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Research Article
Vine Cutting Lengths and Fertilizer Effects on Yield of Sweet Potato (*Ipomoea batatas* L.)

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Abstract

Background and Objective: Low productivity of sweet potato in Ethiopia was associated with different factors among which inappropriate vine cuttings and area-specific fertilizer recommendations are the most important ones in the area. Thus, a field experiment was conducted during the 2020/21 cropping season at Boloso Sore, Wolaita, Southern Ethiopia to determine the optimum vine length and NPS fertilizer rate that gives the highest root yield in sweet potato. **Materials and Methods:** Treatments consisted of four vine cutting lengths (10, 20, 30 and 40 cm) and four NPS rates (0, 75, 150 and 225 kg ha^{-1}) in factorial arrangement and laid out in Randomized Complete Block Design (RCBD) with three replications. **Results:** The ANOVA showed that the interaction effect of vine cutting lengths and NPS rates significantly ($p<0.05$) affected biomass yield, marketable, unmarketable and total root number per plant, marketable and total root yield. The main effect of vine cutting lengths and NPS rates affected days to 90% maturity, vine number, root length and diameter and root dry matter. The highest total root yield (56.73 t ha^{-1}) and marketable yield (54.89 t ha^{-1}) were achieved by vine length of 30 cm and 225 kg NPS ha^{-1}. The highest gross net benefit of 438,267.10 Birr with the highest marginal rate of return (99.40%) was recorded by 30 cm and 225 kg NPS ha^{-1}. **Conclusion:** Hence, based on the current investigation, it can be concluded that vine cutting length of 30 cm with an NPS fertilizer rate of 225 kg ha^{-1} showed superior performance in the Wolaita area.

Key words: Dry matter, fertilizer rates, marketable, storage root, sweet potato, vine length, yield

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Sweet potato (*Ipomoea batatas* L.) is dicotyledonous with creeping and herbaceous perennial vines cultivated as an annual plant. It belongs to the family Convolvulaceae and is a hexaploid which is usually considered the only *Ipomoea* species of economic importance[1,2]. It is widely grown in many tropical and subtropical countries in different ecological regions including Ethiopia[2]. The exact time of the introduction of sweet potato into Ethiopia's traditional farming system is not known. The first introduced cultivar to Ethiopia was from USA and Nigeria[3]. The best soil required for sweet potato production is sandy loam and clay subsoil with a pH range of 5.6-6.6[2,4].

Sweet potato is the 7th most important crop globally and the 2nd most important root crop in Africa[5,6]. The crop was grown in over 100 countries of the world with annual global production of more than 140 million tons per year. The worldwide cultivation area in the year 2018 was 8,062,737 ha and the yield was 114,037 kg ha^{-1}. China is the leading producer of sweet potato (82,474,410 t) in the world and Ethiopia is among the top 15 sweet potato producers in the world[4].

Among varieties of root crops grown in Ethiopia, sweet potato stands 2nd after potato in area coverage. As reported by some authors[5,6] is cultivated on 130,000 ha of land with an annual production of 20,089,290 t of which 95% of its cultivation is in the densely populated areas in the Southern, Southwestern and Eastern parts of the country.

In Ethiopia, at least 20 million people depend on this crop as their source of food. It is also one of the major traditional and attractive food crops among farmers due to its high productivity, universal uses, high caloric content and sensory versatility in terms of taste, texture and flesh colour (white, cream, yellow, orange and purple)[7]. In the Southern region, including the Wolaita area, the crop is known as a lifesaving important food security crop due to its high productivity per unit area and its multiple purposes like animal feed, income sources and relatively drought tolerance. It is a staple or co-staple food for the majority of the people in the region. It has an abundance of uses ranging from consumption of the roots as foods and leaves as either vegetables or animal feed in case of surplus. It is processed into many value-added food products such as flour, bread, sauces, candy, vitamins, pharmaceutical and textile industries and is widely recognized[8].

Sweet potato is usually propagated asexually using vine cuttings. Using vine cuttings as planting material is advantageous over sprouts in that plants derived from cuttings are free from soil-borne diseases, yields obtained from cuttings are more than those obtained from sprouts and are more uniform in size and shape[9]. The bulk nature of planting materials required for large-scale production is another bottleneck for sweet potato production.

Production and productivity of sweet potatoes in Ethiopia in general and in Wolaita, in particular, have many constraints. In Wolaita average root yield was 32.13 t ha^{-1} in the 2015/2016 cropping season whereas, the yield potential of the crop can extend to 73 t ha^{-1} [2]. This yield gap implies lower productivity of the crop in the region that could be attributed to different cultural and nutrient management practices[4].

In general, lack of agronomic packages especially plants nutrient management and scarcity of information on the appropriate rates of fertilizers recommendations, the absence of any formal institutions that multiply and supply quality planting materials for users, shortage of improved varieties, diseases and pests are the major sweet potato production constraints in Ethiopia including Wolaita[8,10].

To overcome the above-mentioned problems, the MoA of Ethiopia has introduced a new brand of blended NPS fertilizer which contains N, P and S with the proportion of 19% N, 38% P_2O_5 and 7% S substituting DAP. However, there is no research recommendation regarding blended NPS rates in the area. Moreover, farmers traditionally use different vine lengths and the number of vine cuttings/hill in the Wolaita area for sweet potato production which significantly affects the yield potential of the crop. In addition to this, there is no information on the optimum combination of vine cutting lengths and blended NPS fertilizer rates for sweet potato production especially, in the Wolaita area. Therefore, to address the gaps the current investigation was initiated with the following objectives.

To determine optimum and cost-effective rates of blended NPS fertilizer rates and vine cutting lengths for maximum storage root yield of sweet potato in Wolaita, Southern Ethiopia.

MATERIALS AND METHODS

Description of the study area: The study was carried out at farmer's field Tadissa Kebele, Boloso Sore Woreda, Wolaita zone, southern regional state, from February to June, 2021. The geographical coordinates of the site are 7°4'24"N latitude and 37°41'30"E longitude having an altitude of 1730 m.a.s.l. The maximum and minimum temperatures were 25.5 and 14°C, respectively. The experimental area receives an average annual rainfall of 1520 mm. The soil type of the experimental site is classified as clay loam textural class with a soil pH of 5.13.

Table 1: Details of treatment combination and their descriptions used during the experiment

Treatments designation	Description of treatment combinations	
	Vine cutting lengths (cm)	NPS fertilizer rates (kg NPS ha^{-1})
T_1	10	0
T_2	20	0
T_3	30	0
T_4	40	0
T_5	10	75
T_6	20	75
T_7	30	75
T_8	40	75
T_9	10	150
T_{10}	20	150
T_{11}	30	150
T_{12}	40	150
T_{13}	10	225
T_{14}	20	225
T_{15}	30	225
T_{16}	40	225

Experimental materials: Sweet potato variety of Aawassa-83 was used as planting material. The variety was released by Hawasa Agricultural Research Center (HARC) in 1983 and it has white flesh. It takes 150-180 days for maturity, is high yielding and one of the most commonly used improved varieties in the area. Urea and NPS (19% N, 38% P_2O_5 and 7% S) fertilizers were used during the study.

Treatments and experimental design: The treatments consisted of four levels of vine cutting lengths (10, 20, 30 and 40 cm) taken from the top or apical part of 6 months old vines and four levels of blended NPS fertilizer rates (0, 75, 150 and 225 kg ha^{-1}). Thus, there were 16 treatment combinations in a factorial arrangement (Table 1). The plant spacing was 0.50×0.40 m between rows and plants, respectively. The gross plot size was 2.5×2.5 m (6.25m^2) which contained five rows, with each row accommodating six plants giving a total of 30 plants/plot. The space between replications and plots was 1.0 and 0.50 m, respectively and the total experimental area was 23.5×18.50 m (434.75 m^2). The experiment was laid out in Randomized Complete Block Design (RCBD) with three replications. Vines were planted at 45° slants on the prepared plot at a depth of 5 cm by hand. Blended NPS fertilizer containing (19% N, 38% P_2O_5 and 7% S) was applied as side band placement 15 days after planting. The recommended amount (100 kg ha^{-1}) of urea was applied in half split way where the first half was 15 days after planting and the remaining half was 30 days after planting. All appropriate agronomic practices such as supplementary irrigation, weeding and earthing up were done uniformly throughout the experimental plots.

Data collection

Days to 90% maturity: Days to maturity were recorded when 90% of the plants in each plot become ready for harvest as indicated by the senescence of the plants.

Several vines/plant (NVPP): The number of the vine was counted from each 10 sampled plants from each plot at maturity and their average was recorded.

Above ground fresh biomass (AGBY) (t ha^{-1}): It was weighed from all plants in the central three rows of each plot at harvest by using hanging digital balance (50 kg) expressed in kg/plot and converted into t ha^{-1}.

Root length (RL) (cm): It was measured using a hand ruler (50 cm) in cm from 20 sample roots collected net plot during harvesting and an average value was used for data analysis.

Root diameter (RD) (cm): it was measured using a digital calliper in cm from 20 sample roots collected from the net plot during harvesting and an average value was recorded for data analysis.

Root number/plant (RNPP): this was obtained by adding marketable and unmarketable roots and expressed in the number/plant.

Marketable root yield (MRY) (t ha^{-1}): It was determined by measuring the weight of marketable roots and expressed on a kg/plot basis by using hanging digital balance at harvest. The yield obtained in the plot was converted to t ha^{-1}.

Unmarketable root yield (UMRY) (t ha^{-1}): It was determined by measuring the weight of unmarketable roots and expressed on a kg/plot basis by using hanging digital balance. The yield obtained in the plot was converted to t ha^{-1}.

Total root yield (TRY) (t ha^{-1}): It is the sum of marketable and unmarketable root yield of the above-mentioned and converted into hectare basis.

Storage root dry matter content (SRDMC) (%): To calculate root dry matter content first 200 g of fresh roots was prepared from marketable categories of roots randomly taken from each harvested plot and roots were sliced, chopped, composited and dried in an oven-dry forced air circulation at 70°C for 72 hrs until it was attained constant weight. Then the dried sample was weighed by sensitive balance (Model No yt-1002 and reading scale 0.01). Finally, the dry root weight was divided by fresh root weight and multiplied by 100 to get root dry matter content (%) (Alemayehu and Jemberie[11]):

$$\text{SRDMC (\%)} = \frac{\text{Dry weight of sample}}{\text{Fresh weight of sample}} \times 100$$

Data for economic analysis: The economic analysis was carried out by using the methodology described by Alemayehu and Jemberie[11] and Boru[12].

Marketable average yield (t ha^{-1}) (AvY): It was taken from the average marketable yield of each treatment.

Adjusted marketable yield (AjY): It was the average yield adjusted downward by 10% to reflect the actual farmers' yields expecting that the yield in the experimental plot is higher than that of the farmers, hence, in economic calculations, the yields of farmers were adjusted by 10% less than that of the research plot (Alemayehu and Jemberie[11] and Boru[12]).

Gross income benefits (GFB): Adjustable marketable root yield multiplied by farm gate price of the yield.

Total variable costs (TVC) (ETB ha^{-1}): This refers to the cost of fertilizers and other inputs and production practices such as vine cutting of sweet potato, labour cost for all activities, land preparation, planting, earthing up, weeding and harvesting, transportation for all treatments.

Net benefit (NB): it was calculated as the amount of money left when the total variable costs for inputs (TVC) are deducted from the total revenue/income (TR).

$$\text{NB} = \text{TR-TVC}$$

Marginal rate of return (MRR) (%): It was calculated by dividing the change in net benefit by the change in total variable cost (Alemayehu and Jemberie[11] and Boru[12]).

$$\text{MRR (\%)} = \frac{\text{Change of net benefit } (\Delta\text{NB})}{\text{Change of total variable cost } (\Delta\text{TVC})} \times 100$$

Data analysis

Analysis of Variance (ANOVA): The data were subjected to Analysis of Variance (ANOVA) of RCBD in factorial arrangements using SAS software (SAS, 2002) version 9.1. All significant mean separation was done using the least significant difference (LSD) value at 5% significance.

RESULTS

Days to 90% maturity: Analysis of variance revealed that days to 90% plant maturity was very highly significantly (p<0.001) affected by the main effects of vine cutting length and blended NPS fertilizer rates but their interaction was non-significant (Table 2).

Regarding vine cutting lengths, the longest days to maturity (88.17) were recorded from vine cutting length of 40 cm whereas, the shortest days to maturity (84.00) were seen from vine cutting length of 10 cm. Similarly, NPS fertilizer rates affected days to maturity in the sweet potato trial. The longest days to maturity (93.23) were recorded from plots without fertilizer (control) whereas the lowest (78.67) was observed by application of 225 kg NPS ha^{-1} The highly significant effect of higher rates of NPS fertilizer hastened maturity by about 15 days as compared to zero fertilizer (Table 3).

Number of vines per plant (NVPP): Analysis of variance revealed that the main effect of vine cutting length and NPS fertilizer rates was significantly (p<0.05) affected the number of vines per plant but their interaction was non-significant (Table 2).

Table 2: ANOVA table of mean square values for the traits studied in Wolaita, Southern Ethiopia, 2020/21

		Mean square values									
Sov	Df	DM	NVPP	AGBY (kg)	RL (cm)	RD (cm)	RNPP	UMRY (kg)	MRY (kg)	TRY (kg)	RDMC (kg)
Rep	2	63.25	2.91	4.62	11.27	97.91	0.03	0.27	3.58	5.76	3.26
NPS	3	36.40***	65.21***	481.65***	305.16***	325.64***	13.56***	42.43***	1218.36***	816.06***	255.77***
VCL	3	467.06***	41.55***	754.04***	163.02***	157.01***	3.01***	7.30***	494.28***	402.58***	65.19***
NPS×VCL	9	1.64^{ns}	1.14^{ns}	121.97***	1.24^{ns}	7.08^{ns}	0.65***	0.25^{ns}	115.26***	119.16***	0.56^{ns}
Error	30	4.45	1.59	2.87	2.41	9.18	0.04	0.18	2.41	2.76	2.50
CV (%)		2.45	16.89	5.90	8.25	10.52	5.39	9.18	7.36	6.45	5.47

Sov: Sources of variation, Df: Degrees of freedom, DM: Days to 90% maturity, NVPP: Number of vines per plant, AGBY: Above ground biomass yield, RL: Root length, RD: Root diameter, RNPP: Root number per plant, UMRY, MRY, TRY: Unmarketable, marketable and total root yield per hectare, respectively, ns: Non-significant and *,**,***Significant, very and very highly significant difference at 5% probability level, respectively

Table 3: Days to 90% maturity and vine number per plant as affected by vine cutting lengths and NPS fertilizer rates of sweet potato in Wolaita, Southern Ethiopia, 2020/21

Treatments	Days to 90% maturity	Vine number per plant
Vine cutting lengths (cm)		
10	84.00[c]	4.54[d]
20	85.72[bc]	6.98[c]
30	86.63[ab]	8.23[b]
40	88.17[a]	10.09[a]
Rate of NPS (kg ha^{-1})		
0	93.23[a]	5.49[d]
75	88.62[b]	6.61[c]
150	84.00[c]	7.94[b]
225	78.67[d]	9.82[a]
LSD (5%)	1.76	1.05
CV (%)	2.45	16.89

Means followed by the same letters within a column showed statistically no difference at a 5% probability level

Table 4: Interaction effect of vine cutting length and NPS fertilizer rates on above-ground fresh biomass yield of sweet potato in Wolaita, Southern Ethiopia, 2020/21

	AGBY (t ha^{-1})			
	NPS (kg ha^{-1})			
Treatments	0	75	150	225
Vine cutting length (cm)				
10	15.57[m]	23.85[ijk]	24.49[hij]	22.92[ijk]
20	21.31[kl]	27.28[fgh]	31.37[d]	42.86[b]
30	22.44[jkl]	29.12[def]	35.17[c]	58.94[a]
40	19.79[l]	25.29[ghi]	28.10[efg]	30.58[de]
LSD (5%)	2.82			
CV (%)	5.90			

Means in a column followed by the same letters are not significantly different at a 5% level of significance

Table 5: Storage root length and diameter as affected by vine cutting lengths and blended NPS fertilizer rates of sweet potato in Wolaita, Southern Ethiopia, 2020/21

Treatments	Root length (cm)	Root diameter (cm)
Vine cutting length (cm)		
10	14.57[d]	24.50[c]
20	20.05[b]	29.68[b]
30	23.14[a]	33.17[a]
40	17.55[c]	27.84[b]
NPS rates (kg ha^{-1})		
0	13.64[d]	22.44[c]
75	16.39[c]	27.86[b]
150	19.85[b]	29.84[b]
225	25.34[a]	35.05[a]
LSD (5%)	1.29	2.53
CV (%)	8.25	10.52

Means in a column followed by the same letters are not significantly different at a 5% level of significance

The result revealed that the highest number of vines per plant (10.09) was produced from the vine cutting length of 40 cm whereas, the lowest vine number per plant (4.54) was recorded from the vine cutting length of 10 cm. Similarly, several vines per plant had shown gradual increment with increasing NPS fertilizer rates. The maximum number of vines per plant (9.82) was obtained from the application of 225 kg NPS ha^{-1}. On the other hand, the lowest vine number (5.49) was obtained from the control treatment (Table 3).

Above-ground fresh biomass yield (AGBY) (t ha^{-1}): Analysis of variance revealed that the above-ground fresh biomass yield of sweet potato was significantly ($p<0.05$) influenced by both main and interaction effects of vine cutting length and NPS fertilizer rates (Table 2). The maximum above-ground fresh biomass yield (58.94 t ha^{-1}) was obtained from a vine cutting length of 30 cm with 225 kg NPS ha^{-1}. Whereas, the minimum was obtained from vine cutting length of 10 cm (15.57 t ha^{-1}) with zero application of NPS fertilizer. Vine cutting length of 30 cm could be expected to have an optimum number of nodes, thus producing more branches with more vegetative growth by application of 225 kg NPS ha^{-1} fertilizer. A significant range of 43.37 t ha^{-1} above ground fresh biomass yield was observed in response to the interaction effects of vine cutting length and fertilizers rates (Table 4).

Storage root length (cm) and root diameter (cm): The data analysis revealed that storage root length and diameter were highly significantly ($p<0.05$) influenced by the main effect of vine cutting length and NPS fertilizer rates but their interactions were non-significant (Table 2). Regarding vine cutting lengths, the longest storage root length (23.14 cm) and thickest storage root diameter (33.17 cm) were recorded by a vine cutting length of 30 cm. The shortest storage root length (14.57 cm) and thinnest diameter (24.50 cm) were recorded by a vine cutting length of 10 cm (Table 5).

Storage root number per plant (RNPP): Data analysis showed that the total storage root number per plant was significantly ($p<0.05$) influenced by both the main and interaction effect of vine cutting length and NPS fertilizer rates (Table 2). The highest total storage root number per plant (5.93) was obtained from vine cutting length of 30 cm with 225 kg NPS ha^{-1} whereas, the lowest (2.94) total storage root number per plant was obtained from vine cutting length of 10 cm with 0 kg NPS ha^{-1} fertilizer application (Table 6). The storage root number per plant had shown more than double the minimum value due to the interaction effects of the factors.

Table 6: Marketable yield and root number as affected by vine cutting lengths and NPS fertilizer rates of sweet potato in Wolaita, Southern Ethiopia, 2020/21

Treatments	NPS rates (kg ha^{-1})	RNPP	MRY (t ha^{-1})
10	0	2.94^{j}	8.58^{l}
	75	3.09^{i}	12.49^{j}
	150	3.46^{gh}	15.60^{hi}
	225	4.21^{d}	20.22^{f}
20	0	3.12^{i}	11.53^{jk}
	75	3.69^{f}	18.94^{fg}
	150	3.79^{f}	23.64^{de}
	225	5.48^{b}	37.69^{b}
30	0	3.16^{i}	13.57^{ij}
	75	3.78^{f}	20.25^{f}
	150	4.02^{e}	27.67^{c}
	225	5.93^{a}	54.89^{a}
40	0	3.20^{i}	9.45^{kl}
	75	3.59^{g}	16.39^{gh}
	150	3.71^{f}	21.24^{ef}
	225	4.81^{c}	25.35^{cd}
LSD (5%)	0.34	2.59	
CV (%)	5.39	7.36	

Means in a column followed by the same letters are not significantly different at the 5% level of significance

Table 7: Unmarketable root yield as affected by vine cutting lengths and blended NPS fertilizer rates of sweet potato in Wolaita, Southern Ethiopia, 2020/21

Treatments	UMRY (t ha^{-1})
Vine cutting length (cm)	
10	4.94^{b}
20	4.49^{c}
30	3.74^{d}
40	5.60^{a}
Rate of NPS (kg ha^{-1})	
0	6.98^{a}
75	5.18^{b}
150	4.12^{c}
225	2.50^{d}
LSD (5%)	0.36
CV (%)	9.18

Means in a column followed by the same letters are not significantly different at a 5% level of significance

Table 8: Interaction effect of vine cutting lengths and blended NPS fertilizer rates on total storage root yield (TRY) of sweet potato in Wolaita, Southern Ethiopia, 2020/21

	TRY (t ha^{-1})			
	NPS (kg ha^{-1})			
Treatments	0	75	150	225
Vine cutting length (cm)				
10	15.49^{j}	18.16^{hij}	20.16^{gh}	22.85^{fg}
20	18.33^{hi}	23.76^{ef}	27.69^{d}	39.98^{b}
30	19.93^{hi}	24.13^{ef}	30.56^{c}	56.73^{a}
40	17.29^{ij}	22.73^{fg}	26.20^{de}	28.59^{cd}
LSD (5%)	2.77			
CV (%)	6.45			

Means in a column followed by the same letters are not significantly different at a 5% level of significance

Marketable root yield (MRY) (t ha^{-1}): The ANOVA result revealed that marketable root yield (t ha^{-1}) was highly significantly ($p<0.05$) influenced by both the main and interaction effect of vine cutting length and blended NPS fertilizer rates (Table 2). The highest marketable roots yield (54.89 t ha^{-1}) was obtained from a vine cutting length of 30 cm at an NPS fertilizer rate of 225 kg ha^{-1} and the lowest marketable roots yield (8.58 t ha^{-1}) was obtained from a vine cutting length of 10 cm with unfertilized plots. Moreover, the result revealed a 539.74% marketable yield advantage of the interaction effects of the treatments (Table 6).

Unmarketable root yield (UMRY) (t ha^{-1}): The ANOVA revealed that vine cutting length and rates of NPS fertilizer significantly ($p<0.05$) affected unmarketable root yield but their interaction was non-significant (Table 2). The maximum unmarketable root yield (5.60 t ha^{-1}) was recorded from a vine cutting length of 40 cm whereas, the minimum unmarketable root yield (3.74 t ha^{-1}) was recorded from a cutting length of 30 cm. Regarding fertilizer rates, the maximum unmarketable root yield (6.98 t ha^{-1}) was obtained from 0 kg NPS ha^{-1} application whereas, the minimum (2.50 t ha^{-1}) was recorded from 225 kg NPS ha^{-1} (Table 7).

Total root yield (TRY) (t ha^{-1}): The result indicated that the total root yield was highly significantly ($p<0.05$) influenced by both the main and interaction effect of vine cutting length and NPS fertilizer rates (Table 2). The highest total root yield (56.73 t ha^{-1}) was recorded from 30 cm vine cutting length with 225 kg NPS ha^{-1} whereas, the lowest total root yield (15.49 t ha^{-1}) was recorded from 10 cm with zero NPS application. Moreover, the result revealed 266.24% or more than triple yield advantage due to the interaction effects of the treatments (Table 8).

Storage root dry matter content (SRDMC) (%): The current investigation revealed that storage root dry matter content was highly significantly ($p<0.001$) influenced by the main effect of vine cutting length and NPS fertilizer but their interaction was non-significant (Table 2). The highest storage root dry matter content (31.48%) was recorded from the vine cutting length of 30 cm whereas, the lowest storage root dry matter content (26.27%) was recorded from the vine cutting length of 10 cm. The result of root dry matter content showed that the vine size of 30 cm performed better than other vine cutting lengths (Table 9).

Table 9: Storage root dry matter content as affected by vine cutting lengths and blended NPS fertilizer rates of sweet potato, Southern Ethiopia, 2020/21

Treatments	SRDMC (%)
Vine cutting length (cm)	
10	26.27[d]
20	30.13[b]
30	31.48[a]
40	27.80[c]
Rate of NPS (kg ha^{-1})	
0	23.40[d]
75	27.29[c]
150	30.86[b]
225	34.12[a]
LSD (5%)	1.32
CV (%)	5.47

LSD (5%): Least significant difference at 5% level, CV (%): Coefficient of variation, Means in a column followed by the same letters are not significantly different at a 5% level of significance

Table 10: Simple cost-benefit-analysis of sweet potato production as influenced by vine cutting lengths and NPS fertilizer rates in Wolaita, Southern Ethiopia, 2020/2021

VCL (cm)	NPS (kg ha^{-1})	TVC (Birr)	TR (Birr)	NB (Birr)	MRR (%)
10	0	129029.35	85115	43914.35	-
	75	208808.60	125695	83113.60	96.60
	150	254147.85	149055	105092.85	94.09
	225	314617.10	179980	134637.10	95.53
20	0	188809.35	115005	73804.35	-
	75	192058.60	117320	74738.60	40.36
	150	390627.85	217295	173332.85	98.62
	225	625957.10	335650	290307.10	98.83
30	0	221479.35	131340	90139.35	-
	75	336728.60	189655	147073.60	97.63
	150	459947.85	251955	207992.85	97.78
	225	921877.10	483610	438267.10	99.40
40	0	154329.35	97765	56564.35	-
	75	269288.60	155935	113353.60	97.63
	150	346257.85	195110	151147.85	96.48
	225	411517.10	228430	183087.10	95.86

VLC: Vine cutting length, TVC: Total variable cost, TR: Total revenue, NB: Net benefit, MRR: Marginal rate of return and Birr: Ethiopian local currency

In the case of fertilizer rates, the highest storage root dry matter content (34.12%) was recorded from 225 kg NPS ha^{-1} whereas the lowest storage root dry matter content was recorded (23.40%) from unfertilized. Increasing the rates of NPS from 0-225 kg NPS ha^{-1} increased the root dry matter content by about 45.81% (Table 9).

Economic analysis: Preliminary assessment of the cost benefits analysis according to the method described by previous studies[11,12], indicated that the highest gross net benefit of 438,267.10 Birr (Ethiopian currency) was recorded by the treatment combination of 30 cm and 225 kg NPS ha^{-1} with again the highest marginal rate of return (99.40%) (Table 10). This was the best combination of the economic optimum that benefits the most. In this case, it was storage root yield which was considered the only economic yield and the price was considered at the farm gate with the local market value during the harvesting season of the crop.

DISCUSSION

Days to 90% maturity were higher with longer vine cutting lengths. This might be due to more number of nodes with long vines that contributed to higher vegetative mass growth which in turn contributed to delayed physiological maturity. Similarly, Dumbuya *et al.*[13] reported the longest days to plant maturity in 40 cm cuttings. Again other authors reported delayed days to plant physiological maturity as the number of nodes or vine lengths increased in sweet potato[14,15]. But in the case of NPS fertilizer rates, crop physiological maturity was hastened by higher rates of fertilizer. This might be attributed to balanced nutrient application enhanced growth and physiological processes that contributed to earlier maturity. The current investigation was in line with the findings of Mohammed *et al.*[16], who reported the lowest day to maturity (105.33) was recorded due to the application of a higher dose of inorganic fertilizers (111 kg ha^{-1} N+92 kg ha^{-1} P_2O_5) whereas, in the longest (112.67) days to maturity was recorded by control (zero application) of fertilizers.

The number of vines per plan increased as the vine lengths increased might be due to a greater number of nodes per vine cutting length and these nodes served as points of emergent vines and favoured larger vine production. This result was supported by Law-Ogbomo and Osaigbovo[17], who reported that a higher number of nodes associated with longer propagule lengths produced more stem development than shorter propagule lengths of sweet potatoes. Again the result agreed with Dumbuya *et al.*[13], who reported that the growth of vine number was influenced by cutting length due to the greater number of nodes in sweet potatoes. Again the highest number of vines with 225 kg ha^{-1} NPS could be since fertilizer application encouraged more independent vines per plant. The current investigation was also in line with the findings of Alemayehu and Jemberie[11] and Singh *et al.*[18], who reported that nitrogen with sulfur fertilizer resulted in a significant and maximum number of stems per plant of the potato crop. Again Issaka *et al.*[19] reported a significant reduction in vine production of sweet potato when P was missed in the nutrients experiment, stressing the importance of P for sweet potato growth.

Above-ground fresh biomass yield the positive response of above-ground fresh biomass yield with increasing levels of inorganic fertilizer could be attributed to the effect of N on sweet potato vegetative growth with an optimum number of nodes in 30 cm vine length. This result was in line with the work of Dumbuya *et al.*[13], who indicated that the higher values for vegetative growth of sweet potato obtained in 30 cm cuttings could be due to the appropriate number of nodes. Similarly, Nebiyu and Getachew *et al.*[20] observed that significant increase in biomass as the length of planting material increased. The findings of other authors Pushpalatha *et al.*[21] indicated that the vegetative growth of sweet potato increased as N fertilization increased from 0-53 kg ha^{-1} with the optimum number of nodes per cuttings. Similar results were reported by Esan *et al.*[22], Relente and Aliso[23], who observed that efficient use of higher inorganic fertilizer increased the above-ground biomass and root yield in the case of sweet potatoes.

Storage root length and diameter the superior performance of 30 cm vine cutting length in storage root length and diameter could be attributed to higher shoot biomass that resulted in the fast establishment of branches, stems and leaves that serve as sources for photosynthesis that might be translocated into storage roots. The better vegetative growth coupled with a higher rated of NPS fertilizer rated gave superior storage root length and diameter. This finding was in line with the work of Nebiyu and Getachew[20], who reported that storage root length and diameter increase with an increase in cutting lengths. In addition, Sora[10] reported the vine cutting length and varieties significantly affected root length and girth in white-fleshed sweet potato varieties.

Similarly, the addition of NPS fertilisation application enhanced the development of storage roots due to an increase in cell size, elongation, enhancement of cell division, nutrient absorption, photosynthesis and general physiological processes that subsequently enhanced root length and diameter as well. This result was in line with the work of Assefa *et al.*[24], who observed that the increasing application of blended NPSB fertilizer from 0-300 kg ha^{-1} significantly increased the percentage of large tuber size by about 141.63% in potatoes. A similar result also was observed by Pushpalatha *et al.*[25], who reported that the tuber length and diameter of sweet potato was found significantly highest during nitrogen fertilizer application. This result was also in agreement with Pushpalatha *et al.*[21], who reported that the tuberous root length and diameter increased as the N level was increased from 0 kg ha^{-1} to 53 kg N ha^{-1} in sweet potatoes. Similarly, Law-Ogbomo and Osaigbovo[17] reported the average tuber size increased with the application of 300 kg NPK ha^{-1} fertilizer rate than that of the control in sweet potato.

Storage root number per plant (RNPP) has the highest storage number per plant by 30 cm vine cutting might be due to the optimum number of nodes which results in sufficient growth in spaces for effective utilization of nutrients and light. This result agreed with the work of Zewide *et al.*[26], who indicated that the size of stem cutting was found to have an influence on the number of roots per plant with longer stem cutting having the highest number of roots per plant in sweet potatoes. Again the findings of Achebe *et al.*[14] indicated that the superior performance of 30 cm vine cutting length could be attributed to its possession of an optimum number of nodes, higher carbohydrate reserve and fast establishment which resulted in optimum branched, effective utilization of nutrients and better vegetative growth and thus increase in yield and yield components of sweet potato.

Fertilizer rates also showed similar results and the higher fertilizer rate of 255 kg NPS ha^{-1} was found to be superior in the number of storage roots per plant. This might be due to the availability of enough nutrients such as N that favoured growth for the better photosynthetic performance of the crop. Phosphorus has also an impact on organic compounds and metabolic process and thereby affect root development which influenced the number of roots at relatively higher rates. Thus, the current result was in agreement with the findings of Zewide *et al.*[26], who confirmed that the application of N, P and S significantly increased the number of potato tubers per unit area. In line with this, Issaka *et al.*[19] reported a significant reduction in root number production when P was omitted in nutrients during the experiment, stressing the importance of P for sweet potato growth and yield.

Marketable, unmarketable and total root yield (t ha^{-1}) had the highest marketable root yield (54.89 t ha^{-1}) obtained from the treatment combination of 30 cm vine length and 225 kg NPS ha^{-1} might be due to appropriate vine length with an optimum number of nodes which resulted in optimum growth and effective utilization of nutrients and sunlight. This result was in line with the work of Essilfie *et al.*[9], who reported that the marketable root yield of sweet potato tends to increase with an increase in the propagule length. He recommended vine length of about 30 cm as an optimum and those beyond 30 cm may result in wastage of planting material while shorter than 30 cm establish slowly and gave poorer yields. Also, the report made by Muli and Mwakina[15] confirmed that the higher vine cutting lengths gave a higher number of roots and marketable root yield. Achebe *et al.*[14] reported that vine size of between 25-30 cm gave a higher marketable root yield of sweet potato. Similar to this experiment, Sora[10] reported that marketable storage root yield was significantly highest by sweet potato variety that received 159, 214 and 239 kg ha^{-1} NPSB fertilizer application. Again Bekele[27] concluded that increasing application rates of blended NPSZnB fertilizer from 0-199 kg ha^{-1} resulted in a significant increase in the marketable tuber yield of potatoes. Similarly, Yeng *et al.*[28] reported that the inorganic fertilizer 30:30:30 NPK (200 kg ha^{-1}) produced a marketable storage root yield of 76% more than the control in sweet potato.

Unlike marketable and total storage root yield, the highest unmarketable root yield was recorded by the treatments of 40 cm vine cuttings and that of zero fertilizer application whereas, the lowest was observed by 30 cm vine cuttings and 225 kg NPS ha^{-1}. This is best complementary to the result in that those with high marketable yield are low in unmarketable yield which might include those which are undersized, deformed and unacceptable for human food and to its standard. This could be attributed to overgrowth and the completion of nutrients and other resources in case of longer vine lengths. Thus, in line with the current investigation, Dumbuya *et al.*[13] reported that unmarketable root yield was increased with longer vine cuttings due to competition among the roots for available nutrients and photo-assimilates. This result agreed with the work of Law-Ogbomo and Osaigbovo[17], who reported that the propagule length of 30 cm vine cuttings tends to more efficiently utilize the available resources to nourish the storage root yields than the longer propagule lengths of 40 cm.

The total storage root yield, simply the sum of marketable and unmarketable yield, was found to be significantly higher in 30 cm vine cutting with the combination of 225 kg NPS ha^{-1}. This might be because optimum growth with enough nutrient supply allowed the maximum yield potential of the crop. In the same analogy as that of marketable yield, the total yield was higher with 30 cm vine cutting and 225 kg NPS ha^{-1}. This result was consistent with Sora[10], who reported that total fresh storage root yield was significantly highest in the sweet potato variety that received 159, 214 and 239 kg ha^{-1} NPSB fertilizer application. The other authors, Mekashaw *et al.*[29] reported that the higher total tuber yields were obtained from potato which was supplied with all NPS fertilizer rates as compared to the control.

The significantly higher storage root dry matter content by treatment combinations of 30 cm vine cuttings and 225 kg NPS ha^{-1} could be attributed to the positive correlation of marketable root and its dry matter content. It could also be related to the high performance of the crop due to optimum growth with enough photo assimilate translocation to sink the crop. This result was in line with the work of Nebiyu and Getachew[20], who indicated that the highest (32.04%) and lowest (30.17%) dry matter content of sweet potato was recorded at 7 and 9-node numbers per cutting, respectively. Assefa *et al.*[24] also reported the increase of tuber dry matter content with increasing application rates from 0 to 200 kg NPSB ha^{-1} probably due to storage accumulation and partitioning of more assimilates in potato tubers. The result agreed with Alemayehu and Jemberie[11] who confirmed that application of 283.75 kg ha^{-1} of blended NPS fertilizer recorded the highest tuber dry matter content in potato varieties tested than control plots.

CONCLUSION

The current investigation revealed that the earlier days to physiological maturity, the maximum number of vines per plan, shoot fresh biomass, storage root length and diameter, storage root number per plant, marketable root yield, total root yield and storage root dry matter content was significantly higher in treatment combination of 30 cm vine cutting length and 225 kg NPS ha^{-1}. Moreover, the economically highest net benefit with the highest marginal rate of return was scored by the same treatment combination. Thus, using 30 cm vine cutting with 225 kg NPS ha^{-1} was found to be appropriate for sweet potato production in Wolaita, southern Ethiopia.

SIGNIFICANCE STATEMENT

This study demonstrated the possible synergistic effect of vine cutting lengths and NPS fertilizer rates on the production and yield of sweet potatoes that can be beneficial for small and large-scale farmers and investors in the area of agriculture for business profitability. This research will also help the others researcher to further scale up the finding with different soil properties and with other fertilizer combinations.

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