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Vine harvesting frequency impact on tuber yield attributes of commonest sweet potato cultivar in Sub-Saharan Africa

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Abstract

Sweet potato (*Ipomoea batatas* L.) root tubers and vines are important for human and animal nutritional requirements, respectively; the vines being additionally used for propagation, but root tuber yield is greatly affected by vine harvesting frequency. This study aimed at assessing the potential effect of vine harvesting frequency of sweet potato German 11 cultivar on attributes of root tuber yield under sprinkler irrigation after 140 days from planting. Treatments used consisted of vine harvesting once (VHO) at 8 weeks after planting, 2 times (VH2T) at 8 and 10 weeks after planting; 3 times (VH3T) at 8, 10 and 12 weeks after planting; and 4 times (VH4T) at 8 weeks, 10 weeks, 12 weeks and at 14 weeks after planting. No vine harvesting was the control. Treatments were arranged in a randomized complete block design (RCBD) and replicated three times. Results revealed that vine harvesting frequency had a relative effect on all root tuber yield attributes of sweet potato. The lower the vine harvesting frequency the higher the yield obtained. Vines harvested once (VHO) at 8 weeks significantly ($P<0.001$) increased root tuber dry matter (DM) (29.3%) and total root tuber yield (14.5 t ha^{-1}) as compared to VH4T, and also gave optimum results in all the root tuber yield parameters measured. Based on the results, optimum German 11 cultivar production capacity is achieved when vine harvesting for livestock feeding and propagation is done only once at 8 weeks.

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Introduction

Sweet potato (*Ipomea batatas* L.) is widely grown for its root tubers for human consumption, and vines for animal feed and propagation. It ranks second in world root and tuber crop production after potato and second after cassava in importance in Africa (Woolfe, 1992).The world sweet potato annual production is around 124 million tonnes on an area of 9.2 million ha (Posas, 2000). Quoted literature, statistics revealed that over 95% of global sweet potato was produced in developing countries, for instance, in 1995 and 1998 (Aniekwe, 2014), but African farmers produced only 7 million tonnes of sweet potato annually; most of which produced under dry land conditions, with no fertilizer use. In Asia, half of the sweet potato produced is used for animal feed, starch, flour and alcohol. Etela *et al.* (2008) reported that feeding the vines to cows as a supplement to a basic diet of other forage increased milk yield. In the tropics and subtropics, sweet potato is produced for human consumption, with its storage tuber being boiled, roasted and then served as major meal or part of a major meal. The vines are used by many farmers, for instance, in Zimbabwe, Zambia and Nigeria as forage for ruminants feeding due to their richness in proteins and minerals needed in livestock feeds (Gonzales *et al.*, 2003; Giang *et al.*, 2004; Kebede *et al.*, 2008; Ahmed *et al.*, 2012). They also defoliate leaves of the sweet potato to prepare relish but they are not clear on the impact on yield after removing the foliage, or to what extent they should remove the vines. The main varieties locally grown by most farmers are named German 11 and Chingovha.

Sweet potato is a warm season crop which, however, has a wide ecological adaptation, drought tolerance due to its low plant growth habit and extensive root system (Hammett *et al.*, 1982; Agili *et al.*, 2012). It therefore thrives under marginal conditions which prevail in Zimbabwe such as drought and infertile soils. Sweet potatoes store well and can be a famine reserve crop especially with the increased effects of climate change being currently experienced in Africa South of the Sahara and beyond. It is considered as one of the food security crops because it gives a continuous supply of nutritious human food and livestock feed throughout its growing cycle (De Vries *et al.*, 1967; Ahmed *et al.*, 2012).

All the parts of the sweet potato plant are valuable. The root tuber contains 80 to 90% carbohydrates, 3.6 to 5.4% crude protein, 0.72 to 1.27% fat, 2.5 to 3.25% fibre and 2.5 to 3.2% ash on a dry matter basis (Duke, 1983), thus outranking most other carbohydrate food crops (Woolfe, 1992). The leaves provide an excellent source of energy, protein, iron, vitamins A, C and fibre (Smart and Simmonds, 1995). It is unquestionably one of the most important food crops in the developing world (Jeremiah, 1992). Vines are used as planting materials. Thus, vines and roots generate income to developing nations. Increased recognition of the great potential of sweet potato crop as an income earner, and as a nutritious food for humans and animals, have resulted in intensified research efforts on commonest cultivars adapted to specific locations to enhance their production (Yamakawa and Yoshimoto, 2002).

Unfortunately, the use of vines as planting material for the sweet potato perpetuation and evolution, and as livestock fodder inevitably cause scarcity of the sweet potato vines and root tubers, particularly during dry hot summer period in mixed crop-livestock production system (Leon and Velade, 2000). This is because there is no known cut-off point for harvesting the vines. The few plants which survive have their yielding potential severely affected. Frequency of vine harvesting is an important management factor that affects sweet potato root yield as well as quality (An, 2003). Root tuber yield can significantly decline due to high vine harvesting frequency (Nguyen and Bautista, 1999). Smith (2004) indicated that the national average root tuber yield of the crop is 6 th^{-1} in Zimbabwe, with wide yield variations of up to 25 t ha^{-1} for sweet potatoes grown under irrigation, when no vines are harvested. Root tuber yields of sweet potatoes grown at several locations were increased by irrigation when no vine harvesting is done (Bowers *et al.*, 1956; Ghuman and Lal, 1983; Hammett *et al.*, 1982; Hernandez *et al.*, 1965; Jones, 1961; Lambeth, 1956; Lana and Peterson, 1956). Drip furrow or sprinkler irrigation can be used for irrigating sweet potato fields.

However, when harvesting vines for various purposes, no work has been done which shows the real frequency which gives optimum yield in smallholder farming areas of Zimbabwe under sprinkler irrigation. Because of a large amount of variations which exist within the sweet potato cultivars (Vimalaand Hariprakash, 2011) and the unknown vine harvesting frequency of German 11 cultivar which optimises tuber yield, the current study was carried out to determine the effects of vine harvesting frequency on number of root tubers per plant, root DM content, root tuber marketable weight, fresh weight and root tuber yield of sweet potatoes cultivar German 11. Yield responses to, mostly grown in Zimbabwe, is unknown. The study on effect vine harvesting frequency, as influenced by the need for planting material and fodder production, should establish the cut-off point of vine harvesting frequency, which enhances optimum yield.

Materials and methods

A field experiment was carried out at Tikwiri irrigation scheme in Makoni District ward 16, situated 25km south west of Rusape Town, Zimbabwe (coordinates 18° 32′ 12″ S, 32° 07′ 29″ E), between October 2014 and April 2015, and repeated in 2015 and 2016 between the same period.

Experimental site

Tikwiri irrigation scheme falls under agro-ecological region 11B, which is 1850m above sea level. In 2013, 2014 and 2015, accumulated rainfall was 500mm, 650mm and 780mm per annum; the mean annual temperatures were 24.2°C,24.2°C and 22.5°C; and mean monthly relative humidity was 87.88% and 88% respectively.

The soil at the experimental site had been planted for four years with maize, soya beans and horticultural crops, for instance tomatoes. The soil is clay loam(sand 34%,clay 30%,silt 36%) with a pH 6.3,0.1 extractable acidity 2,8% organic matter, calcium 26.4 cmol/l, magnesium 10.1 cmol l^{-1},potassium 0.7 cmol l^{-1} and an effective cation exchange capacity of 37.2 cmol kg^{-}.

Treatments and experimental design

The following were the treatments used:

Vines were harvested once (VHO) only at 8 weeks after planting.

Vines harvested2 times (VH2T) at 8 weeks and 10 weeks after planting.

Vines harvested 3 times (VH3T) at 8 weeks, 10 weeks and lastly at 12weeks after planting.

Vines harvested 4 times (VH4T)at 8 weeks, 10 weeks, 12 weeks and at 14 weeks after planting. Control-no vine harvesting.

Land preparation and planting

The field was ploughed, harrowed and ridged. Sweet potato is grown on ridges, raised beds or mounds. This soil configuration provides the developing roots with loose, friable soil such that they expand to their potential size and shape without restriction. It also allows adequate drainage and aeration which are important requirements for successful sweet potato production. The size of each plot was 9m ridge length with a height of 30cm above the ground and a width of 40cm at the base.

Vines of 30cm length with approximately eight nodes were collected from established plants; from medium stem cuttings of mother stocks. Excess leaves were trimmed off from each cutting so that only eight leaves remained per each cutting. The first planting was done on 10 October 2014 and the second (for the repeated experiment) on 18 October 2015 after effective rains. Planting was done in moist soil, whereby two third of the vine length was placed in the ground. Vines were planted at about a 45° angle into the ridges and at an in-row spacing of 30 cm. At this recommended plant spacing, 30 cuttings are required for a 9 m ridge row. The ridge inter-row spacing was 1m. Each plot (treatment) had two ridges. Therefore, a plot was composed of 60 plants.

After planting a slight irrigation was applied to cover all air pockets created so as to enable a good take off. Three weeks after planting, first weeding was done with the objective of re-ridging and cleaning up the field.

Subsequent weeding was later based on weed economic threshold level. Each treatment was replicated three times. The design used was randomised complete block design (RCBD).

Experimental material

A standard sweet potato variety commonly grown in the area namely Germany 11 was originally obtained from Marondera Grassland Research Station, Marondera, Zimbabwe (coordinates 18º 11′ 23″ S 31º 32′ 48″ E). This cultivar has a spreading growth habit which has the ability to regenerate shoots so fast. It has red peels (skin)and a whitish flesh which has a high starch and dry- matter content. It is a medium maturity which takes 140 days to reach physiological maturity.

Fertilization

Fertilization was according to the protocol of Department of Agriculture, Forest and Fisheries (DAFF) (2011). An amount of 100 kg Nitrogen (N), 90 kg Phosphorus (P), 200 kg Potassium (K) and 200 kg Calcium (Ca) were used. All the phosphorus was applied in the basal along with 50 kg N and 50 kg K. The remaining 50 kg N and 150 kg K was divided into two side-dressings at 4 to 6 weeks and at 10 to 12 weeks from planting.

Irrigation

Requirements for water vary with soil type, but can be generally estimated as 18 to 20 mm week^{-1} early in the season, 40 to 45 mm week^{-1} during the growing period. In the current research, water applications were through sprinkler irrigation and based on crop visual assessment and stage (in terms of age) of growth. A light irrigation was applied soon after transplanting as moisture was needed around the base of the propagule, which typically was set at the top of the ridge.

This is crucial for promoting the initiation and development of storage root cells. The soil was then kept moist from 8 weeks onwards as roots had been initiated and were starting to fill out. This is also the period of increased water use by the plants.

Tuber harvesting

Tuber harvesting was done after 140 days from planting, in such a way that all plots were harvested once. Tubers from each treatment per plot were gathered together to enable parameters to be measured.

Measurements of parameters

The parameters studied were: number of tubers per plant, dry matter (DM), content total fresh weight, marketable weight, unmarketable weight and yield per hectare of each treatment.

Data analysis

The data was analysed using Gen Stat version 12. The least significant differences (LSD) test was used to separate treatment means for significant differences at 5% level of significance. Means were further compared and separated within a column using Tukey's HSD test ($P<0.05$).

Results

Number of tubers per plant

There were significant differences in the average number of tubers among all treatments, except the control and VHO (Table 1). However, the lowest number of tubers were realised in the sweet potatoes at VH4T. These recorded an average of 1 tuber plant^{-1} as indicated by a mean value of 1.3 tubers plant^{-1}, and developed 7 tubers less than the control.

DM content

All treatments of vine harvesting highly significantly ($P<0.001$) increased DM content of the sweet potato. The control treatment had DM content of 35% and this formed the benchmark for the comparison.

Sweet potatoes which had VHO had 5.7% lower DM content than the control DM content. The lowest DM content of 14.3% was recorded in the sweet potatoes which had VH4T.

Table 1. Effect of vine harvesting frequency on number of root tubers per plant, root DM content, root tuber marketable weight, fresh weight and root tuber yield after 140 days from planting.

Treatments (harvesting frequency)	No. of tubers $plant^{-1}$	Root tuber dry matter (DM) content (%)	Marketable tuber weight $plant^{-1}$ (g)	Root fresh weight $plant^{-1}$ (g)	Total root tuber yield ha^{-1} (t)
Control*	7.9^{de}	35^{e}	405.2^{e}	520.7^{e}	19.3^{e}
VHO	7.0^{d}	29.3^{d}	353.6^{cd}	391.2^{cd}	14.5^{d}
VH2T	5.1^{c}	24.8^{c}	328.2^{c}	347.1^{c}	12.8^{c}
VH3T	3.2^{b}	18.9^{b}	170.8^{b}	184.3^{b}	6.8^{b}
VH4T	1.3^{a}	14.3^{a}	79.5^{a}	90.1^{a}	3.3^{a}
SE±	1.7	6.5	3.3	8.1	0.2
P. value	0.01	0.001	0.01	0.01	0.001
$LSD_{(0.05)}$	0.87	7.99	2.52	9.07	5.26
CV(%)	10.13	2.51	15.33	21.08	3.79

Means within a column are compared and separated using Tukey's HSD test ($P<0.05$) and different alphabetic letters indicate significant differences. *Control where no vine harvesting was done.

Marketable weight

The control had significantly ($P<0.01$) higher root tuber marketable weight to all the other treatments. Sweet potatoes which had VHO had root tuber marketable weight not significantly different from VH2T. The rest of the treatments produced some statistically significant differences with the control treatment. The difference between the control and VH4T was some 325.7 g.

Fresh weight

There were significant ($P<0.01$) differences between the means of all the vine harvested sweet potatoes. The control treatment recorded 520.7 g and was the highest across all other treatments.

There was significant difference between the VH4T which recorded 90.1 g and the control with a difference of 430.6 g. Furthermore, the test proved that there was a statistical difference between the means and according to the table means, there was a difference of 129.5 g between the control treatment and VHO. VHO treatment was not significantly different from VH2T treatment.

Total root tuber yield (t ha^{-1})

All vine harvesting frequencies relatively reduced root tuber yield. VHO gave 14.4 t ha^{-1}, while no harvesting (control) gave 19.3 t ha^{-1}. VH4T produced the lowest yield (3.330 t ha^{-1}). The difference was 11.1 t ha^{-1}.

Discussion

No vine harvesting (control) had the highest yield results in all parameters (Gonzales *et al.*, 1977). However, no vine harvesting is not very common in Zimbabwe as the vines need to be harvested for propagation and livestock feeding. In this regard, VHO could be considered as the best management as it gave the optimum yield results. The general trend in all the parameters measured showed that results were inversely proportional to the number of vine harvesting practices applied to the sweet potato. The lower the vine harvesting frequency, the higher the results of all the yield parameters measured.

High vine harvesting frequency caused a low increase in tuber number. This is because the yield of sweet potato depends upon the amount of assimilates by the leaves (Dauiya, 2001). It is the leaves which contain chloroplasts which house the complete machinery for photosynthesis. These results are consistent with those of Lugojja *et al.* (2001) who reported that the mean number of sweet potato tuberous roots per hectare decreased significantly following increased vine harvesting. Indeed, the large leaves and long vines of German II can seriously decrease the number of tubers if they are defoliated beyond the cut-off point.

The result of 35% DM content agrees with the DM results of Yeng *et al.* (2012) who obtained 34.5% where inorganic fertilizers were used.

The DM content increased with the decrease in vine harvesting frequency as shown in this experiment.

This is because the formation of storage organs is associated with the deposition in these cells of storage polysaccharides usually starch. The new developing shoot utilize stored energy up to when the leaves are fully established, so if vines are continuously cut off, the reverse gets depleted. It is these storage roots which, when dried, form DM content.

Leaf absence from the plant might mean poor tuber development which finally decreased root tuber marketable weight. According to Garner (2007), the leaf is the photoperiod perception organ of day lengths for good tuber formation and development. Tubers which were more than 50g each were considered marketable. It is the accumulation of DM content which determines weight and size of tubers which is a determinant factor considered in the marketability aspect of tubers.

The increase in vine harvesting frequency responded negatively, with a decrease in root fresh weight. This is because when vines are not cut, there is adequate manufacture and accumulation of photosynthetic products in the tubers resulting in increase in tuber size, eventually influencing high fresh weight. Verlind (2007) reported that when vines are allowed to senescence without vine cutting done, there would be a marked increase in starch and protein content and a drop in sugar content of the tubers hence a gain in fresh weight. So when the shoots redevelop due to vine harvesting there would be mobilisation of carbohydrates out of the tubers (dissimilation process), hence resulting in reduction in fresh weight (Jeffard, 2009). This is in agreement with Stathers *et al.* (2005). Edelman (2010), pointed out that the utilisation of different enzymic systems in the breakdown of storage polysaccharides to sustain shoot growth has a great impact on the fresh weight status of tubers. Similarly, Stathers *et al.* (2005) reported that tuberous root weight of sweet potato was significantly reduced when cuttings were frequently taken from actively growing plants for propagation.

The role of leaves in the perception of day lengths for tuber formation in sweet potato was noted by Hamner and Long (2001). They noted that the leaves act as the perceiving organs, which most sensitive to photoperiod. This photoperiod requirement is for storage organ formation. Again, the conditions which gave the greatest tuber development were associated with the amount and availability of growth of shoots at minimum rate. Therefore, root tuber yield level is influenced by the amount of assimilates manufactures by the leaves, meaning that if the leaves were removed, the rate of assimilation would decrease and ultimately lower root yield levels (Hamner and Long, 2001). Nwinyi (1992) revealed that removal of sweet potato vines during growth reduced photosynthetic power of the whole plant and results in reduction of tuberous root yield. So, the amount of tuber fresh weight and quantity of tubers plant^{-1} are parameters which contribute to yield level ha^{-1} which are also affected by the amount of assimilates generated by the leaves present on the plant.

The control treatment gave root tuber yield of 19,3 t ha^{-1} (Table 1) which agrees with results for Yeng *et al.* (2012) where inorganic fertilizers were used. Average fresh storage root yield of 10 to 25t/ha in 16 to 20 weeks has been obtained for sweet potato for sweet potato cultivars which include German II, when no foliage is harvested (Bhagsari, 2005). So the amount of tuber fresh weight and quantity of tubers plant^{-1} which directly influence yield level ha^{-1} are expected to be high as shown in the current study, depending on the length of the maturity period of the culivar, provided there is no foliage defoliation which is demonstrated by vine harvesting. German II takes an average of 20 weeks to reach maturity; most of the cultivars attain maximum storage root yield in 12 to 22 weeks after planting (Soteinbaner, 2002). Dahniya (1979) reported that frequent defoliation of sweet potato plant disrupted the photosynthetic process, leading to a reduced leaf, root and biomass production.

This result agrees with other reports that defoliation had a negative influence on root production in sweet potato (Ruiz *et al.*, 1980; Nguyen and Bautista, 1999; Kiozya *et al.*, 2001: An *et al.,* 2003).

This study confirmed that the higher the frequency of vine harvesting, the lower the root tuber yields, as indicated by the inverse proportional trend. This happened in all parameters tested. Results showed that vine harvesting once gave the optimum results of all the parameters measured. The significant effect vine harvesting to all parameters measured only shows it can be done so that we have planting material, feed for animals and enough food for human use, but with a cut-off point of harvesting only once where optimum root tuber yield is obtained.

Conclusion

In sub-Saharan Africa, sweet potatoes vines have to be harvested for propagation purposes and sometimes to feed livestock. The study showed that high vine harvesting frequency reduced all root tuber yield attributes of sweet potato. The lower the vine harvesting frequency the higher the yield obtained. Of all the vine harvesting frequencies, VHO at 8 weeks after planting effected superior increase on root tuber DM (29.3%) and total root tuber yield (14.5t ha^{-1}) as compared to VH4T at 8 weeks, 10 weeks, 12 weeks and 14 weeks after planting which gave 14.3% and 3.3 t ha^{-1} respectively. VHO also gave optimum results in all the other root tuber yield measurements.

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