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Influence of Sunnhemp (*Crotalaria juncea* L.) On Agronomic and Sensory Characteristics of Sweetpotato [*Ipomoea batatas* (L.) Lam.] in Swaziland

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Abstract: Sweetpotato [*Ipomoea batatas* (L.) Lam.] is the most important storage root crop grown in Swaziland. Sunnhemp (*Crotalaria juncea* L.) is a leguminous plant that has the potential of being used for soil improvement. In this experiment, sweetpotato cv. Kenya was grown in the field and combined with sunnhemp to assess the effects of sunnhemp green manuring on sweetpotato agronomic characteristics and sensory properties. There was a positive and highly significant ($p < 0.001$) correlation between the number of leaves/plant and leaf area index (LAI) at 20 weeks after planting (WAP); $R^2 = 26.3\%$. At harvest, the number of tubers/plant was positively (but not significantly) correlated to a number of parameters: mass of marketable tubers, $R^2 = 9.1\%$; dry mass of aboveground parts, $R^2 = 0.77\%$; dry mass of tubers, $R^2 = 7.2\%$; dry mass of leaves, $R^2 = 2.6\%$; and total yield, $R^2 = 5.3\%$. Total tuber yields in Malkerns plots were not significantly different from one another (10.8-18.3 t/ha). The lowest yield (10.8 t/ha) was recorded when sunnhemp was incorporated at 6 WAP using 60 kg/ha of sunnhemp seeds. Tuber yields were much lower (1.8 -7.9 t/ha) in the farmer's plots. The highest yield (7.9 t/ha) was attained when sweet potato was planted using inorganic fertilizer; the lowest yield (1.8 t/ha) was recorded when sunnhemp was incorporated at 6 WAP using 120 kg/ha of sunnhemp seeds. In conclusion, panelists preferred sweet potato that was associated with sunnhemp at 60 kg/ha and incorporated at 4 WAP. It was recommended that sunnhemp be planted at 60 kg/ha with sweet potato and sunnhemp be incorporated at 4 WAP.

Key words: Green manuring % Ipomoea batatas %Leguminous plant %Nitrogen fixation % Organoleptic studies % Root storage crop % Sensory studies % Sweetpotato % Tuber yield

INTRODUCTION

Sweetpotato [*Ipomoea batatas* (L.) Lam.] is the major storage root crop commonly grown in Swaziland [1]. Sweet potato is a strategic food crop that is drought tolerant and grows well even in areas with low and unreliable rainfall [2, 3]. Sweetpotato reliably provides food on marginal and degraded soils, with little labor and a small number of inputs from outside the farm [4]. For many years now, frequent drought has become a common feature of Swaziland agriculture, resulting to reduced crop yields [5].

Sweetpotato is not only a source of energy; it also supplies important nutrients and is a natural source of dietary fiber [6]. The average sweetpotato tuber is low in cholesterol and sodium, virtually fat-free; it contains a lot of fiber [7]. For this reason, many athletes consider sweetpotato as one of the top high-energy foods. Sweetpotato is also an excellent source of carotene, which the body converts into vitamin A. The Louisiana Sweet Potato Commission calls sweetpotato "the virtuous vegetable" [7]; this is because a medium-size sweetpotato also provides over 33% of the recommended daily vitamin C requirements.

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In addition to being a good source of complex carbohydrates, vitamin B_6 and potassium, sweetpotato also contains significant amounts of folate [8]. Folate is one of the vitamin B complex vitamins that help animals to produce, repair and maintain new body cells, being necessary for normal red blood cell formation and function. According to American Association for Clinical Chemistry [8] that folate also helps the body to fight heart and kidney disease and assists in DNA synthesis Research on the role of folate in preventing neural tube defects suggests that supplements can prevent neural tube defects. Folate deficiency can impair cell division and protein synthesis, which are critical to growing tissues. Buoyed by current reports and ongoing research concerning beta-carotene, fiber and vitamins A, C and E, the sweetpotato may become the anti-cancer food of the future [7].

Sunnhemp (*Crotalaria juncea* L.) is a leguminous, short-day, annual crop that is drought tolerant and flowers in 100-180 days; it can be used as a green manure crop, for soil improvement and for controlling insects and nematodes [9]. Hooks *et al.* [9, 10] showed that sunnhemp could suppress some root-knot nematode species better than chemical nematocides. This was explained that, unlike a nematocide, which would only kill nematodes at the time of application, sunnhemp incorporated into the soil could continue to suppress nematode populations, while the crop is growing. Wang and McSorley [11] noted that sunnhemp is not typically used as a cover crop, but if used as a cover crop, it might substitute for nematocides. They also reported that by integrating with other pest management strategies, development of new sustainable agricultural cropping systems with *C. juncea* could be promising. Mabuza and Edje [12] reported that although sunnhemp was beneficial to corn (*Zea mays* L.), the tall sunnhemp variety was too aggressive and competitive by its size, thus reducing corn yield. It was stressed [13] that the effects of a green manure plant depended on its maturity and biomass when the legume was incorporated. Information is scarce on sunnhemp use as green manure for sweetpotato in Swaziland, hence the need for this investigation. The objective of the investigation was to determine the effects of sunnhemp green manuring on sweetpotato agronomic properties and sensory qualities.

MATERIALS AND METHODS

Sites of Experiment: The experiment was conducted in two locations: a local farmer's field, less than 1.0 km from Luyengo campus and at Malkerns Research Station (about 4.0 km from Luyengo and 740 m above sea level). Both sites were in the Middleveld agro-ecological zone of Swaziland. Malkerns typically has a rainfall range of 800-1460 mm during the cropping season, with a mean temperature range of 7.3°C-26.6°C during the growing season [14].

Table 1: Treatment codes and treatment descriptions

Treatment Code	Time of sunnhemp incorporation (1 = 4 WAP*; 2 = 6 WAP)	Rate of organic or inorganic fertilizer (kg/ha)	Rate of sunnhemp seeds (kg/ha)	Description of cropping system
1	1	0	0	Sweetpotato without sunnhemp and no fertilizer (Control)
2	1	0	30	Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 4 WAP
3	1	0	60	Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 4 WAP.
4	1	0	120	Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 4 WAP
5	1	300 + LAN**	0	Sweetpotato + inorganic fertilizer
6	2	0	0	Sweetpotato without sunnhemp and no fertilizer (Control)
7	2	0	30	Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP
8	2	0	60	Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 6 WAP
9	2	0	120	Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 6 WAP
10	2	300 + LAN	0	Sweetpotato + inorganic fertilizer

*Weeks after planting;** limestone ammonium nitrate (28% N)

Treatments, Experimental Design and Plot Size: The experiment was a 2 x 5-factorial experiment (Table 1), made up of 10 treatment combinations consisting of two sunnhemp harvesting periods and five soil amendments), arranged in a randomized complete block design. At Malkerns Research Station site, each treatment was replicated four times, but at the farmer's farm, there were three replications, because of space constraints, but the same plant population as at Malkerns, was maintained.

Each plot measured 6.0 m x 6.0 m and consisted of seven (gross) ridges, each measuring 6.0 m in length and three ridges of net plots. There was a 1.0-m distance between treatments and between blocks. There were four discard ridges, two at each end of the plot. Inter-row spacing was 100 cm and the intra-row spacing was 30 cm [15].

Soil Analysis and Liming: Using standard analytical methods [16] soil chemical analysis was conducted at the start and end of the experiment. Anonymous [15] had earlier recommended that in sweetpotato production, if soil pH is below 5.3, dolomitic lime should be applied. Based on the soil test results and recommendations from Malkerns Research Station soil science laboratory, dolomitic lime was applied at both sites at 1.9 tonnes/ha. The purpose of the lime application was to make essential nutrients more available to sweetpotato and sunnhemp through reduced soil acidity. Lime was broadcast on the ridges and worked into the soil.

Land Preparation, Planting, Irrigation and Filling of Gaps: Land was prepared by plowing, disking and ridging using moldboard ploughs, disk harrows and ridgers, respectively. Planting was carried out at each site on the following dates: Malkerns site, 1 December 2009: farmer's farm, 10 December 2009. Cuttings of 'Kenya' variety of sweetpotato were obtained from Malkerns Research Station and planted at each site. Each vine measured 30 cm in length and was planted on top of the ridges. No chemical treatment of cuttings was done before planting; this was to simulate the small-scale farmers' practice of non-use of agro-chemicals. Overhead sprinkler irrigation was applied, twice a week, during the first four weeks after planting (WAP), because of irregular rainfall. The soil was watered to field capacity on each occasion. Gap filling was done within one week of sprouting of sweetpotato cuttings.

Establishment of Sunnhemp: Where sunnhemp was required in a plot, the dwarf, black-seeded variety was planted. Sunnhemp seeds were drilled at the required rate per ridge, 5 cm deep and 15 cm away from the sweetpotato rows. This was done on the same day when sweetpotato was planted at each site. Sunnhemp incorporation. At 4 or 6 WAP (depending on the respective treatments, sunnhemp was cut with a pair of scissors and the cut sunnhemp plants were incorporated into the soil. Hand hoes were used to dig the furrows. The incorporation of the sunnhemp was done at the opposite side of the ridge where the sunnhemp was earlier sown, i.e. sunnhemp plants were not incorporated in the same side of the ridge where the sunnhemp plants previously grew. This was to ensure that the sunnhemp root system was not disturbed during incorporation. Depth of the incorporation furrows was 10-20 cm, depending on how much sunnhemp biomass was buried. The distance between the incorporated sunnhemp rows and the sweetpotato rows was 10 cm.

At incorporation, the cut plants were arranged end-to-end such that the proximal ends of one group of plants were in contact with the distal ends of the next set of plants. This arrangement ensured uniformity in the placement of buried sunnhemp plants.

Fertilizer Application: At planting, fertilizer was applied as follows:

- 350 kg/ha of N:P:K [2:3:2 (37)], that also contained 0.5% Zn, was applied to plots of sweetpotato that required inorganic fertilizer;
- 100 kg/ha of superphosphate (10.5% P) was also applied to plots that required inorganic fertilizer; and
- 100 kg/ha of KCl (60% K) was also applied only to plots that needed inorganic fertilizer. At six WAP, 100 kg/ha of LAN was applied as a side dressing to sweetpotato. All fertilizers were applied by the banding and incorporation method, 15-cm distance away from the planting rows of sweetpotato.

Sunnhemp Establishment: Where sunnhemp was required in a plot, the dwarf variety that had black seed coats was planted. Sunnhemp seeds were drilled at the required rate per ridge, 5 cm deep and 15 cm away from the sweetpotato rows. This was done on the same day when sweetpotato was planted at each site.

Weeding: Weeding was done using hand hoes. The level of weed infestation in the plots determined weeding times. All plots were weeded at the same time at each site. Weed infestation was assessed on the same day at each site, before weeding was done.

Plant Sampling: Destructive plant sampling (four plants per plot) was used to collect data at 8-20 WAP (final harvest at 20 WAP). No samples were taken from the farmer's site so that the farmer would not feel exploited by the frequent taking of samples from his plots; also, the farmer would not think that the regular removal of plant samples from the plots would adversely affect the results of the investigation.

Data Collection: Linear measurements were made using a tape measure; tuber diameter was determined by the use of a pair of vernier calipers. The leaf area of sweetpotato was determined using the cork-borer method recommended by Lutaladio [17] and adopted by Edje and Osiru [18] and Edje and Ossom [19], using the mathematical relationship,

$$\frac{\text{Leaf area of all dried discs}}{\text{Dry mass of all discs}} = \frac{\text{Leaf area of all leaves including discs}}{\text{Dry mass of all leaves including discs.}}$$

Taking 30 Leaf Discs, the Leaf Area Was Calculated As:

$$\text{Leaf area} = \frac{\text{Area of 30 leaf dried discs (cm2)} \text{ x Leaf dry mass (g) of 4 plants used}}{\text{Dry mass of 30 leaf discs (g)}}$$

$$\text{Leaf area} = \frac{\text{Area of 30 leaf discs (cm2) x (dry mass of 30 discs) + (Leaf dry mass of 4 plants used)}}{\text{Dry mass of 30 leaf discs}}$$

Harvesting of sweetpotato was done at 20 WAP, using garden forks. After harvest, the tubers were separated into marketable tubers and non-marketable tubers. Marketable tubers were whole tubers that had no harvest wounds and weighed between 100 g and 1.4 kg [20]; non-marketable tubers were tubers that had harvest wounds or were outside the mass range for marketable tubers.

Assessment of Sunnhemp Technology: In the course of the project, 10 farmers from the same chiefdom were invited to both sites of the experiment, to assess the sweetpotato-sunnhemp cropping system on two field days. On the first field day, the farmers assessed the effects of the sunnhemp or fertilizer treatments on the vegetative growth of the sweetpotato crop, using the counter methodology [21]. Only the cropping system was evaluated at the time, because no crops were harvested yet. On the second field day, the farmers' assessed both vegetative growth and sweetpotato tuber yields.

At the start of the assessment on each day, the 10 farmers were taught how to use the 20-cent coins and assess each parameter being measured. Thereafter, each farmer was asked to assess or rate the technology using 20-cent coins, independently of other farmers. Each farmer initially went through each plot and visually examined the plants, before going back to the beginning of the replicate to start the assessment. The farmers used the 20-cent coins to show their preference or otherwise for each parameter assessed. A record of the farmer's assessment was made. Rainfall and air temperature data were obtained from the meteorological records of Malkerns Research Station [22].

Organoleptic Studies: Whole tubers (300 g fresh mass) from each plot were randomly selected, washed and cooked; 100 g of the same tubers were oven-dried for chemical analysis of nutritional components of the tubers. Ten sweetpotato samples (corresponding to the field treatments) were boiled at the same cooking oven temperature and using the same amount of water on volume of water-to-volume of sweetpotato basis. Descriptive sensory evaluation was used in screening of sweetpotato for its sensory quality.

A total of 32 panelists were involved in the sensory evaluation. Ten boiled sweetpotato samples were presented to the panelists to evaluate the taste, color, sweetness and overall acceptability of the samples. During the evaluation period, the panelists attended one session and were trained on how to assess the samples. All panelists were instructed to make their own individual assessments according to the evaluation criteria provided for each sample on the basis of taste, color, flavor, sweetness, saltiness, sourness and overall acceptability. Then, all panelists were allowed to taste and evaluate the samples for each quality feature using a rating scale of 1-9, where 1 represented the lowest score (least preferred) and 9 represented the highest score (most preferred). Each panelist was given a sheet of paper on which various nutritional and palatability aspects of sweetpotato were described. Each panelist evaluated each cooked sample independently of other panel members.

Data Analysis: Data were analyzed using MSTAT-C statistical package, version 1.3 [23]; mean separation tests were done by using the least significant difference test [24].

RESULTS

Meteorological Information: Table 2 shows some meteorological data collected during the duration of the investigation. Air temperatures ranged from a low of 11.3°C in May 2010 to a high of 28.2°C in February 2010. The total rainfall received during the period was 784.8 mm, with May 2010 being the driest month (10.8 mm), whereas January 2010 was the wettest month (280.8 mm).

Number of Leaves/plant: Table 3 shows that generally, plants under the 4-week sunnhemp regimes developed higher number of leaves/plant than plants under the 6-week sunnhemp regime. Significant differences were found among the treatments at 8, 12 and 20 WAP; no significant differences were detected among the treatments at 16 WAP. The largest mean number of leaves/plant (120.8 leaves/plant) was developed under the 4 WAP incorporation regime using inorganic fertilizer. The lowest number of leaves/plant (94.1 leaves/plant) was attained when sunnhemp was incorporated at 6 WAP, using 30 kg/ha of sunnhemp seeds. Number of leaves/plant declined at 20 WAP. At 20 WAP, there was a positive but not significant correlation between the number of leaves/plant and the following parameters whose coefficients of determination, R^2, are indicated: number of tubers/plant, R^2 = 30.1%; tuber diameter, 0.49%; marketable tubers, 1.39%; aboveground dry mass, R^2 = 20.2%; and tuber dry mass, R^2 = 0.66%. There was a positive and highly significant ($p < 0.001$) correlation between the number of leaves/plant and LAI at 20 WAP; R^2 = 26.3%. Number of leaves/plant in a crop is likely to influence the yield of the crop.

Table 2: Some meteorological data at Malkerns Research Station during the experiment

Month/Year	Temperature (°C) Minimum	Maximum	Total rainfall (mm)
December 2009	15.5	21.8	140.3
January 2010	16.8	26.4	280.8
February 2010	18.2	28.2	89.5
March 2010	17.4	26.4	94.4
April 2010	15.2	24.7	169.0
May 2010	11.3	24.7	10.8
Total	94.4	152.2	784.8
Mean	15.7	25.4	130.8

Source: [22]

Table 3: Number of leaves/plant of sweetpotato under two sunnhemp incorporating periods and five levels of soil amendments at 8-20 weeks after planting

Sunnhemp incorporation time (weeks after planting)	Treatments Soil amendment rates	Weeks after planting 8	12	16	20	Means
4	Sweetpotato without sunnhemp and no fertilizer (Control)	121.5a	121.6a	129.2a	102.3a	118.7
4	Sweetpotato + sunnhemp planted at seed rate of 30 kg/ha and incorporated into the soil at 4 WAP	85.0a	152.3a	150.6a	94.1a	120.5
4	Sweetpotato + sunnhemp planted at seed rate of 60 kg/ha and incorporated into the soil at 4 WAP.	103.0a	117.2ab	138.8a	91.8a	112.7
4	Sweetpotato + sunnhemp planted at seed rate of 120 kg/ha and incorporated into the soil at 4 WAP	103.1a	132.0a	134.6a	98.7ab	117.1
4	Sweetpotato + inorganic fertilizer at planting	111.8a	128.0a	167.3a	75.9b	120.8
	Mean	104.9	130.2	144.1	92.6	118.0
6	Sweetpotato without sunnhemp and no fertilizer (Control)	68.4ab	83.4b	135.6a	96.0a	95.9
6	Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP	79.4ba	86.2b	134.2a	76.5ab	94.1
6	Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 6 WAP	103.7a	114.8b	127.0a	85.7a	107.8
6	Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 6 WAP	81.4a	107.5b	118.2a	129.8a	109.2
6	Sweetpotato + inorganic fertilizer at planting	142.7a	117.9b	114.3a	101.0a	119.0
	Mean	95.3	102.0	125.9	97.8	105.3
Grand mean		100.1	116.1	135.0	95.2	111.6
Standard error, SE (T x R)		20.70	15.10	16.20	13.2	-
Least significant difference @ 5% (SE x 3)		62.10	45.30	48.6	39.60	-

Means followed in the same column by the same letters are not significant at p > 0.05, according to the least significant difference test.

Table 4: Leaf area (cm^2) per plant of sweetpotato under two sunnhemp incorporating periods and five levels of soil amendments at 8-20 weeks after planting

Sunnhemp incorporation time (weeks after planting)	Treatments Soil amendment rates	Leaf area (cm^2) and weeks after planting 8	12	16	20	Means
4	Sweetpotato without sunnhemp and no fertilizer (Control)	231.8d	152.3a	198.8a	139.0a	180.5
4	Sweetpotato + sunnhemp planted at seed rate of 30 kg/ha and incorporated into the soil at 4 WAP	261.0d	137.4a	257.1a	127.6a	195.8
4	Sweetpotato + sunnhemp planted at seed rate of 60 kg/ha and incorporated into the soil at 4 WAP.	287.8d	141.0a	222.0a	136.7a	196.9
4	Sweetpotato + sunnhemp planted at seed rate of 120 kg/ha and incorporated into the soil at 4 WAP	288.8d	150.1a	200.2a	123.7a	190.7
4	Sweetpotato + inorganic fertilizer at planting	316.8d	163.1a	261.8a	143.9a	221.4
	Mean	277.2	148.8	227.9	134.2	197.1
6	Sweetpotato without sunnhemp and no fertilizer (Control)	327.1cd	153.8a	169.4a	138.1a	197.1
6	Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP	272.3cd	137.5a	215.9a	164.2a	197.5
6	Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 6 WAP	215.5a	147.0a	196.8a	121.1a	170.1
6	Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 6 WAP	261.2abcd	139.5a	217.8a	157.5a	194.0
6	Sweetpotato + inorganic fertilizer at planting	451.0b	155.9a	221.1a	144.4a	243.1
	Mean	305.1	146.7	204.2	145.1	200.3
Grand mean		291.3	147.7	216.1	139.6	243.1
Standard error, SE (T x R)		33.89	16.27	46.005	17.02	28.27
Least significant difference @ 5% (SE x 3)		101.67	48.80	138.20	51.06	84.93

Means followed in the same column by the same letters are not significant at $p > 0.05$, according to the least significant difference test.

Table 5: Leaf area index per plant of sweetpotato under two sunnhemp incorporating periods and five levels of soil amendments at 20 weeks after planting

Sunnhemp incorporation time (weeks after planting)	Treatments Soil amendment rates	Leaf area index and weeks after planting 8	12	16	20	Means
4	Sweetpotato without sunnhemp and no fertilizer (Control)	1.9b	1.2a	1.7b	1.2a	1.5
4	Sweetpotato + sunnhemp planted at seed rate of 30 kg/ha and incorporated into the soil at 4 WAP	2.2a	1.2a	2.1b	1.1a	1.7
4	Sweetpotato + sunnhemp planted at seed rate of 60 kg/ha and incorporated into the soil at 4 WAP.	2.4a	1.2a	1.9b	1.1a	1.7
4	Sweetpotato + sunnhemp planted at seed rate of 120 kg/ha and incorporated into the soil at 4 WAP	2.4a	1.2a	1.7b	1.0a	1.7
4	Sweetpotato + inorganic fertilizer at planting	2.6a	1.2a	2.2b	1.2a	1.8
	Mean	2.3	1.2	1.9	1.1	1.6
6	Sweetpotato without sunnhemp and no fertilizer (Control)	2.7a	1.3a	1.4b	1.2a	1.7
6	Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP	2.5a	1.2a	1.8b	1.4a	1.7
6	Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 6 WAP	1.8b	1.1a	1.6b	1.1a	1.4
6	Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 6 WAP	2.2b	1.2a	1.7b	1.3a	1.4
6	Sweetpotato + inorganic fertilizer at planting	3.8a	1.4a	1.8b	1.2a	1.6
	Mean	2.6	1.2	1.7	1.2	1.7
Grand mean		2.4	1.2	1.8	1.2	1.7
Standard error, SE (T x R)		0.28	0.13	0.38	0.14	0.23
Least significant difference @ 5% (SE x 3)		0.84	0.39	1.14	0.42	0.70

Means followed in the same column by the same letters are not significant at $p > 0.05$, according to the least significant difference test.

Table 6: Yields of sweetpotato under two sunnhemp incorporating periods and five levels of soil amendments at 20 weeks after planting

Sunnhemp incorporation time (weeks after planting)	Soil amendment rates	Tuber dry mass (g) from Malkerns plots	Total yields (t/ha) at Malkerns	Total yields (t/ha) at the farmer's farm
4	Sweetpotato; no sunnhemp, no fertilizer	36.3a	16.2a	4.0ab
4	Sweetpotato + sunnhemp; 30 kg/ha; 4 WAP	32.6a	16.4a	2.1b
4	Sweetpotato + sunnhemp; 60 kg/ha; 4 WAP	34.2a	16.1a	2.7b
4	Sweetpotato + sunnhemp; 120 kg/ha; 4 WAP	32.4a	15.8a	2.3b
4	Sweetpotato + inorganic fertilizer at planting	31.1a	17.8a	7.9a
	Mean	33.3	16.5	3.8b
6	Sweetpotato; no sunnhemp, no fertilizer	33.9b	18.3a	2.4b
6	Sweetpotato + sunnhemp; 30 kg/ha; 6 WAP	31.9b	14.6a	2.7b
6	Sweetpotato + sunnhemp; 60 kg/ha; 6 WAP	30.6b	10.8a	2.2b
6	Sweetpotato + sunnhemp;120 kg/ha; 6 WAP	31.5b	12.2a	1.8b
6	Sweetpotato + inorganic fertilizer at planting	32.8ab	16.0a	5.0b
	Mean	32.1	14.4	2.8
Grand mean		32.7	15.4	3.3
Standard error, SE (T x R)		1.48	2.52	1.14
Least significant difference @ 5% (SE x 3)		5.34	7.6	3.42

Means followed in the same column by the same letters are not significant at $p > 0.05$, according to the least significant difference test.

Leaf Area: As shown in Table 4, leaf areas (LA) initially increased from 12 to 16 WAP; thereafter, there was a general decrease in LA by 20 WAP in all cropping systems, compared to LA at 8-16 WAP. This was probably due to senescence, as the number of leaves/plant also declined at 20 WAP. LA was positively and highly significantly ($p < 0.01$) correlated with aboveground dry mass ($R^2 = 52.0\%$), indicating that 52.0% in aboveground dry mass of sweetpotato could be ascribed to LA increases.

Leaf Area Index (LAI): The trends in LAI (Table 5) followed those of LA, with a general decrease in LAI at 20 WAP, compared to 8-16 WAP. The lowest mean LAI were attained under the 6-week regime, when sunnhemp was sown at a seed rate of 60 and 120 kg/ha (LAI values, 1.4 each), whereas the highest LAI (1.8) was recorded in the 4-week regime when sweetpotato was cultivated using inorganic fertilizer. As also observed in LA development, significant ($p < 0.05$) differences in LAI were observed at 8, 12 and 16 WAP, but not at 20 WAP.

Number of Tubers/plant: There was no tuber formation before 8 WAP. Table 8 shows a greater mean number of tubers/plant (2.0) under the 4-week regime. There was a lower number (1.8) of tubers/plant was attained under the 6-week regime, indicating a more beneficial number of tubers/plant when sunnhemp was incorporated at 4 WAP. There were significant differences in the number of tubers/plant among the cropping systems at all times of data collection. At 20 WAP, the number of tubers/plant was positively (but not significantly) correlated to a number of parameters: mass of marketable tubers, R^2 = 9.1%; dry mass of aboveground parts, R^2 = 0.77%; dry mass of tubers, R^2 = 7.2%; dry mass of leaves, R^2 = 2.6%; and total yield, R^2 = 5.3%. However, the number of tubers/plant was negatively correlated ($r = 0.049$; R^2 = 0.24%) to tuber diameter.

Marketable Yield of Storage Roots: Data are shown in Table 6 indicated that Total yields were not significantly different from one another (10.8-18.3 t/ha). The highest yield (18.3 t/ha) was obtained under the control (6-week regime), whereas the lowest yield (10.8 t/ha) was recorded when sunnhemp was incorporated at 6 WAP using 60 kg/ha of sunnhemp seeds. Tuber yields were much lower in the farmer's plots. The highest yield (7.9 t/ha) was obtained when sweetpotato was planted using inorganic fertilizer; the lowest yield (1.8 t/ha) was recorded when sunnhemp was incorporated at 6 WAP using 120 kg/ha of sunnhemp seeds. Tuber yields were much lower in the farmer's plots. The highest yield (7.9 t/ha) was obtained when sweetpotato was planted using inorganic fertilizer; the lowest yield (1.8 t/ha) was recorded when sunnhemp was incorporated at 6 WAP using 120 kg/ha of sunnhemp seeds.

Farmers Assessment of Cropping Systems and Sweetpotato Yields: Table 11 shows the results of farmers using the coin technology [21]to indicate their preferences for cropping systems and sweetpotato yields. In the farmer's farm, the most preferred cropping system that showed the best sweetpotato vegetative growth was sweetpotato planted with inorganic fertilizer under

Table 7: Comparison of coin technology assessment of sunnhemp cropping systems and sweetpotato yields at the farmer's farm and at Malkerns Research Station in 2010

Sunnhemp incorporation time (weeks after planting)	Soil amendment rates	Farmer's farm Cropping system	Farmer's farm Yield	Malkerns Research Station Cropping system	Malkerns Research Station Yield
4	Sweetpotato; no sunnhemp, no fertilizer	2.4b	2.8a	3.4a	2.6a
4	Sweetpotato + sunnhemp; 30 kg/ha; 4 WAP	3.2b	2.4a	2.7a	2.7a
4	Sweetpotato + sunnhemp; 60 kg/ha; 4 WAP	2.3b	3.2a	3.5a	3.6a
4	Sweetpotato + sunnhemp; 120 kg/ha; 4 WAP	2.2b	2.5ab	3.3a	3.4a
4	Sweetpotato + inorganic fertilizer at planting	4.1a	3.1a	2.5a	2.4a
	Mean	2.8	2.8	3.1	2.9
6	Sweetpotato; no sunnhemp, no fertilizer	3.2b	2.9a	3.3a	3.9b
6	Sweetpotato + sunnhemp; 30 kg/ha; 6 WAP	2.8ab	4.6a	3.1a	3.2b
6	Sweetpotato + sunnhemp; 60 kg/ha; 6 WAP	2.2b	3.1a	2.6a	1.8ab
6	Sweetpotato + sunnhemp;120 kg/ha; 6 WAP	2.6ab	2.2b	2.8a	3.1ab
6	Sweetpotato + inorganic fertilizer at planting	3.1ab	3.1ab	2.7a	3.0a
	Mean	2.8	3.2	2.9	3.0
Grand mean		2.8	3.0	3.0	3.0
Standard error, SE (T x R)		0.46	0.68	0.43	0.47
Least significant difference @ 5% (SE x 3)		1.38	2.03	1.29	1.41

Means followed in the same column by the same letters are not significant at $P > 0.05$, according to the least significant difference test.

Table 8: Texture, sweetness, color and overall preference quality of boiled sweetpotato tubers

Treatment description	Texture	Sweetness	Color	Overall preference
Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 4 WAP	10.0 a	10.0 a	9.0 a	7.0 d
Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 6 WAP	10.0 a	10.0 d	10.0 a	10.0 a
Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP	10.0 a	10.0 a	10.0 a	9.0 b
Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 6 WAP	6.0 b	4.0 c	4.0 cd	3.0 e
Sweetpotato without sunnhemp and no fertilizer (Control 1)	5.0 bc	2.0 d	3.0 de	3.0 e
Sweetpotato without sunnhemp and no fertilizer (Control 2)	9.0 a	9.0 a	4.0 cd	9.0 b
Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 4 WAP	4.0 c	7.0 b	3.0 de	9.0 b
Sweetpotato + inorganic fertilizer (4-week regime)	9.0 a	9.0 a	5.0 bc	8.0 c
Sweetpotato + inorganic fertilizer (6-week regime)	5.0 bc	1.0 d	6.0 b	1.8 f
Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 4 WAP	6.0 b	10.0 a	2.0 e	8.0 c

Means followed by the same letters in the same column are not significant ($p > 0.05$), according to Duncan's Multiple Range test

the 4-week sunnhemp-incorporating regime. The inorganic fertilizer use was scored 4.1 (out of 10.0) and was scored significantly ($P < 0.05$) higher than inorganic fertilizer under the 6-week sunnhemp-incorporating regime (score, 3.1 out of 10.0). The inorganic fertilizer use under the 4-week sunnhemp-incorporating regime was also scored significantly ($P < 0.05$) higher (4.1 out of 10.0), than all sunnhemp-incorporation treatments (scores, 2.2-2.8 out of 10.0) and also significantly ($P < 0.05$) higher than the control (score, 2.4 out of 10.0).

Farmers' Assessment of Sweetpotato Yields: As shown in Table 14, farmers rated tuber yields at both sites to be the same (grand mean, both scored 3.0 out of 10). However, under the 4-week incorporation regime, the mean score (2.9 out of 10) of tuber yield in Malkerns Research Station was better than the score (2.8 out of 10) at the farmer's plot. Under the 6-week incorporation regime, the yield of tubers from the farmer's plots was scored higher (3.2 out of 10) compared to the yield score of tubers from Malkerns plots (3.0 out of 10). Using tuber yields alone as the criterion for assessment, the farmers preferred the yields from plots incorporated at 6 WAP (score of 3.2 out of 10) from the farmer's plots. The farmers tended to prefer the smaller-sized tubers from the farmer's plots to the larger-sized tubers from Malkerns Research Station.

Among the sunnhemp treatments, sweetpotato associated with sunnhemp incorporated at 4 WAP (score, 3.2 out of 10.0) was scored significantly ($P < 0.05$) better than other sunnhemp treatments and was not significantly different from inorganic fertilizer use under the 4-week sunnhemp-incorporation regime (4.1 out of 10.0). At Malkerns Research Station site, there were no differences among the cropping systems, including the controls.

Sensory Evaluation: Table 8 shows data of the responses of 32 panelists concerning the texture, sweetness, color and overall preference of boiled sweetpotato tubers that were subjected to the 10 different pre-harvest treatments during production. The boiled sweetpotato samples subjected to pre-harvest: Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 4 WAP; Sweetpotato + sunnhemp planted at a seed rate of 60 kg/ha and incorporated into the soil at 6 WAP; and sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP were found to be the most preferred in terms of texture. The sweetpotato that were subjected to pre-harvest treatment (sweetpotato + inorganic fertilizer at 4-weekly regime) and sweetpotato without sunnhemp and no fertilizer (Control 1) were ranked the second. The sweetpotato samples sweetpotato without sunnhemp and no fertilizer (Control 1) and sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 4 WAP were the least preferred ones in terms of the textural preferences.

As can be seen from the data presented in Table 8, boiled sweetpotato samples subjected to pre-harvest treatments Sweetpotato + sunnhemp; 60 kg/ha; 4 WAP; Sweetpotato + sunnhemp; 60 kg/ha; 6 WAP, Sweetpotato + sunnhemp planted at a seed rate of 120 kg/ha and incorporated into the soil at 4 WAP; and Sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP were the sweetest based on the panelist's perception. Similarly, sweetpotato + sunnhemp; 60 kg/ha; 6 WAP and sweetpotato + sunnhemp planted at a seed rate of 30 kg/ha and incorporated into the soil at 6 WAP had the best color that the panelists' liked most during the sensory evaluation and was found to be significantly ($p < 0.05$) better than the rest in terms of color. Overall, significantly ($P < 0.05$) higher number of panelists liked boiled sweetpotato samples that were subjected to pre-harvest treatment of sweetpotato + sunnhemp; 60 kg/ha, incorporated at 6 WAP.

In summary, boiled sweetpotato samples that were subjected to the pre-harvest treatments: sweetpotato + sunnhemp; 60 kg/ha at 4 WAP; sweetpotato + sunnhemp; 60 kg/ha at 6 WAP; and sweetpotato + sunnhemp; 30 kg/ha at 6 WAP were found to be the best in terms of texture, sweetness, color and overall preference. Boiled sweetpotato (sweetpotato + sunnhemp at 60 kg/ha and incorporated at 4 WAP) was superior to other boiled samples. This was followed by sweetpotato + sunnhemp at 30 kg/ha incorporated at 6 WAP and sweetpotato without sunnhemp and without fertilizer. However, on the other extreme, sweetpotato grown with inorganic fertilizer at planting (6-week incorporation regime) was found to be the least preferred tubers.

Overall, significantly ($p < 0.05$) higher number of panelists liked boiled sweetpotato samples that were subjected to pre-harvest treatment: sweetpotato + sunnhemp; 60 kg/ha; 6 WAP. In summary, boiled sweetpotato samples that were subjected to the pre-harvest treatments: sweetpotato + sunnhemp; 60 kg/ha at 4 WAP; sweetpotato + sunnhemp; 60 kg/ha at 6 WAP; and sweetpotato + sunnhemp; 30 kg/ha at 6 WAP were found to be the best in terms of texture, sweetness, color and overall preference. Boiled sweetpotato (sweetpotato + sunnhemp at 60 kg/ha and incorporated at 6 WAP) was superior to other boiled samples. This was followed by sweetpotato + sunnhemp at 30 kg/ha incorporated at 6 WAP and sweetpotato without sunnhemp and without no fertilizer. However, on the other extreme, sweetpotato grown with inorganic fertilizer at planting (6-week incorporation regime) was found to be the least preferred ones.

DISCUSSION

Meteorological Information: Irrigation was justified at the initial establishment of the experiment, when rainfall was not regular. Rainfall amounts and distribution are known to affect crop growth and yield. Fan *et al.* [25] reported that supplemental irrigation at a critical time to mitigate water stress and increase yields is an efficient practice. The ecologically important environmental factors affecting plant growth include light, temperature and precipitation. It is likely that the yields and general performance of both sunnhemp and sweetpotato observed in this experiment could have been influenced by rainfall amounts and distribution. Price [26] warned that even if global temperatures rise slowly, climate change could slash the yields of some of the world's most important crops almost in half.

Number of Leaves/plant: The decline in the number of leaves/plant at 20 WAP could be attributed to leaf senescence. Colomb *et al.* [27] reported that leaf senescence could be induced by different factors including stress and lack of soil nutrients. Kelley [28] indicated that scientists were making efforts to delay senescence in field crops, by the application of various plant-growth regulators; presumably, such delay could lead to better crop performance and increased crop yields.

Leaf Area: Holshouser and Jones [29] reported that on good soils, increasing plant population might increase LA, but not necessarily increase yield at the same rate, presumably because of sink-source relationship where more photosynthate might have been shunted into biological yield rather than economic yield.

Leaf Area Index: Holshouser and Jones [29] showed that in soybean (*Glycine max* L.). LAI increased with population. About 1,000 LAI values from 0.1-0.18 (minimum; desert and tundra) to 47.0 (maximum; a peculiarity of one allometric method for estimating all-sided LAI in coniferous tree stands) have been reported. Only 14% of the records have LAI greater than 8.0 (a more typical maximum value for one-sided or projected LAI, unlikely to be exceeded except with peculiar conditions or methodology [30].

Number of Tubers/plant: That tuberisation did not start before 8 WAP was consistent with Ossom [20,31], Ossom *et al.*[32,33]. The study of Lynch *et al*. [34] suggested that while the use of tuber number per main stem of potato (*Solanum tuberosum* L.) might be useful as an early season predictor of tuber yield for cultivars, particularly under dry-land conditions, a model using the predictor variables main stem and tuber number would generally be superior due to the additional information it provides when competitive effects are present for light energy within the canopy or for assimilates among developing tubers.

Marketable Yield of Storage Roots: Previous reports Ossom *et al.* [33], Edje and Semoka [35], Sullivan [36], Ossom and Nxumalo [37] and Njoku *et al.* [38] showed that sole sweetpotato usually yielded higher than the associated crop. Ossom and Rhykerd [39] earlier reported a positive but not significant correlation between number of tubers per plant in sweetpotato and marketable tuber yield. A positive correlation between tuber yield and number of tubers in Irish potato was earlier reported by Dereje and Basavaraja [40]. Ossom [41] showed that various factors could influence storage root yield of cassava (*Manihot esculentus* Crantz.), a tuber crop similar to sweetpotato.

Farmer's Assessment of Cropping System and Yields: That the farmers' assessment of the cropping systems in Malkerns Research Station, giving a higher score range (2.5-3.4; mean, 3.0 out of 10.0) than the cropping systems in the farmer's farm plots (2.2-4.1; mean, 2.8 out of 10.0) probably indicated that the farmers were more impressed with the vegetative growth of the sweetpotato at Malkerns Research Station than in the farmers' plots. Edje [21] reported that farmers were able to use the coin technology to differentiate between preferred farming systems and preferred farming practices.

Sensory Evaluation: The Center for Science in the Public Interest ranked the sweetpotato as Number One in nutrition among all vegetables [42]. With a score of 184, baked sweetpotato outscored the next highest scored food (baked Irish potato: score, 83) by more than 100 points. The reasons for such a high rank for sweetpotato was because of its high concentration of dietary fiber, naturally occurring sugars, complex carbohydrates, protein, vitamins A and C, iron and calcium. The usefulness of sweetpotato in nutrition and medicine, relating its glycemic index and serum glucose level in humans was earlier reported by Zakir *et al.* [43].

Conclusion and Recommendation: The conclusions drawn from this investigation were that planting sunnhemp at 30 kg/ha and incorporating at 4 WAP gave a preferred yield (16.4 t/ha) according to farmers' assessment) and appreciably better tuber dry matter (32.6 g) than the controls; farmers' assessment for yield showed preference for sunnhemp sown at the rate of 60 kg/ha and incorporated at 4 WAP at the farmers plots; sensory test panelists preferred the sweetpotato associated with sunnhemp sown at the rate of 60 kg/ha and incorporated at 4 WAP. It is recommended that 60 kg/ha of sunnhemp seed be sown with sweetpotato and incorporated at 4 WAP.

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