GROWTH AND YIELD OF SWEET POTATO (*Ipomoea batatas L.*) MONOCROPS VERSUS INTERCROPS IN THE SEMI-ARID KATUMANI, KENYA †

[CRECIMIENTO Y RENDIMIENTO DE MONOCULTIVOS DE PATATA DULCE (*Ipomoea batatas* L.) VERSUS INTERCULTIVOS EN EL SEMIARIDO KATUMANI, KENIA]

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SUMMARY

Background: Sweet potato producers in Kenya practice either sole cropping of or relay cropping and rarely do intercropping which aims at maximizing on time and space. **Objective.** To assess the relative performance of sweet potato under various cropping systems. **Methodology:** This study was conducted in Katumani, Kenya for two seasons; 2018/2019 and 2019/2020. The treatments comprised of sole cropping of Kabode, sole cropping of Bungoma, Kabode + common bean, Bungoma + common bean, and sole cropping of common beans (*Mwezi mbili*) were laid out in a randomized complete block design (RCBD) in 3 replications. Monocropped sweet potato and beans served as the control treatment. Weather data, leaf area, leaf area index, vine length, and percent canopy cover were collected throughout the cropping period. The data were analysed by a two-way ANOVA at 0.05% significance level followed by a Pearson's correlation analysis on the extent to which length of vines, percent canopy cover, leaf area index, and weather parameters; ETo, aridity index, and rainfall influenced the attained tuber yields. **Results:** Intercropping significantly ($p < 0.05$) reduced sweet potato yields of Kabode and Bungoma varieties by 19.3% and 44%, respectively. Monocropped Kabode yielded 31.4 t ha^{-1}, significantly ($p< 0.05$) higher than monocropped Bungoma with 23.9 t ha^{-1} whereas their common bean intercrops yielded 26.2 t ha^{-1} and 18.1 t ha^{-1}, respectively. Correlation analysis showed that rainfall, ETo, LAI, vine length, and percent canopy cover negatively affected tuber yields. **Implication:** Land equivalent ratio revealed that intercropping sweet potato varieties with common beans was biologically efficient and that the percentage of the land saved averagely ranged from 8% to 33%. More studies should be conducted to determine the extent of sweet potato allelopathy on companion crops and nutrient use under intercropping systems. **Conclusion:** Yield stability analysis showed that orange-fleshed Kabode was the most stable variety across seasons to be grown in Katumani.

Keywords: Cropping systems; Leaf area index; Vine length; Land equivalent ratio; Aridity index.

RESUMEN

Antecedentes: Los productores de camote en Kenia practican ya sea el cultivo único o el cultivo de relevo y rara vez hacen cultivos intercalados que buscan maximizar el tiempo y el espacio. **Objetivo.** Evaluar el desempeño relativo de la batata en varios sistemas de cultivo. **Metodología:** Este estudio se realizó en Katumani, Kenia durante dos temporadas; 2018/2019 y 2019/2020. Los tratamientos compuestos de cultivo único de Kabode, cultivo único de Bungoma, Kabode + frijol común, Bungoma + frijol común y cultivo único de frijol común (Mwezi mbili) se dispusieron en un diseño de bloques completos al azar (RCBD) en 3 repeticiones. El monocultivo de camote y frijoles sirvió como tratamiento control. Se recopilaron datos meteorológicos, área foliar, índice de área foliar, longitud de las enredaderas y porcentaje de cobertura del dosel durante todo el período de cultivo. Los datos se analizaron mediante un ANOVA de dos vías a un nivel de significancia de 0.05% seguido de un análisis de correlación de Pearson sobre la extensión de la longitud de las enredaderas, el porcentaje de cobertura del dosel, el índice de área foliar y los parámetros climáticos; la ETo, el índice de aridez y las lluvias influyeron en los rendimientos de tubérculos obtenidos. **Resultados:** El cultivo intercalado redujo significativamente ($p <0.05$) los rendimientos de camote de las variedades Kabode y Bungoma en 19.3% y 44%, respectivamente. Kabode en monocultivo rindió 31.4 t ha^{-1}, significativamente ($p <0.05$) más alto que Bungoma en monocultivo con 23.9 t ha^{-1} mientras que sus cultivos intercalados de frijol común rindieron 26.2 t ha^{-1} y 18.1 t ha^{-1}, respectivamente. El análisis de correlación mostró que la lluvia, ETo, LAI, la longitud de la vid y el porcentaje de cobertura del dosel afectaron negativamente los rendimientos de tubérculos. **Implicación:** La proporción de equivalentes de tierra reveló que el cultivo intercalado de variedades de camote con frijoles comunes

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fue biológicamente eficiente y que el porcentaje de tierra ahorrada en promedio osciló entre el 8% y el 33%. Se deben realizar más estudios para determinar el alcance de la alelopatía de la batata en cultivos asociados y el uso de nutrientes en sistemas de cultivos intercalados. **Conclusión:** El análisis de estabilidad del rendimiento mostró que la Kabode de pulpa anaranjada era la variedad más estable a lo largo de las temporadas para cultivar en Katumani.

Palabras clave: sistemas de cultivo; índice de área foliar; longitud de la vid; razón equivalente de tierra; índice de aridez.

INTRODUCTION

Sweet potato *(Ipomoea batatas L)* (Huaman, 1992); is an important root crop after Irish potato (*Solanum tuberosum)* (Salaman and Burton, 1985), in Sub Saharan Africa, as well as a vital staple crop (Janssens *et al*., 2014; Affognon *et al*., 2015; McEwan *et al*., 2015). It is an annual crop that morphologically comprises of vines, leaves, and tubers. The crop exhibits either an erect growth habit posing approximately 1-2m of vine length whereas creeping varieties spread on the soil to approximately 2-3m (Nugroho and Widaryanto, 2017). Intercropping sweet potato is a common practice in the semi-arid areas of Kenya (Weerarathne *et al*., 2017).

Integrating legumes such as beans into cropping systems is a vital component of most traditional farming systems, providing an advantage by optimizing on limited resources and maximizing yields with minimal input over a small production area (Kwena *et al*., 2018). Growth resources such as water, nutrients, and light are fully absorbed, hence converted to crop biomass therefore signifying resource use, a characteristic of any cropping system. However, the existence of variances in the individual crops' ability to compete for growth factors between intercrop components may be observed in yield aspects (Amini *et al*., 2013). Legumes raise the soil's nitrogen pool through atmospheric di-nitrogen fixation in association with rhizobia bacteria in roots thereby availing it to use by the consecutive or slow-maturing component crop thus improving on economic yields (Ddamulira *et al*., 2015; De Bruijn 2015; Karuku *et al*., 2019). An intercrop system comprising of late and early maturing crop experiences efficient use of the available solar radiation throughout the cropping period (Fletcher *et al*., 2017). Kinama *et al*. (2011) while intercropping maize with cowpea and Senna observed an increase in photosynthetic radiation intercepted, with a higher light use efficiency in intercrops compared to sole cropping of maize, in conditions where crop growth was not limited by water and nutrients but only by the radiation amount intercepted by the crop's foliage.

Despite intercropping being a common practice in many cropping systems around the world, very few studies have examined the impacts of intercropping sweet potato from any perspective (Asiimwe *et al*., 2016; Idoko *et al*., 2018). Several studies have focused on yield potential under sweet potato maize relay cropping systems (Ewell and Mutuura,1991; Fischler and Wortmann, 1999; Mohammed, 2019), whereases others indicate that sweet potato can also be alley cropped between lines of agroforestry trees or shrubs, preferably fast-growing leguminous species with open crowns that allow the sunshine through (Rusoke *et al*., 2000; Schonbeck and Tillage, 2011). Nevertheless, intercropping sweet potato with grain legumes has not been extensively practiced in Kenya. The study aimed at contributing towards the sustainable production of sweet potato and the general food security situation in Kenya by analysing the performance of sweet potato intercrops in Katumani Research Station in semi-arid Kenya. The objective was: to determine the performance and yield stability of sweet potato intercrops versus monocrops in the ASALs of Eastern Kenya.

MATERIALS AND METHODS

Study site

Field trials were conducted in KALRO–Katumani experimental station, Kalama ward in Machakos Town, coordinates 1°35' 07'' S and 37° 13' 23'' E at 1597m asl (Figure 1) (Jaetzold *et al*., 2006). Kalama ward falls under agro-ecological zone IV, categorized as a semi-arid land (Karuku *et al*., 2019). Ferralo-Chromic Luvisols of Makueni quartz-zitic rock is the predominant soil types found in this site, exhibiting a sandy clay loam texture (Gicheru and Ita, 1987; Mwendia *et al*., 2017).

Kalama experiences a bimodal rainfall distribution, such that the long rains start in late March and end in May whereas the short rains commence in late October and taper off in mid-December with a mean annual rainfall of approximately 711 mm (Jaetzold *et al*., 2006). The mean annual temperature ranges from 13.7 °C to 24.7 °C. The area is almost completely cultivated as arable land. Mixed cropping is practiced with sweet potatoes (*Ipomoea batatas L*) (Huaman, 1992), maize (*Zea mays*) (Chase, 1969), pigeon peas (*Cajanus cajan*) (Morton, 1976), beans (*Phaseolus vulgaris*) (Graham and Ranalli, 1997) and fruit trees being the main crops (Sombroek *et al*., 1982).

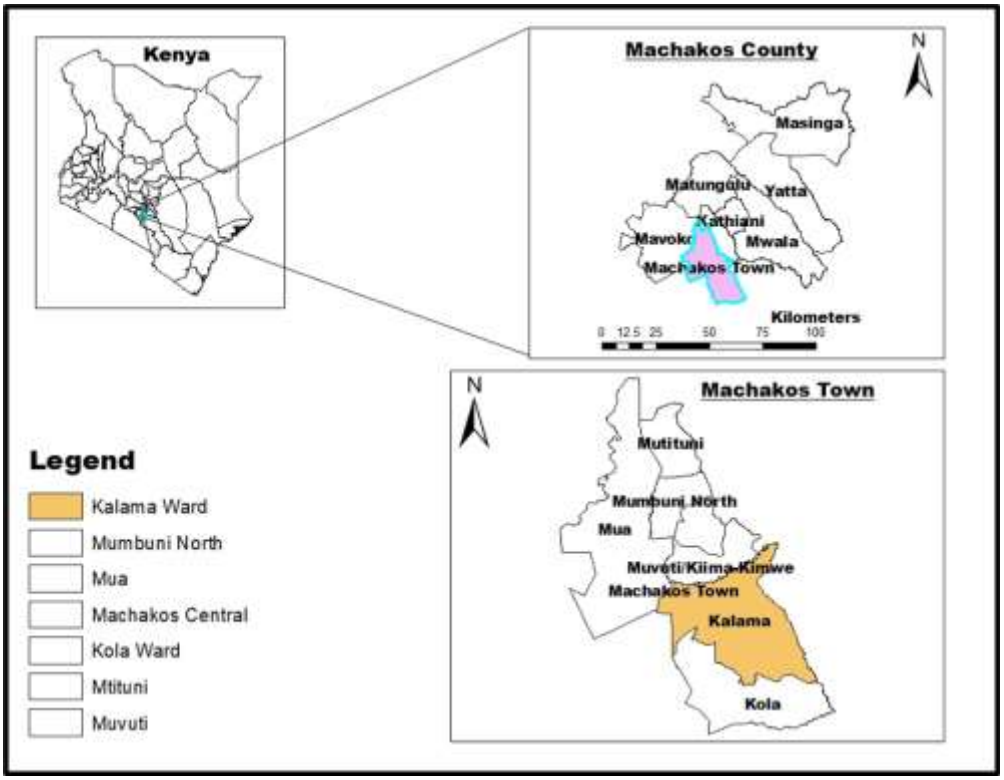

Figure 1. Study Area: Map of Kenya (top left) extract of Machakos county (top right) and Machakos town sub-county insert Kalama ward **(**below); Source: Generated from ARC-GIS.

Experimental design and layout

A total of 15 pots were laid out from South East to North West direction in a Randomized Complete Block Design, with each block having 5 treatments replicated 3 times. The experimental plots were 4m wide and 5m long. Spaces separating the plots and the blocks were 0.5 m and 1m, respectively. The plots were laid out on a 5% natural slope between two *Fanya-chini* terraces. *Fanya-chini* terraces are created by digging and heaping the soil upwards, creating bunds at the upper sides of the ditches. A narrow ledge between the ditch and the bund prevents the soil from fading away (Tenge and Okoba, 2011).

Treatments

Treatment combinations comprised of;

(i) **V1:** Monocropped Kabode (orange-fleshed)
(ii) **V2:** Monocropped Bungoma (white-fleshed)
(iii) **B:** Monocropped common beans *(mwezi mbili)*
(iv) **V1M**: Kabode + common beans intercrop
(v) **V2M:** Bungoma + common beans intercrop

Sweet potato was the main crop of interest as the controls were the sole cropping of sweet potato varieties.

Agronomic practices on the experimental plots

The land was manually cleared using a hand hoe and ridges constructed 1m apart. Sowing was done at the onset of the rains on 20th November 2018 and on 17th October 2019 for season (I) and (II), respectively. Season (I) commenced in November 2018-April 2019, whereas Season (II) from October 2019- March 2020. Sweet potato vines were planted at a spacing of 25cm×60 cm in each plot whereas common beans (mwezi mbili) were planted on top of the ridges at 5 cm depth and 25cm spacing within the row. Hand weeding was done with the aid of a hoe soon as weeds emerged throughout the cropping period. Plants were randomly tagged for accuracy and ease of monitoring growth and data collection. The beans were top-dressed 35 days after sowing with urea at the rate of 100kg ha^{-1}. Pests and diseases were controlled upon incidence. Lambda Cyhalothrin 50g/L was sprayed on beans to control bean fly and Emamectine Benzoate 19g/L to control caterpillars. Earthing up sweet potato ridges with soil was done as the need arose. Beans were harvested upon attaining physiological maturity which was dictated by the browning of leaves and yellowing of pods (Duke, 2012; Mulube, 2017). Harvesting of sweet potato was done 165 days after sowing at the point when the end of the vines had started yellowing. This was accomplished by hand digging with a hoe up the ridges and uprooting the whole plant and removing the tubers.

Data collection

Climate data

Daily weather data on temperature (°C), relative humidity, and rainfall (mm) were obtained from the site meteorological weather station.

Aridity index (AI)

AI was computed as a ratio of Rainfall: ETo such that: AI ≤ 0.05 suggests a hyper-arid climate with poor rainfall levels that scarcely reach 100 mm. AI ≤ 0.2 indicates an arid region with a high rainfall variability varying from 100 mm to 300 mm. AI ≤ 0.5 defines a semi-arid region in which summer rainfall range from 200-250 mm to 450-500 mm in winter. Finally, the AI ≤ 0.75 is graded as dry sub-humid.

Plant Growth and development

Morphological growth traits data collected weekly included percent canopy cover, vine length, leaf area, and leaf area index (LAI) for all crops throughout the cropping seasons. Sweet potato was the main crop of interest as described by Nedunchezhiyan *et al*. (2012). Ten tagged plants for each crop were monitored based on their phenological growth stages.

Canopy cover measurement: The string method prescribed by Khisa *et al*. (2002) was used. A 15m string marked at intervals of 0.5 m and was placed diagonally and horizontally within the experimental plot, noting points intersecting with plant foliage. Percent of soil cover was determined as shown in Eqn 1:

$$\%\text{ cover} = \frac{\text{total number of interceptions}}{\text{Total no of points}} \times 100 \qquad (1)$$

Leaf area (LA) and Leaf area index (LAI): Leaf area was obtained by measuring the lengths and widths of the middle leaves of the ten tagged plants in a plot. Mean of the lengths and widths of the leaves was computed and used to estimate the leaf area (Carvalho *et al*., 2017) (Eqn 2)

$$\text{A (Leaf area)} = 0.56 \text{ x K x } 6.20 \qquad (2)$$

Where: K indicated the product of sweet potato leaf length and breadth whereas 0.56 and 6.20 were constants taking care of the irregularity of sweet potato leaves.

Thereafter, the leaf area index (LAI) was estimated from Eqn 3:

$$\text{LAI (leaf area index)} = \frac{\text{LA}}{\text{A(spacing)}}\left(\frac{cm^2}{cm^2}\right) \qquad (3)$$

Where: LAI ($cm^2\ cm^{-2}$), LA = leaf area (cm^2), and A = the land area (cm^2).

Tuber Yield: Sweet potato fresh tuber weight and yield were collected from every plot, measured using a portable weighing balance. Total tuber weight was summed from all the plots then total tuber yield was computed from Eqn 4 (Nugroho and Widaryanto, 2017).

$$\text{Tuber yield}(\text{kg Ha}^{-1}) = \left(\frac{10000}{\text{sampling plot area}}\right) \times \text{Total tuber yield from sampling area} \qquad (4)$$

Grain Yield: Common beans were harvested upon attaining physiological maturity when pods started drying. Biomass and pods were harvested, sun-dried for two weeks to attain a moisture content of 3.26% to increase its storage longevity as prescribed by (Rani *et al*., 2013). Grain yield was therefore computed based on Eqn 5:

$$\text{Grain yield}(\text{kg Ha}^{-1}) = \frac{\text{grain dry yield (kg)}}{\text{the total area of the plots}} \times 10{,}000\text{m}^2 \qquad (5)$$

Valuating sweet potato intercropping: The productivity indices were used in to estimate intercrop advantage and the extent of competition amongst the species (Weigelt and Jollife, 2003). These competitive indices were determined in terms of land equivalent ratio (LER) and % of the land saved.

Land Equivalent Ratio (LER): estimated the advantages of intercropping sweet potato with the beans. It provides an estimate of a crop system's biological efficiency, as defined by Liu *et al*. (2018). It was determined using Eqn 6;

$$\text{LER} = \left(\frac{\text{Yspi}}{\text{Ysp}}\right) + \left(\frac{\text{Ybi}}{\text{Yb}}\right) \qquad (6)$$

Where; Yspi and Ybi are the yields of sweet potato and beans intercropped whereas Ysp and Yb are yields of sole cropping of sweet potato and beans respectively.

The percentage of land saved showing the extent to which land is saved by intercropping as opposed to mono-cropping cropping (Willey, 1985), Eqn7:

$$\%\ \text{Land saved} = 100 - \left(\frac{1}{\text{LER}} \times 100\right) \quad (7)$$

Statistical analysis

This was done with the aid of GenStat 19th edition (Lane and Payne, 1997). A two-way ANOVA was used to determine effects of treatments and seasons on the measured response variables. A Bonferroni test of significance was performed at alpha 0.05 and used in comparing the means.

RESULTS AND DISCUSSIONS

Weather conditions during sweet potato growth stages

Monthly climatic data during the sweet potato growth stages are shown in Table 1.

The Aridity Index (AI) indicates the relative dryness of the locality (Bannayan *et al*., 2010). Aridity indices reported in season (I) especially during the critical growth stage of the crop; tuber bulking and harvesting were zero, showing the degree of arid severity and may have an impact on economic yields. On the other hand, AI registered at initiation and vegetative was 0.8 and 0.7, respectively, indicating a dry sub-humid period in these growth stages. Low AI indices AI ≤ 0.0 during the tuber bulking and maturation processes revealed a lack of humidity as a result of a lack of moisture recharge, suggesting that the crop water requirements were not significantly fulfilled during its growth period. In season (II), lower 0.4 AI values were recorded at the tuber bulking stage, a characteristic of

Table 1. Climatic data observed during the sweet potato growth stages.

Season	Growth stage	Growth days	ETo (mm)	R (mm)	AI	T-mean °C
Season (I)	Initiation	40	180.2	150	0.8	20.2
	Vegetative	42	167.6	115.4	0.7	19.5
	Tuber bulking	39	203.9	3.8	0	21.1
	Maturity	39	218.6	8.4	0	21.6
Season (II)	Initiation	40	122	219.9	1.8	19.9
	Vegetative	42	136.8	211.9	1.5	19.8
	Tuber bulking	39	159.2	57.9	0.4	20.3
	Maturity	39	158.3	179	1.1	21

R; rainfall, T-mean; temperature, ETo; reference evapotranspiration, AI; aridity index; derived as R/ETo.

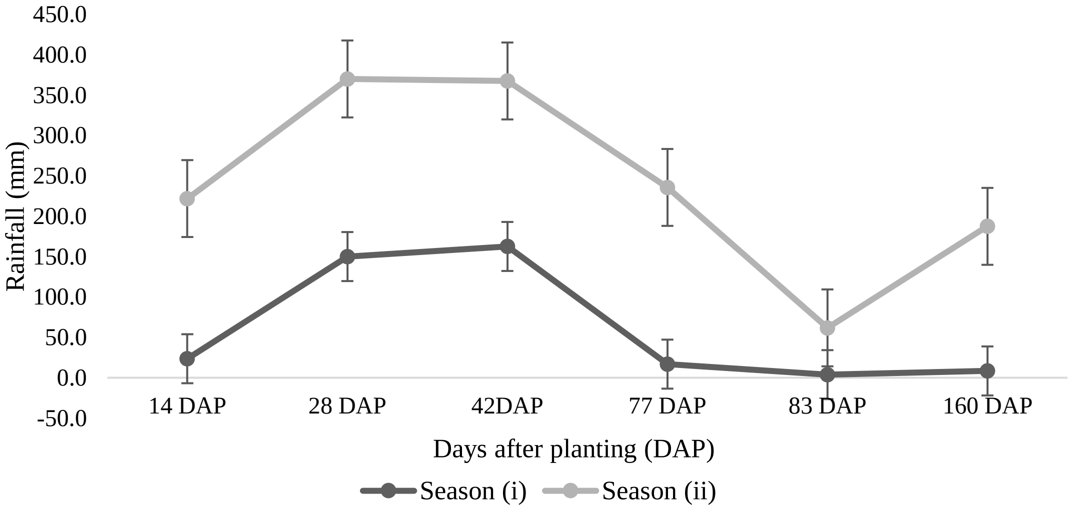

Figure 2. Beginning and ending of the humid period. Error bars represent the standard error of mean rainfall.

the semi-arid zoning. On the other hand, higher AI values observed were 1.8, 1.5 and 1.1 at initiation, development and harvesting, respectively. This implied a degree of wetness that necessitated by soil water recharge from the rainfall received. This study found that an increase in the aridity index in crop production contributed to lengthening of the humid periods. (Hufkens *et al*., 2016).

Rainfall plays a vital role facilitating soil water recharge thereby impacting positively on the soil water balance, (SWB. From observation in season (I), the minimal amount rainfall was recorded at the tuber bulking stage and at final crop maturity; 3.8mm and 8.4mm, respectively. On the other hand, most rainfall was recorded at planting and vegetative development stage (150 and 115.4 mm, respectively). The low rainfall recorded during tuber bulking and at harvest may have led to a yield reduction factor (Ky) of sweet potato as a result of water stress. In tuber production, water stress at the bulking stage may lead to malformation and reduction in tuber sizes (Motsa *et al*., 2015). Season (II) had a significantly higher rainfall compared to season (I) due to the rise in humid regime and a high AI value. The highest rainfall experienced was at initiation 219.9 mm, followed by the development stage 211.9mm, and 179.0 mm at harvest. The lowest amount of rainfall recorded at 57.9 mm was at tuber bulking. Sweet potato requires moist conditions from planting to a point when roots have has fully developed since it can be able to tolerate water stress and recover easily when soil water is recharged with no decline in yields (El-Sharkawy, 2006).

The observed temperatures range of 14°C –29°C for season (I) and were considered high for sweet potato production. Sweet potato normally thrives between 15 and 25 °C (Negeve *et al*.,1992), where temperatures below 15°C deter root formation, whereas those above 25 °C affect photosynthesis (Eguchi *et al*., 2003). The average temperatures recorded at the bulking and harvesting stages were 21.1 °C and 21.6 °C, respectively and considered optimal for sweet potato development. As such, they favored the portioning of photosynthates to the storage roots (Eguchi *et al*., 2004). Gajanayake *et al*. (2015) indicated that high temperatures tend to affect the partitioning of biomass in sweet potato, thereby affecting the final yield. For season (II), the diurnal temperatures ranged between 14.2 and 26.2 °C and the highest mean temperatures recorded during the tuber bulking and at harvest were 20.3 and 21.0 °C, respectively. Ravi and Indira (1999) reported that for sweet potato production, tubers formation, enlargement, and synthesis of starch are mainly catalyzed by air temperature ranging between 14 and 22 °C, concurring with those observed in the study. Further to this, Ravi *et al*. (2014) observed that air and soil temperature regulates the competition between shoot and storage root growth in sweet potatoes.

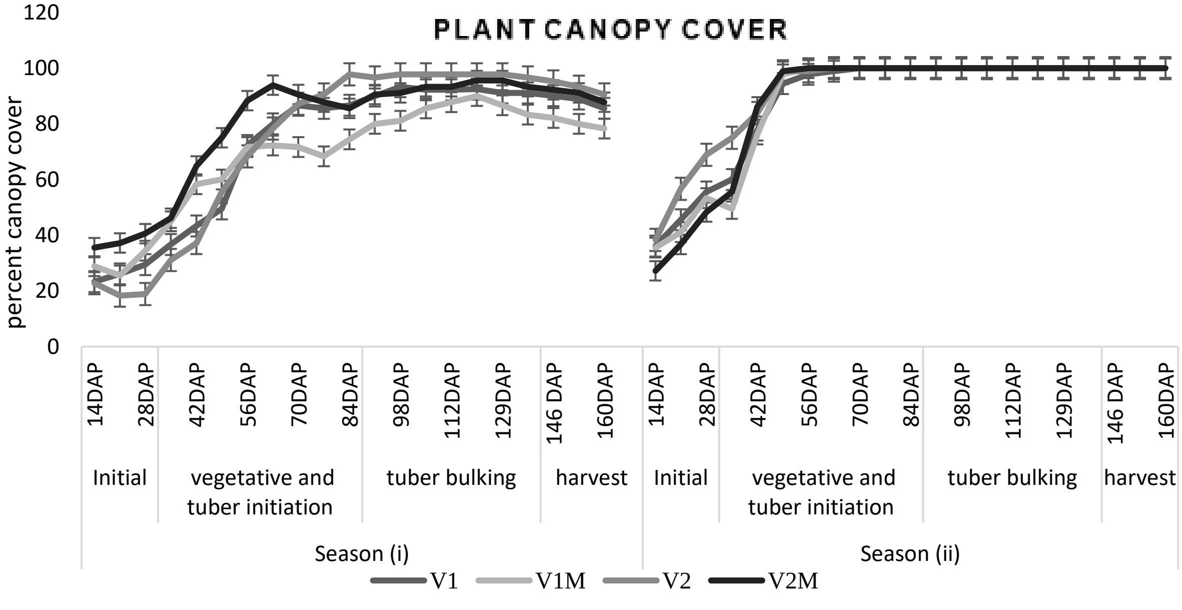

Figure 1. Trends in per cent cover of Kabode and Bungoma sweet potato varieties and their intercrops. V1 Sole cropping of Kabode (orange-fleshed), V1M Kabode+beans, V2 Bungoma variety (white-fleshed) and V2M Bungoma+beans. The error bars indicate standard error of mean canopy cover

Figure 2 illustrates the humid periods experienced throughout the two experimental seasons. From observation, a short humid period was experienced in season (I) with declining humidity observed in the final crop developmental stages. Accordingly, under such conditions, the season was considered to be short; since the supply of water, temperature and AI indices was met by major climatic constraints. Such water supply deficits have been caused by an erratic distribution of rainfall, which may have created a significant imbalance in the soil water budget. Increased temperatures have an impact on climate efficiency in rainfed agriculture, creating a faster rate of aging in crops and thus a shorter life span. (Thorne-Miller *et al*.,1983). The findings of this study are correlated with (Kang *et al*., 2009), which argued that climate change could negatively impact the soil water balance, thus paving the way for minimal crop coverage, thus instigating soil evaporation and, consequently, shortening the crop growth period. On the other hand, season (II) experienced a long period of humidity, which decreased on the 83rd day after planting and was therefore considered sufficient. The length of the wet seasons may be the result of a balance between rainfall and evaporation; root supply and leaf demand (Zelitch, 1975; Monteith, 1977). Throughout the production of sweet potatoes, the water deficit at the tuber bulking stage may lead to a decrease in the leaf area index (LAI), vine length and an increase in the concentration of abscisic acid (ABA) in roots and shoots (Daryanto *et al*., 2017). ABA causes the abscission of lateral bud development in crops (Fichtner and Lunn, 2021). Physiologically, the crop can undergo an increase in its solute osmotic pressure leading to overproduction of growth inhibitors, thereby enhancing its metabolic toxicity and subsequent yield (Obidiegwu *et al*., 2015). Recovering under such circumstances, the principle of drought tolerance and avoidance sets in sweet potato (Okogbenin *et al*. 2013). This could be accomplished through increasing crop water use efficiency, changes in xylem hydraulics, and inhibiting leaf growth (Skirycz *et al*., 2010; Verelst *et al*., 2010).

The sweet potato growth component

Canopy cover

Effect of intercropping systems on per cent canopy cover

Trends in per cent ground cover during the sweet potato growth stages are shown in Figure 3.

Percent canopy cover rose steadily from planting in both seasons, peaking at the vegetative and tuber stages, declining at harvest time. The duration of the growth cycle was 160 days, the initiation period was 40 days, its vegetative growth was 42 days, the tuber was 39 days and the final stage was 39 days (Wohleb *et al*., 2014). Similarly, Kc values for two experimental seasons were: initiation 0.4, development 0.7, tuber bulking 1.2 and at maturity 0.8, depending on local conditions (Mulovhedzi *et al*., 2020). At establishment, the sweet potato crop had a low per cent canopy cover which may have resulted in the minimum water needed to compensate for atmospheric demand (Karuku *et al*., 2014).

The high percent cover recorded by Bungoma-bean (V2M) intercrop, may have created a microclimate by sheltering moist air near the soil surface, thereby reducing soil evaporation and thus retaining soil moisture (Gitari, 2018). A decrease in the percentage of the canopy cover at full crop maturity meant the emergence of leaf senescence at these stages, marked by the yellowing of the older leaves at the base of the plant that followed the fall of the leaf and eventually the death, which presumably decreased the area covered by canopy and leaf.

A steady increase in canopy characteristics was recorded by the crops in season (II), such that; maximum canopy cover across all treatments was experienced from the tuber initiation to harvest. Contrary to season (I), the high ground in season (II) cover could be alluded to the humid period experienced, marked by soil water recharge that necessitude vine elongation, extending its life span (Chhabra *et al*., 2006). In intercropping, canopy structure plays a pivotal role in the absorption of PAR, such that the neighbouring leaves tend to affect one another in the system (Liu *et al*., 2017). The high ground cover could be a premonition of the amount of photosynthetic radiation being intercepted (Maddonni *et al*., 2001). As such intra-canopy light propagation between companion crops creates a lot more PAR interception. If indeed the light penetrates the canopy, its interception increases with the LAI (Leuning *et al*., 1991). As vegetative growth progresses, most crops assimilate a lot of biomass, which is directly proportional to intercepted radiation, thus much yield (Monteith, 1977). Similar studies conducted by Nyawade (2015) have shown that canopy cover is a crucial determinant of the amount of PAR intercepted, which influences the photosynthetic capacity of crops and is expressed in the amount of dry matter produced. The reduction of PAR intercepted under water deficit conditions can also depend on the degree of stress due to decreased leaf expansion and the number of leaves.

The main effects of intercropping on per cent canopy over all phenological growth phases in season (I) differed significantly ($p < 0.05$) as sole cropping of Kabode had 70.4%, whilst its intercrop 67.1%. On the other hand, there were major variations between the sole cropping and intercropped Bungoma varieties. Sole cropping of Bungoma had 77.1 and 71.7% upon intercropping. Data in the study showed that all the intercropped treatments had a lower canopy cover compared to monocropped ones. These results contradict the findings of Gitari *et al*. (2019) that indicate so whenever legumes are used as companion crops, have the potential of promoting the water conservation in central Kenya's wetlands. Similarly, Nyawade *et al*. (2019) and Lozano-Parra *et al*. (2018) argued that higher canopy cover goes hand in hand with a rise in soil moisture and a decrease in soil temperature which has a positive effect on the soil microclimate and hence on the overall productivity of crops.

Table 2. Mean per cent canopy cover for the two cropping seasons.

Cropping systems	Season (I)	Season (II)
Kabode	70.40^a	88.67^a
Kabode+beans	67.07^a	88.55^a
Bungoma	77.08^a	90.31^a
Bungoma +beans	71.69^b	89.29^a
LSD 5%	5.16	6.31
SED	2.617	3.2
F pr.	<.001	< .001

The different letters within the same column show significant differences between the comparing variables at $p < 0.05$

In season (II), the sole cropping of Bungoma variety recorded the highest canopy cover of 90.3% and 89.3% on intercropping with common beans. Similarly, the sole cropping of Kabode variety had 88.7% and 88.6% when intercropped with common beans *(Mwezi-mbili*). Generally, Bungoma variety had the highest groundcover. Morphologically the variety (Bungoma) has broad leaves that spread on the ground. Whereas the lower ground cover from the Kabode variety may be attributed to the narrow leaves forming a small canopy architecture as it depicts an erect growth pattern.

Ground cover varied significantly (P <0.05) between the two seasons, as it was highest in season (II) and lowest in season (I). These differences may be attributed to the favorable climate conditions such as high rainfall and AI values observed in season (II), which may have necessitude soil water recharge. Such that ETa = ETm, thus the more available soil water content may have favoured the multiplication of vegetative parts leading to a high canopy cover (Wiryawan and Hairiah,1983). Intercropping yielded lower ground cover possibly due to competition between species on nutrients, area, and time (Fukai and Trenbath,1993). Competing for growth resources among crop components in the intercrop system tends to reduce crop growth and biomass accumulation relative to monocropping (Dasbak and Asiegbu, 2009). Across the experimental periods, Bungoma variety posed the highest percent canopy cover. It is possible that the crop could have used the available soil water more efficiently, resulting in a high canopy cover and eventually more biomass produced (Karuma *et al*., 2011; Nyawade, 2015). In this regard, varieties with high per cent canopy cover may serve dual purposes (Mwololo *et al*., 2012).

Effect of intercropping on vine length, leaf area index and yield attributes of sweet potato

Vine length

Table 3 presents the interactive cropping effects on the length of sweet potato vines during their phenological growth stages in both seasons.

Table 3. The length of sweet potato vines across the two production seasons.

VINE LENGTH (cm)								
	Season (I)				Season (II)			
Growth stage	V1	V1M	V2	V2M	V1	V1M	V2	V2M
Initial	21.46^a	22.79^a	25.19^a	21.40^a	23.9^a	25.1^a	35.3^a	30.4^a
Vegetative	30.32^{ab}	31.63^{ab}	49.94^{ab}	43.20^b	91.4^b	88.1^b	124.7^{ab}	117.6^b
Tuber initiation	43.78^{bc}	42.82^{bc}	78.62^{bc}	65.91^c	161.6^c	150.4^b	212.9^{bc}	192.9^{bc}
Tuber bulking	52.62^c	52.30^c	96.44^c	78.54^c	237.0^d	215.7^c	288.2^c	260.7^c
Harvest	50.31^c	52.07^c	95.19^c	77.92^c	225.2^{cd}	214.0^c	288.2^c	246.4^c
F pr.	<.001	<.001	<.001	<.001	<.001	<.001	<.001	<.001
s.e.d	3.82	3.51	8.79	5.47	18.78	17.56	25.76	21.15
l.s.d (5%)	8.52	7.82	19.58	12.18	41.84	39.12	57.4	47.13
CV %	11.8	10.7	15.6	11.7	15.6	15.5	16.6	15.3

Key: V1 Sole cropping of Kabode (orange-fleshed), V1M Kabode+beans, V2 Bungoma variety (white-fleshed), and V2M Bungoma+beans.

The different letters across the rows show significant differences among the treatments at $p < 0.05$.

Table 4. Trends in leaf area indices for the two cropping seasons.

LEAF AREA INDEX								
	Season (I)				Season (II)			
Growth stage	V1	V1M	V2	V2M	V1	V1M	V2	V2M
Initial	0.4780^{a}	0.5195^{a}	0.7008^{a}	0.7610^{a}	1.117^{a}	1.010^{a}	1.435^{ab}	1.521^{a}
Vegetative	0.7662^{d}	0.7733^{b}	1.0538^{c}	1.2037^{b}	1.662^{b}	1.689^{b}	2.084^{b}	2.155^{b}
Tuber initiation	0.6717^{cd}	0.6594^{ab}	1.0100^{bc}	1.1203^{ab}	1.609^{b}	1.539^{ab}	1.884^{ab}	1.673^{a}
Tuber bulking	0.6228^{bc}	0.5526^{a}	0.9290^{bc}	0.9916^{ab}	1.532^{ab}	1.467^{ab}	1.575^{ab}	1.421^{a}
Harvest	0.7662^{d}	0.5064^{a}	0.7008^{a}	0.8814^{ab}	1.117^{a}	1.175^{ab}	1.067^{a}	1.204^{a}
F pr.	<.001	<.001	0	0.01	0	0.01	0.01	<.001
s.e.d	0.04	0.05	0.06	0.1	0.12	0.17	0.24	0.13
l.s.d (5%)	0.09	0.1	0.14	0.23	0.26	0.37	0.53	0.29
cv %	7.9	9.4	8.6	12.5	10	14.7	18.1	10.2

Key**:** V1 Sole cropping of Kabode (orange-fleshed), V1M Kabode+beans, V2 Bungoma variety (white-fleshed), and V2M Bungoma+beans

Note: The numbers across the rows with the same letters show significant differences.

The highest mean vine length in season (I) was recorded in monocrops relative to intercrops. On average, the sole cropping of Kabode variety had a mean vine length of 40.4 cm, its intercrop with common beans (*mwezi mbili* variety); was 40.8 cm while the monocropped Bungoma variety had a value of 70.7 cm significantly higher than its corresponding intercrop (57.8cm) ($P<0.05$). These were lower than those observed by Nugroho and Widaryanto (2017) during the rainy season in India and may be due to competition for water and nutrients among interspecies. On the other hand, the longest mean length of vines was recorded in season (II) from the Bungoma variety (both sole cropping of 181.4 cm and intercropped 167.6 cm), while the sole cropping of and intercropped Kabode variety were 147.3 and 137.5 cm, respectively. The length of the vines in all the growing systems increased continuously as the test crops approached the tuber bulking and harvesting phases. This has shown that; apart from tubers, the two varieties can also be a good source of vines, especially in circumstances aimed at the multiplication of the vines.

From observation, Kabode variety had shorter vines compared to Bungoma variety. Coincidentally, Kabode variety produced the highest tuber yields across the two seasons. These results depict Kabodes' efficiency in converting its photosynthetic products to the storage roots. Most of the organophosphates were translocated to the roots instead of vines. Similar results were reported by Parwada *et al*. (2011) who observed high tuber yield in cultivars that had a low vine length. Significant differences ($P<0.05$) in the length of vines between season (I) and (II) could be attributed the presence and lack of humid periods observed during the growth of sweet potato. Meteorological drought stress continues to impede cell enlargement as opposed to their division, thereby reducing the stem or vine expansion and internode diameter of many sweet potato cultivars which can be due to the discrepancies in the length of vines thus percent canopy cover (Pramuk and Runkle, 2005; Lebot, 2019). Under these conditions, the crop was alive and was able to regenerate quickly during the rainy days, presumably due to the reverse translocation of assimilates from the roots to the canopy, thereby reducing the yield. From now on, the pruning of sweet potato vines helps to improve the efficiency of translocating organo-phosphates to storage roots (Nugroho and Widaryanto, 2017). If the vegetative growth is high, they'd obstruct tuber formation, such that the little organophosphates will be left for root formation and thereby creating an imbalance in its accumulation and thus fewer tubers are formed (Dubois *et al*.,2013; Isa *et al*., 2015).

Leaf Area Index

Table 4 indicates the variations in the Leaf area indices of the treatments throughout the experimental seasons.

The leaf area indices had substantial variations ($P<0.05$) between the treatments and within their phenological growth stages throughout the experimental seasons. Averagely season (I) had a lower LAI ranging from 0.5-0.7, whereas season (II) ranged between 1.1 to 2.2. During the vegetative growth phases, the maximum LAI presented for season (I) was (0.8- 1.2) and (1.6-2.2) for season (II). Regardless of the seasons, LAI values were lower than those reported by Nugroho and Widaryanto (2017) and Nedunchezhiyan *et al*. (2012) who found indices ranging from 3.1 to 4.7 and 2.3 to 2.9 respectively, ascribing to the variations in genetic composition of varieties.

Plant leaves poise as the largest percentage of canopy and plays a crucial role in all crop physiological processes, such as PAR absorption, transpiration and photosynthetic potential of the crop, are wholly reliant on LAI (Xu *et al*., 2008). Similar to the length of vines, a higher LAI to a greater extent may pose difficulty the formation of generative organs such as roots (Nugroho and Widaryanto, 2017). Thus, the translocation organic phosphate is more he focused to the vegetative organs rather than the roots. Conversely, Dukuh (2011) reported that higher LAI in sweet potatoes did not have a positive effect on tuber development as the continuous growth of leaves restricted tuber formation. This research is consistent with the findings of Mithra and Somasundaram (2008) which showed that higher LAI in sweet potatoes did not confer any advantage in the final root yield. As a result, it is strongly recommended to prune the vegetative parts at the initiation and bulking stage as it reduces the obstruction of tuber growth.

Tuber Yield

The interactive effect of intercropping on sweet potato tuber yield is shown in Table 5.

Tuber production in season (I) was not significant across treatments ($p \geq 0.05$), such that the sole cropping of Bungoma and Kabode varieties yielded 5.6 tha^{-1} and 5.2 tha^{-1}, respectively. On the other hand, intercropped Bungoma and Kabode variety yielded 3.8 tha^{-1} and 4.2 tha^{-1}, respectively. The low tuber yield reported from both varieties can be due to the humid conditions encountered during the critical growth phase of the crop. Similarly, in South Africa, Laurie and Magoro (2008) obtained approximately 3.9-9.5 tha^{-1} for communal drought-prone gardens compared to 25.2 tha^{-1} at experimental humid stations, supporting the yield gap between poor and well-endowed rainfall environments. The low tuber yield may result from drought-like conditions that may have caused lignification of roots and thus hindering their growth (Ravi and Indira, 1999). Additionally, the high temperatures observed may have aided in redirecting photosynthates towards forming fibrous roots relative to storage roots (Eguchi *et al*., 2003).

Tuber yield in Season (II) was significantly different among the varieties as they presented higher yields under sole cropping of cropping than when intercropped. The sole cropping of Bungoma and Kabode variety yielded 42.2 and 57.6 tha^{-1}, respectively. Over the same season, their intercrops had 32.4 and 48.2 tha^{-1} for Bungoma and Kabode varieties, respectively. Tuber yields were significantly ($p < 0.05$) higher in season (II) compared to season (I). This may be attributable to the prevailing weather conditions such as the higher amount of rainfall received necessitating soil water recharge, raising the amount of photo transpirable soil water and thus favouring photosynthesis and yields formation (Wakrim *et al*., 2005). Differences in the attained tuber yields among the two varieties may can also be attributed to variations in their genetic composition, championing for their adaptability in such a peculiar environment. Intercrop experiments by Belehu (2003) involving sweet potato and taller legumes showed yield reduction. This may have been evidenced by a decrease in photosynthetic activity that can be exacerbated by taller beans due to shading and thus a reduction in insolation. From the current results, the study recommends a shift in the spatial arrangement of sweet potato cropping systems.

Table 5. Effect of intercropping on sweet potato yield in semi-arid areas.

	Tuber yield (t ha^{-1})	
Cropping system	Season I	Season II
Kabode	5.167^{a}	57.62^{c}
Kabode+beans	4.217^{a}	48.17^{bc}
Bungoma	5.633^{a}	42.17^{ab}
Bungoma+beans	3.833^{a}	32.42^{a}
F pr.	0.603^{ns}	0.001^{s}
S.E.D.	1.441	3.16
L.S.D. (5%)	3.527	7.73
CV%	37.5	8.6
F pr.	0.603	0.001

Key:(s) significant, (ns) Not significant. The numbers within the same column followed by the same letter (s) are not significantly different at 0.05.

Bean Yield

The interactive effect of intercropping on common bean grain yields are shown in Table 6. There were no significant differences ($p \leq 0.05$) in grain yields from the treatments as the sole cropping of crop yielded 0.7 tha^{-1}, *Mwezi-mbili* +Kabode and *Mwezi-mbili* +Bungoma intercrop yielded 0.5 tha^{-1} and 0.4 tha^{-1}, respectively. It was also notice that intercropping common beans with sweet potato similarly decreased the grain yield by 31.4 and 50.9 % with both Kabode and Bungoma varieties, respectively. This showed that Kabode was the better fit companion crop with beans in such setting. It was also noticed that sole cropping of treatments yielded more than intercropped ones. This may be due to the inter-specific competition among the crops on growth resources such as water resulting from experienced in season (I).

Table 6. Effect of intercropping sweet potato on grain yield of common beans.

Cropping system	Bean yield (t ha^{-1}) Season I	Bean yield (t ha^{-1}) Season II
Sole cropping of *mwezi mbili* beans	0.7363^{a}	1.6740^{b}
Mwezi mbili +Kabode	0.5050^{a}	0.5172^{a}
Mwezi mbili +Bungoma	0.3615^{a}	0.3925^{a}
S.E.D	0.1107	0.1399
L.S.D (5%)	0.3074	0.3883
CV%	25.4	19.9
F pr.	0.065	0.001

Numbers within the same column followed by the same letter (s) are not significantly different at 0.05.

The sole cropping of *Mwezi-mbili* bean variety, on the other hand, yielded more in season (II) than the intercropped ones. The sole cropped common beans yielded 1.7 tha^{-1}, whereas the intercropped ones had 0.5 and 0.4 tha^{-1} for Kabode and Bungoma varieties, respectively. Intercropped common beans encountered a yield reduction of 76.6 % with Bungoma variety, while 69.1% with Kabode variety. Similarly, Egbe and Isang (2015) reported a decrease in grain yield under the sweet potato soybeans intercrop system linking it to the smothering and allelopathic effect caused by sweet potatoes. Studies by Xuan *et al*. (2012) on sweet potato allelopathy also reported a decrease in cogon grass growth by 50 per cent. This meant that sweet potatoes could act as a smoother against invasive species or companion crops.

Intercrop Economics

In season (I) the mixed crop LER was; Kabode+ beans (1.5) and Bungoma+beans (1.2), while in season (II) the LER registered in Kabode was 1.1 and 1.0 respectively. LER's highest value was registered as opposed to season (II) in season (I). Sweet potato and common bean mixtures with LER=1.0 suggested that there was no advantage over sole cropping of cultivation, while those mixtures with LER > 1 showed a multiple cropping advantage over monoculture biological output and also an indication of genotypic compatibility between the two crops. These findings are consistent with (Njoku *et al*., 2011), reporting similar results in the Okra sweet potato cropping system in Nigeria. The highest percentage of the land saved during the two growing seasons was obtained by intercropping Kabode with common beans season (I) (33.33%) and season (II) (9.10%), while in intercropping Bungoma variety with beans in Season (II), 16.67% of the land was saved whereas in season (I) land was saved implying resource utilization in intercropping.

Table 7. Land equivalent ratio and percentage of the land saved in sweet potato/bean intercropping system.

Season	Cropping system	Land equivalent ratio (LER)	Land saved (%)
Season (I)	Kabode+ beans	1.5	33.33%
	Bungoma+beans	1.2	16.67%
Season (II)	Kabode+ beans	1.1	9.10%
	Bungoma+beans	1	0.00%

CONCLUSION

Orange and white sweet potato varieties showed a relatively high growth response to the semi-arid climate. Intercropping provided a higher ground cover recommended for most conservation farming practices. The land was efficiently used in intercropping (LER > 1.0). Sweet potato yields were significantly (P<0.05) lower in intercrops than monocropped treatments. The Kabode variety (orange-fleshed) was suggested as a super variety which should be grown in these regions due to its high yield potential. It is evident from our study that sweet potato-bean intercrops, despite decreasing sweet potato tuber yields were more productive as sole cropping of crops. Further research should be carried out to determine the degree of sweet potato allelopathy to companion crops and nutrient use under intercropping.

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