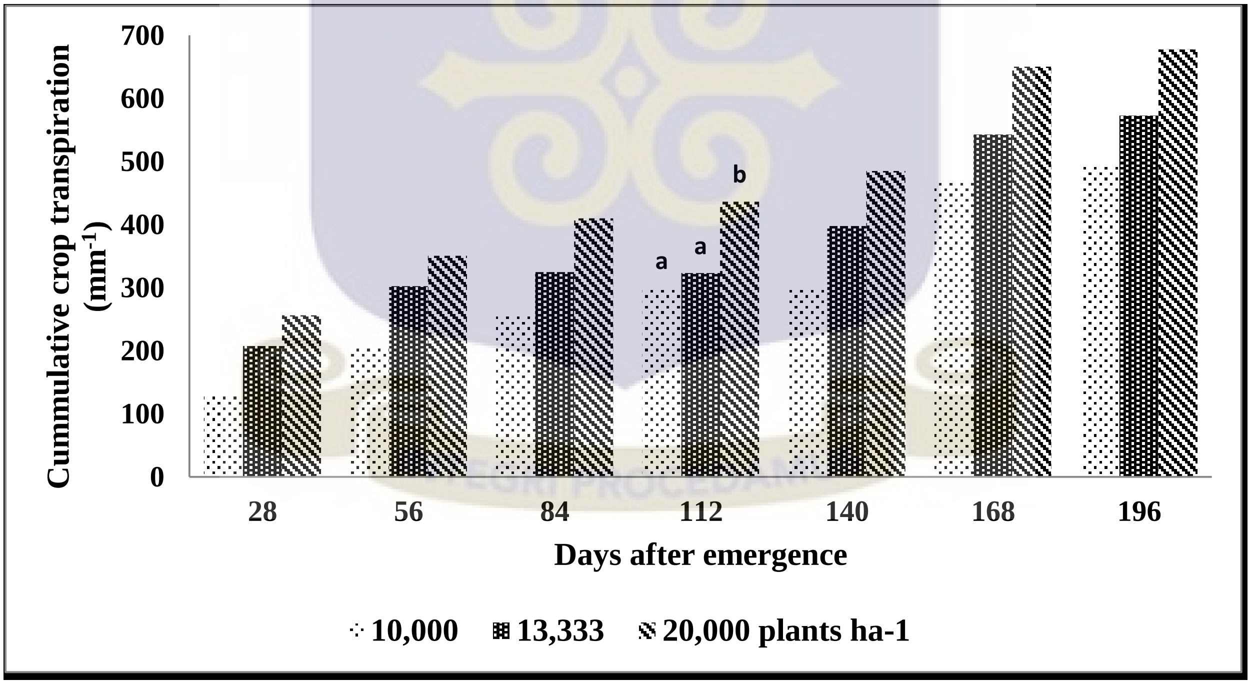


Figure 4.7.1B. Crop transpiration of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.7.2 Soil evaporation

4.7.2.1 Soil Evaporation (E_s) for Bankye Hemaa

Soil evaporation (Es) under Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$, was 194.2 mm on 28 DAE, 246.9 mm on 56 DAE, 250.1 mm on 84 DAE, 250.8 mm on 112 DAE, 251.5 mm on 140 DAE, 252.4 mm on 168 DAE and 253.2 mm on 196 DAE (Figure 4.7.2A).

Also for Bankye Hemaa, grown at 13, 333 plants ha $^{-1}$, Es was 166.4 mm on 28 DAE, 214.3 mm on 56 DAE, 219.6 mm on 84 DAE, 220.2 mm on 112 DAE, 221.3 mm on 140 DAE, 222.2 mm on 168 DAE and 222.5 mm on 196 DAE (Figure 4.7.2A).

Furthermore, Es for Bankye Hemaa, grown at 20,000 plants ha $^{-1}$,was 163.9 mm on 28 DAE, 216.6 mm on 56 DAE, 218.8 mm on 84 DAE, 219.8 mm on 112 DAE, 219.8 mm on 140 DAE, 220.6 mm on 168 DAE and 220.7 mm on 196 DAE (Figure 4.7.2A).

Significant differences ($P < 0.05$) were observed on 28 DAE, 56 DAE, 84 DAE, 112 DAE, 140 DAE, 168 DAE and 196 DAE in Es for the different plant densities (Figure 4.7.2A).

4.7.2.2 Soil Evaporation (E_s) for Capevars Bankye

Soil evaporation (Es) under Capevars Bankye, grown at 10, 000 plants ha $^{-1}$, was 262.1 mm on 28 DAE, 310.7 mm on 56 DAE, 315.1 mm on 84 DAE, 315.7 mm on 112 DAE, 316.1 mm on 140 DAE, 318.7 mm on 168 DAE and 319.1 mm^{-1} on 196 DAE (Figure 4.7.2B).

Also for Capevars Bankye grown at 13,333 plants ha $^{-1}$, Es was 175.8 mm on 28 DAE, 210.5 mm on 56 DAE, 214.1 mm^{-1} on 84 DAE, 214.6 mm on 112 DAE, 215.5 mm on 140 DAE, 217.4 mm on 168 DAE and 218.1 mm^{-1} on 196 DAE (Figure 4.7.2B).

Furthermore, Es for Capevars Bankye, grown at 20,000 plants ha $^{-1}$, was 104.9 mm^{-1} on 28 DAE, 145.0 mm on 56 DAE, 145.7 mm on 84 DAE, 146.0 mm on 112 DAE, 147.3 mm on 140 DAE, 149.4 mm on 168 DAE and 149.7 mm on 196 DAE (Figure 4.7.2B).

Significant difference ($P < 0.05$) was observed on 28 DAE in Es for the different plant densities (Figure 4.7.2B).

Though, Es values for Capevars Bankye, for the different plant densities were not statistically different the highest seasonal soil evaporation (Es) value of 319.1 mm occurred under 10,000 plants ha $^{-1}$ on 196 DAE respectively (Figure 4.7.2B). Furthermore, the interactive effect of plant densities and cassava varieties on Es was not significantly different ($P > 0.05$) (Figure 4.7.2B).

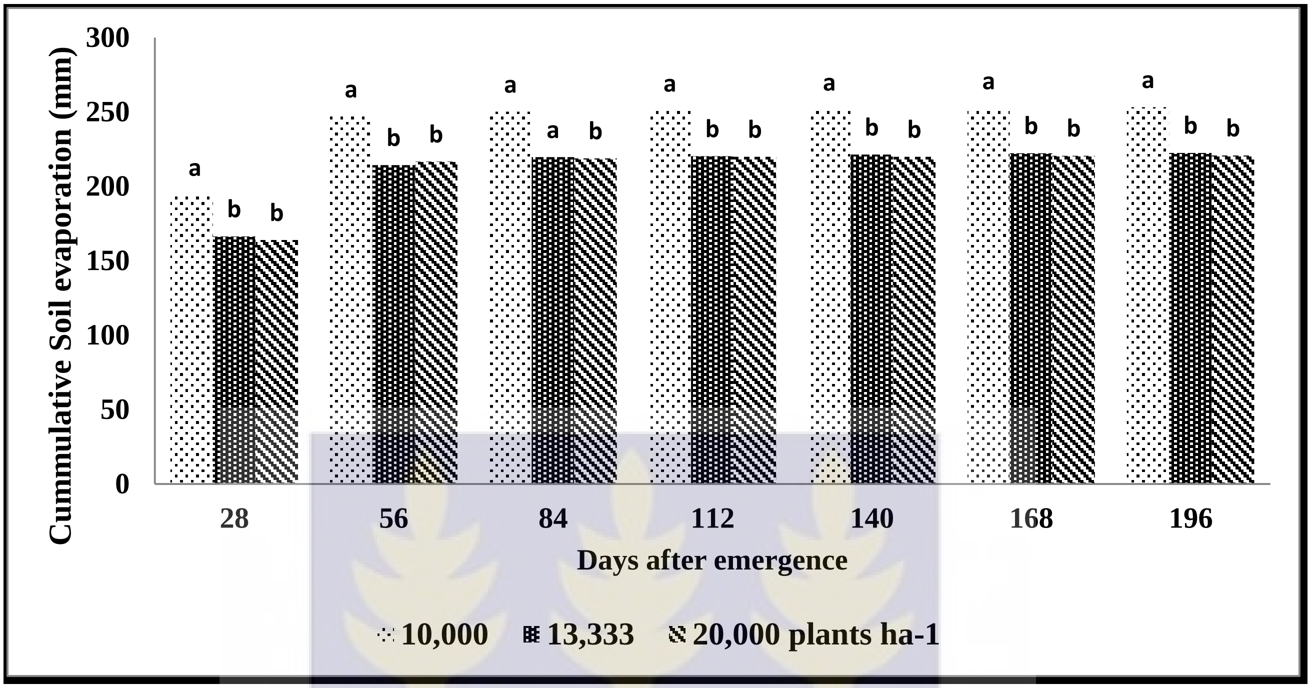


Figure 4.7.2A. Soil evaporation of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

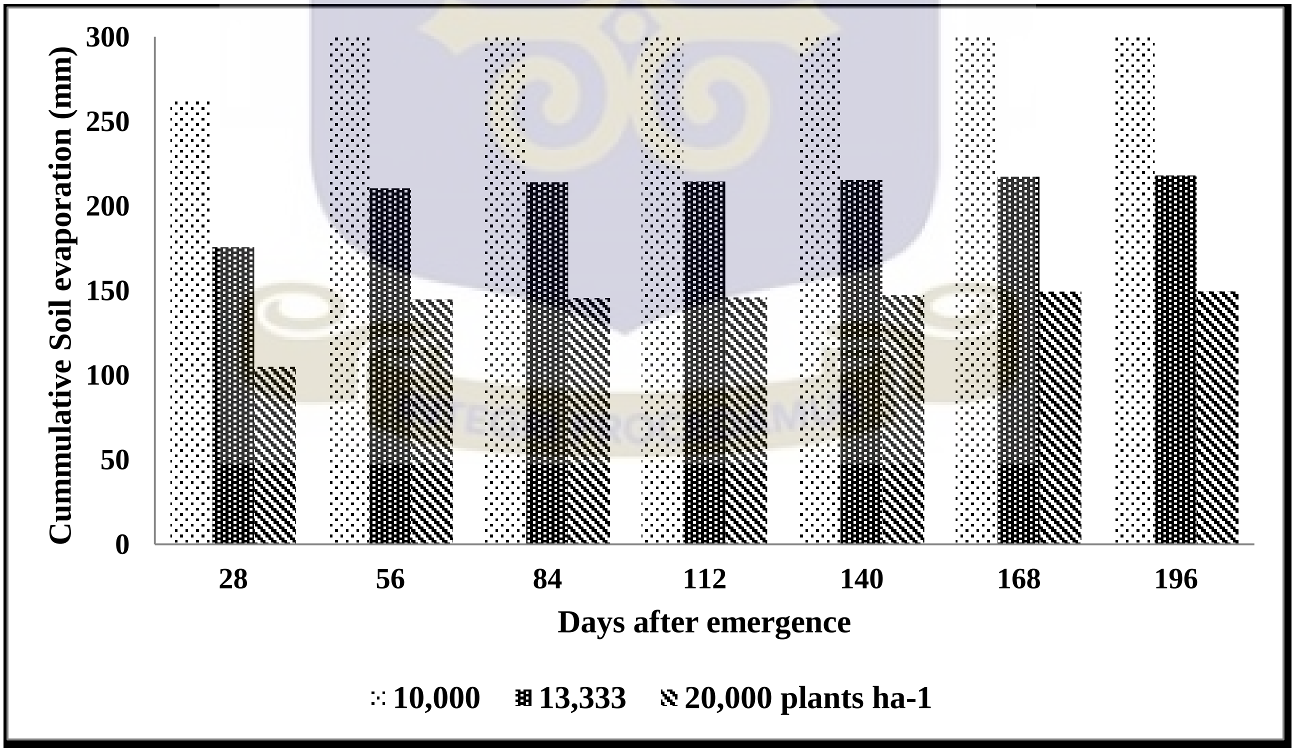


Figure 4.7.2B. Soil evaporation of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.8 Water use efficiency

4.8.1 Water use efficiency based on dry matter (WUE_{TDM}) for Bankye Hemaa

The water use efficiency of Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$ was 1.7 kg ha-^{1} mm^{-1} on 28 DAE, 2.5 kg ha^{-1} mm^{-1} on 56 DAE, 5.3 kg ha^{-1}mm^{-1} on 84 DAE, 7.3 kg ha^{-1} mm^{-1} on 112 DAE, 8.2 kg ha^{-1} mm^{-1} on 140 DAE, 9.6 kg ha^{-1} mm^{-1} on 168 DAE and 11.6 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.8.1A).

Also, WUE_{TDM} of Bankye Hemaa, grown at 13,333 plants ha $^{-1}$,was 2.3 kg ha-^{1} mm^{-1} on 28 DAE, 3.7 kg ha^{-1} mm^{-1} on 56 DAE, 6.0 kg ha^{-1}mm^{-1} on 84 DAE, 8.8 kg ha^{-1} mm^{-1} on 112 DAE, 9.8 kg ha^{-1} mm^{-1} on 140 DAE , 10.0 kg ha^{-1} mm^{-1} on 168 DAE and 12.0 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.8.1A).

Furthermore, WUE_{TDM} of Bankye Hemaa, grown at 20,000 plants ha $^{-1}$ was 3.7 kg ha-^{1} mm^{-1} on 28 DAE, 3.6 kg ha^{-1} mm^{-1} on 56 DAE, 6.7 kg ha^{-1}mm^{-1} on 84 DAE, 9.7 kg ha^{-1} mm^{-1} on 112 DAE, 10.1 kg ha^{-1} mm^{-1} on 140 DAE , 9.9 kg ha^{-1} mm^{-1} on 168 DAE and 12.4 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.8.1A).

On the other hand, significant differences in WUE_{TDM} were observed among the plant densities on 28 DAE, 56 DAE and 84 DAE for Bankye Hemaa (Figure 4.8.1A), with extremely significant (P=0.0039) interactive effects of cassava variety and the plant densities occurring on 84 DAE.

4.8.2 Water use efficiency based on dry matter (WUE_{TDM}) for Capevars Bankye

The water use efficiency of Capevars Bankye, grown at 10, 000 plants ha $^{-1}$, was 2.0 kg ha-^{1} mm^{-1} on 28 DAE, 1.7 kg ha^{-1} mm^{-1} on 56 DAE ,6.7 kg ha^{-1}mm^{-1} on 84 DAE, 5.9 kg ha^{-1} mm^{-1} on 112 DAE, 6.5 kg ha^{-1} mm^{-1} on 140 DAE, 6.3 kg ha^{-1} mm^{-1} on 168 DAE and 7.2 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.8.2B).

Also, WUE_{TDM} of Capevars Bankye, grown at 13,333 plants ha $^{-1}$ was 3.2 kg ha-^{1} mm^{-1} on 28 DAE, 3.4 kg ha^{-1} mm^{-1} on 56 DAE, 7.8 kg ha^{-1}mm^{-1} on 84 DAE, 8.3 kg ha^{-1} mm^{-1} on 112 DAE, 8.5 kg ha^{-1} mm^{-1} on 140 DAE, 8.2 kg ha^{-1} mm^{-1} on 168 DAE and 9.1 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.8.1A).

Furthermore, WUE_{TDM} of Capevars Bankye, grown at 20,000 plants ha $^{-1}$ was 3.7 kg ha-^{1} mm^{-1} on 28 DAE, 3.8 kg ha^{-1} mm^{-1} on 56 DAE, 9.1 kg ha^{-1}mm^{-1} on 84 DAE, 10.1 kg ha^{-1} mm^{-1} on 112 DAE, 8.6 kg ha^{-1} mm^{-1} on 140 DAE, 9.2 kg ha^{-1} mm^{-1} on 168 DAE and 9.9 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.8.2B). Significant differences ($P < 0.05$) were observed in WUE_{TDM} among the planting densities for Capevars Bankye on 28 DAE and 56 DAE (Figure 4.8.2B).

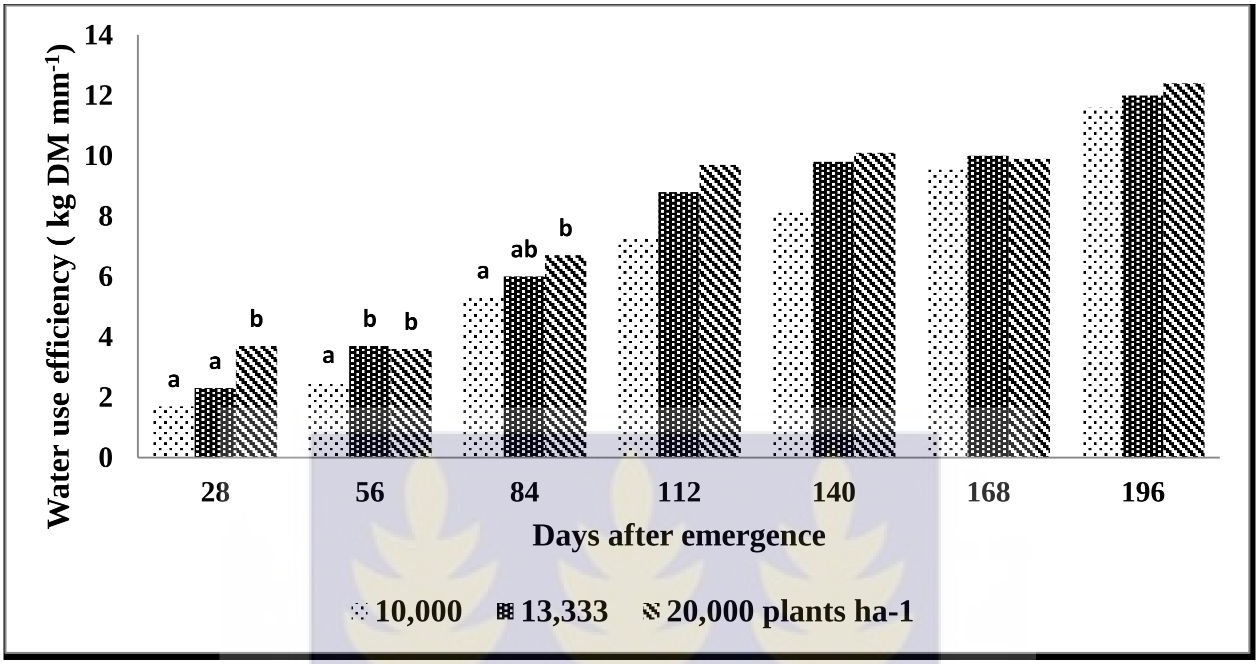


Figure 4.8.1 A. Water use efficiency based on total dry matter yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

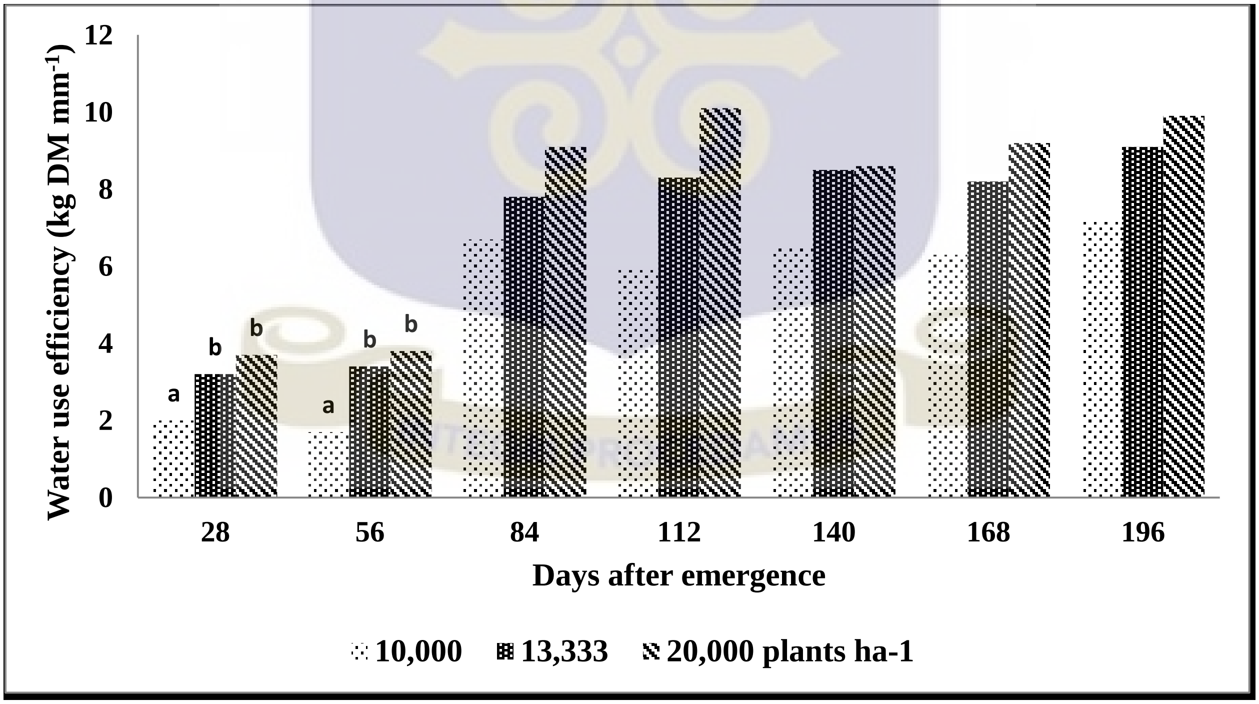


Figure 4.8.2B. Water use efficiency based on total dry matter yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters or without letters are not significantly different.

4.9 Transpiration use efficiency (TUE)

4.9.1 Transpiration use efficiency based on dry matter (TUE_{TDM}) for Bankye Hemaa

The transpiration use efficiency of Bankye Hemaa, grown at 10, 000 plants ha $^{-1}$ was 3.9 kg ha-^{1} mm^{-1} on 28 DAE, 5.2 kg ha^{-1} mm^{-1} on 56 DAE, 12.0 kg ha^{-1}mm^{-1} on 84 DAE, 13.2 kg ha^{-1} mm^{-1} on 112 DAE, 13.9 kg ha^{-1} mm^{-1} on 140 DAE, 14.7 kg ha^{-1} mm^{-1} on 168 DAE and 17.0 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.9.1A).

Also, TUE_{TDM} of Bankye Hemaa, grown at 13,333 plants ha $^{-1}$, was 4.7 kg ha-^{1} mm^{-1} on 28 DAE, 7.1 kg ha^{-1} mm^{-1} on 56 DAE, 10.5 kg ha^{-1}mm^{-1} on 84 DAE, 14.7 kg ha^{-1} mm^{-1} on 112 DAE, 14.9 kg ha^{-1} mm^{-1} on 140 DAE, 13.9 kg ha^{-1} mm^{-1} on 168 DAE and 18.0 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.9.1A).

Furthermore, TUE_{TDM} of Bankye Hemaa, grown at 20,000 plants ha $^{-1}$, was 6.8 kg ha-^{1} mm^{-1} on 28 DAE, 6.4 kg ha^{-1} mm^{-1} on 56 DAE, 13.0 kg ha^{-1}mm^{-1} on 84 DAE, 15.8 kg ha^{-1} mm^{-1} on 112 DAE, 15.4 kg ha^{-1} mm^{-1} on 140 DAE, 13.7 kg ha^{-1} mm^{-1} on 168 DAE and 17.0 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.9.1A).Additionally, significant differences ($P< 0.05$) were observed in TUE_{TDM} for Bankye Hemaa among the plant densities on 28 DAE and 112 DAE (Figure 4.9.1A).

4.9.2 Transpiration use efficiency based on dry matter (TUE_{TDM}) for Capevars Bankye

For Capevars Bankye grown at 10, 000 plants ha $^{-1}$, TUE_{TDM} was 6.1 kg ha-^{1} mm^{-1} on 28 DAE, 4.2 kg ha^{-1} mm^{-1} on 56 DAE, 14.9 kg ha^{-1}mm^{-1} on 84 DAE, 12.7 kg ha^{-1} mm^{-1} on 112 DAE, 13.3 kg ha^{-1} mm^{-1} on 140 DAE, 10.7 kg ha^{-1} mm^{-1} on 168 DAE, and 11.9 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.9.2B).

Also TUE_{TDM} for Capevars Bankye, grown at 13,333 plants ha $^{-1}$, was 6.0 kg ha-^{1} mm^{-1} on 28 DAE, 5.5 kg ha^{-1} mm^{-1} on 56 DAE, 12.8 kg ha^{-1}mm^{-1} on 84 DAE, 13.3 kg ha^{-1} mm^{-1} on 112 DAE, 14.1 kg ha^{-1} mm^{-1} on 140 DAE, 11.5 kg ha^{-1} mm^{-1} on 168 DAE and 12.6 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.9.2B).

Furthermore, TUE_{TDM} for Capevars Bankye, grown at 20,000 plants ha $^{-1}$, was 5.2 kg ha-^{1} mm^{-1} on 28 DAE, 5.4 kg ha^{-1} mm^{-1} on 56 DAE, 12.3 kg ha^{-1}mm^{-1} on 84 DAE, 13.4 kg ha^{-1} mm^{-1} on 112 DAE, 11.3 kg ha^{-1} mm^{-1} on 140 DAE, 12.8 kg ha^{-1} mm^{-1} on 168 DAE and 12.1 kg ha^{-1} mm^{-1} on 196 DAE (Figure 4.9.2B).

Additionally, significant differences ($P < 0.05$) in TUE_{TDM} were observed for Capevars Bankye among the planting densities on 28 DAE, 84 DAE, 140 DAE and 196 DAE (Figure 4.9.2B), with extremely significant ($P < 0.001$) interactive effects between cassava variety and plant densities on 196 DAE on TUE_{TDM} (Figure 4.9.2B).

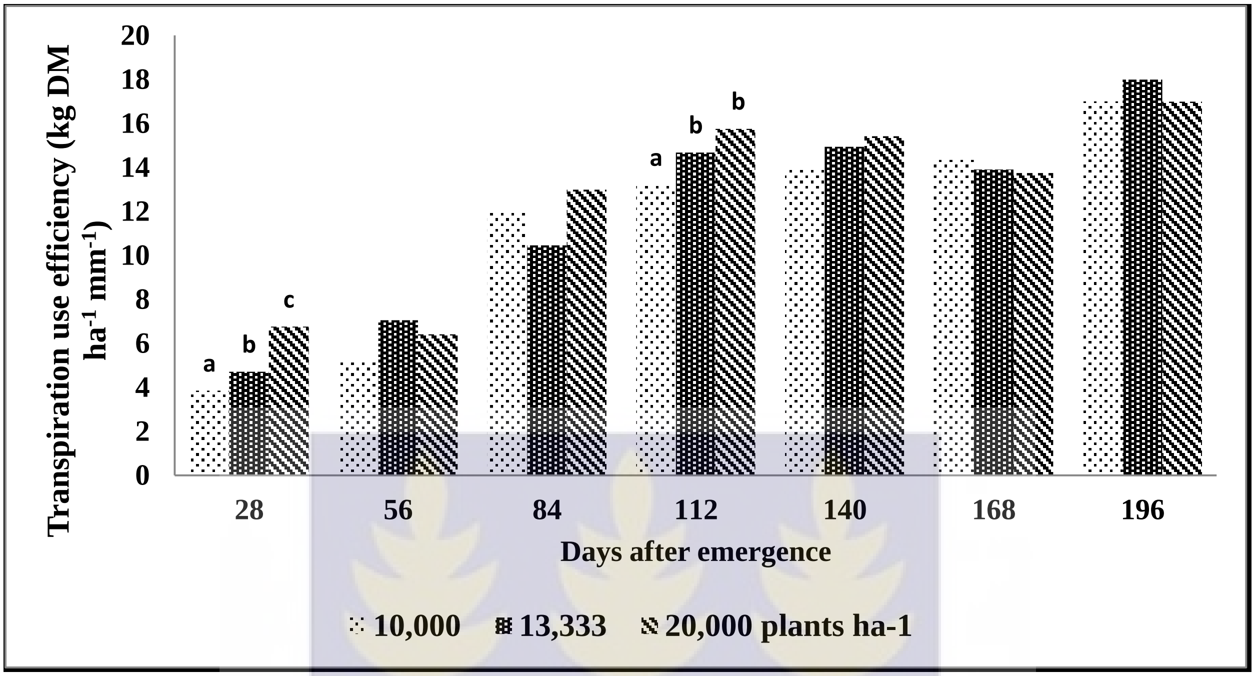


Figure 4.9.1A. Transpiration use efficiency based on total dry matter yield of Bankye Hemaa at different growth stages for different plant densities. Bars with the same letters and without letters are not significantly different.

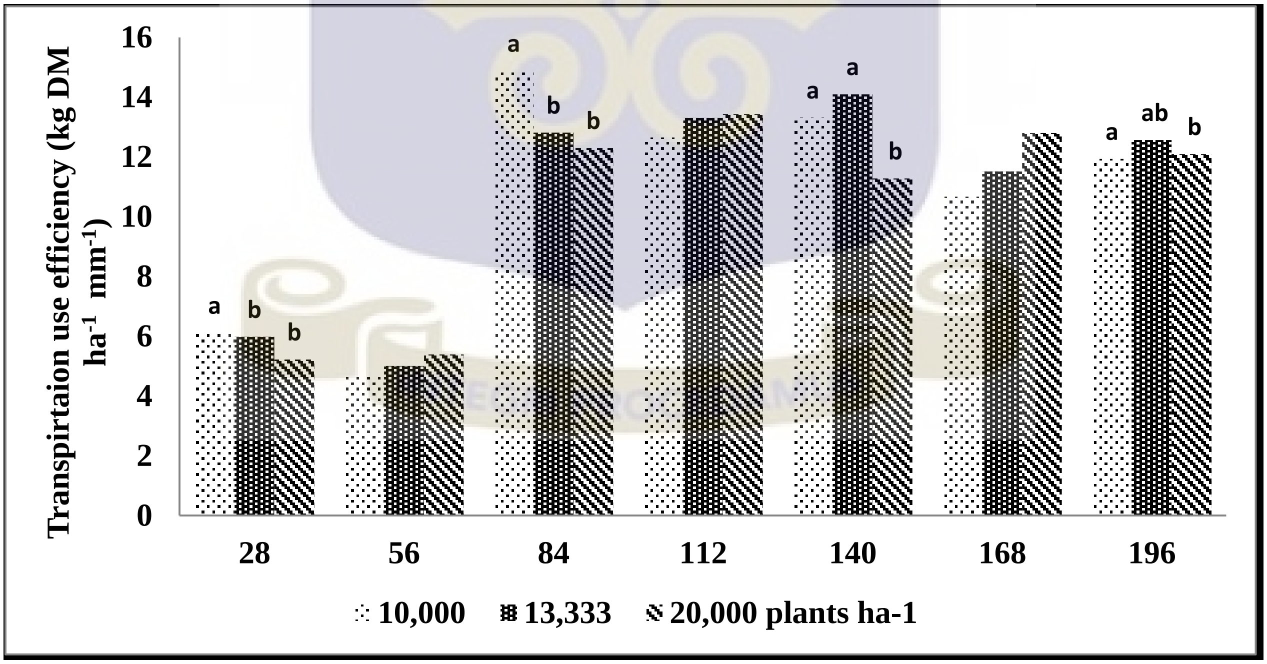


Figure 4.9.1B. Transpiration use efficiency in terms of total dry matter yield of Capevars Bankye at different growth stages for different plant densities. Bars with the same letters and without letters or not significantly different.

CHAPTER FIVE

5.0 Discussion

5.1 Leaf area index (LAI)

High yielding cassava varieties have high leaf area index (Adejinj *et al.*, 2011; Lahai *et al.*, 1999). Leaf area index (LAI) is an important factor which determines the photosynthetic capacity of cassava plant. It is affected by climatic factors, soil fertility levels, and cultural practices. Initial LAI of cassava development is slow and increases between 4 and 6 months after planting, reaches a maximum value, then declines during the latter part of the growing season due to leaf abscission (CIAT, 1979).

The leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye, took between 60 and 80 DAE to attain an LAI of 1.0 and between 120 and 150 DAE to attain 3.0, a trend which agrees to that reported by Veltkamp (1985a). The highest LAI values attained by Bankye Hemaa and Capevars Bankye were 6.88 and 6.00, respectively, which are normally in the range of 6.0 – 8.0 as reported by Irikura *et al.*, 1979. Both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1} produced high yields and harvest index (HI) which explained their higher LAI values, indicating higher photosynthetic capacity and efficiency reported by (Adejinj *et al.*, 2011; Lahai *et al.*, 1999).

Consequently, a high positive correlation existed between LAI and harvest index (HI) stressing the importance of LAI in yield determination, a similar trend reported by Lahai *et al.*, 1999 and Lebot (2009).

5.2 Total dry biomass matter

Total dry matter production is a good estimator of the degree of adaptation of a crop variety in an environment (Kamara *et al.*, 2003). The total dry matter (TDM) accumulated by Bankye Hemaa and Capevars Bankye was slow during the first two months after emergence and increased rapidly during the subsequent months, peaking at 10,002.0 kg ha^{-1} for Bankye Hemaa and 8,200 kg ha^{-1} for Capevars Bankye grown at 20,000 plants ha^{-1} on 196 DAE.

Generally, both cassava varieties, Bankye Hemaa and Capevars Bankye for all plant densities allocated a high proportion of total biomass accumulated between 60-65% to the storage roots then the stems and leaves gives a higher yield, which agrees with results by Osiru and Hahn (1998). Cassava variety Bankye Hemaa grown at 20,000 plant ha^{-1} produced the highest seasonal TDM of 10,002.0 kg ha^{-1}, highest LAI value 6.88 and root yield of 21.30 t/ha^{-1}. These results agree with reports by Akparobi *et al.*, (1998) and Lebot (2009) that cassava varieties which produce high LAI values also produces high root yield and TDM. Also, Lahai *et al.* (1999) and Adejinj *et al.* (2011) reported that high yielding crop varieties have high LAI and therefore cassava varieties with high LAI produces high root yield, indicating a high photosynthetic capacity of these crop varieties and a positive correlation between LAI and root yield. However maximum dry matter values of 10,002.0 kg ha^{-1} for Bankye Hemaa and 8,200 kg ha^{-1} for Capevars Bankye and its biomass partitioning was reached with higher planting densities, indicating a linear relationship between TDM and planting densities.

Partitioning of dry matter (DM) is particularly important in cassava because the crop simultaneously develop leaves, stem and storage roots and supply of assimilates is partitioned between these parts (Ekanayake *et al.*, 1998; Cock, 1984). This results in a delicate balance between shoot and storage root growth for maximum yield (Ramanujam, 1985). Cassava varieties Bankye Hemaa and Capevars Bankye, grown under different plant densities accumulated more dry matter (DM) in the leaves than in stem and storage roots up to 84 DAE after which the storage root increased rapidly, reaching about 50-60% of the TDM at about 112 DAE. These findings agree with reports by Osiru and Halm (1998) and Tăvora *et al.* (1995).

5.3 Yield and Harvest index (HI)

Root yield (t ha^{-1}) of both cassava varieties, peaked at 21.3 t ha^{-1} and 18.1 t ha^{-1} for Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1}. In general root yield (t ha^{-1}) increased with planting density, a trend which agrees with results reported by Nweke *et al.* (1994) and Rojas *et al.* (2007). Also, root yield of Bankye Hemaa and Capevars Bankye increased with Harvest index (HI) which is in agreement with the research findings by Cock *et al.* (1979).

5.4 Actual evapotranspiration

The seasonal actual evapotranspiration (AET) of rain-fed Bankye Hemaa and Capevars Bankye grown at 10,000, 13,333 and 20,000 plants ha^{-1} planting densities ranged between 325.3 mm and 827.6 mm for a seasonal rainfall of 861.1 mm, showing that the seasonal AET was fairly the same for both cassava varieties and planting densities. This suggests that the seasonal rainfall was adequate and therefore distribution did not significantly affect AET of the cassava varieties grown in the different planting densities. Thus, there were no marked differences in AET for the different planting distances. Comparatively, highest evapotranspiration (AET) values occurred in

20,000 followed by 13,333 and 10,000 plants ha^{-1} respectively for both Bankye Hemaa and Capevars Bankye. The differences in AET among planting distances are accounted for as a result of differences in leaf area index (LAI). Higher planting distance accounts for larger LAI, which in turn increased canopy interception of radiation energy, leading to increased AET. Linearity of the yield versus evapotranspiration relation denotes that water use efficiency would increase with increase in evapotranspiration as a consequence of increased transpiration/evapotranspiration ratio because the intercept has a constant value. For this reason, water use efficiency also increases with increase in crop water supply up to a certain point (Gajri *et al.*, 1993).

5.5 Water use efficiency (WUE)

Water use efficiency (WUE) is an important crop index which can be used to assess how soil water has been used efficiently for total biomass production and economic yield production (Hunsaker *et al.*, 1996). Water use efficiency (WUE) has also been used to evaluate drought tolerance in cassava (Okogbenin *et al.*, 2013). Both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 10,000, 13,333 and 20,000 plants ha^{-1} planting distances were similarly efficient in the use of soil water for TDM production during the growing period as they used similar amount of soil water to produce similar levels of TDM.

Comparatively, highest $\mathrm{WUE}_{\mathrm{TDM}}$ values were observed for 20,000 plants ha^{-1} planting density for Bankye Hemaa and Capevars Bankye was due to higher TDM.

5.6 Relationship between total dry matter (TDM) and actual Evapotranspiration (AET)

Regression analysis showed a strong linear relationship between TDM and AET for Bankye Hemaa and Capevars Bankye. The coefficient of determination, R^2, for the linear regression models was 0.95, 0.93 and 0.93 for Bankye Hemaa grown under 10,000, 13,333 and 20,000 plants ha^{-1} respectively (Figure 5.6). Similarly, R^2 for the linear regression models was 0.85, 0.88 and 0.88 for Capevars Bankye grown under 10,000, 13,333 and 20,000 plants ha^{-1} respectively (Figure 5.6). Thus the linear regression model captured at least 85% of data used for the model development.

Based on the linear regression models, similar regression coefficient values of WUE_{TDM} for Bankye Hemaa was 0.049 kg ha^{-1} mm^{-1}, 0.048 kg ha^{-1} mm^{-1} and 0.048 kg ha^{-1} mm^{-1} for the 10,000, 13,333 and 20,000 plants ha^{-1} planting densities respectively (figure 5.6). Similarly, the regression coefficient values of WUE_{TDM} for Capevars Bankye was 0.071 kg ha^{-1} mm^{-1}, 0.061 kg ha^{-1} mm^{-1} and 0.060 kg ha^{-1} mm^{-1} for the 10,000, 13,333 and 20,000 plants ha^{-1} planting density, respectively (Figure 5.6).

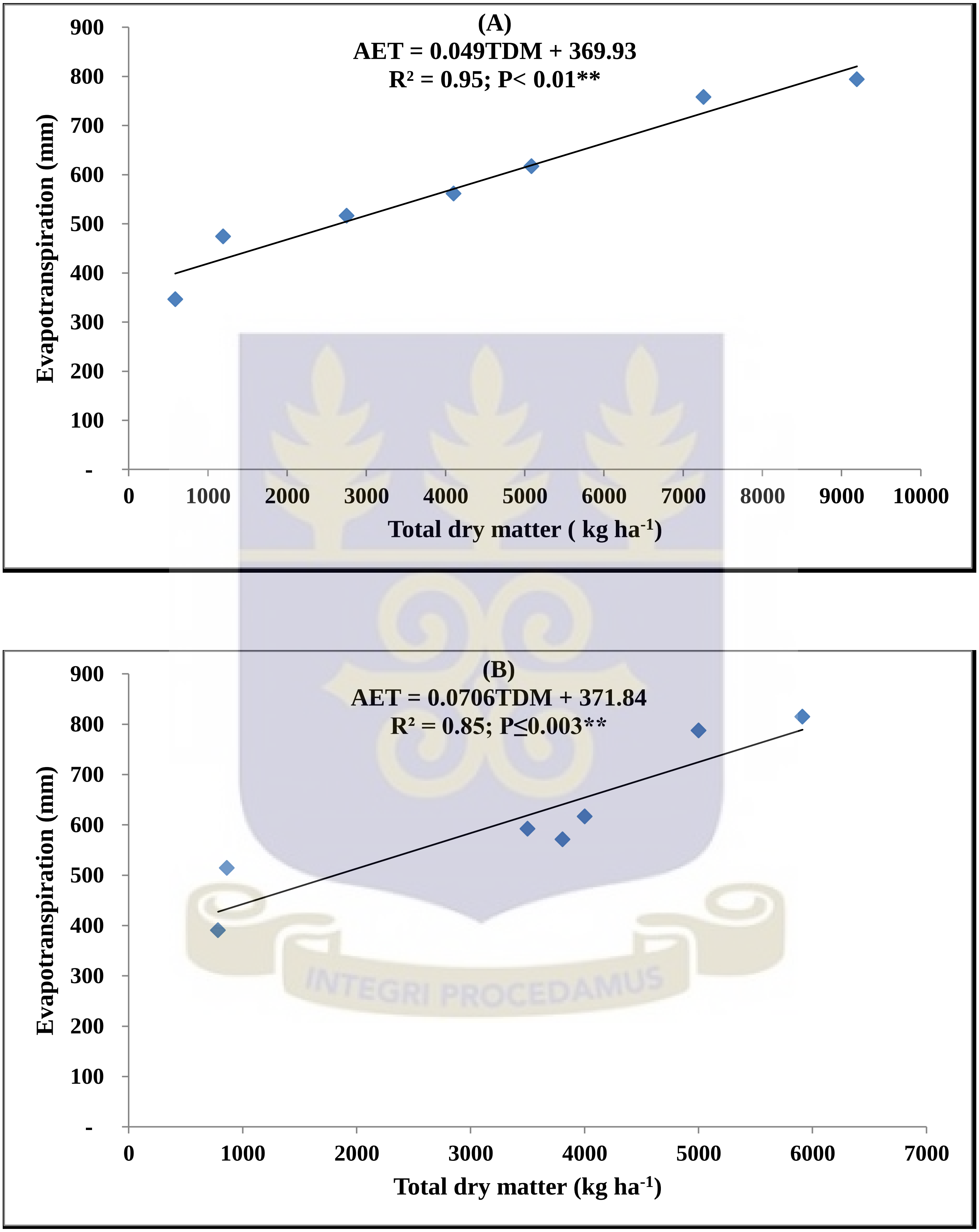
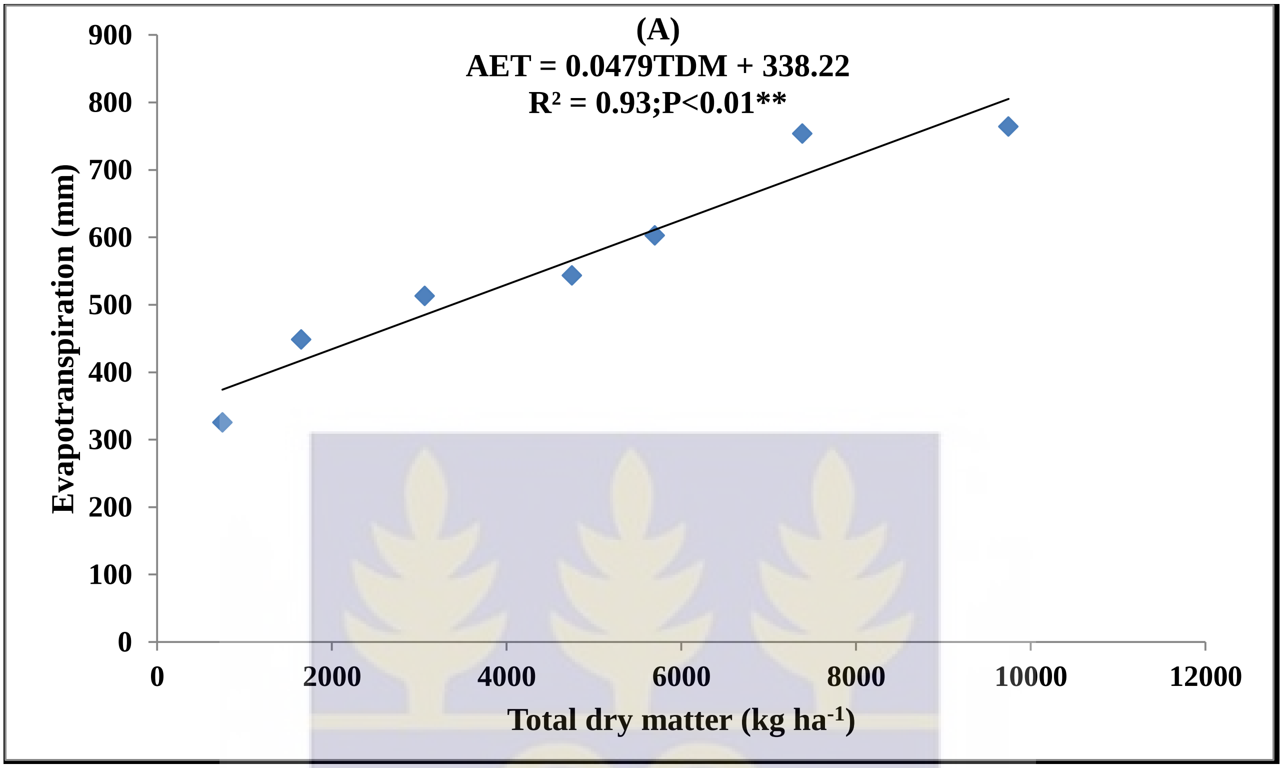


Figure 5.6A. Relationship between total dry matter and evapotranspiration of Bankye Hemaa (A) Capevars Bankye (B) for plant density 10,000 plants ha^{-1}.



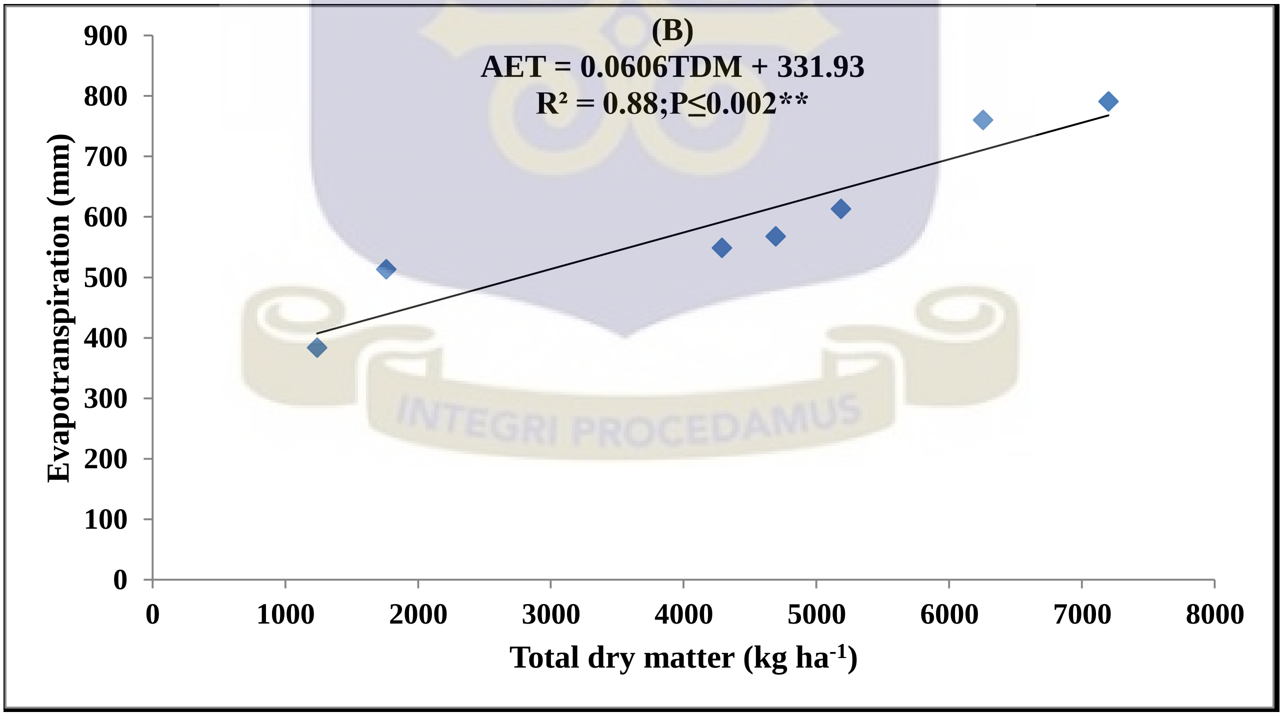
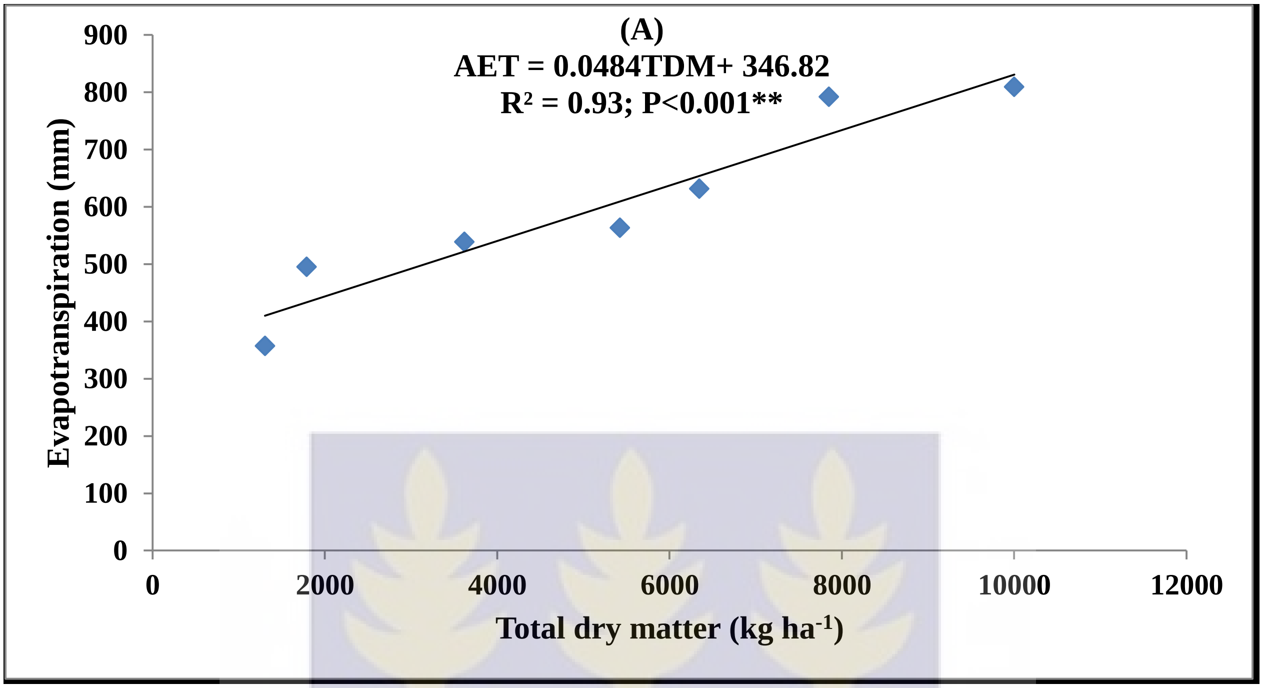


Figure 5.6B. Relationship between total dry matter and evapotranspiration of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 13,333 plants ha^{-1}.



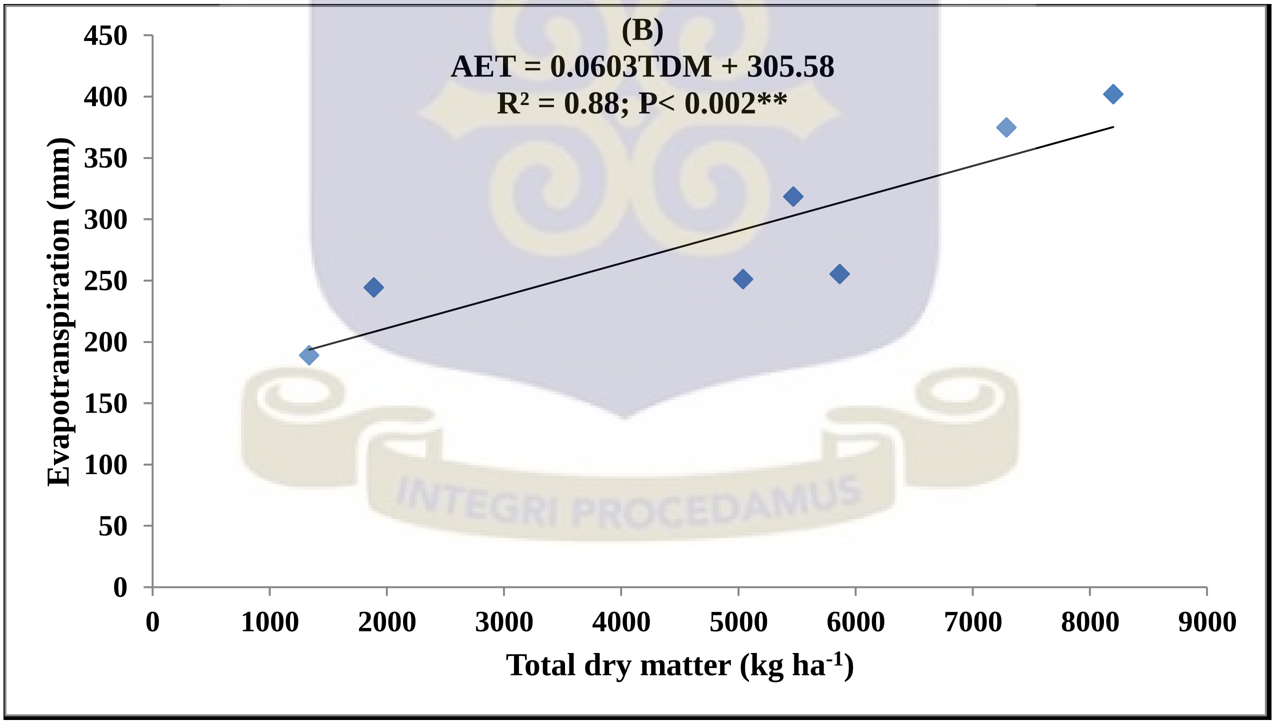


Figure 5.6C.Relationship between total dry matter and evapotranspiration of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 20,000 plants ha^{-1}.

5.7 Relationship between Water use efficiency and total biomass

The linear regression of WUE_{TDM} against TDM for planting density of 10,000 plants ha $^{-1}$ resulted in good linear regression models with r^2 value of 0.96 and 0.90 for Bankye Hemaa and Capevars Bankye, respectively. Similar regression coefficient value of 0.0011 mm^{-1} and 0.0011 mm^{-1} were obtained for Bankye Hemaa and Capevars Bankye, respectively (Figure 5.7A). Additionally, the linear regression analysis of the pooled WUE_{TDM} and TDM data for both cassava varieties resulted in a linear model WUE_{TDM} = 0.0011TDM + 1.4628 with r^2=0.90 (Figure 5.7D). This further confirms that Bankye Hemaa and Capevars Bankye grown at 10,000 plants ha^{-1} behave similarly in terms of biomass accumulation and efficiency of soil moisture utilization.

Also, Bankye Hemaa and Capevars Bankye grown at 13, 3333 plants ha^{-1} showed a good linear relationship between WUE_{TDM} and TDM, with coefficient of determination, r^2 values of 0.96 and 0.90, respectively (Figure 5.7B). Similar significant regression coefficient values of 0.0011 mm^{-1} for Bankye Hemaa and 0.0011 mm^{-1} for Capevars Bankye were obtained (Figure 5.7B). Additionally, the regression analysis of all the WUE_{TDM} and TDM data for both cassava varieties resulted in a good linear model WUE_{TDM}= 0.0011TDM + 2.18 with r^2 value of 0.90 (Figure 5.7E).

Furthermore, Bankye Hemaa and Capevars Bankye, grown at 20,000 plant ha^{-1} also showed a good linear relationship between WUE_{TDM} and TDM, with r^2 value of 0.93 for Bankye Hemaa and 0.90 for Capevars Bankye again, similar regression coefficient values of 0.001 mm^{-1} for Bankye Hemaa and 0.001 mm^{-1} for Capevars Bankye were obtained for the regression analysis (Figure 5.7C). Finally the linear regression analysis of pooled WUE_{TDM} and TDM data for both cassava varieties resulted in a good linear model $WUE_{TDM} = 0.0001TDM + 2.6754$ with r^2 value of 0.90 (Figure 5.7F).The similar regression coefficient value obtained under planting densities of 10,000 plants ha^{-1}, 13,333 plants ha^{-1} and 20,000 plants ha^{-1} for both cassava varieties, (5.7D, 5.7E and 5.7F) confirms that Bankye Hemaa and Capevars Bankye generally use similar amount of soil water for biomass production. Furthermore, the seasonal rainfall was sufficient to support similar water use efficiency (WUE) for biomass production for Bankye Hemaa and Capevars Bankye.

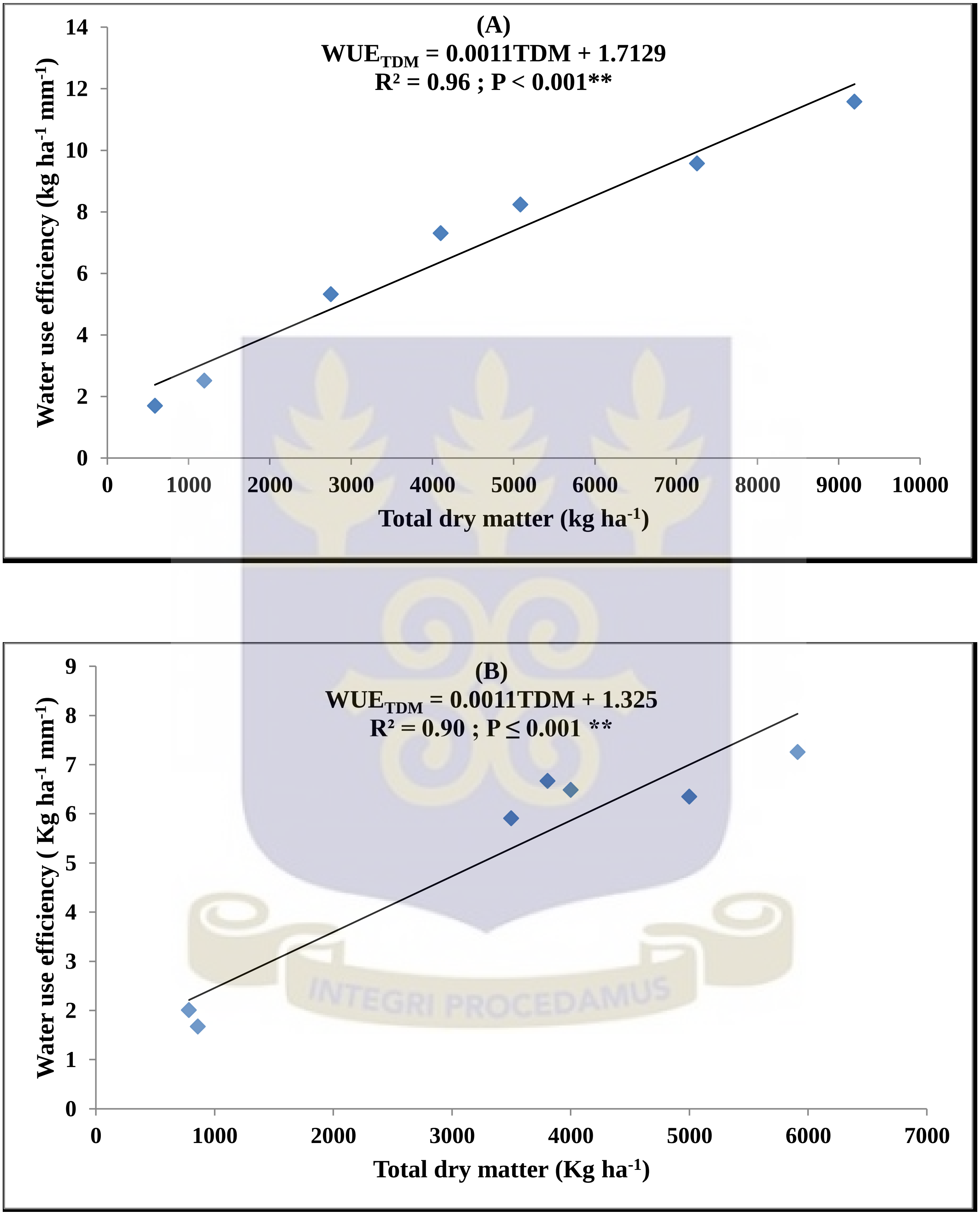


Figure 5.7A. Relationship between water use efficiency and total dry matter of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 10,000 plants ha^{-1}.

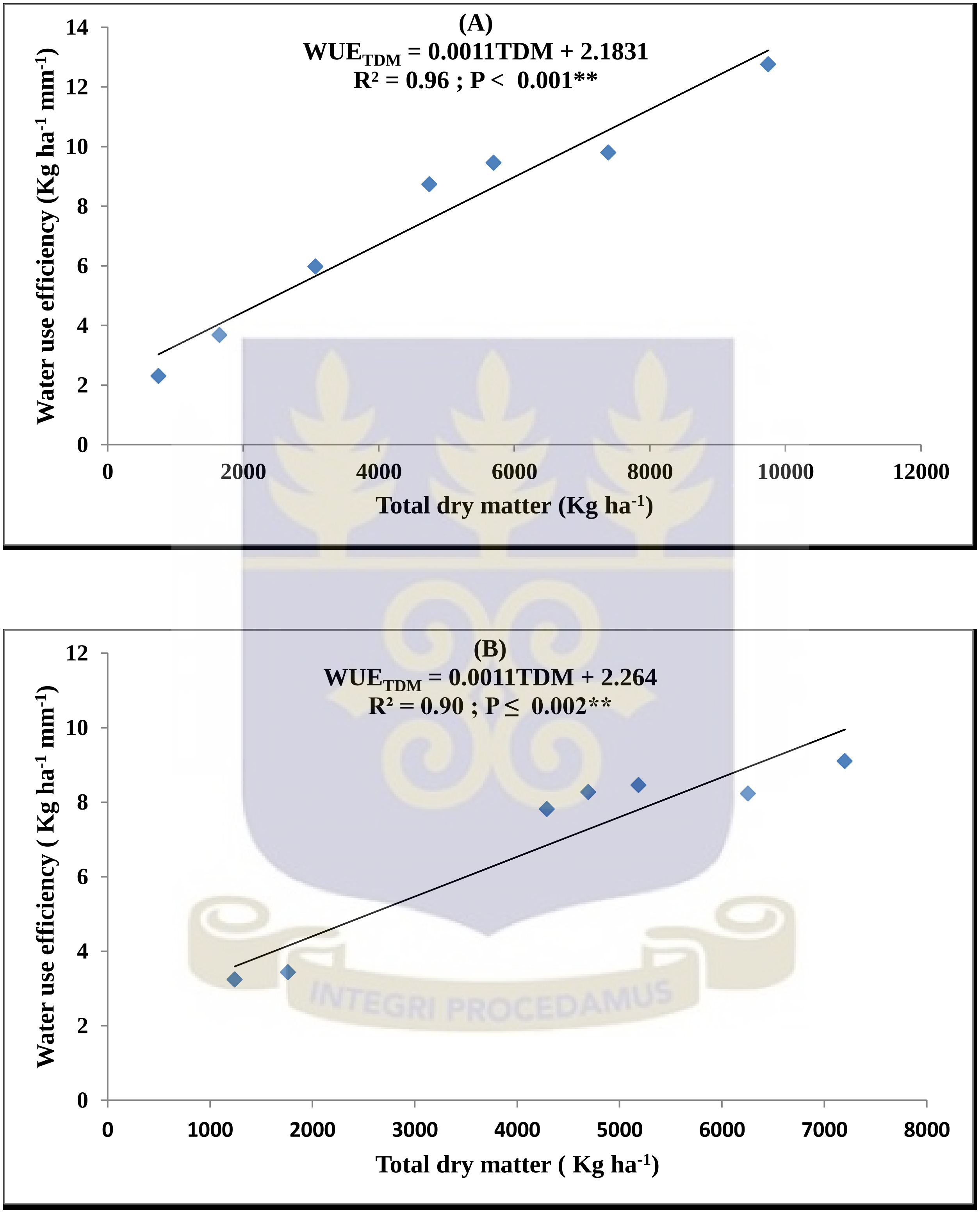
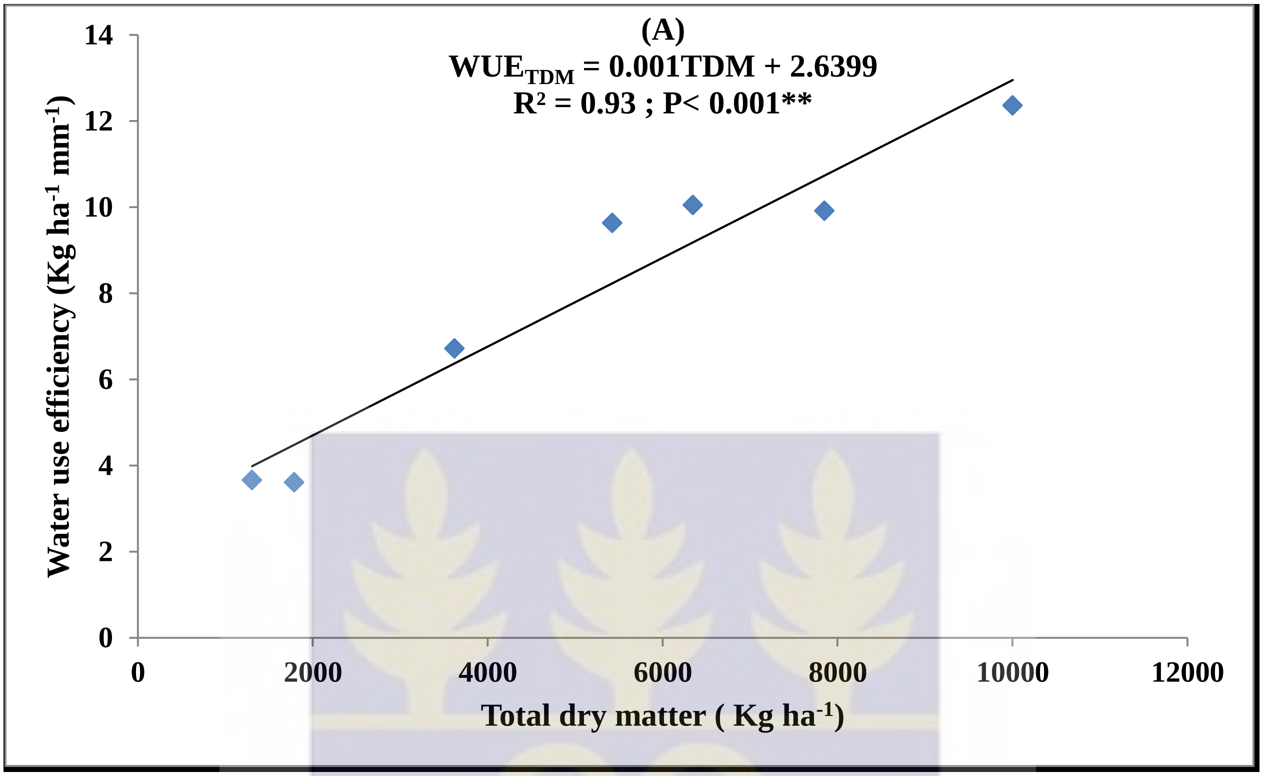


Figure 5.7B. Relationship between water use efficiency and total dry matter of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 13,333 plants ha^{-1}.



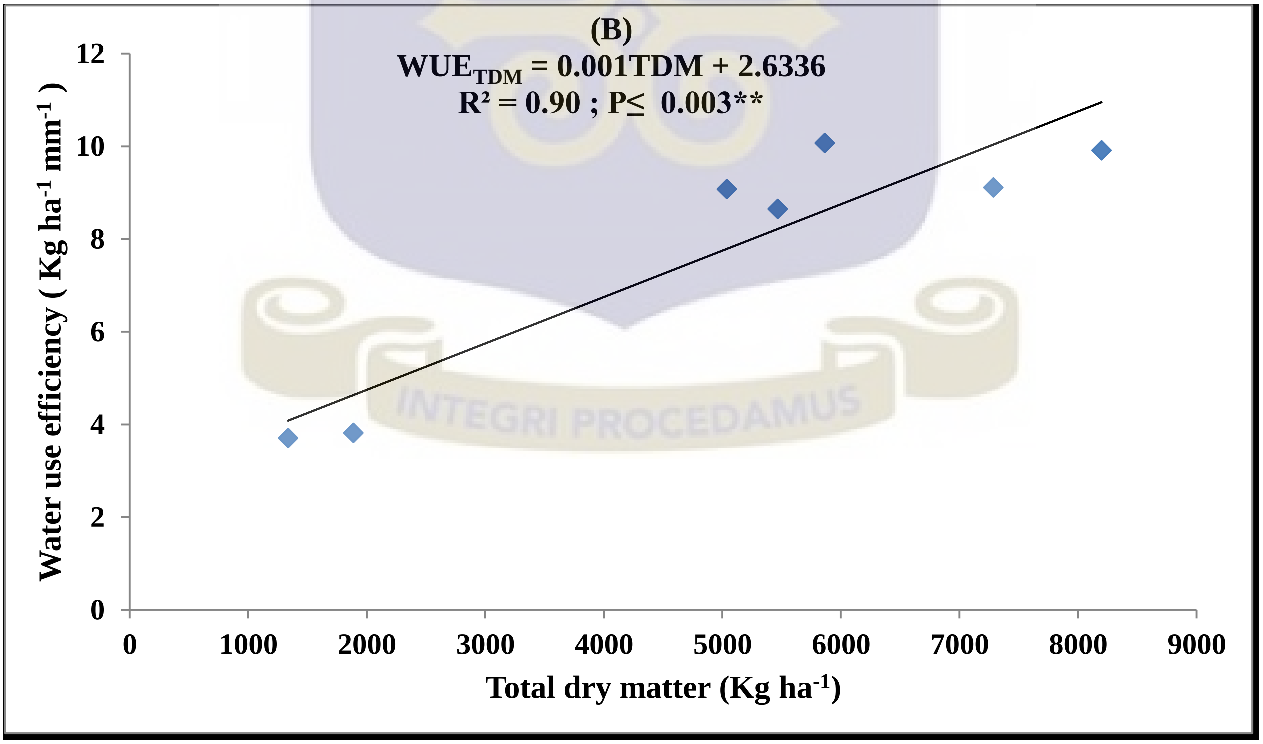


Figure 5.7C. Relationship between water use efficiency and total dry matter of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 20,000 plants ha^{-1}.

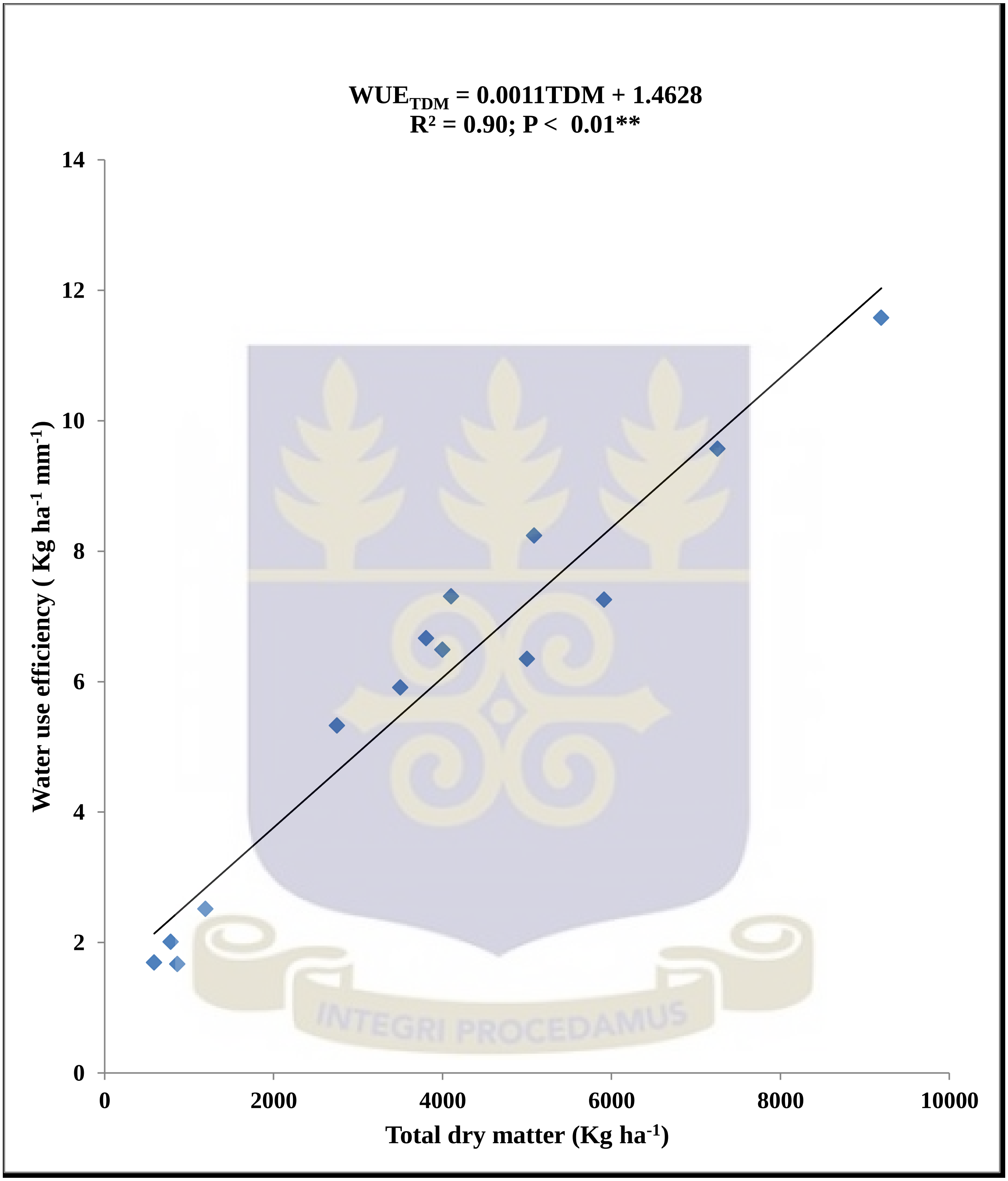


Figure 5.7D.Relationship between water use efficiency and total dry matter for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 10,000 plants ha^{-1}, pooled data for both varieties.

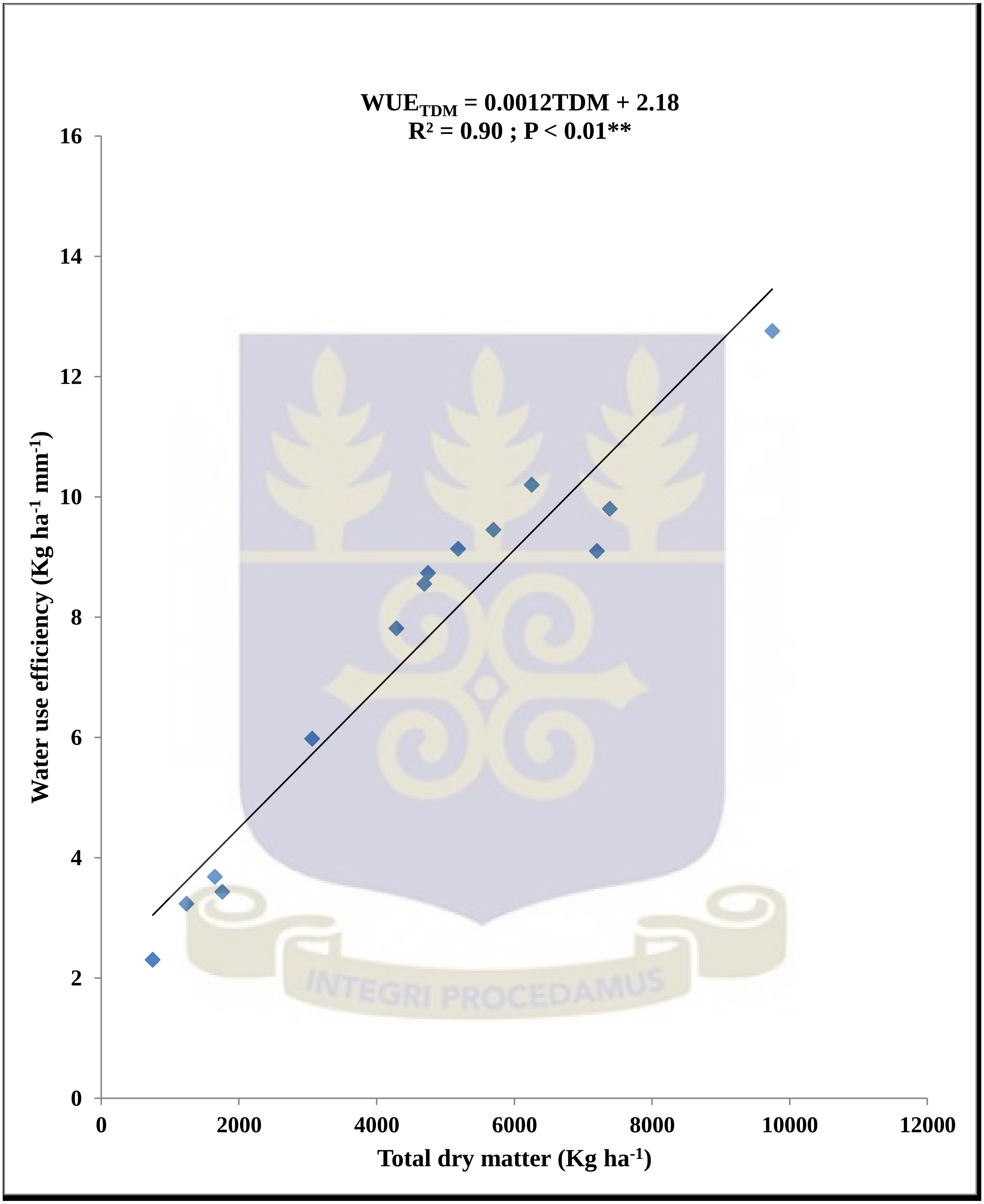


Figure 5.7E. Relationship between water use efficiency and total dry matter for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 13,333 plants ha^{-1}, pooled data for both varieties.

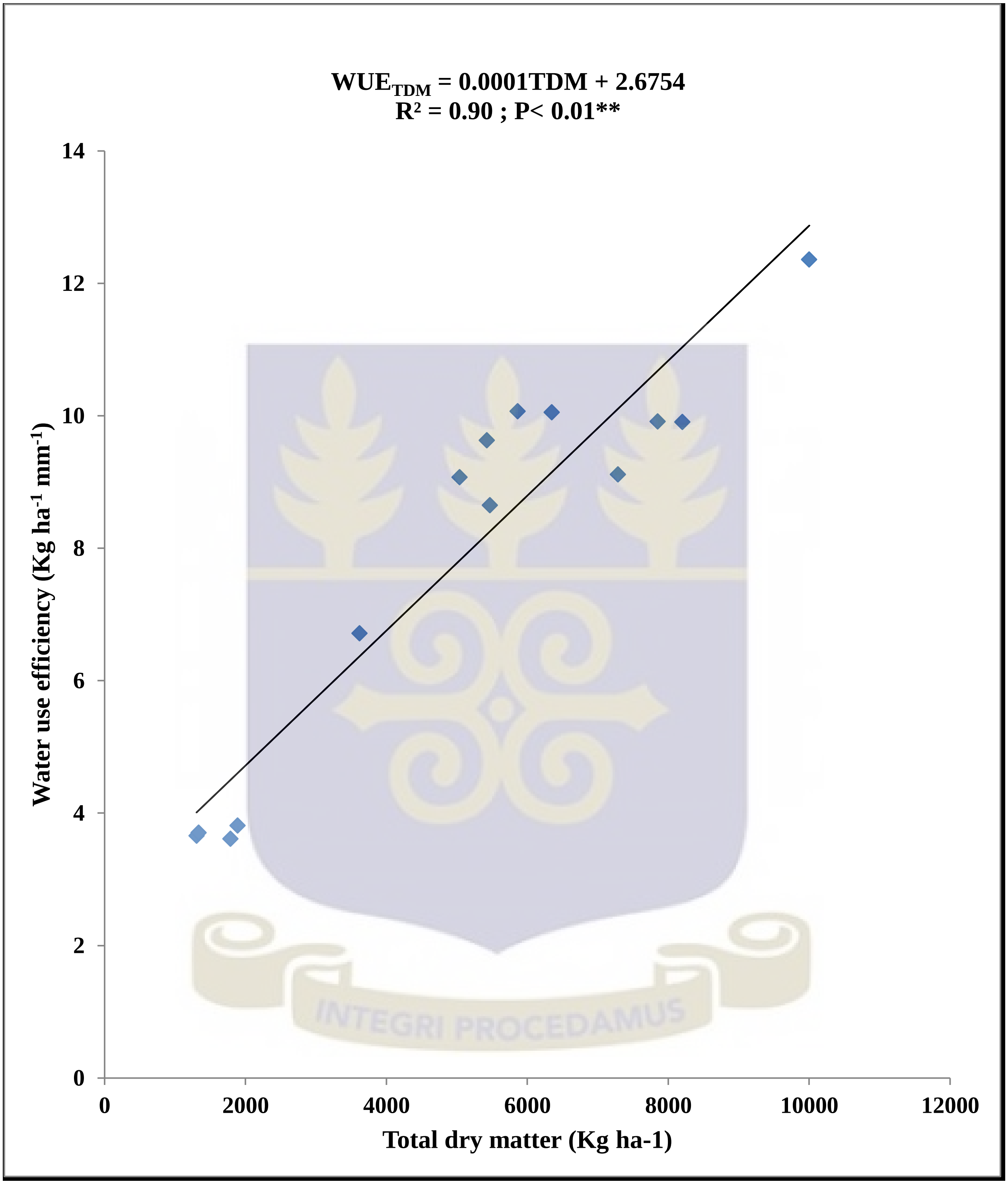


Figure 5.7F. Relationship between water use efficiency and total dry matter for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1}, pooled data for both varieties.

5.8 Relationship between actual evapotranspiration and leaf area index

The linear regression between evapotranspiration (AET) and leaf area index (LAI) for Bankye Hemaa and Capevars Bankye grown under the three (3) different plant densities resulted in good linear models with a good r^2 value. For Bankye Hemaa and Capevars Bankye grown under 10,000 plants ha^{-1} the linear relationship between AET and LAI the coefficient of determination, r^2 was 0.80 and 0.83, respectively (Figure 5.8A). However, correlation between the pooled data of AET and LAI for Bankye Hemaa and Capevars Bankye grown under 10,000 plants ha^{-1} generated a good positive linear relationship AET = 65.376LAI + 354.64 with $r^2 = 0.77$ (Figure 5.8D).

Also, Bankye Hemaa and Capevars Bankye grown under 13,333 plants ha^{-1} showed a good linear relationship between AET and LAI with r^2 being 0.80 and 0.70, respectively (Figure 5.8B).The pooled data for both cassava varieties also equally generated a good linear relationship AET = 61.575LAI + 332.1 with $r^2 = 0.73$ (Figure 5.8E).

Similarly, Bankye Hemaa and Capevars Bankye grown under 20,000 plants ha^{-1} also showed a fairly good positive linear relationship between AET and LAI with r^2 being 0.80 and 0.50, respectively (Figure 5.8C).The pooled data for both cassava variety also generated equally fairly good linear relationship AET = 60.868LAI + 336.7 with $r^2 = 0.67$ (Figure 5.8F). Additionally, pooled data of AET and LAI for Bankye Hemaa and Capevars Bankye grown under all the different plant densities was good and linearly related (Figure 5.8D, Figure 5.8E and Figure 5.8F).

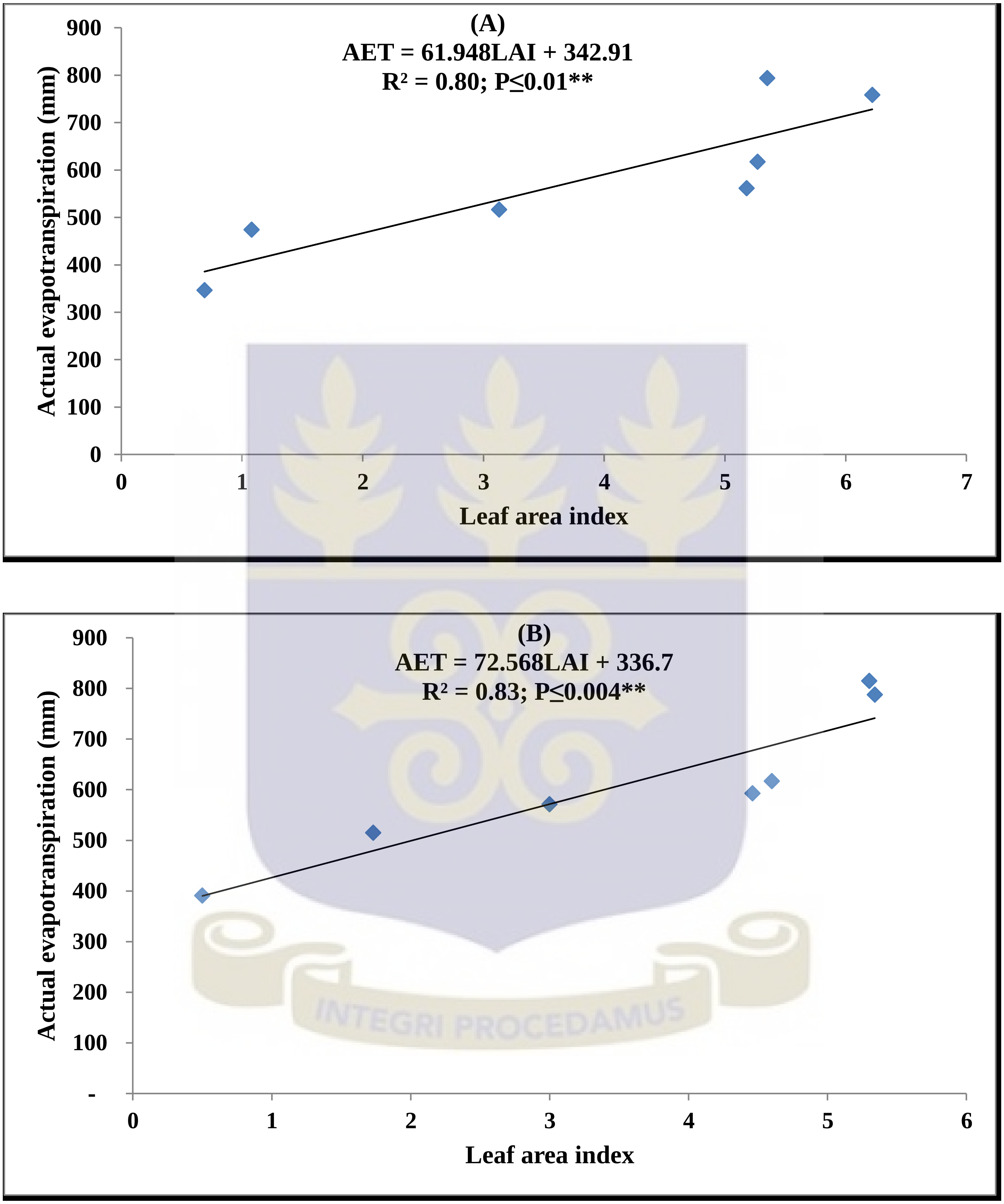


Figure 5.8A. Relationship between actual evapotranspiration and leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 10,000 plants ha^{-1}.

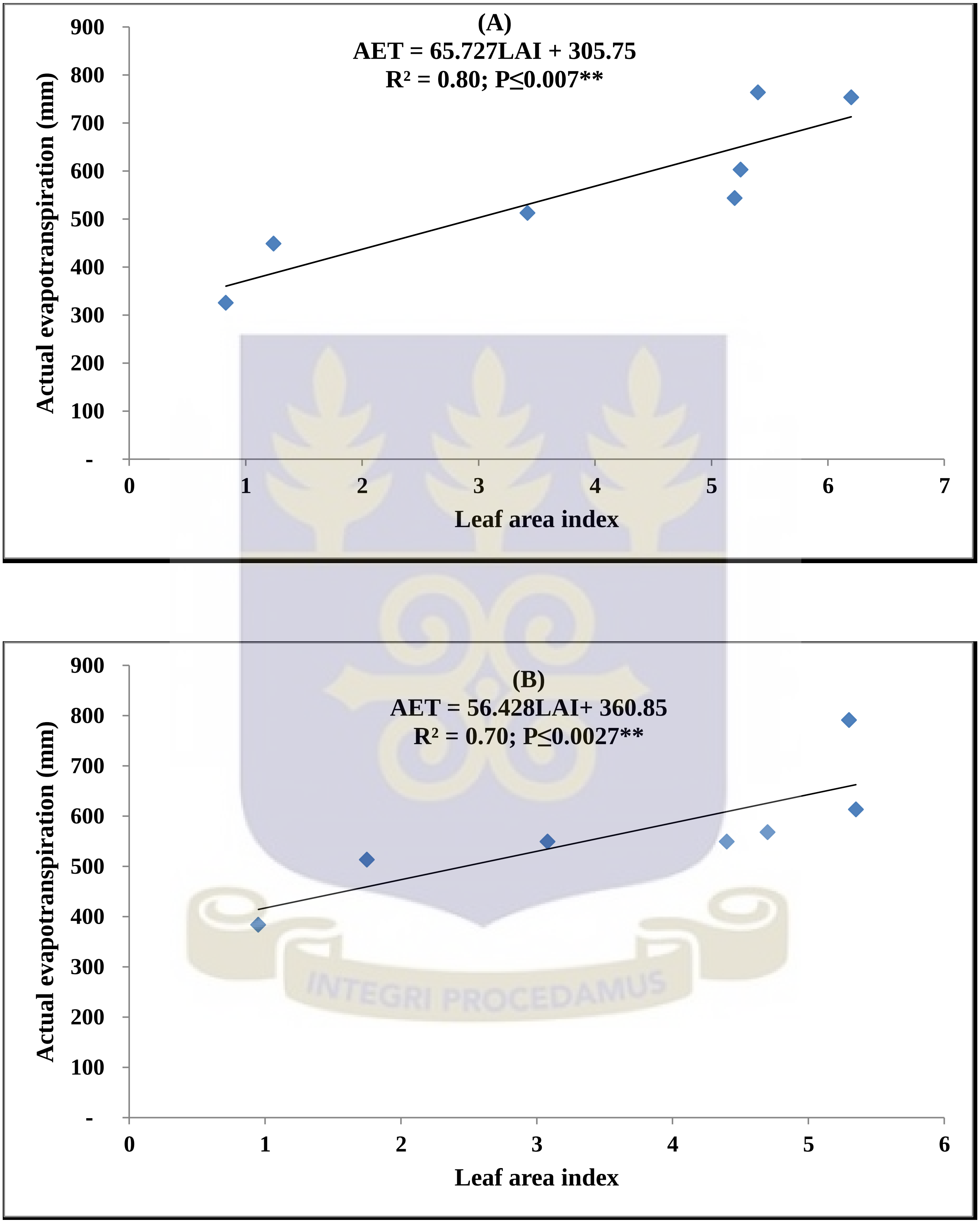
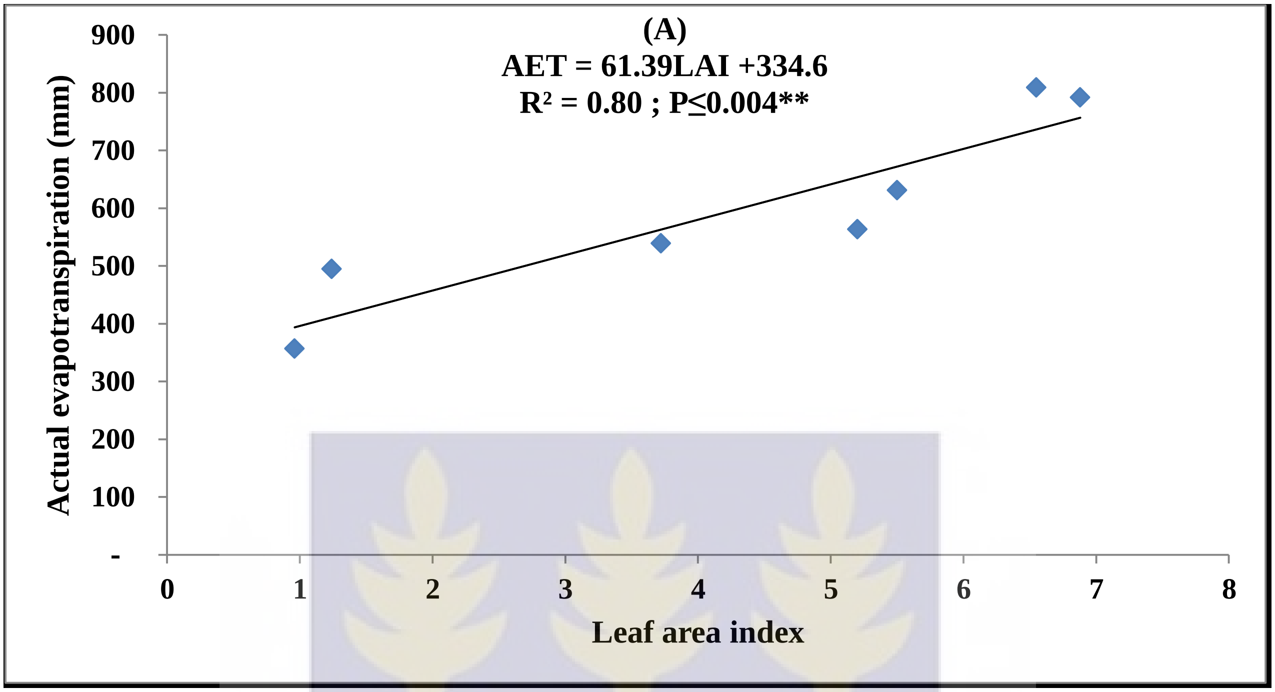


Figure 5.8B. Relationship between actual evapotranspiration and leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 13,333 plants ha^{-1}.



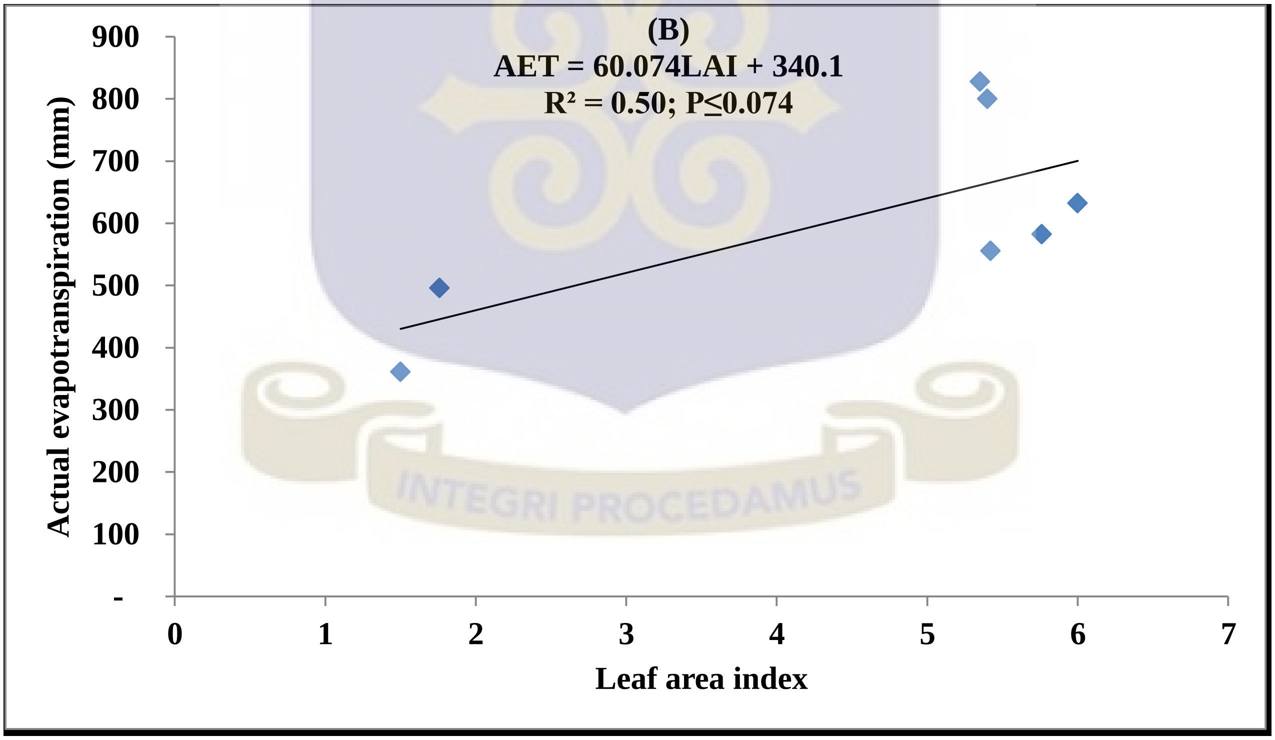


Figure 5.8C. Relationship between actual evapotranspiration and leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1}.

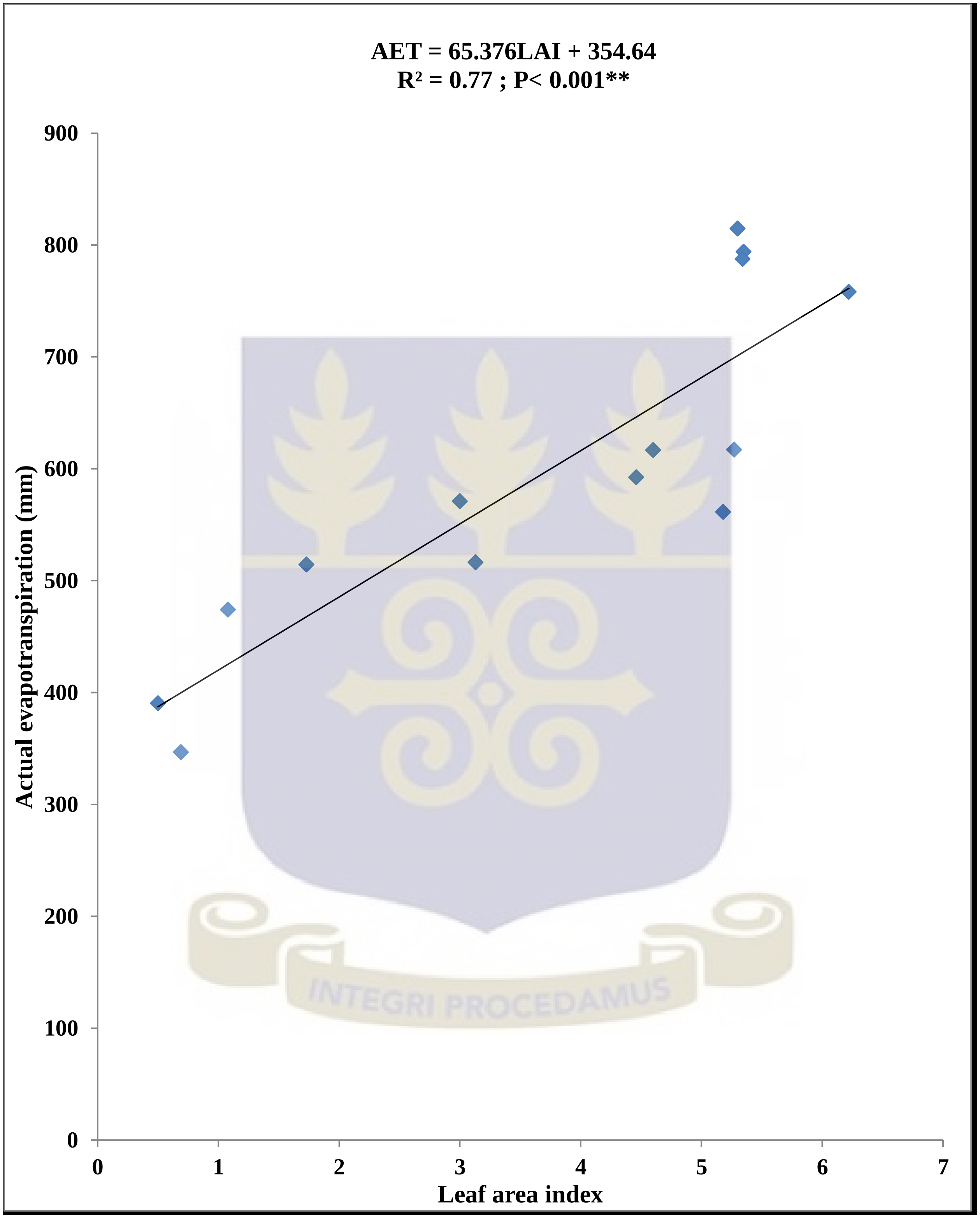


Figure 5.8D. Relationship between actual evapotranspiration and leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 10,000 plants ha^{-1}, pooled data for both varieties.

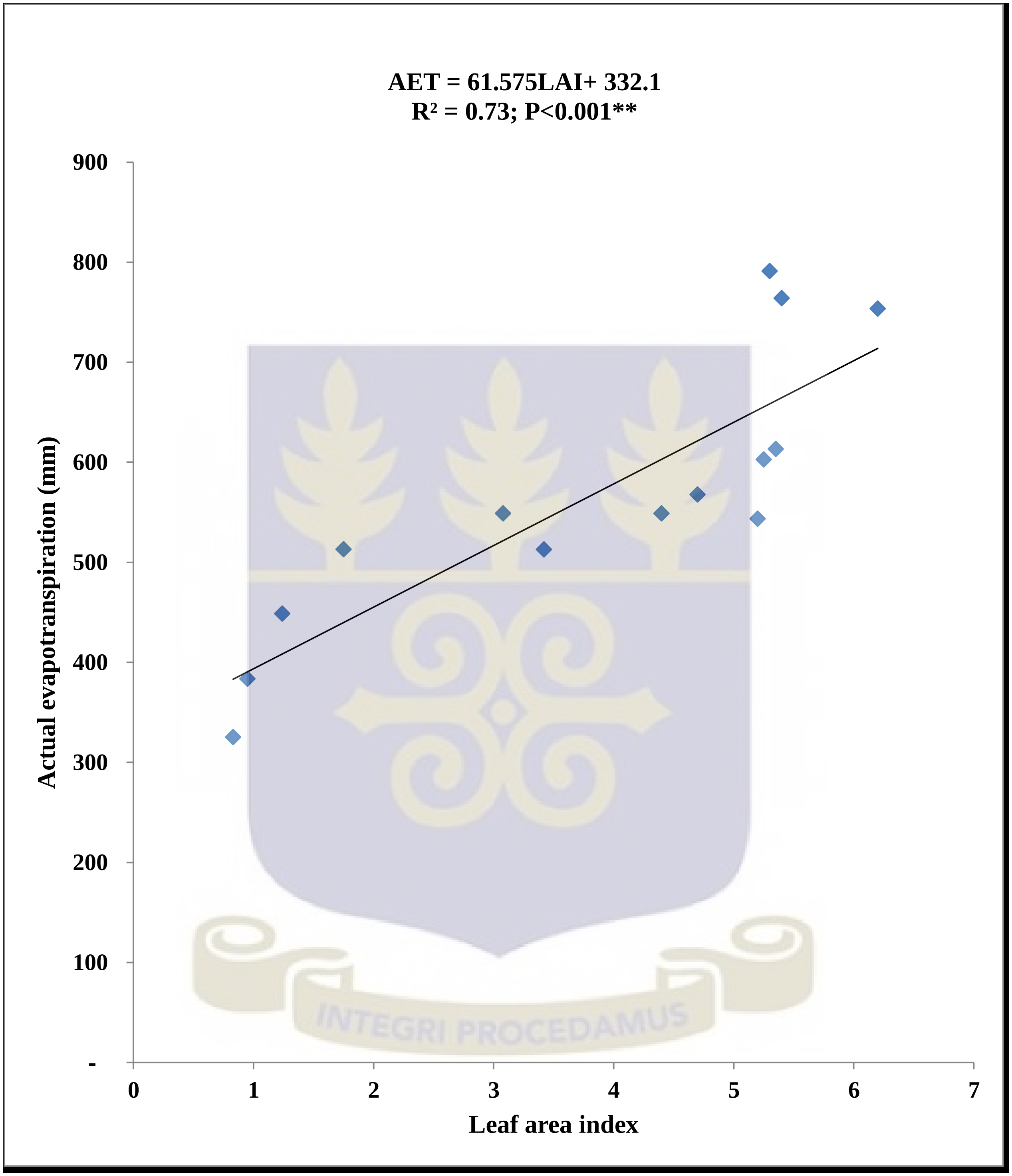


Figure 5.8E. Relationship between actual evapotranspiration and leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 13,333 plants ha^{-1}, pooled data for both varieties.

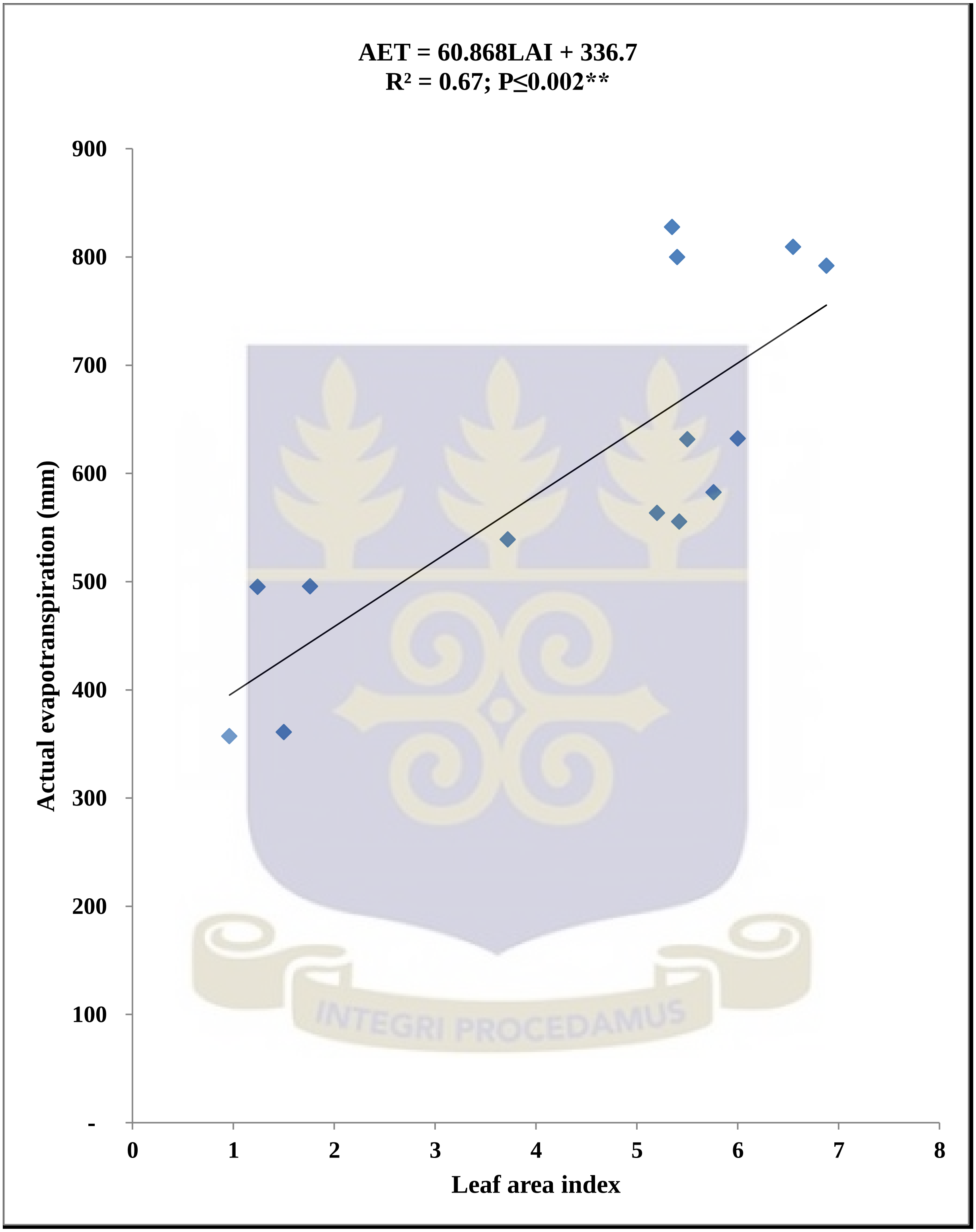


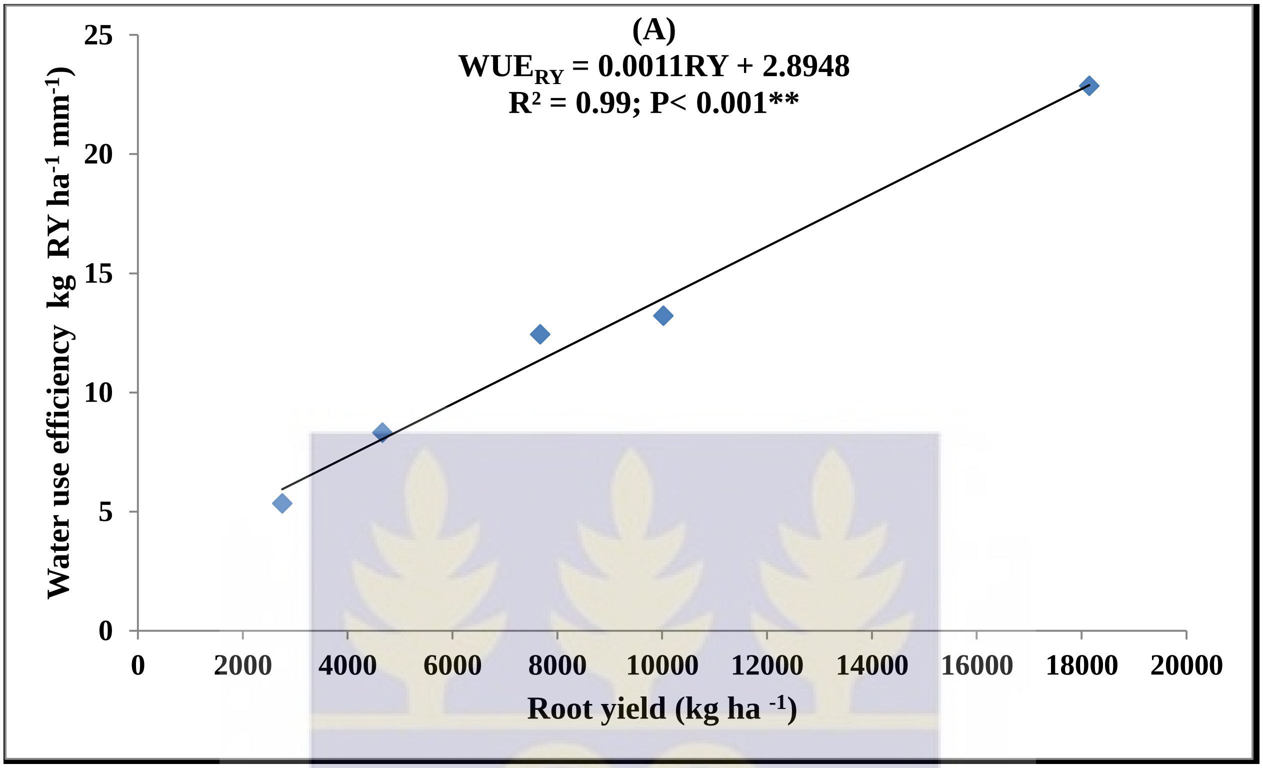
Figure 5.8F. Relationship between actual evapotranspiration and leaf area index for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1}, pooled data for both varieties.

5.9 Relationship between water use efficiency and root yield

The linear regression of water use efficiency in terms of root yield (WUE_{RY}) and root yield for Bankye Hemaa and Capevars Bankye grown under the three (3) different plant densities resulted in good linear models with a stronger r^2 value. For Bankye Hemaa and Capevars Bankye grown under 10,000 plants ha^{-1} a stronger linear relationship between WUE_{RY} and root yield was obtained with the same value of coefficient of determination, r^2 of 0.99 (Figure 5.9A). However, the correlation between the pooled data of WUE and root yield for Bankye Hemaa and Capevars Bankye grown under 10,000 plants ha^{-1} generated a strong positive linear relationship $WUE_{RY} = 0.0012RY + 3.125$ with $r^2 = 0.94$ (Figure 5.9D).

Also, Bankye Hemaa and Capevars Bankye grown under 13,333 plants ha^{-1} had a good linear relationship between WUE_{RY} and root yield with r^2 being 0.99 and 0.74, respectively (Figure 5.9B). The pooled data for both cassava variety also generated equally good linear relationship $WUE_{RY} = 0.001RY + 4.052$ with $r^2 = 0.92$ (Figure 5.9E).

Similarly, Bankye Hemaa and Capevars Bankye grown under 20,000 plants ha^{-1} also had a good positive, stronger linear relationship between WUE_{RY} and root yield with r^2 being 0.99 and 0.93, respectively (Figure 5.9C). The pooled data for both cassava variety also generated equally good linear relationship $WUE_{RY} = 0.001RY + 4.7749$ with $r^2 = 0.97$ (Figure 5.9F). Additionally, pooled data of WUE_{RY} and root yield for Bankye Hemaa and Capevars Bankye grown under all the different plant densities was strong and linearly related (Figure 5.9A, Figure 5.9B, and Figure 5.9C) and (Figure 5.9D, Figure 5.9E, and Figure 5.9F).



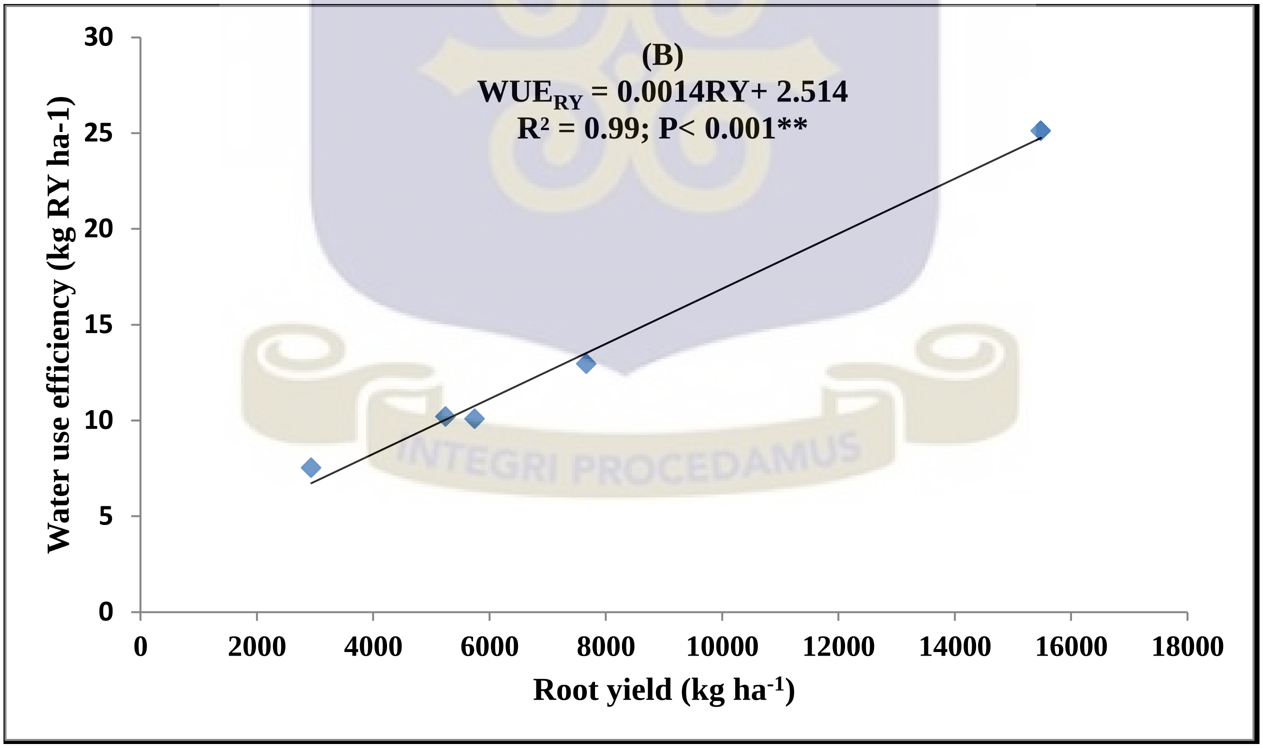


Figure 5.9A. Relationship between water use efficiency and root yield of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 10,000 plants ha^{-1}.

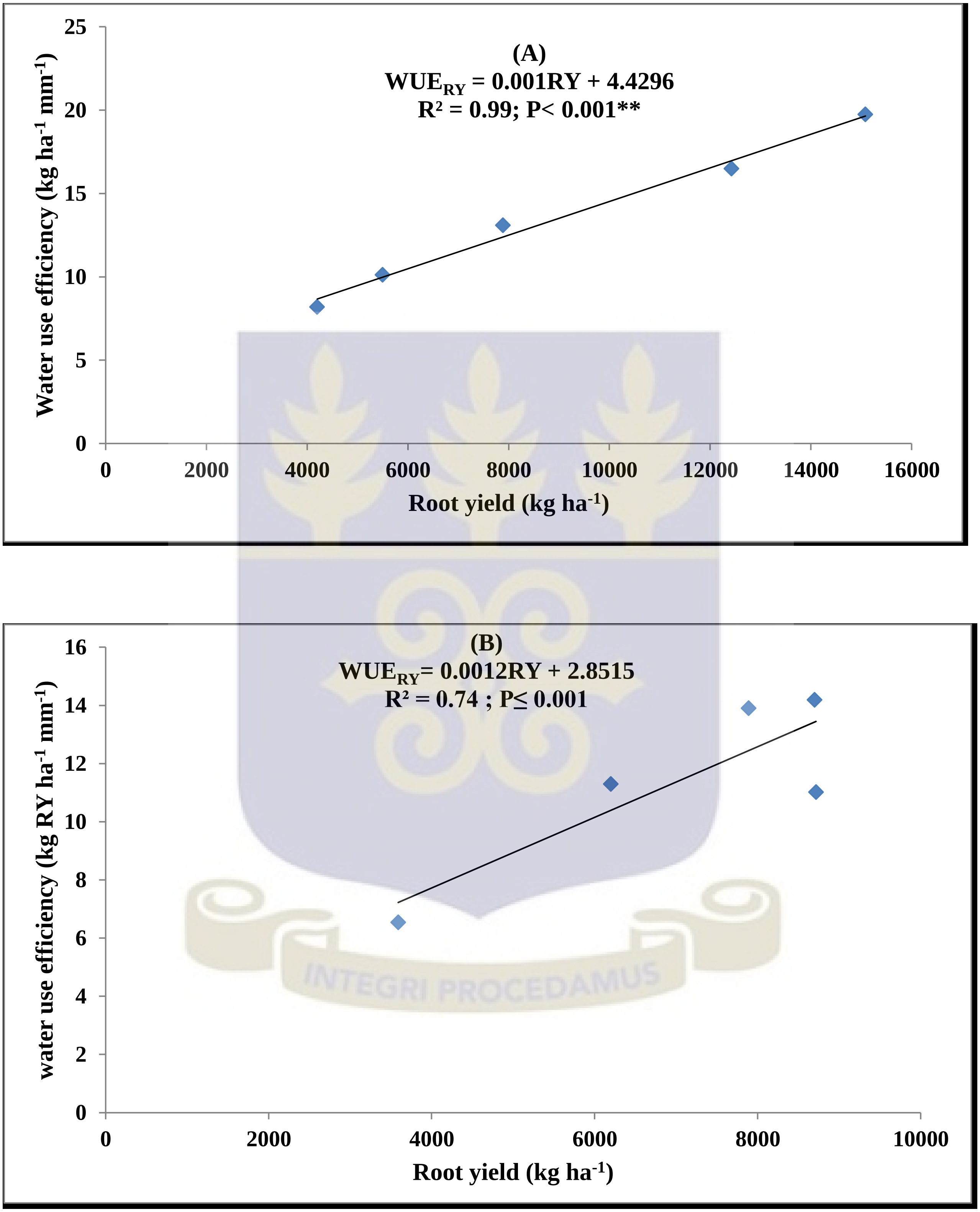
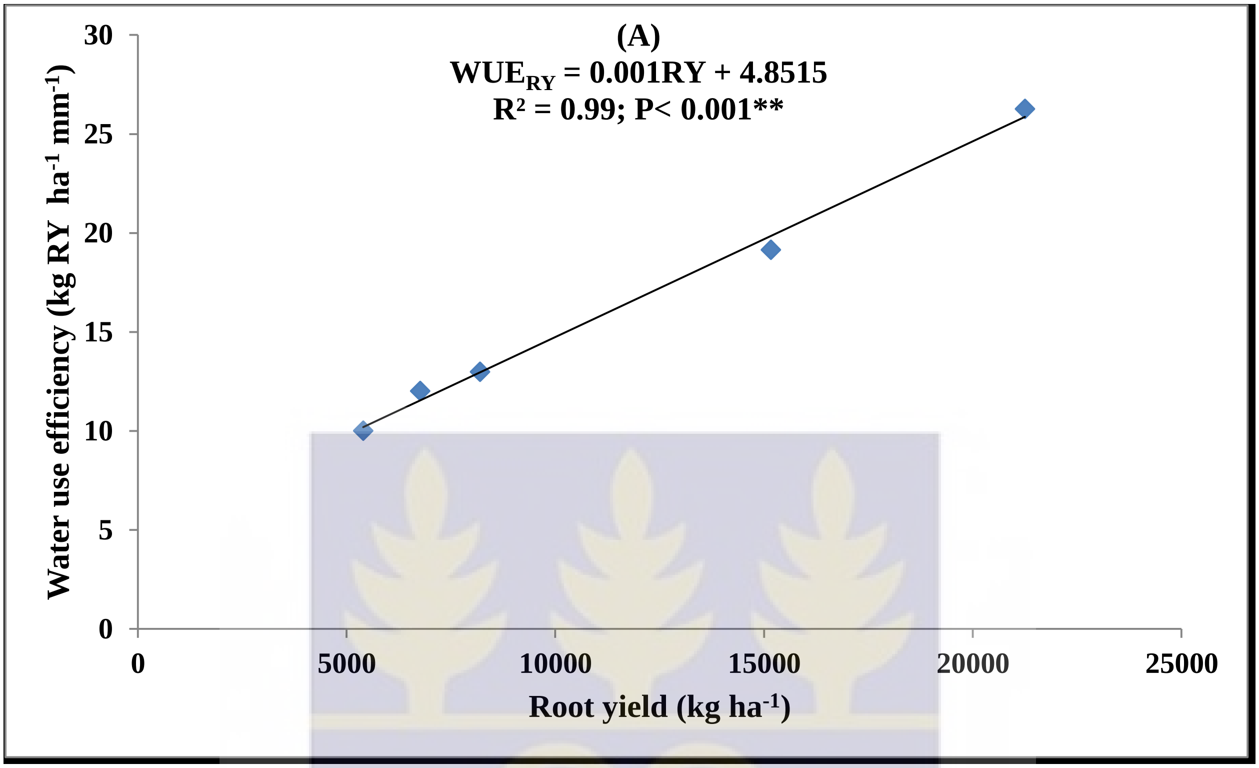


Figure 5.9B. Relationship between water use efficiency and root yield of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 13,333 plants ha^{-1}.



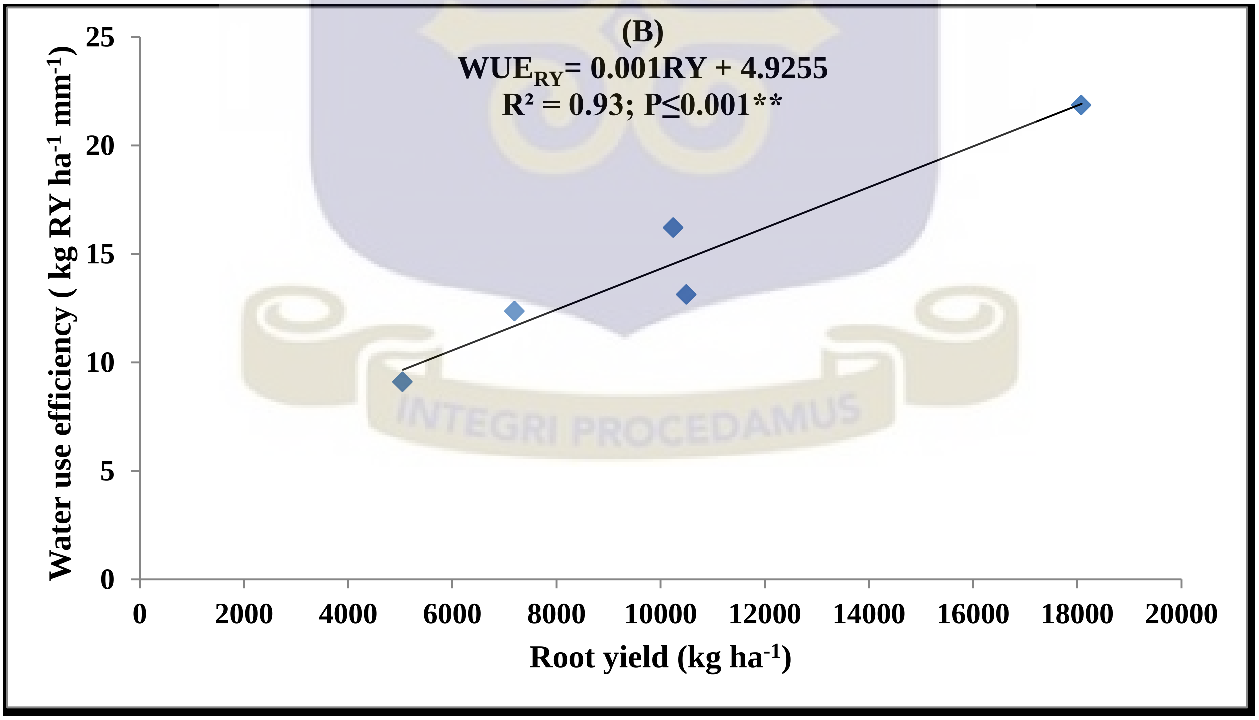


Figure 5.9C. Relationship between water use efficiency and root yield of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 20,000 plants ha^{-1}.

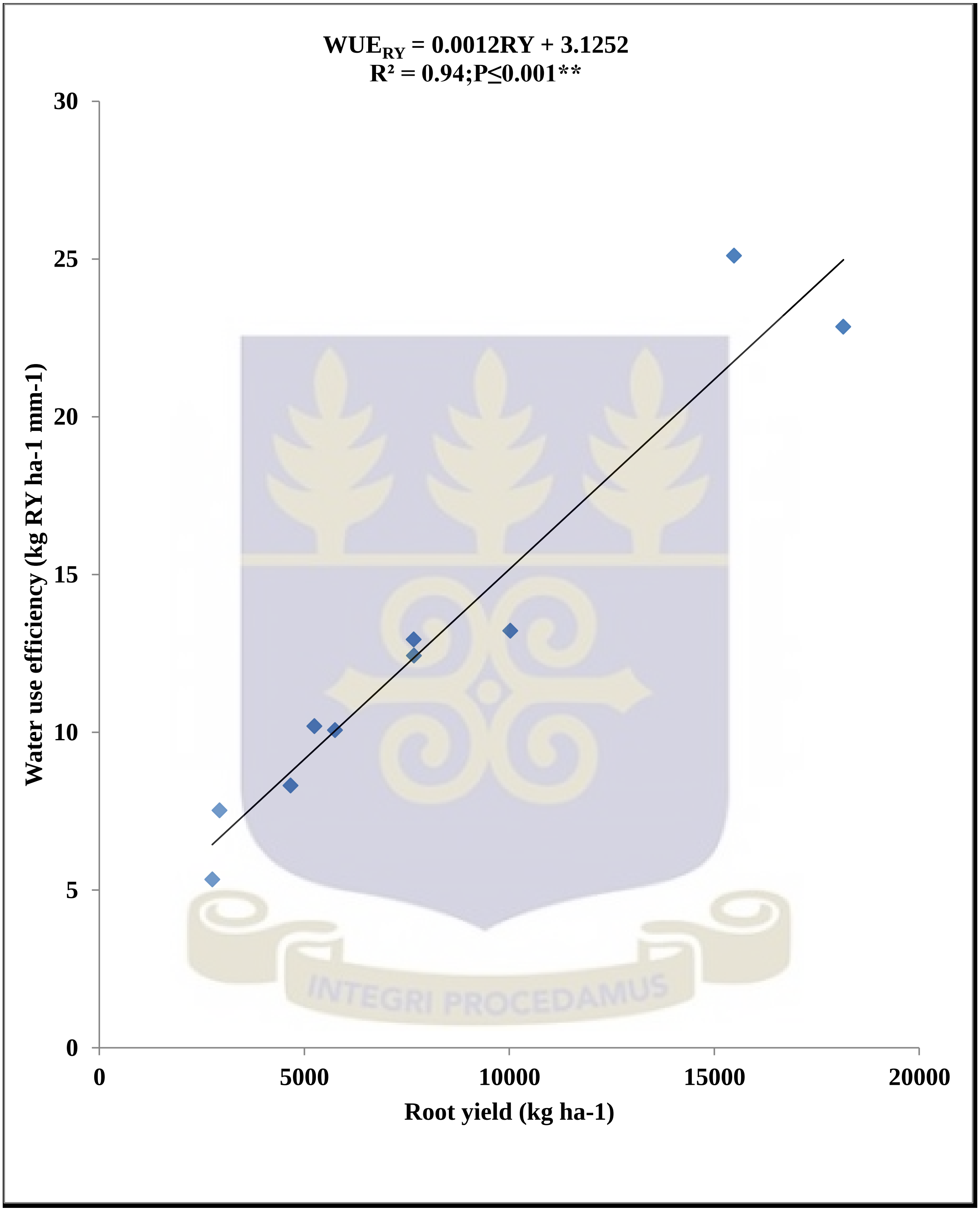


Figure 5.9D. Relationship between water use efficiency and root (tuber) yield for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 10,000 plants ha^{-1}, pooled data for both varieties.

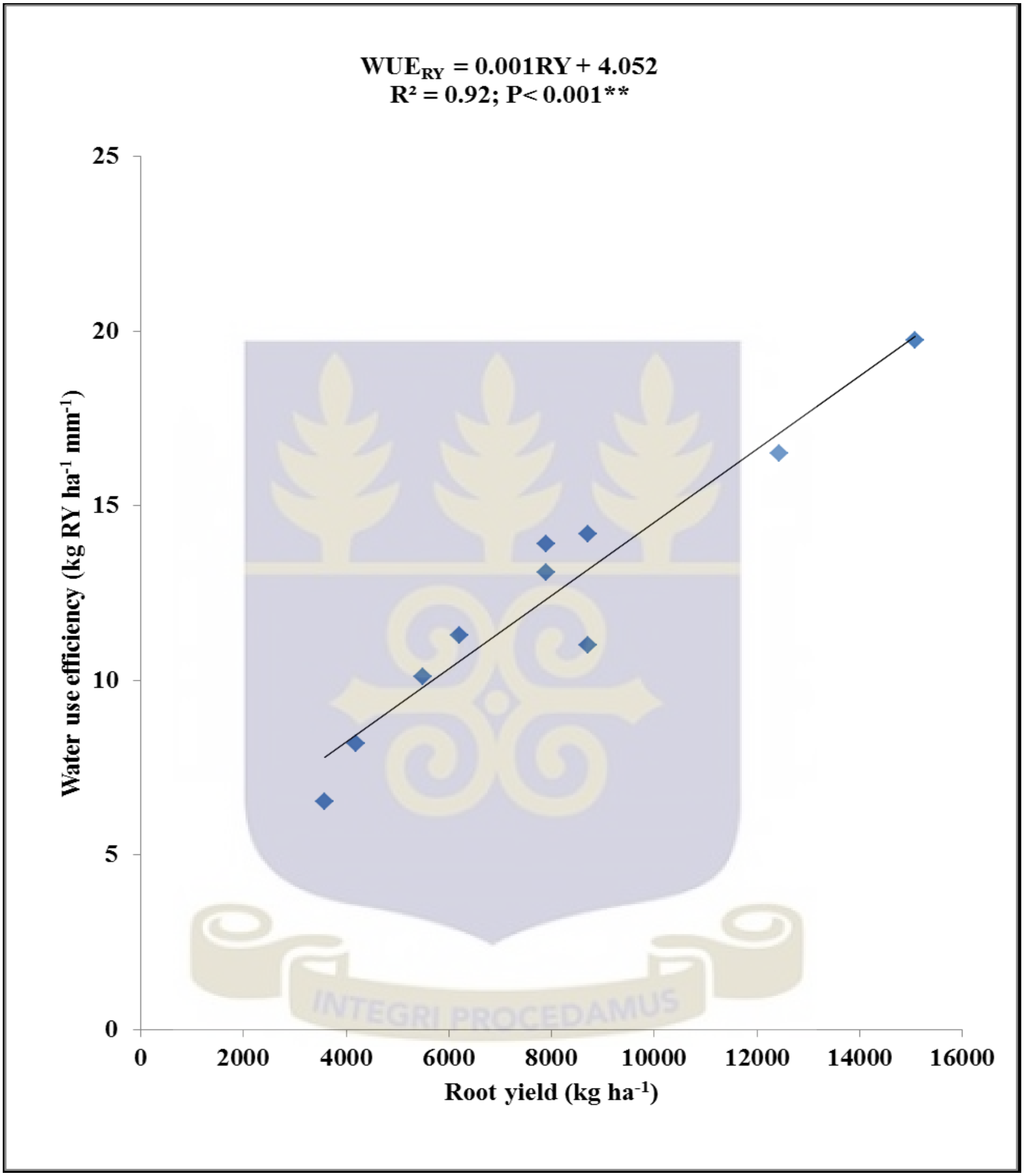


Figure 5.9E. Relationship between water use efficiency and root (tuber) yield for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 13,333 plants ha^{-1}, pooled data for both varieties.

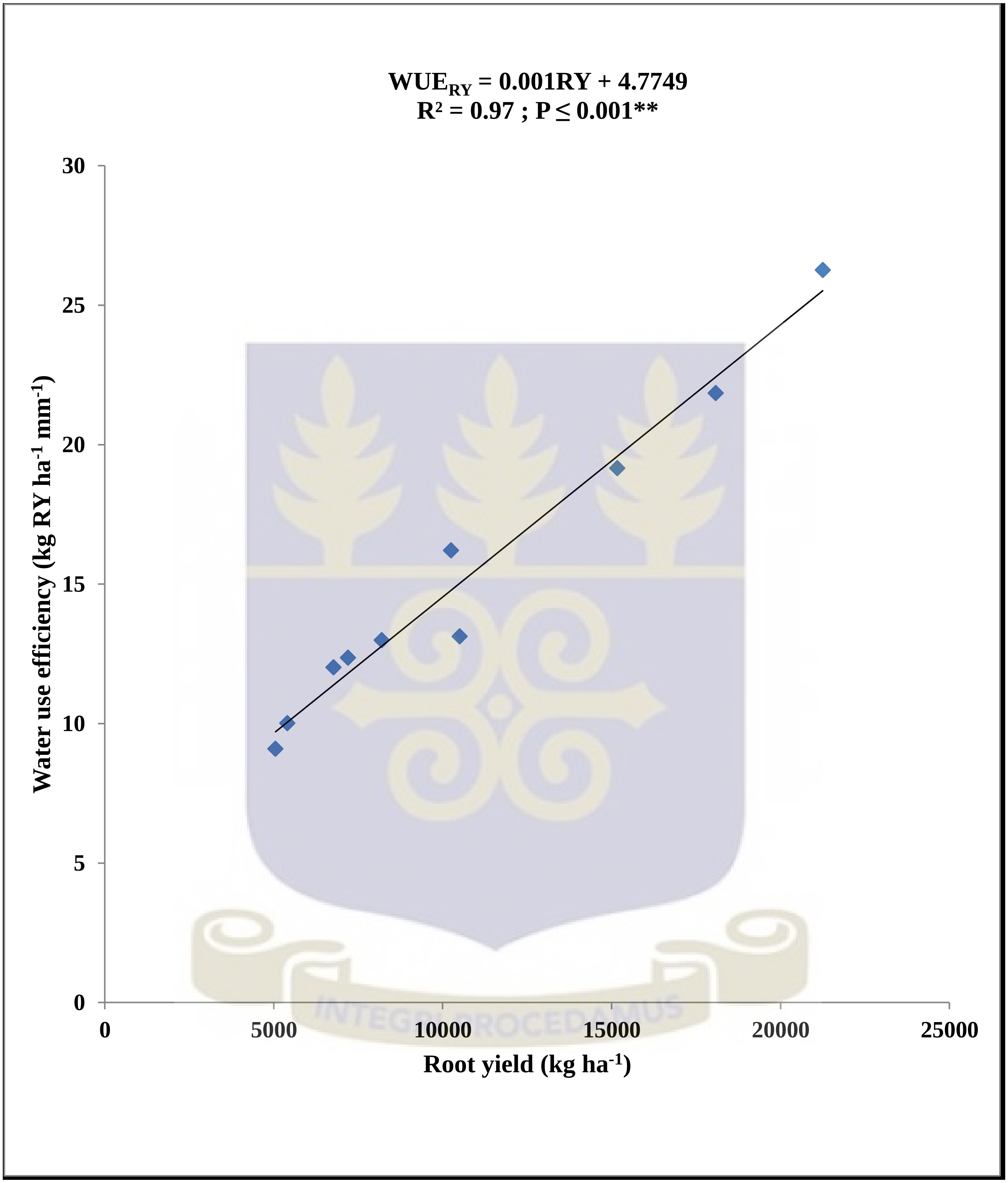


Figure 5.9F. Relationship between water use efficiency and root (tuber) yield for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000plants ha^{-1}, pooled data for both varieties.

5.10 Relationship between transpiration use efficiency and root yield

The linear regression of transpiration use efficiency in term of root yield (TUE_{RY}) for Bankye Hemaa and Capevars Bankye grown under the three (3) different plant densities resulted in good and strong linear models. A strong linear relationship was observed between TUE_{RY} and root yield for Bankye Hemaa planted at 10,000 plants ha^{-1} with r^2 being 0.95 (Figure 5.10A).

However, a similar strong linear relationship existed between TUE_{RY} and root yield for Capevars Bankye planted at 10,000 plants ha^{-1} as r^2 was 0.90 (Figure 5.10A). However, the linear regression between the pooled data of TUE_{RY} and root yield for Bankye Hemaa and Capevars Bankye grown under 10,000 plants ha^{-1} generated a good positive linear relationship $TUE_{RY} = 0.0014RY + 9.6834$ with $r^2=0.93$ (Figure 5.10D).

On the other hand, Bankye Hemaa and Capevars Bankye grown at 13,333 plants ha^{-1} had a good and strong linear relationship between TUE_{RY} and root yield with r^2 being 0.95 (Figure 5.10B). However, a waek linear relationship existed between TUE_{RY} and root yield for Capevars Bankye planted at 13,333 plants ha^{-1} as r^2 was 0.34 (Figure 5.10B). However, the linear regression between the pooled data of TUE_{RY} and root yield for Bankye Hemaa and Capevars Bankye grown under 13,000 plants ha^{-1} generated a strong positive linear relationship $TUE_{RY} = 0.0012RY + 10.074$ with $r^2 = 0.70$ (Figure 5.10E).

However, r^2 value for the linear model relating TUE_{RY} and root yield for Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1} was 0.97 and 0.82, respectively (Figure 5.10C). Similar mean regression coefficient value of about 0.0011 mm^{-1} was obtained (Figure 5.10C). This suggests that Bankye Hemaa and Capevars Bankye transpired similar amounts of soil water to produce similar root yield. Consequently, the linear regression between the pooled data of

TUE_{RY} and root yield for Bankye Hemaa and Capevars Bankye grown under 20,000 plants ha^{-1} generated a strong positive linear relationship $TUE_{RY} = 0.0012RY + 11.102$ with $r^2 = 0.90$ (Figure 5.10F).

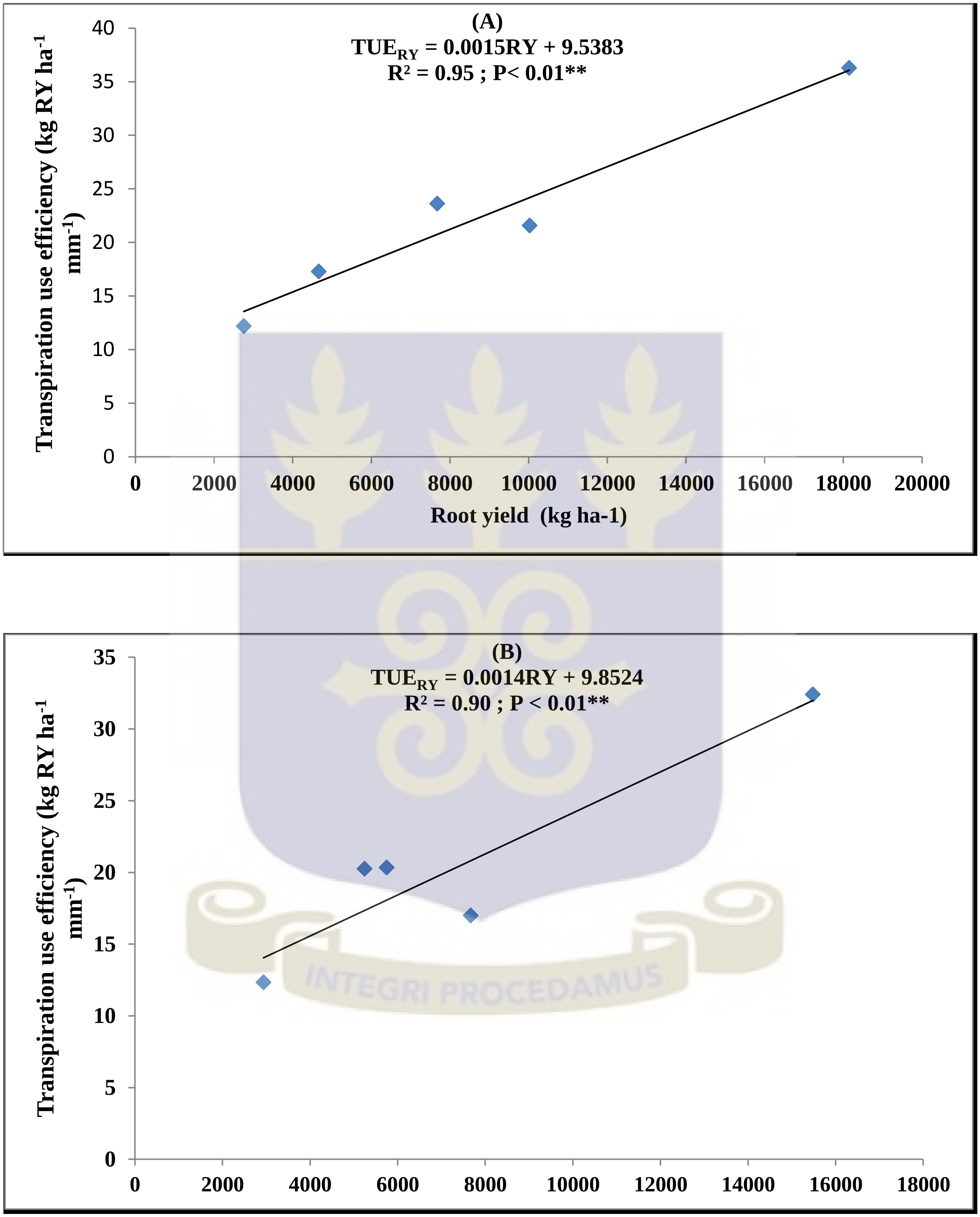
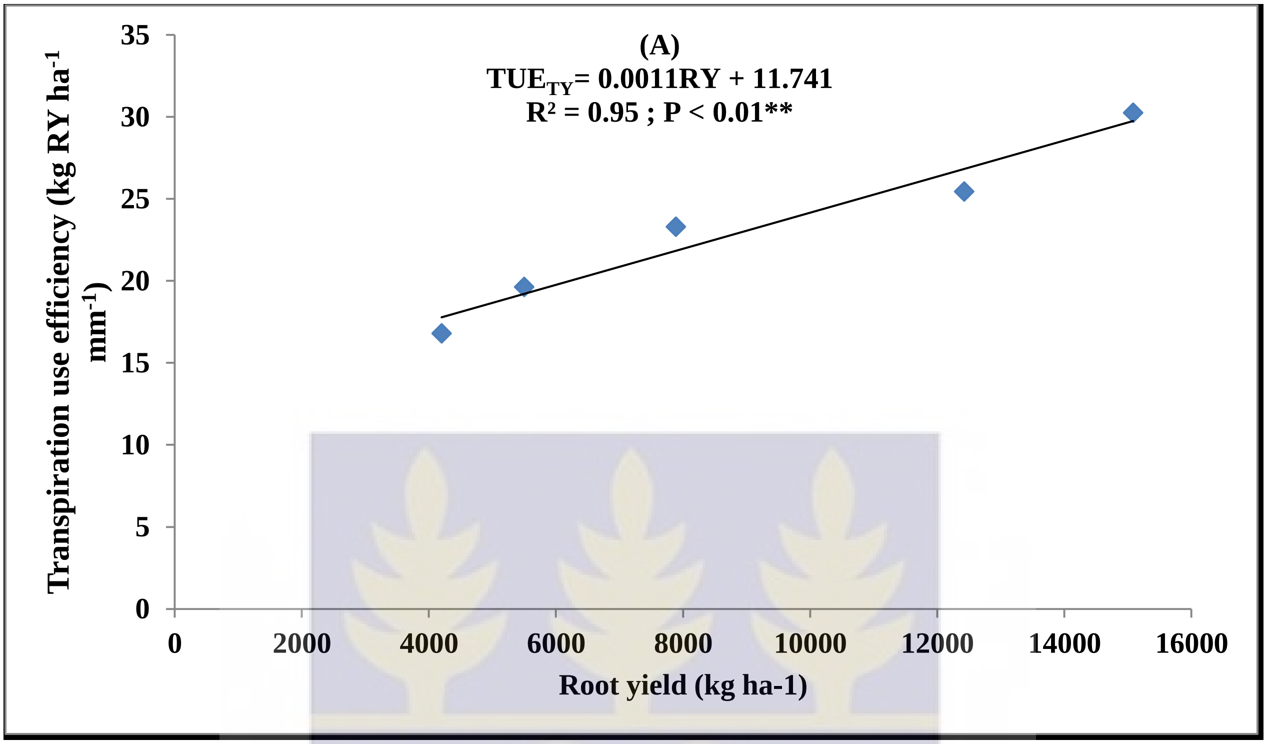


Figure 5.10A. Relationship between transpiration use efficiency and root yield of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 10,000 plants ha^{-1}.



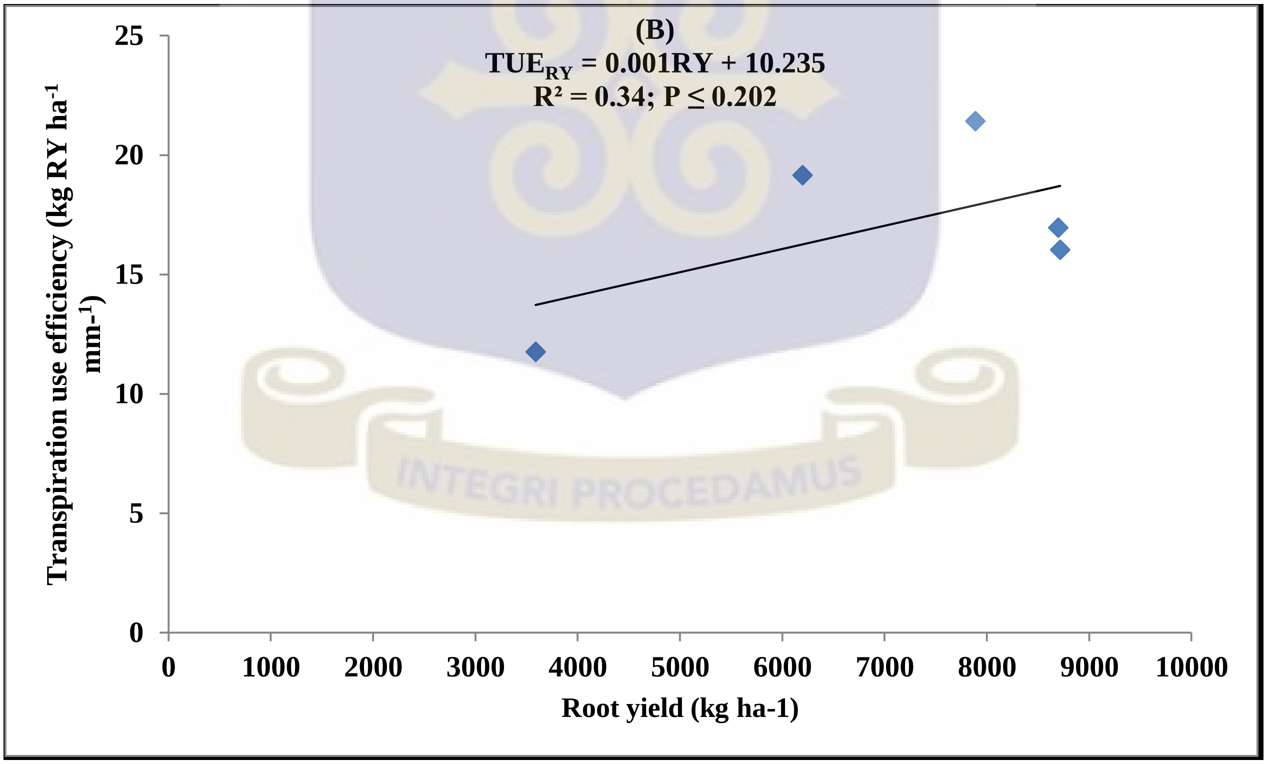
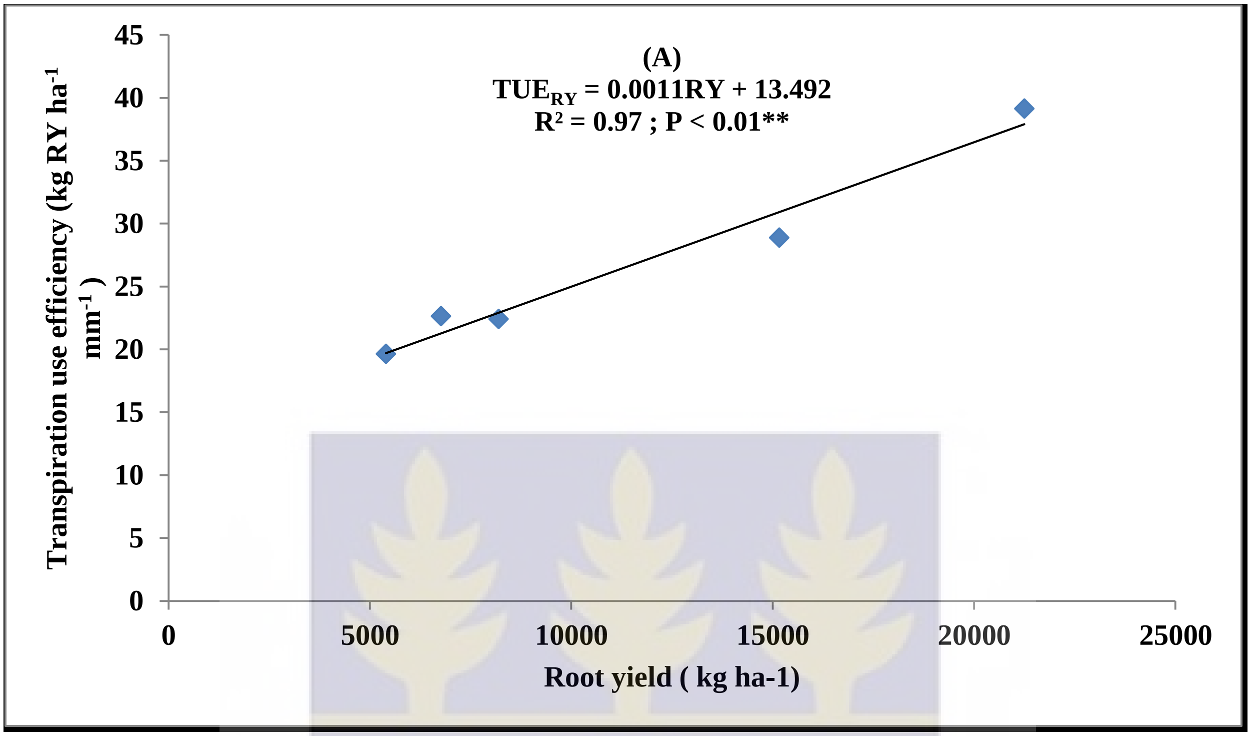


Figure 5.10B. Relationship between transpiration use efficiency and root yield of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 13,333 plants ha^{-1}.



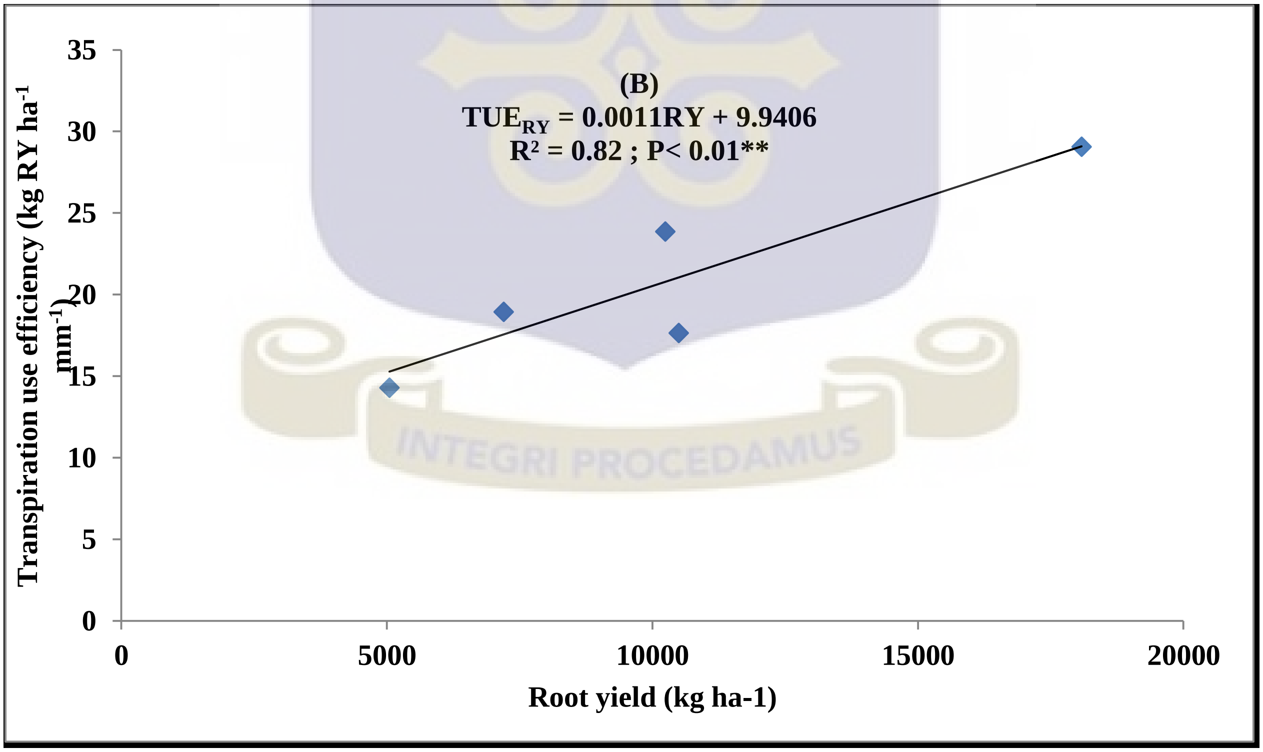


Figure 5.10C. Relationship between transpiration use efficiency and root yield of Bankye Hemaa (A) and Capevars Bankye (B) for plant density 20,000 plants ha^{-1}.

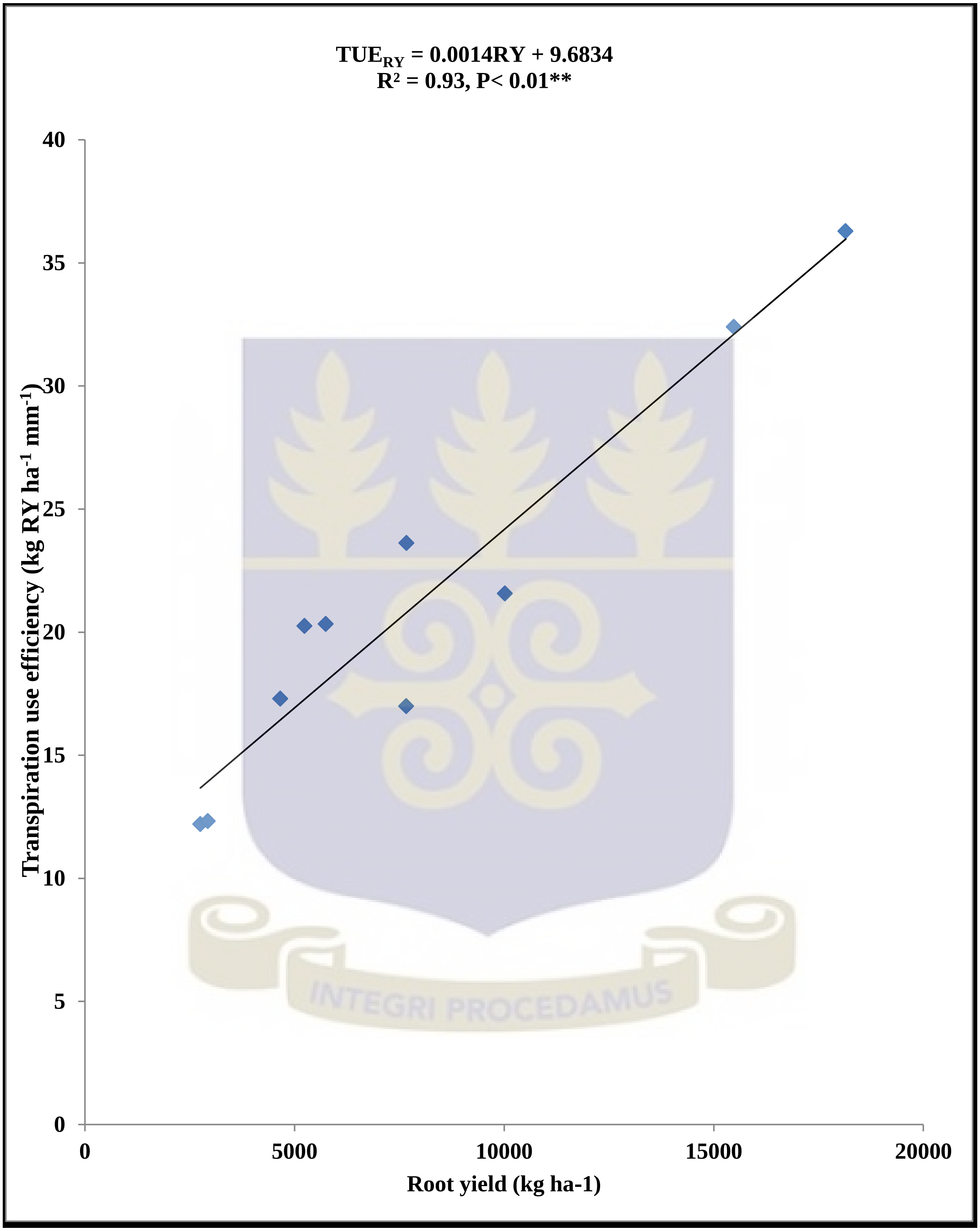


Figure 5.10D. Relationship between transpiration use efficiency and root (tuber) yield for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 10,000 plants ha^{-1}, pooled data for both varieties.

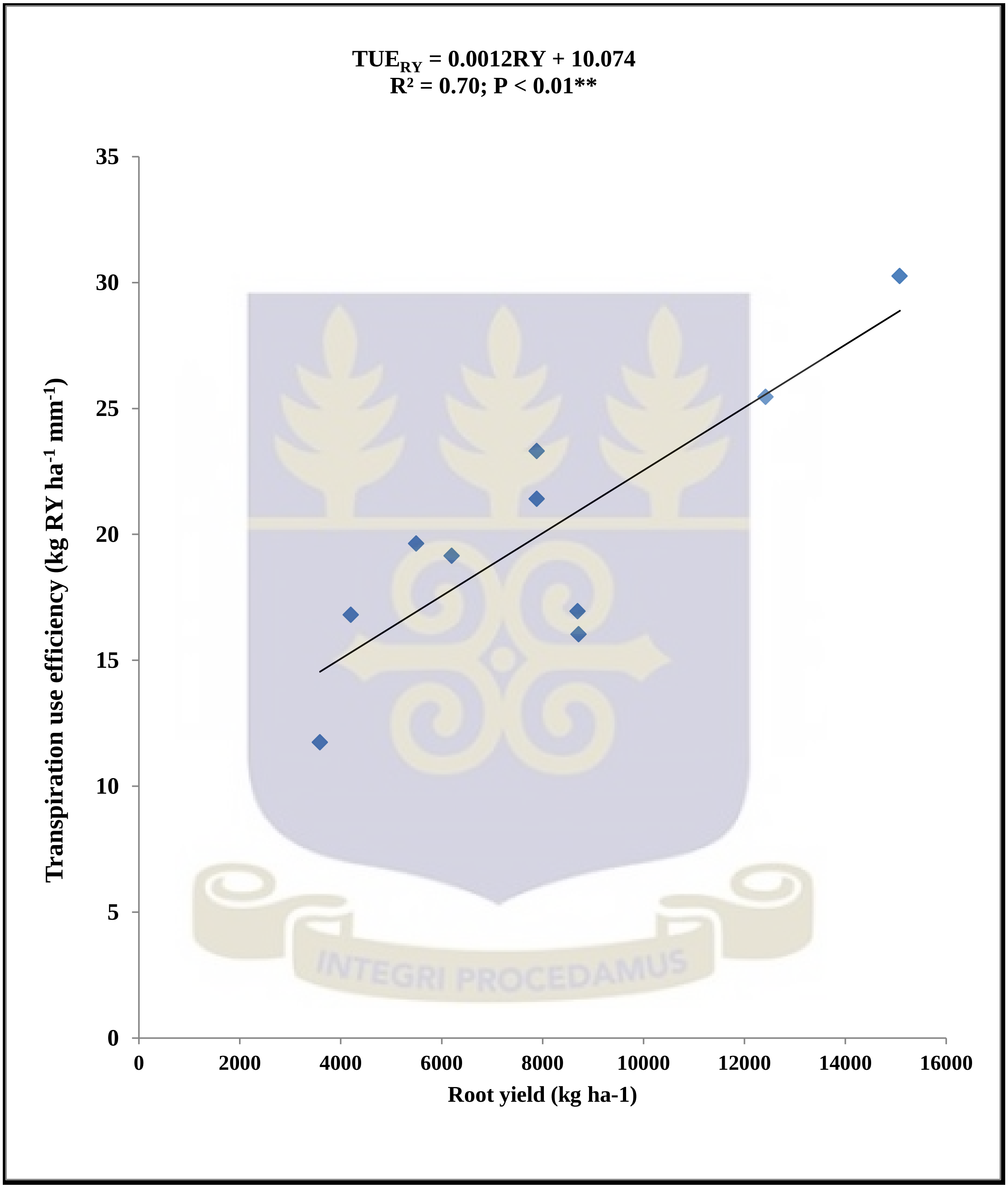


Figure 5.10E. Relationship between transpiration use efficiency and root (tuber) yield for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 13,333 plants ha^{-1}, pooled data for both varieties.

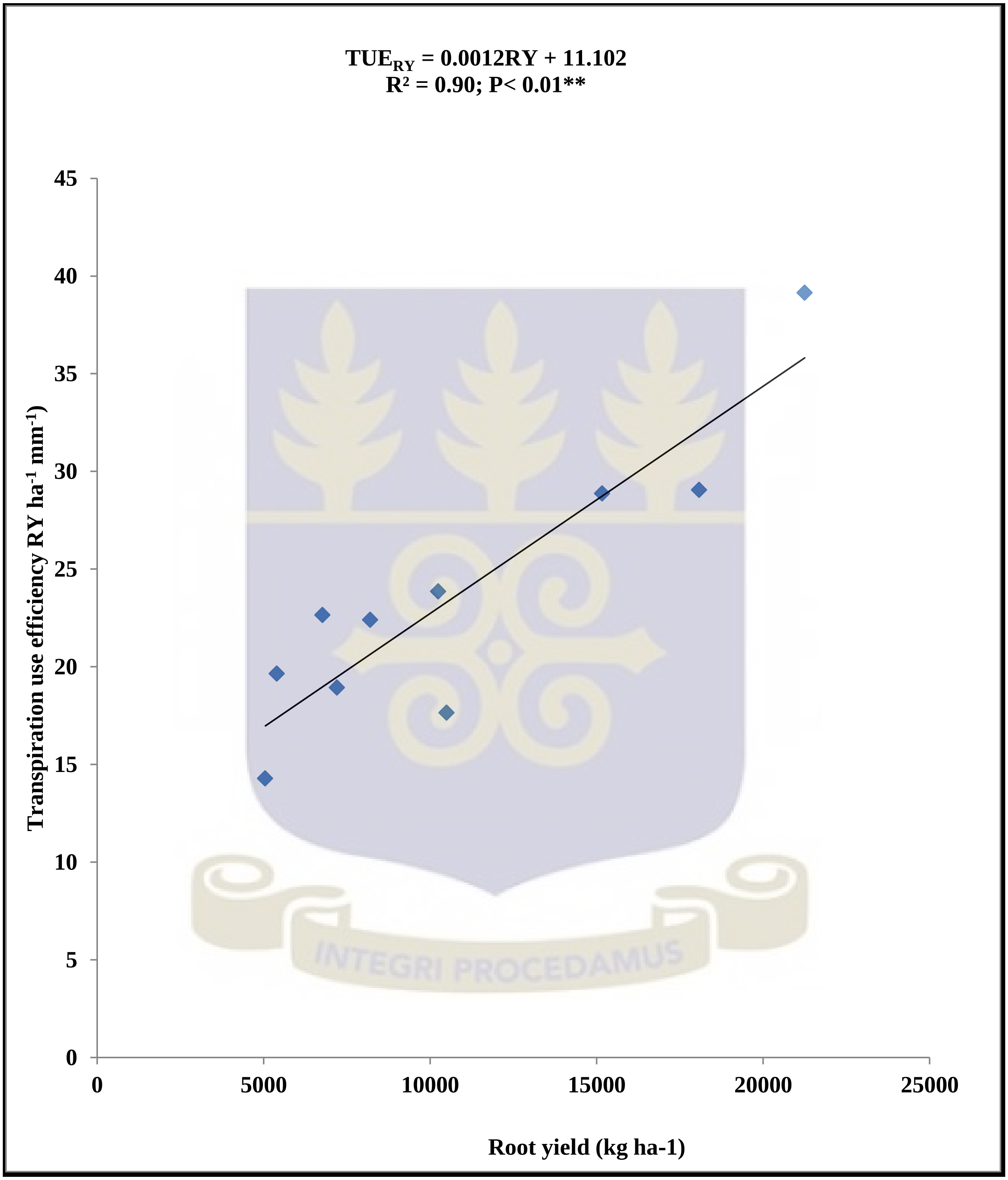


Figure 5.10F. Relationship between transpiration use efficiency and root (tuber) yield for both cassava varieties, Bankye Hemaa and Capevars Bankye grown at 20,000 plants ha^{-1}, pooled data for both varieties.

CHAPTER SIX

6.0 Conclusions and Recommendations

6.1 Conclusions

The study showed that the cultivation of two cassava varieties, Bankye Hemaa and Capevars Bankye at plant densities of 10,000, 13, 333 and 20,000 plants ha $^{-1}$ resulted in statistically similar TDM and AET. However, LAI, T, $E_{s,}$ WUE_{TDM} ,TUE_{TDM}, and WUE_{RY} were statistically different among the planting densities for the two cassava varieties. The cassava variety Bankye Hemaa grown under the plant density 20,000 plants ha $^{-1}$ had the highest biomass partitioning of 0.69 (Harvest Index). This suggests that Bankye Hemaa under plant density of 20,000 plants ha $^{-1}$ performed better, has higher photosynthetic capability and used soil moisture more efficiently compared to Capevars Bankye. Conversely crop transpiration for Bankye Hemaa and Capevars Bankye is highest in plant density of 20,000 plants ha $^{-1}$ as a result of comparatively reduced soil evaporation.

Simple linear models described adequately the relation existing between WUE_{TDM} and TDM for Bankye Hemaa and Capevars Bankye grown under the three (3) different plant densities for the combined data of both varieties. Stronger positive correlations existed between WUE_{RY} and RY for both cassava varieties grown under the three (3) different plant densities.

Finally, a good positive correlation also existed also between TUE_{RY} and RY for both cassava varieties grown under the three (3) different plant densities. The study showed that WUE_{RY} and TUE_{RY} for Bankye Hemaa and Capevars Bankye were highly correlated with root yield for each of the plant densities used.

However, the planting density 20,000 plants ha^{-1} is most appropriate for growing Bankye Hemaa and Capevars Bankye in the Kwabenya-Atomic area under rain-fed conditions because of their comparatively higher TDM, RY and efficient soil water use.

6.2 Recommendations

Additional research is recommended to evaluate the productivity and water use efficiency by rain-fed early maturing cassava varieties under different nutrient management conditions.

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APPENDIX

Appendix 1: Analysis of variance of LAI on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1.42	0.71	0.78	
Main plot (Variety)	1	1.15	1.15	1.26	0.378^{ns}
Residual (a)	2	1.82	0.91	7.11	
Sub. Plot (Planting Distance)	2	1.56	0.78	6.08	0.025^{s}
Int. (Variety x Planting Distance)	2	2.20	1.10	8.56	0.010^{s}
Residual (b)	8	1.02	0.12		
Total	17	9.21			

ns = not significant **s= Significant**

Appendix 2: Analysis of variance of LAI on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	3.46	1.73	1.34	
Main plot (Variety)	1	4.25	4.25	3.30	0.211^{ns}
Residual (a)	2	2.57	1.28	1.36	
Sub. Plot (Planting Distance)	2	1.57	0.78	0.83	0.472^{ns}
Int. (Variety x Planting Distance)	2	1.13	0.56	0.59	0.574^{ns}
Residual (b)	8	7.60	0.95		
Total	17	20.59			

ns = not significant **s= Significant**

Appendix 3: Analysis of variance of LAI on 84 Days after emergence (DAE)

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
REP	2	16.72	8.36	2.97	
Main plot (Variety)	1	1.78	1.78	0.63	0.510^{ns}
Residual (a)	2	5.63	2.81	0.46	
Sub. Plot (Planting Distance)	2	80.74	40.37	6.65	0.020^{s}
Int. (Variety x Planting Distance)	2	0.02	0.01	0.001	0.998^{ns}
Residual (b)	8	48.60	6.07		
Total	17	153.51			

ns = not significant **s= Significant**

Appendix 4: Analysis of variance of LAI on 112 Days after emergence (DAE)

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
REP	2	17.34	8.67	4.33	
Main plot (Variety)	1	6.45	6.45	3.22	0.214^{ns}
Residual (a)	2	4.00	2.00	0.75	
Sub. Plot (Planting Distance)	2	90.77	45.38	17.10	0.001^{s}
Int. (Variety x Planting Distance)	2	0.32	0.16	0.06	0.941^{ns}
Residual (b)	8	21.23	2.65		
Total	17	140.14			

ns = not significant **s= Significant**

Appendix 5: Analysis of variance of LAI on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	18.56	9.28	5.75	
Main plot (Variety)	1	6.02	6.02	3.73	0.193^{ns}
Residual (a)	2	3.22	1.61	0.50	
Sub. Plot (Planting Distance)	2	117.70	58.85	18.10	0.001^s
Int. (Variety x Planting Distance)	2	0.43	0.21	0.07	0.93^{ns}
Residual (b)	8	26.00	3.25		
Total	17	171.96			

ns = not significant **s= Significant**

Appendix 6: Analysis of variance of LAI on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	11.13	5.56	32.94	
Main plot (Variety)	1	4.18	4.18	24.76	0.038^s
Residual (a)	2	0.33	0.16	0.03	
Sub. Plot (Planting Distance)	2	118.77	59.38	11.01	0.005^s
Int. (Variety x Planting Distance)	2	0.90	0.45	0.08	0.920^{ns}
Residual (b)	8	43.15	5.39		
Total	17	178.49			

ns = not significant **s= Significant**

Appendix 7: Analysis of variance of LAI on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	15.66	7.83	0.31	
Main plot (Variety)	1	3.39	3.39	0.14	0.748^{ns}
Residual (a)	2	49.80	24.90	1.50	
Sub. Plot (Planting Distance)	2	400.34	200.17	12.08	0.004^{s}
Int. (Variety x Planting Distance)	2	25.40	12.70	0.77	0.496^{ns}
Residual (b)	8	132.52	16.57		
Total	17	627.12			

ns = not significant **s= Significant**

Appendix 8: Analysis of variance on leaf dry matter (kg ha^{-1}) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	372.00	186.00	0.47	
Main Plot (Variety)	1	14006.00	14006.00	35.41	0.027^{s}
Residual (a)	2	791.00	396.00	0.10	
Sub Plot (Planting Distance)	2	66156.00	33078.00	8.51	0.010^{s}
Int. (Variety x Planting Distance)	2	8839.00	4419.00	1.14	0.368^{ns}
Residual (b)	8	31113.00	3889.00		
Total	17	121278.00			

ns = not significant **s= Significant**

Appendix 9: Analysis of variance on leaf dry matter (kg ha^{-1}) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	280.80	140.40	0.06	
Main Plot (Variety)	1	8.30	8.30	0.001	0.957^{ns}
Residual (a)	2	4455.20	2227.60	2.35	
Sub Plot (Planting Distance)	2	74971.80	37485.90	39.48	<.001^{s}
Int. (Variety x Planting Distance)	2	3469.20	1734.60	1.83	0.222^{ns}
Residual (b)	8	7595.80	949.50		
Total	17	90781.10			

ns = not significant **= significant**

Appendix 10: Analysis of variance on leaf dry matter (kg ha^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	6973.00	3486.00	0.99	
Main Plot (Variety)	1	46201.00	46201.00	13.09	0.069^{ns}
Residual (a)	2	7058.00	3529.00	0.88	
Sub Plot (Planting Distance)	2	307856.00	153928.00	38.50	<.001^{s}
Int. (Variety x Planting Distance)	2	10486.00	5243.00	1.31	0.322^{ns}
Residual (b)	8	31984.00	3998.00		
Total	17	410558.00			

ns = not significant **s= Significant**

Appendix 11: Analysis of variance on leaf dry matter (kg ha^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	5438.00	2719.00	3.88	
Main Plot (Variety)	1	0.01	0.01	0.01	0.990^{ns}
Residual (a)	2	1400.00	700.00	0.30	
Sub Plot (Planting Distance)	2	19987.00	9993.00	4.29	0.054^{ns}
Int. (Variety x Planting Distance)	2	5463.00	2732.00	1.17	0.357^{ns}
Residual (b)	8	18628.00	2328.00		
Total	17	50916.00			

ns = not significant **s= significant**

Appendix 12: Analysis of variance on leaf dry matter (kg ha^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	293.20	146.60	3.39	
Main Plot (Variety)	1	48019.00	48019.00	1110.60	$<.001^{s}$
Residual (a)	2	86.50	43.20	0.39	
Sub Plot (Planting Distance)	2	32064.50	16032.20	146.04	$<.001^{s}$
Int. (Variety x Planting Distance)	2	25857.00	12928.50	117.76	$<.001^{s}$
Residual (b)	8	878.30	109.80		
Total	17	107198.50			

ns = not significant **s= Significant**

Appendix 13: Analysis of variance on leaf dry matter (kg ha^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	211.80	105.90	1.89	
Main Plot (Variety)	1	16525.60	16525.60	294.23	0.003^{s}
Residual (a)	2	112.30	56.20	0.21	
Sub Plot (Planting Distance)	2	8274.20	4137.10	15.31	0.002^{s}
Int. (Variety x Planting Distance)	2	7492.00	3746.00	13.87	0.003^{s}
Residual (b)	8	2161.20	270.10		
Total	17	34777.00			

ns = not significant **s= significant**

Appendix 14: Analysis of variance on leaf dry matter (kg ha^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	176.50	88.30	4.18	
Main Plot (Variety)	1	13469.90	13469.90	638.46	0.002^{s}
Residual (a)	2	42.20	21.10	0.19	
Sub Plot (Planting Distance)	2	8623.70	4311.80	38.18	<.001^{s}
Int. (Variety x Planting Distance)	2	8457.90	4228.90	37.44	<.001^{s}
Residual (b)	8	903.60	112.90		
Total	17	31673.70			

ns = not significant **s= significant**

Appendix 15: Analysis of variance on stem dry matter (kg ha^{-1}) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1002.20	501.10	1.97	
Main Plot (Variety)	1	2584.70	2584.70	10.10	0.086^{ns}
Residual (a)	2	509.70	254.90	0.45	
Sub Plot (Planting Distance)	2	12156.80	6078.40	10.81	0.005^{s}
Int. (Variety x Planting Distance)	2	1632.60	816.30	1.45	0.290^{ns}
Residual (b)	8	4499.80	562.50		
Total	17	22385.90			

ns = not significant **s= Significant**

Appendix 16: Analysis of variance on stem dry matter (kg ha^{-1}) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	416.20	208.10	0.26	
Main Plot (Variety)	1	1008.00	1008.00	1.27	0.376^{ns}
Residual (a)	2	1582.90	791.40	1.30	
Sub Plot (Planting Distance)	2	52748.50	26374.30	43.31	<.001^{s}
Int. (Variety x Planting Distance)	2	7595.80	3797.90	6.24	0.023^{s}
Residual (b)	8	4871.30	608.90		
Total	17	68222.70			

ns = not significant **s= significant**

Appendix 17: Analysis of variance on stem dry matter (kg ha^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	2389.00	1194.00	0.13	
Main Plot (Variety)	1	23516.00	23516.00	2.61	0.247^{ns}
Residual (a)	2	17993.00	8997.00	0.74	
Sub Plot (Planting Distance)	2	208497.00	104249.00	8.53	0.010^{s}
Int. (Variety x Planting Distance)	2	2577.00	1289.00	0.11	0.901^{ns}
Residual (b)	8	97736.00	12217.00		
Total	17	352708.00			

ns = not significant **s= Significant**

Appendix 18: Analysis of variance on stem dry matter (kg ha^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	12562.00	6281.00	80.33	
Main Plot (Variety)	1	1189.00	1189.00	15.21	0.060^{ns}
Residual (a)	2	156.00	78.00	0.01	
Sub Plot (Planting Distance)	2	144681.00	72340.00	6.17	0.024^{ns}
Int. (Variety x Planting Distance)	2	7459.00	3730.00	0.32	0.736^{ns}
Residual (b)	8	93814.00	11727.00		
Total	17	259861.00			

ns = not significant **s= significant**

Appendix 19: Analysis of variance on stem dry matter (kg ha^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	58949.00	29474.00	1.22	
Main Plot (Variety)	1	8459.00	8459.00	0.35	0.614^{ns}
Residual (a)	2	48241.00	24121.00	5.60	
Sub Plot (Planting Distance)	2	62721.00	31360.00	7.29	0.016^{s}
Int. (Variety x Planting Distance)	2	2564.00	1282.00	0.30	0.750^{ns}
Residual (b)	8	34435.00	4304.00		
Total	17	215368.00			

ns = not significant **s= Significant**

Appendix 20: Analysis of variance on stem dry matter (kg ha^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	13518.00	6759.00	0.62	
Main Plot (Variety)	1	132269.00	132269.00	12.17	0.073^{ns}
Residual (a)	2	21737.00	10868.00	0.59	
Sub Plot (Planting Distance)	2	109758.00	54879.00	2.97	0.109^{ns}
Int. (Variety x Planting Distance)	2	40382.00	20191.00	1.09	0.381^{ns}
Residual (b)	8	148037.00	18505.00		
Total	17	465701.00			

ns = not significant **s= significant**

Appendix 21: Analysis of variance on stem dry matter (kg ha^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	56618.00	28309.00	0.35	
Main Plot (Variety)	1	74878.00	74878.00	0.93	0.436^{ns}
Residual (a)	2	160647.00	80324.00	1.88	
Sub Plot (Planting Distance)	2	131425.00	65713.00	1.54	0.272^{ns}
Int. (Variety x Planting Distance)	2	50370.00	25185.00	0.59	0.577^{ns}
Residual (b)	8	341971.00	42746.00		
Total	17	815910.00			

ns = not significant **s= Significant**

Appendix 22: Analysis of variance on root dry matter (kg ha^{-1}) on 84 Days after emergence (DAE)

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
REP	2	4545.00	2273.00	0.19	
Main Plot (Variety)	1	770040.00	770040.00	63.64	0.015^{s}
Residual (a)	2	24201.00	12100.00	3.08	
Sub Plot (Planting Distance)	2	820279.00	410140.00	104.36	<.001^{s}
Int. (Variety x Planting Distance)	2	50017.00	25008.00	6.36	0.022^{s}
Residual (b)	8	31440.00	3930.00		
Total	17	1700523.00			

ns = not significant **s= Significant**

Appendix 23: Analysis of variance on root dry matter (kg ha^{-1}) on 112 Days after emergence (DAE)

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
REP	2	1134.00	567.00	6.23	
Main Plot (Variety)	1	27347.00	27347.00	300.33	0.003^{s}
Residual (a)	2	182.00	91.00	0.06	
Sub Plot (planting Distance)	2	314690.00	157345.00	100.97	<.001^{s}
Int. (Variety Planting Distance)	2	76197.00	38098.00	24.45	<.001^{s}
Residual (b)	8	12466.00	1558.00		
Total	17	432016.00			

ns = not significant **s= significant**

Appendix 24: Analysis of variance on root dry matter (kg ha^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	207814.00	103907.00	1.00	
Main Plot (Variety)	1	217602.00	217602.00	2.10	0.284^{ns}
Residual (a)	2	207436.00	103718.00	0.65	
Sub Plot (Planting Distance)	2	297390.00	148695.00	0.93	0.432^{ns}
Int. (Variety x Planting Distance)	2	14892.00	7446.00	0.05	0.955^{ns}
Residual (b)	8	1272650.00	159081.00		
Total	17	2217785.00			

ns = not significant **s= Significant**

Appendix 25: Analysis of variance on root dry matter (kg ha^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	314989.00	157494.00	0.73	
Main Plot (Variety)	1	1330570.00	1330570.00	6.19	0.131^{ns}
Residual (a)	2	430073.00	215037.00	1.41	
Sub Plot (Planting Distance)	2	340972.00	170486.00	1.12	0.373^{ns}
Int. (Variety x Planting Distance)	2	724472.00	362236.00	2.38	0.155^{ns}
Residual (b)	8	1218987.00	152373.00		
Total	17	4360063.00			

ns = not significant **s= significant**

Appendix 26: Analysis of variance on root dry matter (kg ha^{-1}) on 196 Days after emergence (DAE)

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
REP	2	11067.00	5533.00	0.61	
Main Plot (Variety)	1	972269.00	972269.00	107.33	0.009^{s}
Residual (a)	2	18118.00	9059.00	0.29	
Sub Plot (Planting Distance)	2	856964.00	428482.00	13.91	0.002^{s}
Int. (Variety x Planting Distance)	2	450481.00	225241.00	7.31	0.016^{s}
Residual (b)	8	246376.00	30797.00		
Total	17	2555274.00			

ns = not significant **s= Significant**

Appendix 27: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1218331.00	609166.00	2.11	
Main plot (Variety)	1	258418.00	258418.00	0.90	0.444^{ns}
Residual (a)	2	577023.00	288511.00	1.70	
Sub. Plot (Planting Distance)	2	68088.00	34044.00	0.20	0.823^{ns}
Int. (Variety x Planting Distance)	2	131078.00	655394.00	3.85	0.067^{ns}
Residual (b)	8	1360192.00	170024.00		
Total	17	4792840.00			

ns = not significant **s=significant**

Appendix 28: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1254786.00	627393.00	1.10	
Main plot (Variety)	1	89402.00	89402.00	0.16	0.731^{ns}
Residual (a)	2	1141586.00	570793.00	0.74	
Sub. Plot (Planting Distance)	2	1238003.00	61900.00	0.80	0.483^{ns}
Int. (Variety x Planting Distance)	2	1396099.00	698049.00	0.90	0.444^{ns}
Residual (b)	8	6196163.00	774520.00		
Total	17	11316039.00			

ns = not significant **s=significant**

Appendix 29: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	26536136.00	13268068.00	11.17	
Main plot (Variety)	1	3523840.00	3523840.00	2.97	0.227^{ns}
Residual (a)	2	2375457.00	1187728.00	0.30	
Sub. Plot (Planting Distance)	2	21368429.00	10684214.00	2.72	0.125^{ns}
Int. (Variety x Planting Distance)	2	12496679.00	6248339.00	1.59	0.262^{ns}
Residual (b)	8	31385441.00	3923180.00		
Total	17	97685981.00			

ns = not significant **s=significant**

Appendix 30: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	3881136.00	1940568.00	0.16	
Main plot (Variety)	1	270978.00	270978.00	0.02	0.895^{ns}
Residual (a)	2	24535139.00	12267569.00	7.09	
Sub. Plot (Planting Distance)	2	13347537.00	6673768.00	3.86	0.067^{ns}
Int. (Variety x Planting Distance)	2	1912787.00	956393.00	0.55	0.596^{ns}
Residual (b)	8	13846771.00	1730846.00		
Total	17	57794347.00			

ns = not significant **s=significant**

Appendix 31: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1741652.00	870826.00	0.10	
Main plot (Variety)	1	8745022.00	8745022.00	0.97	0.428^{ns}
Residual (a)	2	17992649.00	8996325.00	2.02	
Sub. Plot (Planting Distance)	2	11561686.00	5780843.00	1.30	0.325^{ns}
Int. (Variety x Planting Distance)	2	25976275.00	1298813.00	2.92	0.112^{ns}
Residual (b)	8	35598361.00	4449795.00		
Total	17	101615646.00			

ns = not significant **s=significant**

Appendix 32: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	5186020.00	2593010.00	0.27	
Main plot (Variety)	1	5131740.00	5131740.00	0.53	0.544^{ns}
Residual (a)	2	19511956.00	9755978.00	0.62	
Sub. Plot (Planting Distance)	2	12913038.00	6456519.00	0.41	0.678^{ns}
Int. (Variety x Planting Distance)	2	8779866.00	4389933.00	0.28	0.764^{ns}
Residual (b)	8	126320871.00	15790109.00		
Total	17	177843489.00			

ns = not significant **s=significant**

Appendix 33: Analysis of variance of total accumulated biomass (kg ha^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	13385575.00	6692787.00	0.18	
Main plot (Variety)	1	11043574.00	11043574.00	0.30	0.640^{ns}
Residual (a)	2	74150634.00	37075317.00	2.29	
Sub. Plot (Planting Distance)	2	40578540.00	20289270.00	1.25	0.337^{ns}
Int. (Variety x Planting Distance)	2	77795195.00	38897597.00	2.40	0.153^{ns}
Residual (b)	8	129682875.00	16210359.00		
Total	17	346636393.00			

ns = not significant **s=significant**

Appendix 34: Analysis of variance of root yield (t/ha^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	0.96	0.48	35.79	
Main plot (Variety)	1	0.13	0.13	9.94	0.088^{ns}
Residual (a)	2	0.03	0.01	0.02	
Sub. Plot (Planting Distance)	2	1.93	0.97	1.73	0.237^{ns}
Int. (Variety x Planting Distance)	2	0.07	0.03	0.06	0.943^{ns}
Residual (b)	8	4.45	0.56		
Total	17	7.59			

ns = not significant **s=significant**

Appendix 35: Analysis of variance of root yield (t/ha^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	2.76	1.38	1.37	
Main plot (Variety)	1	1.42	1.42	1.41	0.357 ^{ns}
Residual (a)	2	2.01	1.01	1.20	
Sub. Plot (Planting Distance)	2	1.50	0.74	0.88	0.451^{ns}
Int. (Variety x Planting Distance)	2	2.69	1.34	1.59	0.261^{ns}
Residual (b)	8	6.74	0.84		
Total	17	17.09			

ns = not significant **s=significant**

Appendix 36: Analysis of variance of root yield (t/ha^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	2.62	1.31	18.14	
Main plot (Variety)	1	0.02	0.02	0.26	0.662^{ns}
Residual (a)	2	0.15	0.07	0.28	
Sub. Plot (Planting Distance)	2	2.12	1.06	4.06	0.061^{ns}
Int. (Variety x Planting Distance)	2	4.75	2.37	9.09	0.009^{s}
Residual (b)	8	2.09	0.26		
Total	17	11.75			

ns = not significant **s=significant**

Appendix 37: Analysis of variance of root yield (t/ha^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1.23	0.61	0.78	
Main plot (Variety)	1	2.15	2.15	2.74	0.240^{ns}
Residual (a)	2	1.57	0.78	0.70	
Sub. Plot (Planting Distance)	2	7.16	3.58	3.20	0.096^{ns}
Int. (Variety x Planting Distance)	2	4.99	2.49	2.23	0.170^{ns}
Residual (b)	8	8.95	1.12		
Total	17	26.06			

ns = not significant **s=significant**

Appendix 38: Analysis of variance of root yield (t/ha^{-1}) on 196 Days after emergence (DAE)

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
REP	2	0.69	0.34	0.56	
Main plot (Variety)	1	3.69	3.69	6.08	0.132^{ns}
Residual (a)	2	1.22	0.61	0.35	
Sub. Plot (Planting Distance)	2	24.42	12.21	7.05	0.017^{s}
Int. (Variety x Planting Distance)	2	8.94	4.47	2.58	0.136^{ns}
Residual (b)	8	13.86	1.73		
Total	17	52.82			

ns = not significant **s=significant**

Appendix 39: Analysis of variance of harvest index (%) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	32.84	16.42	0.69	
Main plot (Variety)	1	74.83	74.83	3.12	0.219^{ns}
Residual (a)	2	47.94	23.97	1.67	
Sub. Plot (Planting Distance)	2	53.89	26.95	1.88	0.214^{ns}
Int. (Variety x Planting Distance)	2	7.41	3.71	0.26	0.778^{ns}
Residual (b)	8	114.63	14.33		
Total	17	331.55			

ns = not significant **s=significant**

Appendix 40: Analysis of variance of harvest index (%) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	55.05	27.52	3.43	
Main plot (Variety)	1	39.93	39.93	4.98	0.155^{ns}
Residual (a)	2	16.03	8.01	1.59	
Sub. Plot (Planting Distance)	2	0.15	0.07	0.01	0.986^{ns}
Int. (Variety x Planting Distance)	2	56.94	28.47	5.66	0.029^{s}
Residual (b)	8	40.24	5.03		
Total	17	208.33			

ns = not significant **s=significant**

Appendix 41: Analysis of variance of harvest index (%) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	32.84	16.42	0.69	
Main plot (Variety)	1	74.83	74.83	3.12	0.219^{ns}
Residual (a)	2	47.94	23.97	1.67	
Sub. Plot (Planting Distance)	2	53.89	26.95	1.88	0.214^{ns}
Int. (Variety x Planting Distance)	2	7.41	3.71	0.26	0.778^{ns}
Residual (b)	8	114.63	14.33		
Total	17	331.55			

ns = not significant **s=significant**

Appendix 42: Analysis of variance of harvest index (%) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	8.39	4.19	0.44	
Main plot (Variety)	1	25.87	25.87	2.69	0.243^{ns}
Residual (a)	2	19.22	9.61	1.64	
Sub. Plot (Planting Distance)	2	10.23	5.11	0.87	0.453^{ns}
Int. (Variety x Planting Distance)	2	41.38	20.69	3.54	0.079^{ns}
Residual (b)	8	46.78	5.85		
Total	17	151.88			

ns = not significant **s=significant**

Appendix 43: Analysis of variance of harvest index (%) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	10.71	5.36	11.63	
Main plot (Variety)	1	28.05	28.05	60.91	0.016^{s}
Residual (a)	2	0.92	0.46	0.27	
Sub. Plot (Planting Distance)	2	19.96	9.98	5.74	0.028^{s}
Int. (Variety x Planting Distance)	2	9.89	4.95	2.85	0.117^{s}
Residual (b)	8	13.90	1.74		
Total	17	83.44			

ns = not significant **s=significant**

Appendix 44: Analysis of variance of actual evapotranspiration (mm) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1706.00	853.00	3.82	
Main plot (Variety)	1	5586.00	5586.00	25.04	0.038^{ns}
Residual (a)	2	446.00	223.00	0.22	
Sub. Plot (Planting Distance)	2	623.00	311.00	0.31	0.741^{ns}
Int. (Variety x Planting Distance)	2	2359.00	1180.00	1.18	0.356^{ns}
Residual (b)	8	8009.00	1001.00		
Total	17	18729.00			

ns = not significant **s=significant**

Appendix 45: Analysis of variance of actual evapotranspiration (mm) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	976.40	488.20	1.81	
Main plot (Variety)	1	5537.00	5537.00	20.48	0.046^{ns}
Residual (a)	2	540.80	270.40	0.30	
Sub. Plot (Planting Distance)	2	779.10	389.60	0.43	0.664^{ns}
Int. (Variety x Planting Distance)	2	3133.40	1566.70	1.73	0.237^{ns}
Residual (b)	8	7237.40	904.70		
Total	17	18204.2			

ns = not significant **s=significant**

Appendix 46: Analysis of variance of actual evapotranspiration (mm) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	627.80	313.90	0.21	
Main plot (Variety)	1	5731.60	5731.60	3.85	0.189^{ns}
Residual (a)	2	2977.10	1488.50	2.38	
Sub. Plot (Planting Distance)	2	891.50	445.80	0.71	0.518^{ns}
Int. (Variety x Planting Distance)	2	1079.50	539.80	0.86	0.457^{ns}
Residual (b)	8	4993.10	624.10		
Total	17	16300.60			

ns = not significant **s=significant**

Appendix 47: Analysis of variance of actual evapotranspiration (mm) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	645.10	322.50	0.31	
Main plot (Variety)	1	12740.50	12740.50	2.64	0.246^{ns}
Residual (a)	2	2076.50	1038.20	1.44	
Sub. Plot (Planting Distance)	2	1522.80	761.40	1.06	0.392^{ns}
Int. (Variety x Planting Distance)	2	104.00	52.00	0.07	0.392^{ns}
Residual (b)	8	5772.10	721.50		
Total	17	12860.90			

ns = not significant **s=significant**

Appendix 48: Analysis of variance of actual evapotranspiration (mm) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	4625.00	2312.50	1.79	
Main plot (Variety)	1	59.80	59.80	0.05	0.850^{ns}
Residual (a)	2	2585.20	1292.60	1.40	
Sub. Plot (Planting Distance)	2	1743.50	871.70	0.95	0.428^{ns}
Int. (Variety x Planting Distance)	2	112.40	56.20	0.06	0.941^{ns}
Residual (b)	8	7368.30	921.00		
Total	17	16494.20			

ns = not significant **s=significant**

Appendix 49: Analysis of variance of actual evapotranspiration (mm) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	8230.00	4115.00	13.44	
Main plot (Variety)	1	984.00	984.00	3.21	0.215^{ns}
Residual (a)	2	612.00	306.00	0.25	
Sub. Plot (Planting Distance)	2	4577.00	2288.00	1.88	0.213^{ns}
Int. (Variety x Planting Distance)	2	477.00	238.00	0.20	0.826^{ns}
Residual (b)	8	9714.00	1214.00		
Total	17	24595.00			

ns = not significant **s=significant**

Appendix 50: Analysis of variance of actual evapotranspiration (mm) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	6028.00	3014.00	22.50	
Main plot (Variety)	1	2198.00	2198.00	16.41	0.056^{ns}
Residual (a)	2	268.00	134.00	0.09	
Sub. Plot (Planting Distance)	2	5155.00	2577.00	1.82	0.223^{ns}
Int. (Variety x Planting Distance)	2	64.00	32.00	0.02	0.978^{ns}
Residual (b)	8	11307.00	1413.00		
Total	17	25019.00			

ns = not significant **s=significant**

Appendix 51: Analysis of variance of transpiration (mm^{-1}) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	14.00	7.00	0.02	
Main plot (Variety)	1	3808.00	3808.00	9.01	0.095^{ns}
Residual (a)	2	845.00	423.00	0.42	
Sub. Plot (Planting Distance)	2	21356.00	10678.00	10.50	0.006^{s}
Int. (Variety x Planting Distance)	2	6551.00	3275.00	3.22	0.094^{ns}
Residual (b)	8	8125.00	1016.00		
Total	17	40699.00			

ns = not significant **s=significant**

Appendix 52: Analysis of variance of transpiration (mm^{-1}) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1311.00	656.00	0.59	
Main plot (Variety)	1	6821.00	6821.00	6.18	0.131^{ns}
Residual (a)	2	2209.00	1105.00	1.00	
Sub. Plot (Planting Distance)	2	29531.00	14766.00	13.36	0.003^{s}
Int. (Variety x Planting Distance)	2	8810.00	4405.00	3.99	0.063^{ns}
Residual (b)	8	8842.00	1105.00		
Total	17	57524.00			

ns = not significant **s=significant**

Appendix 53: Analysis of variance of transpiration (mm^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	971.80	485.90	0.61	
Main plot (Variety)	1	7272.20	7272.20	9.15	0.094^{ns}
Residual (a)	2	1588.90	794.50	1.47	
Sub. Plot (Planting Distance)	2	32441.30	16220.60	29.97	$<.001^{s}$
Int. (Variety x Planting Distance)	2	7519.20	3759.60	6.95	0.018^{s}
Residual (b)	8	4330.20	541.30		
Total	17	54123.70			

ns = not significant **s=significant**

Appendix 54: Analysis of variance of transpiration (mm^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	572.30	286.10	0.37	
Main plot (Variety)	1	3866.10	3866.10	5.04	0.154^{ns}
Residual (a)	2	1532.80	766.40	1.29	
Sub. Plot (Planting Distance)	2	28118.80	14059.40	23.74	$<.001^{s}$
Int. (Variety x Planting Distance)	2	11989.40	5994.70	10.12	$<.006^{ns}$
Residual (b)	8	4737.60	592.20		
Total	17	50817.00			

ns = not significant **s=significant**

Appendix 55: Analysis of variance of transpiration (mm^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	3267.20	1633.60	7.98	
Main plot (Variety)	1	309.20	309.20	1.51	0.344^{ns}
Residual (a)	2	409.40	204.70	0.29	
Sub. Plot (Planting Distance)	2	39794.20	19897.10	28.15	$<.001^{s}$
Int. (Variety x Planting Distance)	2	14560.40	7280.20	10.30	0.006^{s}
Residual (b)	8	5655.50	706.90		
Total	17	63996.00			

ns = not significant **s=significant**

Appendix 56: Analysis of variance of transpiration (mm^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	9396.00	4698.00	4.71	
Main plot (Variety)	1	1465.00	1465.00	1.47	0.349^{ns}
Residual (a)	2	1994.00	997.00	0.88	
Sub. Plot (Planting Distance)	2	46356.00	23178.00	20.54	$<.001^{s}$
Int. (Variety x Planting Distance)	2	10213.00	5106.00	4.53	0.048^{ns}
Residual (b)	8	9028.00	1128.00		
Total	17	78452.00			

ns = not significant **s=significant**

Appendix 57: Analysis of variance of transpiration (mm^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	4145.00	2072.00	1.52	
Main plot (Variety)	1	2870.00	2870.00	2.11	0.283^{ns}
Residual (a)	2	2718.00	1359.00	1.19	
Sub. Plot (Planting Distance)	2	41070.00	20535.00	17.92	0.001^{s}
Int. (Variety x Planting Distance)	2	13679.00	6840.00	5.97	0.026^{s}
Residual (b)	8	9168.00	1146.00		
Total	17	73652.00			

ns = not significant **s=significant**

Appendix 58: Analysis of variance of soil evaporation (mm^{-1}) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1449.70	724.80	0.64	
Main plot (Variety)	1	166.20	166.20	0.15	0.739^{ns}
Residual (a)	2	2270.30	1135.10	2.01	
Sub. Plot (Planting Distance)	2	26794.10	13397.00	23.71	<.001^{s}
Int. (Variety x Planting Distance)	2	12096.70	6048.30	10.71	0.005^{s}
Residual (b)	8	4519.70	565.00		
Total	17	47296.70			

ns = not significant **s=significant**

Appendix 59: Analysis of variance of soil evaporation (mm^{-1}) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1482.00	741.00	0.31	
Main plot (Variety)	1	68.10	68.10	0.03	0.882^{ns}
Residual (a)	2	4815.60	2407.80	3.11	
Sub. Plot (Planting Distance)	2	30051.30	15025.60	19.40	<.001^{s}
Int. (Variety x Planting Distance)	2	13770.20	6885.10	8.89	0.009^{s}
Residual (b)	8	6196.20	774.50		
Total	17	56383.30			

ns = not significant **s=significant**

Appendix 60: Analysis of variance of soil evaporation (mm^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1717.00	858.50	0.36	
Main plot (Variety)	1	92.00	92.00	0.04	0.862^{ns}
Residual (a)	2	4720.90	2360.40	2.99	
Sub. Plot (Planting Distance)	2	31195.90	15598.00	19.78	<.001^{s}
Int. (Variety x Planting Distance)	2	14312.80	7156.40	9.08	0.009^{s}
Residual (b)	8	6307.30	788.40		
Total	17	58345.90			

ns = not significant **s=significant**

Appendix 61: Analysis of variance of soil evaporation (mm^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1758.60	879.30	0.38	
Main plot (Variety)	1	96.10	96.10	0.04	0.858^{ns}
Residual (a)	2	4685.70	2342.80	2.93	
Sub. Plot (Planting Distance)	2	31351.20	15675.60	19.63	<.001^{s}
Int. (Variety x Planting Distance)	2	14319.50	7159.80	8.97	0.009^{s}
Residual (b)	8	6387.40	798.40		
Total	17	58598.50			

ns = not significant **s=significant**

Appendix 62: Analysis of variance of soil evaporation (mm^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1852.00	926.00	0.40	
Main plot (Variety)	1	96.60	96.60	0.04	0.858^{ns}
Residual (a)	2	4685.30	2342.60	3.04	
Sub. Plot (Planting Distance)	2	31055.70	15527.80	20.13	<.001^{s}
Int. (Variety x Planting Distance)	2	14128.20	7064.10	9.16	0.009^{s}
Residual (b)	8	6171.60	771.50		
Total	17	57989.40			

ns = not significant **s=significant**

Appendix 63: Analysis of variance of soil evaporation (mm^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1938.00	969.00	0.40	
Main plot (Variety)	1	48.00	48.00	0.02	0.901^{ns}
Residual (a)	2	4804.10	2402.10	3.14	
Sub. Plot (Planting Distance)	2	31309.70	15654.90	20.46	<.001^{s}
Int. (Variety x Planting Distance)	2	14192.80	7096.40	9.28	0.008^{s}
Residual (b)	8	6120.40	765.00		
Total	17	58413.10			

ns = not significant **s=significant**

Appendix 64: Analysis of variance of soil evaporation (mm^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	2010.60	1005.30	0.43	
Main plot (Variety)	1	44.20	44.20	0.02	0.903^{ns}
Residual (a)	2	4677.00	2338.50	3.01	
Sub. Plot (Planting Distance)	2	31498.10	15749.00	20.27	<.001^{s}
Int. (Variety x Planting Distance)	2	14045.90	7023.00	9.04	0.009^{s}
Residual (b)	8	6216.60	777.10		
Total	17	58492.50			

ns = not significant **s=significant**

Appendix 65: Analysis of variance of water use efficiency (kg DM ha^{-1} mm^{-1}) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	0.04111	0.02056	1.95	
Main plot (Variety)	1	0.10889	0.10889	10.32	0.085^{ns}
Residual (a)	2	0.02111	0.01056	0.34	
Sub. Plot (Planting Distance)	2	1.14111	0.57056	18.18	0.001^{s}
Int. (Variety x Planting Distance)	2	0.05444	0.02722	0.87	0.456^{ns}
Residual (b)	8	0.25111	0.03139		
Total	17	1.61778			

ns = not significant **s=significant**

Appendix 66: Analysis of variance of water use efficiency (kg DM ha^{-1}mm^{-1}) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	0.00444	0.00222	0.25	
Main plot (Variety)	1	0.05556	0.05556	6.25	0.130^{ns}
Residual (a)	2	0.01778	0.00889	0.34	
Sub. Plot (Planting Distance)	2	1.07111	0.53556	20.29	<.001^{s}
Int. (Variety x Planting Distance)	2	0.12444	0.06222	2.36	0.157^{ns}
Residual (b)	8	0.21111	0.02639		
Total	17	1.48444			

ns = not significant **s=significant**

Appendix 67: Analysis of variance of water use efficiency (kg DM ha-1mm^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	0.3411	0.1706	0.98	
Main plot (Variety)	1	1.5606	1.5606	8.97	0.096^{ns}
Residual (a)	2	0.3478	0.1739	1.60	
Sub. Plot (Planting Distance)	2	1.0844	0.5422	4.98	0.039^{s}
Int. (Variety x Planting Distance)	2	0.0844	0.0422	0.39	0.691^{ns}
Residual (b)	8	0.8711	0.1089		
Total	17	4.2894			

ns = not significant **s=significant**

Appendix 68: Analysis of variance of water use efficiency (kg DM ha^{-1}mm^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	0.0044	0.0022	0.06	
Main plot (Variety)	1	0.1089	0.1089	3.06	0.002^{ns}
Residual (a)	2	0.0711	0.0356	0.31	
Sub. Plot (Planting Distance)	2	3.5678	1.7839	15.55	0.020^{s}
Int. (Variety x Planting Distance)	2	0.3011	0.1506	1.31	0.321^{ns}
Residual (b)	8	0.9178	0.1147		
Total	17	4.9711			

ns = not significant **s=significant**

Appendix 69: Analysis of variance of water use efficiency (kg DM ha^{-1}mm^{-1}) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1.7478	0.8739	1.10	
Main plot (Variety)	1	1.0756	1.0756	1.37	0.365^{ns}
Residual (a)	2	1.5878	0.7939	1.44	
Sub. Plot (Planting Distance)	2	1.4211	0.7106	1.29	0.326^{ns}
Int. (Variety x Planting Distance)	2	0.0211	0.0106	0.02	0.981^{ns}
Residual (b)	8	4.3978	0.5497		
Total	17	10.2511			

ns = not significant **s=significant**

Appendix 70: Analysis of variance of water use efficiency (kg DM ha^{-1}mm^{-1}) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	1.5811	0.7906	1.83	
Main plot (Variety)	1	1.8050	1.8050	4.18	0.178^{ns}
Residual (a)	2	0.8633	0.4317	0.86	
Sub. Plot (Planting Distance)	2	0.9078	0.4539	0.91	0.442^{ns}
Int. (Variety x Planting Distance)	2	0.4900	0.2450	0.49	0.630^{ns}
Residual (b)	8	4.0089	0.5011		
Total	17	9.6561			

ns = not significant **s=significant**

Appendix 71: Analysis of variance of water use efficiency (kg DM ha^{-1}mm^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	0.3878	0.1939	0.79	
Main plot (Variety)	1	6.1250	6.1250	25.00	0.038^{s}
Residual (a)	2	0.4900	0.2450	1.37	
Sub. Plot (Planting Distance)	2	1.2678	0.6339	3.53	0.080^{ns}
Int. (Variety x Planting Distance)	2	0.2233	0.1117	0.62	0.561^{ns}
Residual (b)	8	1.4356	0.1794		
Total	17	9.9294			

ns = not significant **s=significant**

Appendix 72: Analysis of variance of transpiration use efficiency (kg DM $ha^{-1}mm^{-1}$) on 28 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	20.72	10.36	1.26	
Main plot (Variety)	1	13.82	13.82	1.68	0.324^{ns}
Residual (a)	2	16.40	8.20	1.54	
Sub. Plot (Planting Distance)	2	163.23	81.62	15.33	0.002^{s}
Int. (Variety x Planting Distance)	2	67.08	33.54	6.30	0.023^{s}
Residual (b)	8	42.59	5.32		
Total	17	323.83			

ns = not significant **s=significant**

Appendix 73: Analysis of variance of transpiration use efficiency (kg DM $ha^{-1}mm^{-1}$) on 56 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	21.67	10.83	0.42	
Main plot (Variety)	1	2.08	2.08	0.08	0.802^{ns}
Residual (a)	2	51.12	25.56	1.28	
Sub. Plot (Planting Distance)	2	48.12	24.06	1.20	0.350^{ns}
Int. (Variety x Planting Distance)	2	89.93	44.97	2.24	0.168^{ns}
Residual (b)	8	160.33	20.04		
Total	17	373.26			

ns = not significant **s=significant**

Appendix 74: Analysis of variance of transpiration use efficiency (kg DM ha^{-1}mm^{-1}) on 84 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	29.512	14.76	20.79	
Main plot (Variety)	1	68.21	68.21	96.12	0.010^{s}
Residual (a)	2	1.42	0.71	0.16	
Sub. Plot (Planting Distance)	2	95.29	47.65	10.79	0.005^{s}
Int. (Variety x Planting Distance)	2	38.21	19.11	4.33	0.053^{ns}
Residual (b)	8	35.34	4.42		
Total	17	267.99			

ns = not significant **s=significant**

Appendix 75: Analysis of variance of transpiration use efficiency (kg DM ha^{-1}mm^{-1}) on 112 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	6.24	3.12	0.34	
Main plot (Variety)	1	0.01	0.01	0.001	0.979^{ns}
Residual (a)	2	18.46	9.23	0.74	
Sub. Plot (Planting Distance)	2	223.58	111.79	8.93	0.009^{s}
Int. (Variety x Planting Distance)	2	18.68	9.34	0.75	0.504^{ns}
Residual (b)	8	100.09	12.51		
Total	17	367.06			

ns = not significant **s=significant**

Appendix 76: Analysis of variance of transpiration use efficiency (kg DM $ha^{-1}mm^{-1}$) on 140 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	2.39	1.19	1.21	
Main plot (Variety)	1	23.12	23.12	23.53	0.040^{s}
Residual (a)	2	1.97	0.98	0.21	
Sub. Plot (Planting Distance)	2	84.44	42.22	9.06	0.009^{s}
Int. (Variety x Planting Distance)	2	12.12	6.06	1.30	0.324^{s}
Residual (b)	8	37.28	4.66		
Total	17	161.32			

ns = not significant **s=significant**

Appendix 77: Analysis of variance of transpiration use efficiency (kg DM $ha^{-1}mm^{-1}$) on 168 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	50.72	25.36	13.23	
Main plot (Variety)	1	33.57	33.57	17.50	0.053^{ns}
Residual (a)	2	3.84	1.92	0.36	
Sub. Plot (Planting Distance)	2	26.49	13.24	2.49	0.145^{ns}
Int. (Variety x Planting Distance)	2	34.59	17.29	3.25	0.093^{ns}
Residual (b)	8	42.60	5.33		
Total	17	191.80			

ns = not significant **s=significant**

Appendix 78: Analysis of variance of transpiration use efficiency (kg DM ha^{-1}mm^{-1}) on 196 Days after emergence (DAE)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
REP	2	80.02	40.01	1084.09	
Main plot (Variety)	1	87.56	87.56	2372.56	<.001^{s}
Residual (a)	2	0.07	0.04	0.01	
Sub. Plot (Planting Distance)	2	45.46	22.73	4.57	0.048^{s}
Int. (Variety x Planting Distance)	2	64.37	32.19	6.47	0.021^{s}
Residual (b)	8	39.83	4.98		
Total	17	317.30			

ns = not significant **s=significant**

Appendix 79: Regression analysis between total accumulated biomass and actual evapotranspiration of plant density 10,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	142082.00	142082.00	105.38	<.001^{s}
Residual	5	6742.00	1348.00		
Total	6	148824.00	24804.00		

ns = not significant **s=significant**

Appendix 80: Regression analysis between total accumulated biomass and actual evapotranspiration of plant density 13,333 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	140718.00	140718.00	68.66	<.001^{s}
Residual	5	10248.00	2050.00		
Total	6	150966.00	25161.00		

ns = not significant **s=significant**

Appendix 81: Regression analysis between total accumulated biomass and actual evapotranspiration of plant density 20,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	142324.00	142324.00	49.70	< 0.001^{s}
Residual	5	14318.00	2864.00		
Total	6	156642.00	26107.00		

ns = not significant **s=significant**

Appendix 82: Regression analysis between total accumulated biomass and actual evapotranspiration of plant density 10,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	113544.00	113544.00	28.92	0.003^{s}
Residual	5	19633.00	3927.00		
Total	6	133178.00	22196.00		

ns = not significant **s=significant**

Appendix 83: Regression analysis between total accumulated biomass and actual evapotranspiration of plant density 13,333 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	106144.00	106144.00	37.08	0.002^{s}
Residual	5	14313.00	2863.00		
Total	6	120457.00	20076.00		

ns = not significant **s=significant**

Appendix 84: Regression analysis between total accumulated biomass and actual evapotranspiration of plant density 20,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	143762.00	143762.00	37.91	0.002^{s}
Residual	5	18960.00	3792.00		
Total	6	162722.00	27120.00		

ns = not significant **s=significant**

Appendix 85: Regression analysis between water use efficiency and total accumulated biomass of plant density 10,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	76.24	76.24	129.63	<.001^{s}
Residual	5	2.94	0.59		
Total	6	79.18	13.19		

ns = not significant **s=significant**

Appendix 86: Regression analysis between water use efficiency and total accumulated biomass of plant density 13,333 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	78.62	78.62	109.64	<.001^{s}
Residual	5	3.58	0.72		
Total	6	82.210	13.70		

ns = not significant **s=significant**

Appendix 87: Regression analysis between water use efficiency and total accumulated biomass of plant density 20,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	64.57	64.57	68.15	< 0.001^{s}
Residual	5	4.74	0.95		
Total	6	69.30	11.55		

ns = not significant **s=significant**

Appendix 88: Regression analysis between water use efficiency and total accumulated biomass of plant density 10,000 plants ha^{-1} for Capevars Bankye

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
Regression	1	29.26	29.26	44.64	0.001^{s}
Residual	5	3.28	0.66		
Total	6	32.53	5.42		

ns = not significant **s=significant**

Appendix 89: Regression analysis between water use efficiency and total accumulated biomass of plant density 13,333 plants ha^{-1} for Capevars Bankye

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
Regression	1	32.96	32.96	39.05	0.002^{s}
Residual	5	4.22	0.85		
Total	6	37.18	6.196		

ns = not significant **s=significant**

Appendix 90: Regression analysis between water use efficiency and total accumulated biomass of plant density 20,000 plants ha^{-1} for Capevars Bankye

Source of Variation	**Degree of Freedom**	**Sum of Squares**	**Mean Square**	**Variance Ratio**	**p-value 5%**
Regression	1	34.39	34.39	28.82	0.003^{s}
Residual	5	5.97	1.19		
Total	6	40.36	6.73		

ns = not significant **s=significant**

Appendix 91: Regression analysis between water use efficiency and total accumulated biomass of plant density 10,000 plants ha^{-1} (pooled data for all cassava varieties).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	111.96	111.96	199.63	<.001^{s}
Residual	12	6.73	0.56		
Total	13	118.69	9.129		

ns = not significant **s=significant**

Appendix 92: Regression analysis between water use efficiency and total accumulated biomass of plant density 13,333 plants ha^{-1} (pooled data for all cassava varieties).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	112.58	112.58	167.88	<.001^{s}
Residual	12	8.047	0.67		
Total	13	120.62	9.278		

ns = not significant **s=significant**

Appendix 93: Regression analysis between water use efficiency and total accumulated biomass of plant density 20,000 plants ha^{-1} (pooled data for all cassava varieties)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	99.47	99.47	100.75	<.001^{s}
Residual	12	11.85	0.99		
Total	13	111.32	8.56		

ns = not significant **s=significant**

Appendix 94: Regression analysis between actual evapotranspiration (AET) and leaf area (LAI) of plant density 10,000 plants ha^{-1} for Bankye Hemaa.

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	114259.00	114259.00	16.53	0.010^{s}
Residual	5	34565.00	6913.00		
Total	6	148824.00	24804.00		

ns = not significant **s=significant**

Appendix 95: Regression analysis between actual evapotranspiration (AET) and leaf area index (LAI) of plant density 13,333 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	120259.00	19272.00	19.58	0.007^{s}
Residual	5	30707.00	6141.00		
Total	6	150966.00	25161.00		

ns = not significant **s=significant**

Appendix 96: Regression analysis between actual evapotranspiration (AET) and leaf area index (LAI) of plant density 20,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	131225.00	1131225.00	25.81	0.004^{s}
Residual	5	25417.00	5083.00		
Total	6	156642.00	26107.00		

ns = not significant **s=significant**

Appendix 97: Regression analysis between actual evapotranspiration (AET) and leaf area (LAI) of plant density 10,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	111643.00	111643.00	25.92	0.004^{s}
Residual	5	21535.00	4307.00		
Total	6	133178.00	22196.00		

ns = not significant **s=significant**

Appendix 98: Regression analysis between actual evapotranspiration (AET) and leaf area index (LAI) of plant density 13,333 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	59021.00	59021.00	9.62	0.027^{s}
Residual	5	30691.00	6138.00		
Total	6	89712.00	14952.00		

ns = not significant **s=significant**

Appendix 99: Regression analysis between actual evapotranspiration (AET) and leaf area index (LAI) of plant density 20,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	81964.00	81964.00	5.07	0.074^{ns}
Residual	5	80758.00	16152.00		
Total	6	162722.00	27120.00		

ns = not significant **s=significant**

Appendix 100: Regression analysis between soil evaporation and leaf area (LAI) of plant density 10,000 plants ha^{-1} (pooled data for all cassava varieties)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	219104.00	219104.00	39.62	<.001^{s}
Residual	12	66355.00	5530.00		
Total	13	285459.00	21958.00		

ns = not significant **s=significant**

Appendix 101: Regression analysis between soil evaporation and leaf area index (LAI) of plant density 13,333 plants ha^{-1} (pooled data for all cassava varieties)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	176962.00	176962.00	33.32	<.001^{s}
Residual	12	63729.00	5311.00		
Total	13	240691.00	18515.00		

ns = not significant **s=significant**

Appendix 102: Regression analysis between actual evapotranspiration (AET) and leaf area index (LAI) of plant density 20,000 plants ha^{-1} (pooled data for all cassava varieties)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	213515.00	213515.00	24.13	<0.001^{s}
Residual	12	106199.00	8850.00		
Total	13	319714.00	24593.00		

ns = not significant **s=significant**

Appendix 103: Regression analysis between water use efficiency and root yield of plant density 10,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	388.48	388.48	216.69	<.001^{s}
Residual	5	8.964	1.79		
Total	6	397.44	66.24		

ns = not significant **s=significant**

Appendix 104: Regression analysis between water use efficiency and root yield of plant density 13,333 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	336.19	336.19	130.94	<.001^{s}
Residual	5	12.84	2.57		
Total	6	349.02	58.17		

ns = not significant **s=significant**

Appendix 105: Regression analysis between water use efficiency and root yield of plant density 20,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	528.07	528.07	151.06	<.001^{s}
Residual	5	17.48	3.49		
Total	6	545.55	90.923		

ns = not significant **s=significant**

Appendix 106: Regression analysis between water use efficiency and root yield of plant density 10,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	434.19	434.19	334.59	<.001^{s}
Residual	5	6.48	1.29		
Total	6	440.68	73.45		

ns = not significant **s=significant**

Appendix 107: Regression analysis between water use efficiency and root yield of plant density 13,333 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	210.78	210.78	85.31	<.001^{s}
Residual	5	12.35	2.47		
Total	6	223.14	37.19		

ns = not significant **s=significant**

Appendix 108: Regression analysis between water use efficiency and root yield of plant density 20,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	374.10	374.10	93.66	<.001^{s}
Residual	5	19.97	3.99		
Total	6	394.07	65.68		

ns = not significant **s=significant**

Appendix 109: Regression analysis between water use efficiency and root yield of plant density 10,000 plants ha^{-1} (pooled data for all cassava varieties).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	800.06	800.06	250.70	<.001^{s}
Residual	12	38.30	3.19		
Total	13	838.36	64.49		

ns = not significant **s=significant**

Appendix 110: Regression analysis between water use efficiency and root yield of plant density 13,333 plants ha^{-1} (pooled data for all cassava varieties).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	550.17	550.17	224.30	<.001^{s}
Residual	12	29.43	2.45		
Total	13	579.60	44.59		

ns = not significant **s=significant**

Appendix 111: Regression analysis between water use efficiency and root yield of plant density 20,000 plants ha^{-1} (pooled data for all cassava varieties)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	905.62	905.62	290.01	<.001^{s}
Residual	12	37.47	3.12		
Total	13	943.09	72.55		

ns = not significant **s=significant**

Appendix 112: Regression analysis between transpiration use efficiency and root yield of plant density 10,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	874.09	874.09	923.55	<.001^{s}
Residual	5	2.84	0.95		
Total	6	876.93	219.23		

ns = not significant **s=significant**

Appendix 113: Regression analysis between transpiration use efficiency and root yield of plant density 13,333 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	265.87	265.87	398.78	<.001^{s}
Residual	5	2.00	0.67		
Total	6	267.87	66.97		

ns = not significant **s=significant**

Appendix 114: Regression analysis between transpiration use efficiency and root yield of plant density 20,000 plants ha^{-1} for Bankye Hemaa

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	587.67	587.67	201.49	<.001^{s}
Residual	5	8.75	2.92		
Total	6	596.42	149.12		

ns = not significant **s=significant**

Appendix 115: Regression analysis between transpiration use efficiency and root yield of plant density 10,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	523.99	523.99	169.61	<.001^{s}
Residual	5	9.27	3.11		
Total	6	533.26	133.31		

ns = not significant **s=significant**

Appendix 116: Regression analysis between transpiration use efficiency and root yield of plant density 13,333 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	31.51	31.51	2.64	0.202^{ns}
Residual	5	35.77	11.92		
Total	6	67.27	16.82		

ns = not significant **s=significant**

Appendix 117: Regression analysis between transpiration use efficiency and root yield of plant density 20,000 plants ha^{-1} for Capevars Bankye

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	272.57	272.57	28.00	0.013^{s}
Residual	5	29.20	9.73		
Total	6	301.77	75.44		

ns = not significant **s=significant**

Appendix 118: Regression analysis between transpiration use efficiency and root yield of plant density 10,000 plants ha^{-1} (pooled data for all cassava varieties).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	1426.73	1426.73	877.91	<.001^{s}
Residual	12	13.00	1.63		
Total	13	1439.73	159.97		

ns = not significant **s=significant**

Appendix 119: Regression analysis between transpiration use efficiency and root yield of plant density 13,333 plants ha^{-1} (pooled data for all cassava varieties).

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	353.64	353.64	57.85	<.001^{s}
Residual	12	48.90	6.11		
Total	13	402.54	44.73		

ns = not significant **s=significant**

Appendix 120: Regression analysis between transpiration use efficiency and root yield of plant density 20,000 plants ha^{-1} (pooled data for all cassava varieties)

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	Variance Ratio	p-value 5%
Regression	1	880.95	880.95	165.14	<.001^{s}
Residual	12	42.68	5.34		
Total	13	923.63	102.63		

ns = not significant **s=significant**