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RESEARCH ARTICLE



Effect of different types of sweet potato (*Ipomea batatas*) cultivars on growth performance in woven polypropylene plastic bags

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ABSTRACT

The sweet potato is one of the exceptionally healthy foods that requires low inputs for production. However, in South Africa the majority of people purchase their staple food, owing to land scarcity. The woven polypropylene plastic bag (WPPB) planting technology, could be a solution for food production in limited spaces. The objective of this study was to investigate the effect of different sweet potato cultivars on growth performance using the WPPB technology. Compared to the standard ('Blesbok') cultivar, all the tested cultivars ('Bosbok', 'Bophelo', 'Mafutha' and 'Mvuvhelo') had higher chlorophyll content. 'Bophelo' and 'Mvuvhelo' obtained thickest (0.40 and 0.45 cm) stem diameters. 'Mafutha' achieved the highest (64.30 cm) vine length and number of shoots (4.64). Noticeably, 'Mafutha' produced the highest (4.50) number of flowers compared to the standard. 'Bophelo' obtained the highest (122 g) dry shoot mass and 'Bosbok' recorded the highest (11.2) number of enlarged roots (NER). Contrary to that, 'Mafutha' had the lowest (3.4) NER. In conclusion, 'Mafutha' performed well in terms of the above-ground plant parameters, whereas 'Bosbok' was best with regard to the below-ground plant parameters. Therefore, planting 'Bosbok' and 'Mafutha' cultivars in WPPBs achieved the best below and above growth performances, respectively.

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Introduction

Globally, the sweet potato (*Ipomea batatas* L.) root crop ranks the seventh most important crop after rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), Irish potato (*Solanum tuberosum* L.), maize (*Zea mays* L.), cassava (*Manihot esculenta* Crantz.) and barley (*Hordeum vulgare* L.) (FAO Statistics 2011). China was reported as the world's largest sweet potato producer, with 76.2% of global production (UNCTAD 2012). In Africa, subsistence farmers value the sweet potato root crop as it grows in a variety of climates with few inputs and can withstand drought. In South Africa, sweet potatoes are ranked the second largest root crop produced (82,000 tons in 2018/19) following carrots (*Daucus carota* L.). It has a well-developed commercial market, but also plays an important role in food security and alleviating malnutrition. The major production areas are Limpopo, Mpumalanga, Brits area in North West, and parts of KwaZulu-Natal and Western Cape provinces, but it is largely grown by small-holder and resource-poor farmers in virtually all provinces of South Africa (Laurie et al. 2018).

In South Africa, the sweet potato breeding programme at Agricultural Research Council, Vegetable and Ornamental Plant Institute, Roodeplaat, Pretoria, released the white-fleshed sweet potato cultivar 'Blesbok' as well as the orange-fleshed sweet potato 'Bophelo'. It was reported that 'Blesbok' cultivar, which comprise a white-to-cream-flesh colour and a purple skin, is the most commonly consumed sweet potato that is freely available in the market (Laurie 2004). Other released cultivars such as 'Bophelo' (orange-fleshed), 'Mafutha' (orange/yellow-fleshed) and 'Mvuvhelo' (cream/yellow-fleshed), their market is still informant (Laurie 2004).

Nutritionally, the sweet potato is a rich source of carbohydrates (26.3 g/100 g) than other staple foods, such as maize (15.6 g/100 g), sorghum (*Sorghum bicolor* L.) (17.0 g/100 g) and potatoes (18.5 g/100 g), however, the protein content is lower than in potatoes and other grain crops (Woolfe 1992). The crop is also rich in vitamins A, B and C, as well as minerals like phosphorus, iron and calcium and it is also a good food-security crop and can be sold for cash. Most sweet

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potato varieties differ greatly in their skin and flesh colour (yellow, cream, white and orange) appearance as well as nutritional value, due to the chloroplast pigments of each cultivar based on their nature, isolation, proximate content and chemical structure (Ingabire and Vasanthakalam 2011). The yellow to dark-orange-fleshed sweet potato had been reported to contain a high accumulation of beta-carotene, whereas the cream to white-fleshed sweet potato contains an appreciable amount of lycopene. Due to their high beta-carotene content, both the yellow- and orange-fleshed sweet potatoes could be used as supplements for the elimination of vitamin A deficiency in young children and for managing aging in older people (Adepoju and Adejumo 2015).

Generally, the sweet potato root crop has been classified as having the potential to address the growing food shortages as it provides high yield in terms of edible energy per unit area per unit time. Also, the sweet potato vines and foliage are an important source of vitamins, proteins and starch when used as animal feed (Chakrabarti et al. 2014). However, land scarcity is one of the major challenges faced by many households and the resource-poor farmers for the production of food crops like sweet potatoes.

Land scarcity brings to the fore an unintended socio-economic consequence associated with urbanisation as urban land-use for agriculture becomes increasingly difficult to acquire by many poor households and subsistence farmers. The woven polypropylene plastic bag technology, if well developed for various agricultural crops, would enable subsistence growers to grow enough food crops in a small open space by planting a specified number of plants on the sides and top of the bags filled with growing medium of choice (Gallaher et al. 2013). A vent or opening is then created in the centre of the bag using a plastic tubing filled with small concrete for irrigation purposes and water distribution throughout the growing bag. The woven polypropylene plastic bag technology can act as an important strategy for poverty alleviation and social inclusion of disadvantaged groups such as immigrants, HIV-AIDS affected households, people with disabilities, female-headed households with children, elderly people and unemployed youths.

Generally, in South Africa, the use of woven polypropylene plastic bags for growing agricultural crops in urban, semi-urban, informal settlements and other rural areas where production land is difficult to acquire has not been documented. This study intends to report for the first time, the use of woven polypropylene plastic bags for food production in rural, urban, semi-urban and informal settlements of South Africa, focusing on the most

consumed starchy root crop, the sweet potato. The objective of this study, therefore, was to investigate the effect of growing different types of sweet potato cultivars on the growth performances of the root crop using the woven polypropylene plastic bag technology.

Materials and methods

Description of the study area and plant material

The study was conducted at the Green Biotechnologies Research Centre of Excellence (GBRCE) situated at the University of Limpopo, South Africa (23°53'10"S, 29°44'15"E). The location has hot and dry summers (November–January), with daily maximum temperatures ranging from 28 to 38°C. The average annual rainfall had previously been less than 500 mm, with the distribution skewed towards summers. The area had a slope of 0.05%, containing Hutton soil with loamy soil (65% sand, 30% clay, 5% silt, 1.6% organic C and E_{Ce} 0.148 dS/m). Five registered cultivars of sweet potato stem cuttings ('Blesbok', 'Bophelo', 'Bosbok', 'Mafutha' and 'Mvuvhelo') were obtained from the Agricultural Research Council-Vegetable and Ornamental Plants Institute, Roodeplaat in Pretoria, South Africa (25°36'51"S, 29°21'16.2"E). The experiment was conducted from February to July 2019 and repeated in the same months in 2020, using woven polypropylene plastic bags under open field conditions.

Treatments and experiment design

The sweet potato cultivars namely, 'Blesbok', 'Bophelo', 'Bosbok', 'Mafutha' and 'Mvuvhelo' were used and served as treatments. 'Blesbok' sweet potato cultivar served as standard. The treatments were arranged in a randomised complete block design (RCBD) with 10 replicates ($n = 50$). The experimental site measured 10.5 m long and 5.3 m wide (55.6 m²), with an intra- and inter-spacing of 0.25 m apart.

Procedures and growing area preparations

A sheet of black polythene plastic (10 × 5 m) was first laid on the ground in order to protect unwanted weeds and grass from interfering with the bag. The woven polypropylene plastic bags (80 cm × 45 cm) purchased locally were used to grow the sweet potato cultivars. A 10 cm diameter central tunnel containing a 50 cm long plastic pipe was created and filled with concrete stones of 20–40 mm aggregate and inserted in the centre of the bag for ease of drainage and water distribution during irrigation within the bag. Forty (40)

kilograms growing media mixture of steam pasteurised loam soil and compost (3:1 v/v) was used to fill-up the bag outside the drainage tunnel. The filled bags were then perforated with a total of eight (8) holes, four (4) at the top and 4 alternating holes on the sides, each 10 cm apart. When the bag was almost full, the plastic pipe was removed leaving only a column of stones running vertically down the centre of each bag (UNU-ESDA 2010). A 10 L of tap water was then dispensed right at the centre (stone column) of the bags until field capacity was reached prior to planting.

Planting of sweet potato cultivars stem cuttings

Semi-hardwood stem cuttings (15–20 cm) with four nodal buds from each sweet potato cultivar were used as planting material. Plant growth regulator indole-3-butyric acid at concentrations of 3 mg/L, was used to enhance root development of the stem cutting. A total of eight (8) cuttings were planted in each bag, four (4) on the top and the remaining 4 on the side holes. Irrigation was done with a 5 L watering can when the soil moisture content dropped below 50%, monitored with a jet-fill tension-metre (model 14.04.05, Eijkelkamp, Spain). After a month, when the stem cuttings developed new shoot growth, the cuttings were fertilised with 40 g 2:3:2 (26) NPK + 0.5% Zn + 5% S + 5% Ca, yielding 74.3 g N, 111.4 g, yielded P, 74.3 g K, 5 g Zn and 50 g Ca per bag. The scouting for pests and diseases was carried out weekly, as recommended (DAFF 2010).

Data collection

At 150 days after planting, plant growth parameters were collected and recorded. The number of flowers (NF) was counted every other day during flowering stage and recorded. At termination of the experiment, vine length (VL) was measured with a ruler, the chlorophyll content of the leaves (LCC) was measured with the Chlorophyll metre (CCM200 Plus, Opti-36 Sciences, U.S.A.), while stem diameters (SD) were determined using a Vernier caliper (standard, Mitutoyo, India). The number of shoots (NS) were counted, collected and weighed to obtain the fresh shoot mass (FSM). Thereafter, the collected shoots were oven dried at 60°C for 72 h and weighed to obtain the dry shoot mass (DSM). The number of edible roots (NER) was also counted and the results were reported per woven polypropylene plastic bag.

Data analysis

The Shapiro–Wilk test was performed to determine the normal distribution of the collected data (Shapiro and

Wilk 1965; Ghasemi and Zahediasl 2012). Data were then subjected to analysis of variance using SAS software (SAS Institute 2008). When treatments were significant at 5% probability level, the degrees of freedom and their associated mean sum of squares were partitioned to determine the percentage contribution of the sources of variation to the total treatment variation (TTV). Mean separation was achieved using Fischer Least Significant Difference (LSD) test. Bar charts were also used to show the differences. Unless otherwise stated, only treatments means significant at a probability level of 5% were discussed.

Results and discussion

Treatments had a highly significant ($P \leq .01$) effect on LCC, SD (cm), VL (cm), NS, NF, DSM (g) and NER, contributing 56, 59, 83, 61, 86, 41 and 75% to TTV, respectively (Table 1). Compared to the standard ('Blesbok'), all varieties achieved the highest LCC (Figure 1(A)). The accumulated LCC (12.67, 13.14, 13.45 and 10.47) was achieved in 'Bosbok', 'Bophelo', 'Mafutha' and 'Mvuvhelo' cultivars, respectively (Table 2). In contrast, 'Bophelo' and 'Mvuvhelo' were the thickest (0.40 and 0.45 cm) in SD compared to the standard, while the smallest (0.35 and 0.32 cm) SD was observed in 'Bosbok' and 'Mafutha' cultivars, respectively (Table 2 and Figure 1(B)). Cultivar 'Mafutha' achieved the highest (64.30 cm) VL than the standard, but 'Bophelo' (40.40 cm), 'Bosbok' (47.37 cm), and 'Mvuvhelo' (30.23 cm) had the smallest VL compared to the standard (Figure 1(C)). Similarly, 'Mafutha' scored the highest (4.64) NS than all cultivars, followed by 'Bophelo' (4.27), 'Bosbok' (4.01) and 'Mvuvhelo' (3.28) when compared to the standard (Table 2 and Figure 1(D)). Noticeably, of all the cultivars tested, 'Mafutha' cultivars produced the highest (4.50) NF, followed by 'Bosbok' (1.70) cultivars, while 'Bophelo' (0.10) and 'Mvuvhelo' (0.30) cultivars produced the smallest NF (Table 2 and Figure 1(E)). In contrast, the highest DSM was achieved in 'Bophelo' (122 g), followed by 'Bosbok' (82.00 g) and 'Mafutha' (89.90 g) compared to the standard, while the lowest (68.00 g) DSM was achieved in 'Mvuvhelo' SP cultivar (Table 2 and Figure 1(F)). The highest (11.2) NER was recorded in 'Bosbok', followed by 'Bophelo' (8.6) sweet potato cultivar compared to the standard. However, the lowest NER was observed in 'Mafutha' (3.4) cultivar, followed by 'Mvuvhelo' (7.10) sweet potato cultivar (Table 2 and Figure 1(G)).

The highest LCC content in the leaves of all the tested cultivars, suggested that green pigments are associated with a central magnesium ion. The leaf chlorophyll content is an important photosynthetic pigment in

Table 1. Mean sum of squares for leaf chlorophyll content (LCC), stem diameter (SD) (cm), vine length (VL) (cm), number of shoots (NS), number of flowers (NF), dry shoot mass (DSM) and number of enlarged roots (NER) of different sweet potato cultivars grown in woven polypropylene plastic bags ($n = 50$).

Sources	DF	LCC		SD (cm)		VL (cm)		NS		NF		DSM (g)		NER	
		MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)	MSS	TTV (%)
Block	9	18.733	33	0.0125	28	160.52	7	2.974	32	2.356	6	5175.08	14.278	13	
Treatment	4	31.320	56***	0.0258	59***	1840.64	83***	5.602	61***	34.000	86***	4376.27	80.400	75***	
Error	36	5.973	11	0.0058	13	232.811	10	0.667	7	3.078	8	1013.83	12.733	12	
Total	49	56.026	100	0.0441	100	2233.97	100	9.243	100	39.434	100	10 565	107.411	100	

^{ns}Not significant at $P \leq .05$; ^{***}Significant at $P \leq .01$.

plants, largely determining the photosynthetic capacity and hence plant growth (Ying et al. 2018). Generally, plant growth needs a source of energy for development (Baker 2008). In the current observation, all the tested sweet potato cultivars had high LCC compared to the standard ('Blesbok') (Table 2). A similar observation was reported in another study, in which different cultivars of sweet potato leaves had higher LCC than other leaves of the Chinese sweet potato cultivars (Chen et al. 2013). According to the results of this study, all tested sweet potato cultivars induced high nitrogen content in their leaves, which is responsible for high chloroplast content responsible for good root development.

The thickest SD was recorded in 'Bophelo' and 'Mvuvhelo' cultivars, although the thinnest SD was observed in 'Bosbok' and 'Mafutha' (Figure 1(B)). This could be attributed to sweet potato variety characteristics. Trunk diameter varies by cultivar and can range from thinner to thicker depending on soil type, nutrient uptake and the amount of sunlight. In general, thicker pigmented vine diameters are able to support larger storage-modified roots. Raemaekers (2001) confirmed that vine diameter and growth habit of sweet potato are dependent on the variety and the environment, especially the climatic growth conditions and plant nutrition. Ravi et al. (2009) suggested that thicker vine diameter could be due to the progressive process associated with the appearance of multiple genes influenced by multiple environmental factors. The sweet potato cultivars 'Bophelo' and 'Mvuvhelo' showed the greatest environmental manipulability as it was able to grow a thicker SD, a concept of pervasive change, indicating that crop adaptation was physical rather than environmental. Fleisher et al. (2011) observed an increase in SD at low stem planting densities, which could be attributed to low competition between plants for both nutrients and photosynthetic active radiation.

Sweet potato genotypes are classified as either upright, bushy, medium-stature or sprawling based on the length of their vines. Vine length varies per variety and can range from about 1 m to over 6 m. In this study, 'Mafutha' cultivar developed the longest VL, followed by the standard cultivar, 'Blesbok'. The observation in this study confirmed similar observation in a study by Mark and Korch (2020) who obtained the longest vines from SPK-004 cultivars than those from SHABA at nine weeks after planting. Consequently, the cultivars 'Bophelo', 'Bosbok' and 'Mvuvhelo' developed relatively short vines, which could be attributed to their branched vegetative growth pattern associated with shorter vines.

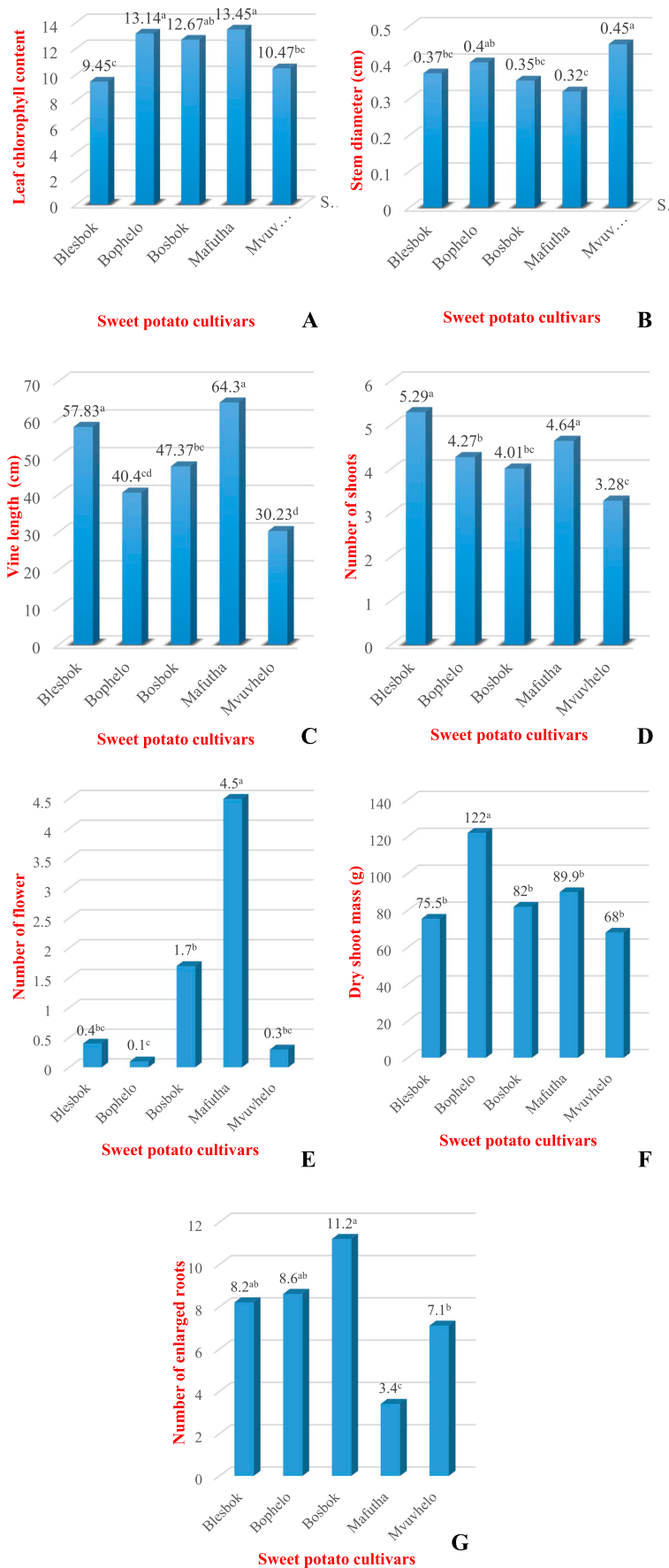


Figure 1. Responses of (A) leaf chlorophyll content, (B) stem diameter (cm), (C) vine length (cm), (D) number of shoots, (E) number of flowers, (F) dry shoot mass (g) and (G) number of enlarged roots of different sweet potato cultivars grown in the woven polypropylene plastic bags ($n = 50$).

Table 2. Responses of leaf chlorophyll content (LCC), stem diameter (SD) (cm), vine length (VL) (cm), number of shoots (NS), number of flowers (NF), dry shoot mass (DSM) and number of enlarged roots (NER) of different sweet potato cultivars grown in woven polypropylene plastic bags ($n = 50$).

Treatments	LCC ^Y Variable	SD (cm) ^Y Variable	VL (cm) ^Y Variable	NS ^Y Variable	NF ^Y Variable	DSM (g) ^Y Variable	NER ^Y Variable
'Blesbok'	9.45 ^c	0.37 ^{bc}	57.83 ^a	5.29 ^a	0.40 ^{bc}	75.50 ^b	8.200 ^{ab}
'Bophelo'	13.14 ^a	0.40 ^{ab}	40.40 ^{cd}	4.27 ^b	0.10 ^c	122.00 ^a	8.600 ^{ab}
'Bosbok'	12.67 ^{ab}	0.35 ^{bc}	47.37 ^{bc}	4.01 ^{bc}	1.70 ^b	82.00 ^b	11.200 ^a
'Mafutha'	13.45 ^a	0.32 ^c	64.30 ^a	4.64 ^a	4.50 ^a	89.90 ^b	3.400 ^c
'Mvuvhelo'	10.47 ^{bc}	0.45 ^a	30.23 ^d	3.28 ^c	0.30 ^{bc}	68.00 ^b	7.100 ^b

^YColumn means with the same letter were not significantly different ($P \leq .05$) according to Fischer's Least Significant difference test.

The results of this study also demonstrated that 'Mafutha' cultivar had the highest NS. This observation could be due to differences in the genetic makeup of the sweet potato cultivars and their response to growing media nutrients linked to the growing conditions. Mukherjee (2002) reported that the tendency of sweet potato cultivars to develop multiple shoots in one growing environment and not in the other, may be due to a specific environmental adaptation. Multiple shoot formation is important in sweet potatoes as more leaves are necessary for photosynthesis. Incidentally, the vines and foliage of the sweet potato plant can be used as forage for cattle, sheep, goat, pig, poultry and rabbit production without any adverse effect on growth, milk and meat production (Murugan et al. 2012). Hossain (2020) described that nutrient supply, plant spacing, photoperiod and soil moisture could affect branching intensity in sweet potato plants.

A report by Francesco (2005), confirmed that sweet potato flowers grow either in clusters or individually in the axils of the leaves. Generally, the sweet potato plant's ability to flower under normal field conditions differs between cultivars as most cultivars flower easily under suitable environmental conditions (Pakkies 2018). In this study, the NF were significantly influenced by sweet potato cultivars. The highest NF was measured in the 'Mafutha', followed by 'Bosbok' sweet potato cultivar. 'Bophelo' and 'Mvuvhelo' cultivars had the lowest NF compared to the standard (Figure 1(E)), which could be ascribed to the fact that sweet potato cultivars use nutrients differently due to the differences in their genetic makeup.

The highest DSM reported in this study was achieved in 'Bophelo' sweet potato cultivar, followed by 'Mafutha' and 'Bosbok.' The high DSM accumulation in 'Bophelo' sweet potato cultivar could be the fact that the cultivar had numerous short branches with thick SD and shoots, which enabled the cultivar to retain more water and remain succulent for longer periods without major defoliation than cultivars with long thin stems (Motsa 2014). Generally, plant growth is an accumulation of DSM over

a period (Widaryanto and Saitama 2017), whereas plant DSM is described as translocation of photosynthates to all parts of the plant. Therefore, growth rate of a plant is determined by the leaf rate that intercepts the solar radiation with optimum photosynthesis rate (Paulus 2010).

'Bosbok' sweet potato cultivar produced the highest NER, followed by the sweet potato cultivars 'Bophelo', 'Mafutha' and 'Mvuvhelo' compared to standard (Figure 1(G)). According to Nedunchezhiyan et al. (2012), differences in yield production of storage roots could be due to differences in environmental conditions or genetic makeup. Since the environmental conditions were assumed to be similar for all cultivars planted in the woven polypropylene plastic bags, the observed differences could be attributed to genetic differences between cultivars. The cultivars 'Mafutha' and 'Mvuvhelo' sweet potato had lower NER. Nakatani and Komeichi (1992) postulated that storage root production in sweet potato depends on a source-sink relationship. The rate of sinking differs between sweet potato cultivars, leading to yield variability (Bhagsari and Ashley 1990) and in some sweet potato strains, the spread is more towards shoot production and others towards storage root production.

Conclusion

In conclusion, growth performance of the different sweet potato cultivars tested was affected by the growth environment, which was the woven polypropylene plastic bags. 'Mafutha' cultivar performed well in the production of the above-ground plant parameters, which included the sweet potato vines and shoots – an excellent source of animal feed, rich in starch, protein and vitamins. The usage of vines and shoots helps in saving production cost for poor resource farmers and household individuals to sustain milk and meat-producing animals. On the other hand, the high NER produced in 'Bosbok' cultivar are important in human consumption as the underground edible roots

are an excellent source of beta-carotene, as well as many other vitamins, minerals and plant compounds. Therefore, for more production of the above plant growth parameters, cultivar 'Mafutha' is recommended. However, for the production of high edible storage roots, cultivar 'Bosbok' is highly recommended when using the woven polypropylene plastic bag technology.

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Notes on Contributors

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