International Scholars Journals

African Journal of Agronomy ISSN 2375-1177 Vol. 5 (4), pp. 333-345, November, 2017. Available online at www.internationalscholarsjournals.org © International Scholars Journals

Full Length Research Paper

Sweetpotato slip planting density and slip length optimization for mass production of quality planting material in smallholder farm settings

Rogers Kakuhenzire[1], Meshack Mwenda[1], Fredrick Grant[1] and John Kalaye[2]

[1]International Potato Centre, P.O. Box 2473, Morogoro, [2]Tanzania. ARI Uyole, Box 400 Mbeya, Tanzania.

Accepted 11 October, 2017

Sweetpotato production in unimodal rainfall farming systems in sub-Saharan Africa is constrained by inadequate quality planting material. Technologies for efficient production of sweetpotato planting material are imperative to improve this sub-sector. Consequently, two separate field experiments, using five orange-fleshed sweetpotato varieties were conducted to determine the optimum slip spacing and slip length for optimal vine growth and vine-cutting production as planting material. Slip spacing levels were (15x15), (20x20), (25x25) and (30x30) cm. The slip length treatments were; 15, 20, 25 and 30 cm all planted at 20x20 cm spacing. The experimental sites were ARI Uyole, Mbeya in 2016 and 2017 and SUA, Morogoro only in 2017. Both experiments were set in split-split plots in randomized complete blocks with three replications. The vine growth rate (cm day^{-1}) and vine-cutting yield m^{-2} were significantly ($P \leq 0.05$) higher at Morogoro than at Uyole. Cultivars; Kakamega and Ejumula, respectively had significantly ($P \leq 0.05$) higher vine-cutting yield than Kiegea and Mataya while cultivar Kabode had intermediate yield. Vine-cutting yield was significantly ($P \leq 0.05$) higher at (15x15) cm than at (30x30) and increased with repeated vine harvesting. The effect of slip length though significant ($P \leq 0.05$) over varieties, years and locations was inconsistent except for fresh foliage yield (t ha^{-1}).

Keywords: Orange-fleshed sweetpotato, repeated harvesting, vine-cutting length, vine yield.

INTRODUCTION

Sweetpotato (*Ipomoea batatas* [L.] Lam) is an important staple crop in warm, semi-arid tropics and wet sub-tropics particularly in sub-Saharan Africa (SSA). The crop is currently grown in more than 110 countries globally across diverse agro-eco-climatic zones (Srinivas, 2009; Beyene *et al*., 2015; Abidin *et al*., 2016). Sweetpotato is reputedly drought tolerant with ability to produce appreciable yields with limited soil moisture and in marginally fertile soils where most other crops particularly tropical cereals would fail (Jones *et al*., 2012; Markos and Loha, 2016). This makes sweetpotato highly adaptable to fragile agro-ecologies with low soil fertility and limited rainfall but retain ability to provide fair yields where most other crops would ordinarily fail (Braun, 2001; Jones *et al*., 2012).Sweetpotato is easy to grow, some production constraints notwithstanding, requiring little or no agro-chemicals or regular supply of planting material from external sources compared to other common crops (Jahan *et al*., 2001, Jones *et al*., 2012). However, this is antecedent for low yields in most farming systems. This needs to be addressed if sweetpotato is to be competitively grown to support the growing population in view of the increasing unstable rainfall patterns.

The sweetpotato yield in SSA in 2014 was 5.8 t ha^{-1} which is less than half of the world average, (12.8 t ha^{-1}) during the same year (FAO, 2015). This yield is far below the expected potential on the assumption that sweetpotato can tolerate low soils fertility and does not require improved farm inputs than most other crops (Jones *et al*., 2012). The low yields of sweetpotato in SSA could be attributed to; limited

---

Corresponding author. E-mail: r.kakuhenzire@cgiar.org

availability of adapted high yielding varieties, poor agronomic practices, pest and disease attacks and inadequate availability of high quality planting material among other constraints (Markos and Loha, 2016). The low sweetpotato yields will not be sustainable with growing human populations, increasingly unreliable rainfall and, the increasing demand and importance of sweetpotato in the local food systems. Thus, more efficient and effective sweetpotato planting material production technologies need to be developed and promoted to ensure their quick and easy availability at the onset of the planting season (FAO, 2009).

Sweetpotato is conventionally propagated using vegetative vine-cuttings or slips (Braun, 2001, Stathers *et al*., 2013). Botanical seeds can be used as sweetpotato planting material but only for breeding purposes due to crop heterozygosity and inability for the seed to germinate except after special treatment (Maniyam *et al*., 2012; Markos & Loha, 2016). Sweetpotato storage roots also can be used as a source of planting material, however, slips from actively growing plants are preferred because they are assumed to be free from soil-borne pests and diseases besides producing a relatively more uniform crop (Dannien *et al*., 2013). Secondly, using vine-cuttings to initiate mass bulking of planting material saves sweetpotato storage roots that would otherwise be used for food than future planting material (Anon., 2011). Thirdly, vine-cuttings from vegetative sweetpotato plants have higher yields and produce storage roots of more uniform size and shape than planting materials got from storage root sprouts (Markos and Loha, 2016). Nevertheless, sprouts from storage roots can be used under certain circumstances or special programs as a source of initial multiplication stock to initiate the vine bulking processes particularly in zones with extremely long dry spells and limited irrigation facilities. In using vine-cuttings as sweetpotato planting material, apical portions are more preferred than cuttings from the middle and basal stem sections because they regenerate into vigorous plants, establish faster and have higher storage root yield (Stathers *et al*., 2013; Beyene *et al*., 2015). Nevertheless, when sweetpotato planting material is in short supply, all sections of the twining stem can be used but expecting lower yield from cuttings obtained near the base of the stem (Wilson, 1988).

The fresh storage root yield of sweetpotato among other factors is influenced by the vine planting density (spacing), length of the vine-cutting and, length and number of nodes of the buried portion of the vine cutting (Belehu, 2003). Knowledge about the impact of some of these factors on vine cutting yield of a sweetpotato crop intended for production of planting material is scarce or unavailable. The number of slips produced per unit area or unit time may be influenced by the sweetpotato variety, soil fertility, soil moisture availability, slip spacing at planting and length of the planted slip. The vine growth rate is also affected by environmental factors such as altitude, temperature and heat. The number vine-cuttings harvested per unit area as planting material may be further influenced by vine internode length and growing conditions (Jahan, *et al,* 2001, Stathers *et al*., 2013). Under optimal growth conditions, storage root yield of sweetpotato is affected by the vine length and number of nodes that are buried in the mound at planting (Belehu, 2003). Sweetpotato vine internode length in optimal growth conditions is mainly influenced by variety genetic traits. The internode length would probably influence the length of a vine cutting to be harvested if a standard number of nodes has to be buried at planting to have similar storage root yields between sweetpotato varieties with short and long vine internodes.

Sweetpotato vine internode length is highly variable among sweetpotato varieties and growth conditions, ranging from a few centimeters up to 10 cm influencing number of nodes per unit length of vine (Jahan, *et al.,* 2001). The number of nodes per unit length of vine and consequently the number of nodes that would be buried in the soil at planting influences final fresh storage root yield under optimal growth conditions (Belehu, 2003). However, the impact of slip length intended for vine-cutting production during bulking of sweetpotato planting material has not been adequately quantified and documented. This makes it difficult to recommend the minimum or maximum length of a vine-cutting that would have the highest chance of regeneration and field establishment to produce maximum, standard length sweetpotato vine-cuttings per unit area in vine bulking nurseries where limited initial stock is usually available to start the vine bulking process.

Similarly, information and recommendations on the slip spacing in mass vine production nurseries is largely scanty yet sweetpotato planting material is always in short supply at the beginning of every cropping season partly due to lack of appropriate production technologies. This too needs to be addressed considering that production of sweetpotato planting material is becoming increasingly commercial requiring technologies that would improve vine bulking efficiency.

In unimodal rainfall agro-ecologies, there is usually a long dry spell that makes it difficult for sweetpotato farmers to maintain planting materials until the next planting season in a vegetative live form (Lukonge *et al*., 2015). To achieve this, copious amounts of water for regular irrigation would be required to keep the vines alive. However, such amounts of irrigation water endowments to maintain large open field plots for vine conservation during the dry spells are not usually available. Thus, farmers maintain very small vine conservation plots which they keep alive with any available water including waste water from kitchens and bathrooms or keep storage roots in sand which are later sprouted to provide initial stock for starting vine bulking process (Stathers *et al*., 2013). However, these practices cannot offer large quantities of sweetpotato planting material until the onset of rains and when mass vine bulking can start effectively. Consequently, sweetpotato farmers often start with small quantities of planting at the onset of the rains which they bulk repeatedly before the start of sweetpotato planting for production of storage root (Braun, 2001). However, planting materials produced this way is usually not enough to plant all planned fields for sweetpotato growing in any given year (Maniyam *et al.*, 2012). Therefore, more efficient technologies are required to generate large quantities of sweetpotato planting material in a short time at the onset of rains from limited planting stock that would have been conserved during the dry spell. This would be particularly important for commercially-oriented sweetpotato storage root and planting material producers. These technologies would also optimize sweetpotato vine-cutting production and improve availability of quality planting materials for storage root production at the peak of the planting season. Late availability of planting material in the sweetpotato planting calendar would affect vine-cutting regeneration, crop field establishment and leading to poor storage root yields.

The length and spacing of slips for mass vine bulking especially in nursery beds may be critically important for the number of vine-cuttings produced per unit area and time. Both factors may also influence slip survival, field establishment, vine growth rate and eventual vine-cutting yield. Evidence is scarce on the effects of slip length, slip spacing and repeated vine harvesting of a sweetpotato crop intended for production of planting material in vine bulking nurseries. When the initial sweetpotato planting stock is limiting, there is tendency to cut them into very short pieces to maximize nursey bed space that may be planted probably at the expense of slip survival, regeneration and field establishment (Braun, 2001). Alternatively, the slips may be cut too long with little or additional benefit at the expenses of planting a larger nursery bed area. In other situations, the slips may be planted wide apart to fill available space in a nursery bed resulting in sub-optimal use of land and irrigation water. Additionally, the minimum slip length for optimal field survival, regeneration and establishment for maximum vine cutting yield is not exactly known in most sweetpotato farming systems in SSA. Planting very long slips may not be advantageous over using short ones, especially when there is adequate soil moisture to support adequate field survival and slip regeneration. Similarly, information on the effect of slip planting density in vine bulking nurseries is inadequate and needs to be re-investigated. Thus, two separate field experiments were conducted to determine an appropriate slip spacing (planting density) and slip length at planting for maximum yield of sweetpotato vine-cuttings per unit area in vine bulking nurseries for efficient production of sweetpotato planting material.

MATERIALS AND METHODS

Establishment of field experiments

Two separate field experiments were conducted at ARI Uyole, Mbeya (S 08°54.86′ E 033°31.293′; Altitude, 1798 m), in southern highlands and at Sokoine University of Agriculture (SUA) in Morogoro (S 06°50.237′ E 037°38.583′; Altitude, 515 m) in Tanzania. The main objective of the experiments was to determine an appropriate spacing (slip density) and optimum slip length for maximum yield of sweetpotato vine cuttings as planting material. In each experiment, five orange-fleshed sweetpotato varieties; Ejumula, Kabode, Kakamega, Kiegea and Mataya were used. In the slip spacing experiment, four slip spacing levels; (15x15), (20x20), (25x25) and (30x30) cm were used. All the used slips in this trial irrespective of variety and spacing treatment were 20 cm long. In the experiment for determining the effect of slip length on vine cutting yield, four levels of slip length; 15, 20, 25 and 30 cm were used. The slips irrespective of variety or length were planted at of (20x20) cm spacing. Both experiments at both sites were laid in as split-plot design in randomized complete blocks with three replications. In each experiment, the sweetpotato varieties constituted the main plot while slip spacing or slip length formed the sub-plots. In each case, the sub-plot size was 1.8 m long by 1.5 m wide as raised nursery beds. All the sub-plots in each replication were separated by one-metre wide alleys. A nitrogenous fertilizer, urea (46% N), was used at 80 kg ha^{-1} applied in three splits; at the time of planting, first weeding, between 30 and 40 days after planting while the third split was applied after the first vine harvesting. The two experiments were conducted under rain-fed conditions with supplemental irrigation in the absence of rainfall for at least ten days to ensure adequate soil moisture supply.

Data collection

At 30 days after planting, the number of slips that had fully sprouted and established in each sub-plot were counted, recorded and percent vine establishment computed. At the same time, five hills per sub-plot were randomly selected and tagged. The length of the longest vine from each of the selected hills was measured every week until the first vine harvesting, 75-80 days after planting. At first vine harvesting also, the total number of hills that survived were counted and recorded. Ratoon crops after the first harvesting round were harvested every 60 days. At each vine harvesting, 10 hills were randomly selected from each sub-plot, vines clipped just above the point of sprouting on the mother slip. The vines that were more than 20 cm long were counted and recorded. Two vines; the longest and any vine from each of the ten selected hills were measured and length recorded, and average vine length from the ten hills per plot was calculated. All the harvested vines, including those from the selected hills from each sub-plot were bundled and weighed.

The number of 30 cm long vine cuttings harvested from each sub-plot was obtained as a product of the average number of vines per hill, number of hills harvested per sub-plot and mean vine length and divided by 30. This quotient constituted the number of vine cuttings of the recommended length for sweetpotato fresh storage root production (Stathers *et al*., 2013). The number of vine cuttings harvested per sub-plot was standardized as vine-cutting yield per square metre and discounted by 10% to correct for vine extremities that may be too young or too old to be used as planting material.

Data analysis

The significance of treatment factors and their interactions on the measured variables were tested using analysis of variance. Means of significant treatments and interactions were compared using Fisher's protected least significant difference test at 5% probability. The statistical analyses employed relevant procedures in GenStat 11th Ed computer package. Pertinent graphs where necessary were drawn using MS Excel and standardized using Genstat statistical package for appropriate data presentation.

RESULTS AND DISCUSSION

Effects of slip spacing and repeated harvesting on vine growth and vine-cutting yield

Analyses of variance revealed that vine growth rate (cm day^{-1}) was significantly influenced by vine harvesting round ($P \leq 0.05$), sweetpotato variety ($P \leq 0.001$) and interaction between the two factors ($P \leq 0.01$) but not slip spacing or its interaction with any of the factors (Table 1). The number of vine cutting harvested per square metre was significantly ($P \leq 0.05$) influenced by the harvesting round ($P \leq 0.01$), sweetpotato variety ($P \leq 0.001$), slip spacing ($P \leq 0.001$) as well as interaction between harvesting round and sweetpotato variety ($P \leq 0.001$) and harvesting round with slip spacing ($P \leq 0.01$) (Table 1). Total fresh foliage yield (t ha^{-1}) was significantly ($P \leq 0.05$) influenced by the harvesting round ($P \leq 0.001$), sweetpotato variety ($P \leq 0.01$), slip spacing ($P \leq 0.001$) and interaction between harvesting round and slip spacing ($P \leq 0.05$) (Table 1).

Effect of sweetpotato slip spacing on vine growth rate

Comparison of vine growth rates among sweetpotato varieties and harvesting rounds showed that vars. Kakamega and Ejumula, respectively had significantly ($P \leq 0.05$) higher vine growth rates than Kabode, Kiegea and Mataya which did not significantly ($P \leq 0.05$) differ from each other in growth rate (Table 2). The rate of vine growth was significantly ($P \leq 0.05$) higher during the second than the first and third harvesting rounds (Table 2). The high vine growth rate for vars. Kakamega and Ejumula, when all the varieties are optimally adapted, means that it would take a shorter time to get ample planting material from the two varieties than from vars. Kabode, Kiegea and Mataya in optimal growing conditions.

Effect of slip spacing on sweetpotato vine-cutting yield

The number of vine-cuttings harvested per square metre increased with decrease in slip spacing and was significantly ($P \leq 0.05$) higher at (15x15) cm than at (30x30) cm (Table 3). However, there were no significant ($P \leq 0.05$) differences in vine-cutting yield between juxtaposed slip spacing treatments (Table 3). The high vine-cutting yield per unit area at close spacing may be due to the inherent higher plant density at close than wide spacing the same way high plant density positively influences the yield of many other crops until a certain threshold population density is attained (Asiimwe *et al*., 2016).

Vine-cuttings yield per unit area increased progressively with repeated harvesting (Table 3). However, it was significantly ($P \leq 0.05$) higher during the third than the first and second harvesting rounds, respectively (Table 3). However, the first and second harvesting rounds did not significantly ($P \leq 0.05$) differ from each other (Table 3). This sharply contrasted with vine growth rate which was significantly ($P \leq 0.05$) higher during the second harvesting round than the first and third harvesting events (Table 3). Vine-cutting yield is known to increase progressively with repeated vine harvesting (Stathers *et al*., 2013). This may be due to increased lateral branching in the ratoon than in the first crop. Harvesting may neutralize the effects of apical dominance by vine clipping with successive vine harvesting encouraging multiple branch formation and possible higher vine-cutting yield in subsequent vine harvesting events. The absence of interaction between slip spacing and sweetpotato variety on vine-cutting yield basing on these data indicates no necessity for adjusting slip spacing at planting for different sweetpotato varieties.

Total fresh foliage yield (t ha^{-1}) was significantly ($P \leq 0.05$) higher at close than wide spacing, progressively increased with successive vine harvesting and was significantly ($P \leq 0.05$) higher during the second and third harvesting round than the first (Table 4). Maximizing total fresh foliage yield for sweetpotato is important because it provides the necessary vine-cuttings as planting material or excess foliage particularly when it is available outside the sweetpotato planting window, can be maximized as animal feed (Asiimwe *et al*., 2016). Thus, close slip spacing and repeated harvesting would critically increase total foliage yield possibly due to enhanced branching in the ratoon crop by removing the effects of apical dominance particularly after harvesting the first crop.

Table 1. Mean squares from analyses of variance for effect of slip spacing, variety and repeated harvesting on vine growth rate (cm day^{-1}), number of vine cuttings (n m^{-2}) and fresh vine yield (t ha^{-1}) at ARI Uyole in 2016 and 2017

Source of variation	d.f.	Vine growth rate (cm day^{-1})	Number of vine cuttings m^{-2}	Total fresh foliage yield (t ha^{-1})
Replication	2	0.041	29422	19.0
Harvesting round (H)	2	1.0363^{**}	834759^{**}	12540.3^{***}
Residual	4	0.0493	26379	160.3
Variety (V)	4	2.5711^{***}	427202^{***}	3019.3^{**}
Harvest round x Variety	8	0.1211^{**}	110281^{***}	385.2
Residual	24	0.0254	12884	460.0
Spacing (S)	3	0.0286	194114^{***}	367.9^{**}
Harvest round x Spacing	6	0.0242	31233^{**}	196.6^{*}
Variety x Spacing	12	0.0148	14413	84.8
H x V x S	24	0.0069	8539	67.1
Residual	90	0.0191	7842	75.1
C .V. (%)		19.7	42.5	25.5

Table 2. Effect of sweetpotato variety and repeated harvesting on vine growth rate (cm day^{-1}) at ARI Uyole in 2016 and 2017

Sweetpotato variety	Harvesting round			Mean growth rate (cm day^{-1})
	First	Second	Third	
Kabode	0.592	0.530	0.365	0.496
Mataya	0.390	0.652	0.487	0.510
Kiegea	0.483	0.787	0.449	0.573
Ejumula	0.740	0.982	0.673	0.798
Kakamega	0.940	1.310	1.129	1.126
Mean*	**0.629**	**0.852**	**0.621**	

LSD$_{0.05}$ values for variety, harvest round and their interaction are 0.077, 0.113 and 0.147, respectively.

Table 3. Effect of slip spacing and repeated harvesting on number of vine cuttings harvested per square metre at ARI Uyole in 2016 and 2017 cropping seasons

Spacing (cm)	Harvesting round			Mean number of cuttings m^{-2}
	First	Second	Third	
15 x 15	124.7	256.0	442.6	274.4
20 x 20	122.2	210.8	420.9	251.3
25 x 25	104.2	146.2	269.9	173.4
30 x 30	69.2	119.1	214.0	134.1
Mean	**105.1**	**183.0**	**336.9**	

LSD$_{0.05}$ values for slip spacing levels, harvesting rounds and interaction between spacing and harvesting rounds are 82.3, 37.2 and 87.6, respectively.

Effect of slip length on sweetpotato vine growth and vine-cutting production

Analysis of variance revealed that vine growth rate (cm day^{-1}), number of vine cuttings harvested m^{-2} and total fresh foliage yield (t ha^{-1}) were significantly influenced by repeated vine harvesting ($P \leq 0.01$), sweetpotato variety ($P \leq 0.001$) and interaction between harvest round and sweetpotato variety ($P \leq 0.05$) (Table 5). The length of the planted slip had no significant ($P \leq 0.05$) effect vine growth rate and vine-cutting yield (Table 5). However, interaction between slip length and sweetpotato variety significantly ($P \leq 0.05$) influenced vine-cutting yield m^{-2} (Table 5). This may indicate a probable need for adjusting slip length to sweetpotato variety differences for nursery bed vine-cutting production. Analysis of variance further revealed that the total above-ground fresh

Table 4. Effect of sweetpotato slip spacing and repeated harvesting on total fresh foliage yield (t ha^{-1}) at ARI Uyole in 2016 and 2017.

Slip spacing (cm)	Harvesting round			Mean
	First	Second	Third	
15x15	19.8	42.3	48.4	36.8
20x20	16.9	40.2	44.1	33.8
25x25	17.7	45.9	42.5	35.4
30x30	14.9	42.4	33.2	30.2
Mean	**17.3**	**42.7**	**42.0**	

$LSD_{0.05}$ values for slip spacing levels, harvesting rounds and interaction between spacing and harvesting rounds are 3.6, 6.4 and 7.4, respectively.

foliage yield was significantly ($P \leq 0.01$) affected by the main effects of repeated harvesting, sweetpotato variety ($P \leq 0.01$) and slip length but not their interactions (Table 5).

Assessment of vine growth over sweetpotato varieties and harvesting rounds indicated that the vine growth rate (cm day^{-1}) was significantly ($P \leq 0.05$) higher during the second than the first and third harvesting rounds (Table 6). The vine growth rate was significantly ($P \leq 0.05$) higher for vars. Kakamega and Ejumula, respectively than vars. Mataya, Kiegea and Kabode which did not significantly ($P \leq 0.05$) differ from each other (Table 6) as observed in the slip spacing experiment.

Analysis of variance had revealed that vine cutting yield was significantly ($P \leq 0.05$) influenced by interaction between sweetpotato variety and slip length, however, mean vine cutting yield comparison across varieties over slip length levels revealed no consistent response pattern to make firm conclusions (Fig. 1).However, total above-ground fresh foliage yield increased with increase in slip length irrespective of variety or harvesting round (Fig. 2). Long sweetpotato slips produced significantly ($P \leq 0.05$) higher total fresh foliage yield than short ones (Fig. 2) similar to what is obtained with storage root production (Wilson, 1988).Therefore, to obtain higher total fresh foliage yield particularly in fodder production, long slips could possibly produce more feed per unit area than short ones although this did not correspondingly result in higher vine-cutting yield per unit area.

Effect of agro-ecological location, sweetpotato variety and slip spacing interactions on vine growth and vine-cutting production

The growth and performance of sweetpotato as most other crops is affected by agro-eco-climatic differences (Kapinga *et al*., 1995). Analysis of variance showed that vine growth rate (cm day^{-1}) was significantly influenced by agro-ecological location ($P \leq 0.01$), sweetpotato variety ($P \leq 0.001$) and interaction between agro-ecological location and sweetpotato variety ($P \leq 0.001$) but not the slip spacing (Table 7). On the other hand, vine-cutting yield m^{-2} was significantly affected by sweetpotato variety ($P \leq 0.001$), slip spacing ($P \leq 0.001$) and interaction between slip spacing and sweetpotato variety ($P \leq 0.01$) (Table 7). The total fresh foliage yield (t ha^{-1}) was significantly ($P \leq 0.05$) influenced by slip spacing but no other treatment factors or their interactions (Table 7).

The rate of vine growth is important in sweetpotato vine multiplication especially in mono-modal rainfall agro-ecosystems where large quantities of planting material is required in a narrow sweetpotato planting window for storage root production (Lukonge *et al*., 2015). The vine growth rate was significantly ($P \leq 0.05$) higher at SUA, Morogoro than at ARI Uyole in Mbeya for each of the experimental varieties (Fig. 3). Consistent with the similar experiment conducted over several cropping seasons at ARI Uyole in Mbeya, the vine growth rate was significantly ($P \leq 0.05$) higher for vars. Kakamega and Ejumula across the two locations (Fig. 3). However, there were no significant ($P \leq 0.05$) difference in vine growth rate among vars. Kabode, Kiegea and Mataya at Uyole while significant ($P \leq 0.05$) differences were evident among all the varieties at SUA, Morogoro (Fig. 3). The data further shows that it would be faster and easier to generate more sweetpotato planting material at SUA, Morogoro than at ARI Uyole in Mbeya with the varieties used in this study during the same cropping season in optimal soil moisture availability.

Seeding density as a result of plant spacing variation affects most plant performance parameters in both natural and artificially planted culture systems (Asiimwe *et al*., 2016).The vine-cutting yield m^{-2} across sweetpotato varieties decreased significantly ($P \leq 0.05$) with increasing slip spacing over agro-ecological locations. The vine cutting yield at both sites was significantly ($P \leq 0.05$) higher at close spacing (15x15) cm than at wide (30 cm) spacing (Fig. 4).

Table 5. Mean squares from analyses of variance for effect of sweetpotato slip length, variety and repeated harvesting on vine growth rate, vine-cuttings yield and total fresh foliage production at ARI Uyole in 2016 and 2017.

Source of variation	d.f.	Vine growth rate (cm day^{-1})	Number of vine cuttings per unit area	Above-ground fresh foliage yield (t ha^{-1})
Replications	2	0.011	9820	6817.1
Harvesting round (H)	2	1.802**	507735**	122475.0**
Residual	4	0.066	12709	2389.1
Variety (V)	4	3.038***	399849***	12269.4**
Harvesting round x Variety	8	0.146*	52963*	2140.2
Residual	24	0.044	18479	1883.6
Slip length (L)	3	0.027	11632	1944.3**
Harvesting round x Slip length	6	0.027	5748	379.8
Variety x Slip length	12	0.017	19463*	194.8
H x V x L	24	0.013	4388	185.5
Residual	90	0.014	9778	482.4
C.V. (%)		17.9	44.4	30.1

Table 6. Effect of sweetpotato variety and harvesting round after planting slips of different length on the vine growth rate (cm day^{-1}) at ARI Uyole in 2016 and 2017.

Variety	Harvesting round			Mean
	First	Second	Third	
Mataya	0.197	0.691	0.476	0.455
Kiegea	0.260	0.774	0.446	0.493
Kabode	0.522	0.544	0.427	0.498
Ejumula	0.645	0.927	0.704	0.759
Kakamega	0.912	1.325	1.188	1.142
Mean	**0.507**	**0.852**	**0.648**	

$LSD_{0.05}$ values for harvesting round, sweetpotato variety and their interaction are 0.130, 0.102 and 0.185, respectively.

Sweetpotato varieties Kakamega and Ejumula had significantly ($P \leq 0.05$) higher vine-cutting yield m^{-2} than Kabode, Kiegea and Mataya irrespective of agro-ecological locations (Fig. 4). There was no significant interaction between slip spacing and agro-ecological location for vine-cutting yield indicating that the same slip spacing can be used in both Mbeya and Morogoro with little or no impact in vine-cutting yield. However, at both locations, to obtain large quantities of vine-cuttings, it is imperative to plant slips in nurseries at the closest spacing (15 cm x 15 cm) used in this experiment. Secondly, considering that all the sweetpotato varieties used in these experiments were similarly adapted at both locations and assuming equal client acceptability, vars. Kakamega and Ejumula would provide significantly ($P \leq 0.05$) more planting material than vars. Kabode, Kiegea and Mataya grown over the same period of time (Fig. 4).

Effect of agro-ecological location and slip length interactions on sweetpotato vine growth and vine-cutting yield

Would a given agro-ecology influence the decision on the length of slips that would be used for mass vine-cutting production in view of eco-climatic impact on plant adaptation? Analysis of variance revealed that vine growth rate was significantly affected by agro-ecological location ($P<0.001$), sweetpotato variety ($P<0.001$), slip length ($P \leq 0.05$) and interaction between location and sweet-

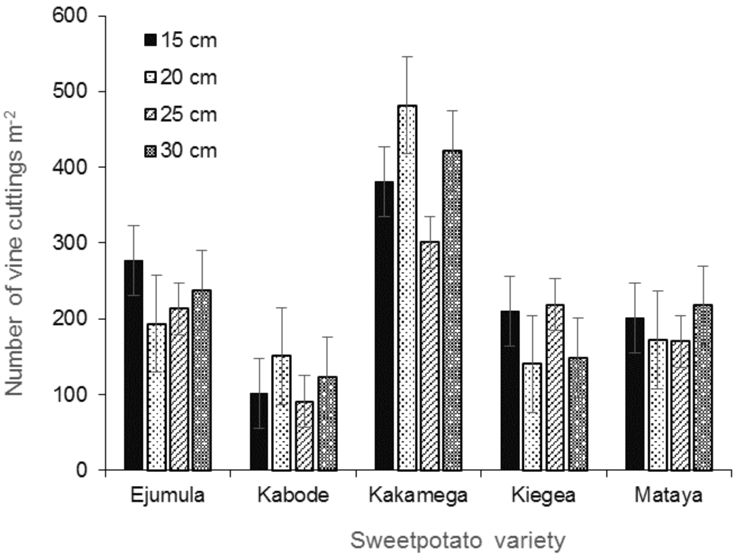

Figure 1. Effect of sweetpotato variety and planted slip length (cm) on vine cutting production per square metre in repeated vine-harvesting at ARI Uyole in 2016 and 2017 Sweetpotato slip length (cm).

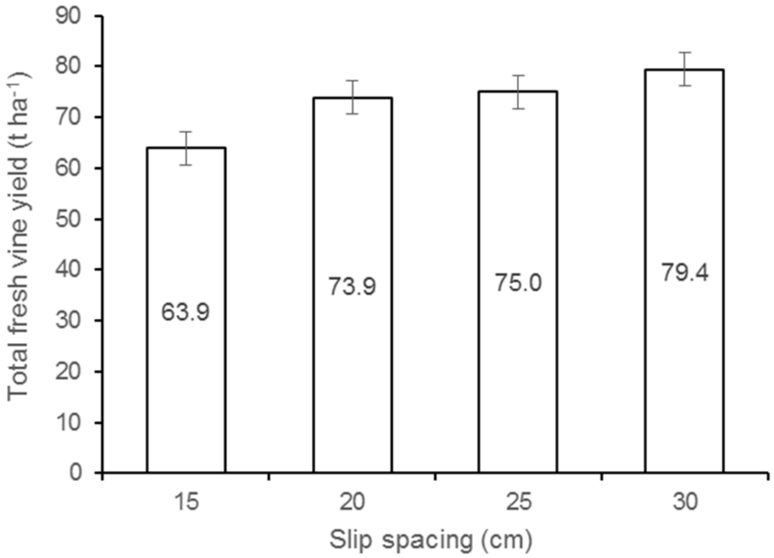

Figure 2. Effect of sweetpotato slip length on total fresh foliage yield (t ha^{1}) in repeated vine harvesting at ARI Uyole, Mbeya in 2016 and 2017 cropping seasons.

potato variety ($P<0.001$) (Table 8). Similarly, vine-cutting yield m^{-2} was significantly influenced by the main effects of sweetpotato variety ($P<0.001$), slip length ($P\leq0.01$) and interaction between sweetpotato variety with slip length ($P\leq0.05$). There were also significant ($P\leq0.05$) interaction among location, sweetpotato variety and slip length for vine-cutting yield (Table 8). Total fresh foliage yield (t ha^{-1}) was significantly ($P\leq0.01$) affected by agro-ecological location and slip length and no other treatment factors or their interactions (Table 8). Examination of pertinent means for significant treatment factors and their interactions showed that the vine growth rate was significantly ($P\leq0.05$) higher at Morogoro (17.7 mm day^{-1}) than at ARI Uyole (4.4 mm day^{-1}) ($LSD_{0.05}$ = 1.23). The vine growth rate at both ARI Uyole and SUA, Morogoro increased with increase in slip length, being significantly ($P\leq0.05$) higher with long slips than short ones (Table 9).

Table 7. Mean squares from analysis of variance for effect of sweetpotato variety and slip spacing at planting at Uyole and Morogoro in 2017 cropping season.

Source of variation	d.f.	Vine growth rate (cm day^{-1})	Number of vine cuttings m^{-2}	Fresh foliage yield (t ha^{-1})
Replication	2	0.15	54266	31443.9
Location	1	49.58^{**}	375074	142932.2
Residual	2	0.19	69607	26804.3
Variety	4	4.29^{***}	175593^{***}	1677.2
Location x Variety	4	1.65^{***}	34415	3170.1
Residual	16	0.13	21391	3921.1
Spacing	3	0.05	190788^{***}	1761.8^{*}
Location x Spacing	3	0.06	4315	756.3
Variety x Spacing	12	0.03	22420^{**}	379.6
Location x Variety x Spacing	12	0.02	3091	300.8
Residual	60	0.03	7641	530.8
CV (%)		16.5	47.4	35.3

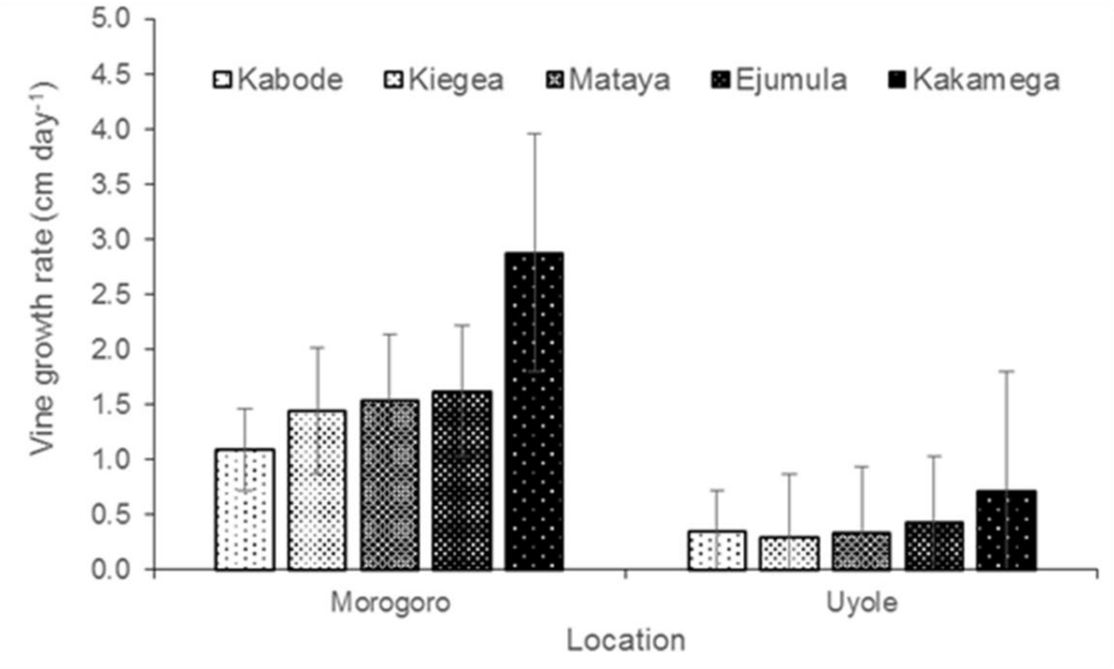

Figure 3. Effect of agro-ecological location and sweetpotato variety on vine growth rate at SUA, Morogoro and at ARI Uyole, Mbeya in 2017 cropping season.

As observed before in a multi-year trial at ARI Uyole, vars. Kakamega and Ejumula had significantly (P≤0.05) higher vine growth rates than Kabode, Kiegea and Mataya, respectively (Table 9).

Interactions among location, sweetpotato variety and slip length for vine-cutting yield was significant (P≤0.05) however, the response pattern in respective varieties over slip length levels across the trial sites was not consistent to make strong recommendations on the length of vine-cutting that can be used in vine bulking nurseries (Fig. 5). Evidently however, vine-cutting yield m^2 was significantly (P≤0.05) higher for vars. Kakamega and Ejumula, respectively at both Morogoro and ARI Uyole than the other experimental varieties (Fig. 5). Vine cutting yield per unit area was also significantly higher at SUA Morogoro than at ARI Uyole (Fig. 5).

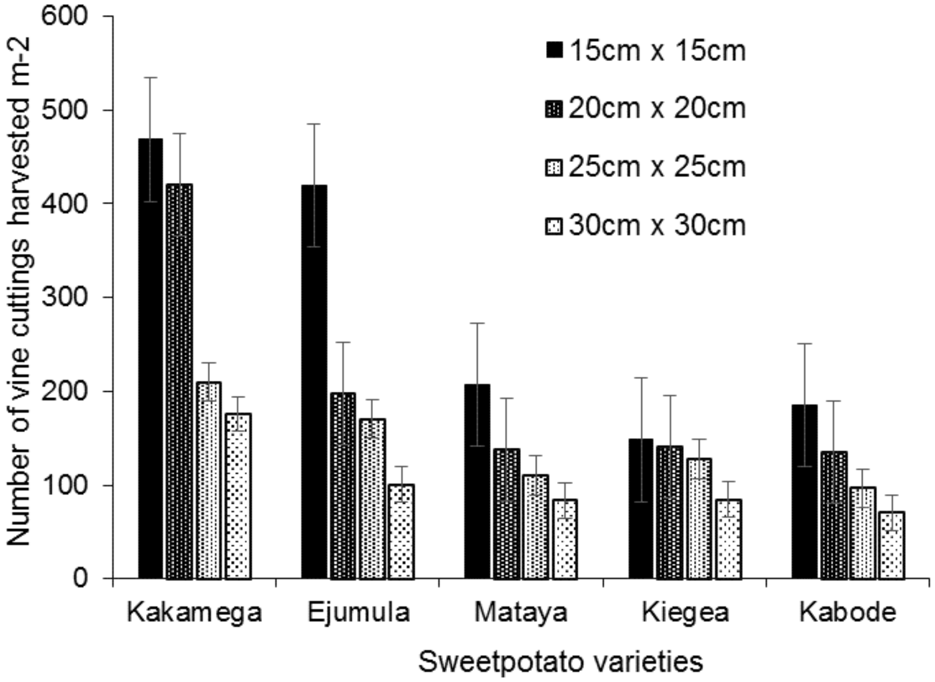

Figure 4. Effect of slip spacing (cm) on vine-cuttings yield per square metre at ARI Uyole, Mbeya and at Sokoine University of Agriculture (SUA), Morogoro in 2017.

Table 8. Mean squares from analysis of variance for effect of sweetpotato slip length and variety on vine growth rate (cm day^{-1}), number of vine cuttings harvested m^{-2} and total fresh foliage yield (t ha^{-1}) at ARI Uyole and SUA Morogoro in 2017 cropping season.

Source of variation	d.f.	Vine growth rate (cm day^{-1})	Number of harvested vine cuttings m^{-2}	Total fresh foliage yield (t ha^{-1})
Replication	2	0.016	12438	261.2
Location	1	52.979***	295856	56654.8**
Residual	2	0.025	48809	139.6
Variety	4	3.381***	146587***	2693.7
Location x Variety	4	1.100***	10643	1872.3
Residual	16	0.103	7562	1266.0
Slip length	3	0.153*	17692**	1102.2**
Location x Slip length	3	0.054	244	68.8
Variety x Slip length	12	0.028	7132*	285.9
Location x Variety x Slip length	12	0.056	7020*	216.7
Residual	60	0.050	3587	187.9
CV (%)		20.1	34.7	21.8

Considering lack of consistent pattern in vine-cutting yield with variation in slip length across varieties and sites, it is necessary to re-examine the effects of slip length on vine-cutting production in sweetpotato vine bulking particularly when the initial planting stock is limiting and vine-cutting production needs to be maximized to meet planting material needs in a short time.

The sweetpotato planting material stock for initiating vine bulking when limited in quantity may be cut too short with hope of increasing their number and thus planting large nursery area. This may be possible but at the expense of reduced slip survival and regeneration. Alternatively, when the initial stock is rather adequate, it be cut too long with limited benefit in massive vine cutting production particularly when irrigation resources may be limiting. Thus, optimizing the length of the slip to be used in vine bulking would reduce waste or loss of valuable stock and irrigation water that would have been used to produce large quantities of planting material in time to fit in the sweetpotato planting window for storage root pro-

Table 9. Effect of slip length (cm) and sweetpotato variety on vine growth rate (cm day^{-1}) at SUA, Morogoro and ARI Uyole, Mbeya in 2017 cropping season.

Variety	Planted slip length (cm)				Mean
	15	20	25	30	
Kabode	0.684	0.710	0.700	0.721	0.704
Kiegea	0.879	0.985	0.989	0.974	0.957
Mataya	0.914	1.086	0.909	1.170	1.020
Ejumula	1.087	1.043	1.143	1.274	1.137
Kakamega	1.566	1.715	1.724	1.856	1.715
Mean	**1.026**	**1.108**	**1.109**	**1.199**	

LSD$_{0.05}$ values between sweetpotato varieties, planted slip length and interaction between variety and slip length are 0.196, 0.115 and 0.259, respectively.

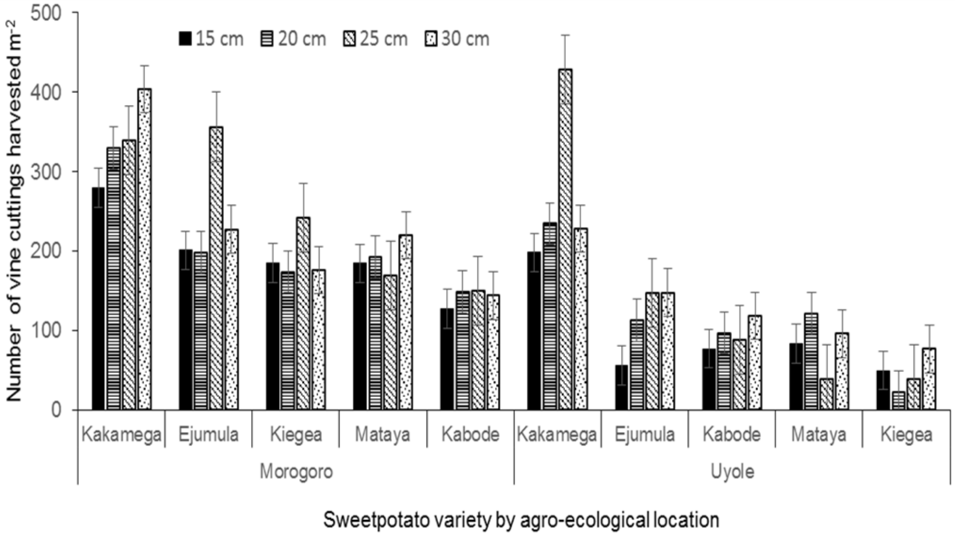

Figure 5. Effect of sweetpotato slip length (cm) and variety on number of vine-cuttings harvested per square metre at SUA Morogoro and ARI Uyole in 2017 cropping season.

duction in unimodal rainfall farming systems.

CONCLUSION AND RECOMMENDATIONS

The data from the two experiments revealed that production of sweetpotato planting material in mass vine bulking is influenced most by repeated vine harvesting, agro-ecological location, sweetpotato varieties and slip spacing, and least by the length of the slip. Vine-cutting yield per unit area in vine bulking in nurseries increased with repeated vine harvesting however, yield was significantly ($P \leq 0.05$) higher during the third than the second and first harvesting rounds. Similarly, the vine-cutting yield was higher at a low altitude in Morogoro than at the high altitude at ARI Uyole in Mbeya. This means that to maximize vine-cutting production particularly for large area distribution, it would be more beneficial to start vine bulking at lower altitude in Morogoro provided the virus infection pressure is low or can be controlled and transfer the produce to a higher altitude for further bulking. This is possible since the planting window for sweetpotato storage root production between the two agro-ecologies is separated in time. By starting mass vine bulking at low altitude, the crop would be cut back well before that start of the cropping season at high altitude. This would give it chance to quickly regenerate and offer better vine-cutting production in the ratoon crop than what would be obtain in the primary crop. If vine bulking would have to be done at high altitude, it should be initiated early enough under irrigation due to the slow vine growth rate to ensure that the produced planting material fits in the sweetpotato planting window in the relevant agro-ecology. Among the five varieties that were used in this study, vars. Kakamega and Ejumula were more prolific and produced more vine-cuttings per unit area than Kabode, Mataya and Ejumula. Assuming similar cultivar adaptation and acceptability and conditions being equal, varieties Kakamega and Ejumula would provide more planting material faster than vars. Kabode, Kiegea and Mataya.

Vine-cutting yield per unit area increased with reducing in slip spacing in vine multiplication nurseries. The highest vine-cutting yield was obtained at (15x15) cm and least at (30x30) cm slip spacing. The effect of slip length on vine-cutting yield basing on these data was however was inconsistent, did not show any particular response pattern across cropping seasons, sweetpotato varieties, repeated vine harvesting or agro-ecological locations and would require further investigation. Similarly, the tested slip spacing levels were perfect square in nature, rectangular spacing arrangements may probably have a profound effect on the slip planting density and possibly influence slip survival, regeneration and vine-cutting yield. To expand the scope of obtaining appropriate vine production technologies in vine bulking nurseries, it would be imperative to test other slip planting densities in different rectangular arrangements. This would probably generate more suitable slip spacing recommendations for more efficient vine-cutting production particularly for smallholder sweetpotato farmers in SSA.

ACKNOWLEDGEMENTS

This research was undertaken as part of the CGIAR Research Program on Roots, Tubers and Bananas (RTB). Funding support for this work was provided by USAID Feed the Future Program. The authors further thank the management of ARI Uyole, Mbeya and Sokoine University of Agriculture, Morogoro in Tanzania for their support, Drs. Robert Mwanga and Sam Namanda of CIP Uganda for their valuable technical review and advice.

DISCLAIMER

The views expressed in this article are for the authors and do not in any way reflect the opinions of USAID or The Federal Government of the United States of America.

REFERENCES

Abidin PE, Kazembe J, Atuna RA, Amagloh FK, Asare K, Dery EK and Carey EE (2016). Sand Storage, Extending the Shelf-Life of Fresh Sweetpotato Roots for Home Consumption and Market Sales. Journal of Food Science and Engineering 6: 227-236. doi: 10.17265/2159-5828/2016.04.005.

Anon. (2011). Sweetpotato (*Ipomea batatas* Lin.) Production Guide in South Africa. Directorate of Production, Department of Agriculture, Forestry and Fisheries. Republic of South Africa. pp20.

Asiimwe A, Tabu IM, Lemaga B and Tumwegamire S (2016). Effect of maize intercrop plant densities on yield and β-carotene contents of orange-fleshed sweetpotatoes. African Crop Science Journal 24: 75-87.

Belehu T (2003). Effect of vine-cutting characteristics on yield and yield components of Sweetpotato. M.Sc. Thesis. University of Pritoria. pp140.

Beyene K, Nebiyu A and Getachew M (2015). Effect of the number of ndes and storaghe duration of vine cuttings on growth, yield and yiled components of sweetpotato in south eastern Ethiopia. Journal of Biology, Agriculture and Healthcare 5:51-64.

Braun B (2001). Maintenance of sweetpotato planting materials in Namibia: Options for the development of a vine production and distribution system. Agricola 2001:15-19.

Dannien S, Homare D, Hughes M, Lavatt J, Coleman E, and Jackson G (2013). Growing Healthy Sweetpotato: Best practices for producing planting material. ACIAR Monograph 153. Australia Council of International Agricultural Research. Canberra, Australia. pp176.

FAO (2009). Quality declared planting material protocols and standards for vegetatively- propagated crops. FAO Plant Production and Protection Paper No. 195. FAO, Rome. pp156.

FAO (2015). The Food and Agriculture Organization of the Unaited Nations. Agricultural (Crop) Production 2014. http://www.fao.org/faostat/en/#data/QC.

Jahan MA, Islam AK and Siddique, MA (2001). Studies on growth and yield of sweetpotato influenced by seedlings and mulching. Agriculturae Conspectus Scientificus 72: 357-359.

Jones D, Gugerty MK and Anderson CL (2012). Sweetpotato value chains: Tanzania. Evans School of Policy and Analysis Research. University of Washington. Policy Brief No. 211. pp19.

Kapinga RE, Ewell PT, Jeremiah SC, and Kileo R (1995). Sweetpotato in Tanzanian Fanning and Food Systems: Implications for Research. International Potato Center, Sub-Saharan, Africa Region, Nairobi, Kenya. pp55.

Lukonge EJ, Gibson RW, Laizer L, Amour R, Phillips DP (2015). Delivering New Technologies to the Tanzanian Sweetpotato Crop Through Its Informal Seed System. Agroecology and Sustainable Food Systems 39: 861–884. 2015. DOI: 10.1080/21683565.2015.1046537.

Maniyam N, Gangatharan B and Susantha KJ (2012). Sweet potato Agronomy. Fruit, Vegetable, Cereal Science and Biotechnology. Regional Centre of Central Tuber Crops Research Institute. India. pp8.

Markos D and Loha G (2016). Sweetpotato agronomy research in Ethiopia. Summary of past findings and Furure reserch direction. Agricultural and Future Science Research 3: 1-11.

Srinivas T (2009). Economics of sweetpotato production and marketing. In Loebenstein, G. and Thottappilly, G. (Eds). *The Sweetpotato*. Springer Science. pp. 235-269. DOI 10.1007/978-1-4020-0-12.

Stathers T, Low J, Mwanga R, Carey T, David S, Namanda S, McEwan M, Bechoff A, Malinga J, Benjamin M, Katcher H, Blankenship J, Andrade M, Agili S, Njoku J, Sindi K, Mulongo G, Tumwegamire S, Njoku A, Abidin E and Mbabu A (2013). *Everything You Ever Wanted To Know About Sweetpotato*: Reaching Agents of Change ToT Manual. Vol. 3: Sweetpotato Seed Systems. International Potato Center, Nairobi, Kenya. pp1-143.

Wilson JE (1988). Sweetpotato (*Ipomea batatas*) planting materials. Institute for Research, Extension and Training in Agriculture, University of Hawaii. pp.12.