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Research Article

Yield and Profitability of Sweet Potato (*Ipomoea batatas* (L.) Lam) as a Function of Increasing Levels of Phosphorus and Varieties in Southern Ethiopia

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Sweet potato is among the most important food security crops in Ethiopia. However, its productivity is constrained by poor soil fertility and a lack of improved varieties. A field experiment was conducted to evaluate the growth and yield response and profitability of three sweet potato varieties to rates of phosphorus (P) in Southern Ethiopia. Five rates of P (0, 10, 20, 30, and 40 kg ha^{-1}) and three sweet potato varieties (Awassa-83, Kulfo, and Local) were considered as treatments that were laid out in a randomized complete block design with three replications. The vine length, internodes length, diameter, and the number of vines were significantly varied among varieties while P had a nonsignificant effect on these parameters. The tuber yield of sweet potato was influenced by the combined effect of variety and P rate. The highest marketable yield (30.22 t ha^{-1}) was obtained at 30 kg P ha^{-1} from variety Awassa-83 and the lowest marketable yield (6.57 t ha^{-1}) was obtained from Kulfo at 0 kg P ha^{-1}. Thus, improvement of sweet potato productivity in the study area could be achieved through the use of Awassa-83 variety with P at a rate of 10 kg ha^{-1}.

1. Introduction

Sweet potato (*Ipomoea batatas* Lam.) ranks second following Irish potato in the world root and tuber crop production and the third most important crop after potato and cassava largely grown in East Africa [1]. In Ethiopia, sweet potato ranks first in total production (37.2%) and second in area coverage (15.21%) next to Irish potato compared to other root and tuber crops cultivated [2].

In Ethiopia, potential yield of sweet potato under research station and on-farm research with improved management practices is ≥50 and 35.0 t ha^{-1}, respectively [2, 3]. However, the average respective yields of the crop at national, regional (SNNP), and Zonal (Wolaita) levels were 42, 25.42, and 37.87 t ha^{-1}, respectively [4]. The productivity of sweet potato in Boloso Sore District is 13 t ha^{-1} which is far below that of research station, national, and regional average yield (BSDAS, unpublished data). Many diverse and complex biotic, abiotic, and human factors contribute to the low productivity of sweet potato in the study area. Some of the production constraints are a lack of good quality planting materials, poor soil management practices, diseases, weeds, insect pests, and limited or no use of chemical fertilizer.

Among the nutrients, P is widely used by plants and is most deficient in tropical soils [5], and most of the Ethiopian soils are low in available P. Hameda et al. [6] reported that different P-rates reflected a significant effect on total and marketable tuber yield, tuber dry matter, average tuber root weight, and average tuber root diameter. Hassan et al. [7] and Dumbuya et al. [8] also found that fertilization of sweet potato plants with P resulted in significant increase in total and marketable yield, although they did not quantify the marginal rate of return.

Table 1: Some physicochemical properties of soil in the experimental site.

Parameters	Values	Interpretation	References
Particle size (%)			
Sandy	60		
Silt	33		
Clay	7		
Textural class		Sandy loam	
Chemical property			
pH	5.6	Moderately acidic	Landon [10]
TN	0.0857	Poor	Tekalign [11]
AP (mg/kg)	3.64	Low	Tekalign [11]
CEC (cmol/kg)	22.06	Moderate	Landon [10]

In Ethiopia, some researchers had previously evaluated the responses of sweet potato to different application rates of organic (FYM) and inorganic (N and P) fertilizers at different locations [9]. Soil fertility studies conducted over different locations for various crops in the country generally have shown good yield response to applied P fertilizers indicating the deficiency of P in the soil [5]. To improve the productivity of sweet potato, the best-performing variety and site-specific P rate for its economic feasibility should be determined. Hence, this study was initiated to evaluate the response and economic profitability of sweet potato varieties to P rates.

2. Materials and Methods

2.1. Description of Experimental Site. Field experiment was conducted during the 2016 main cropping season (March 1 to June 30) at Tadissa on a farmer's field in Boloso Sore District, Wolaita zone, Southern Ethiopia. Geographical coordinate of the site is 7°04′ N latitude and 37°41′ E longitude with an altitude of 1830 masl. The soil is sandy loam in texture, moderately acidic, low in available P and total nitrogen, and moderate in cation exchange capacity (Table 1). The mean annual rainfall is 1520 mm with a bimodal pattern. The average mean temperature is 20.02°C.

2.2. Treatments and Experimental Design. Treatments consisted of three sweet potato varieties (Awassa-83, Kulfo, and Local) and five rates of P (0, 10, 20, 30, 40 kg ha^{-1}). The treatments were combined in a 3×5 factorial arrangement and laid out in a randomized complete block design with three replications.

2.3. Experimental Materials and Procedures. Before planting, the land was well prepared manually using an oxen plough. Di-ammonium phosphate (DAP) (18% N, 46% P_2O_5) was used as a source of phosphorus that was applied at planting. Similarly, urea (46% N) at a rate of 50 kg ha^{-1} was used as a source of nitrogen and applied uniformly to all plots at planting by considering the amount of N found in each level of DAP. Vine cuttings having a length of 30 cm were planted at a spacing of 60 (between rows) and 30 cm (between plants) according to the recommendation of Geleta [12]. The plot size was 2.4 by 2.4 m. A distance of 100 and 150 cm was maintained between plots and blocks, respectively.

2.4. Data Collection. To collect soil data, representative soil samples were taken using an auger from the depth of 0–30 cm at different points of the experimental field before planting to make one composite sample. The samples were used to determine the following soil parameters: texture, pH, total nitrogen (TN), available phosphorus (AP), and cation exchange capacity (CEC). Texture was analyzed at the Wolaita Sodo soil testing center, southern Ethiopia. Soil pH was determined at the 1 : 2.5 soil to water ratio using a glass electrode attached to a pH digital meter [13]. Total nitrogen and available phosphorus were determined according to the methods of Dewis and Freitas [14] and Olsen and Dean [15], respectively. CEC was determined using Kjeldhal procedure as described by Ranist et al. [16].

Six plants were systematically selected from the middle two rows by considering border effects to collect vine length, vine internode length, and vine girth. Vine length (cm) was measured from the base of the main shoot to the tip. Vine internode length (cm) was measured between the fourth and fifth nodes from the tip. Vine girth (cm) is the mean diameter of the vine measured between the fourth and fifth node from the tip of the main shoot and measured with the aid of calliper.

Root data taken include the number of roots per plant (number of roots produced per plant), storage root length (cm) (vertical length of the root measured from the tip to the scar of separation), storage root diameter (cm) (diameter of the root taken from the middle portion), and the root dry matter weight (obtained from roots cut into smaller pieces and dried in a hot oven at 80°C for 48 hours). The weight was taken by using a sensitive balance. Marketable yield (t ha^{-1}) is the weight of clean, uninfected roots that fall in the size range of 100 to 500 g. This was taken by weighing the roots collected from the harvestable plot. Total yield (t ha^{-1}) is the sum total of both marketable and unmarketable storage root yields obtained from the harvestable plot. The collection of data from one year experiment is the limitation of this study.

2.5. Economic Profitability. To consolidate the statistical analysis of the agronomic data, economic analysis was done for each treatment. For economic evaluation, cost, return, and benefit to cost ratios were calculated according to the procedure given by CIMMYT [17]. Total variable cost (TVC) = sum of all variable costs in a given treatment. Storage root yield (SRY) = total yield harvested from one hectare. Adjusted yield (AJY) = SRY × 90%, the average yield adjusted downward by a certain percentage to reflect the difference between the experimental yield and the yield of farmers. Total revenue (TR) = AJY × field price of the storage root; the gross field benefit for each treatment was calculated by multiplying the field price by the adjusted yield. Net revenue (NR) = total revenue (TR) − total variable cost (TVC); the final line of the partial budget is the net benefits. It was calculated by subtracting the total costs that vary from the gross field benefits for each treatment. Marginal rate of

Table 2: Main effect of varieties and P rates on vine length, internode length, vine diameter, and vine number of sweet potato.

Varieties	VL	VIL	VD	VN
Awassa-83	100.3[b]	4.1[b]	3.5[a]	9.54[b]
Kulfo	64.38[c]	2.86[c]	2.61[c]	16.77[a]
Local	149.94[a]	4.49[a]	3.01[b]	9.1[b]
LSD (0.05)	15.03	0.34	0.19	2.04
P rates (kg ha^{-1})				
0	103.87	3.96	2.96	12.33
10	100.52	3.54	2.92	10.66
20	103.36	3.8	3.08	11.63
30	109.48	3.8	3.04	12.18
40	107.13	3.94	3.19	12.22
LSD (0.05)	NS	NS	NS	NS
CV (%)	19.16	11.83	8.27	23.11

Means followed by the same letters are not significantly different at the 5% level of significance. VL = vine length (cm), VIL = vine internodes length (cm), VD = vine diameter (cm), VN = vine number, CV = coefficient of variation, and LSD = least significant difference at 5% probability level.

Table 3: Analysis of variance for below ground yield and yield components of sweet potato as affected by varieties and P rates at Tadissa, Boloso Sore District, Ethiopia, 2016.

Parameters	Source of variation			
	MSV	MSP	MSV*P	MSE
VL (cm)	27,689.75*	109.26 ns	132.42 ns	403.69
VIL (cm)	10.9*	0.27 ns	0.18 ns	0.204
VD (cm)	2.98*	0.11 ns	0.11 ns	0.063
VN (no)	278.44*	4.36 ns	2.6 ns	7.44
NRP (no)	80.67*	0.36 ns	0.51 ns	3.07
SRL (cm)	337.42*	5.47 ns	6.95*	2.74
SRW (t ha^{-1})	627*	25.78*	9.41*	3.12
RDW (t ha^{-1})	627*	25.78*	9.41*	3.12
MY (t ha^{-1})	479.58*	301.53*	10.35**	1.92
TY (t ha^{-1})	643.66*	275.23*	9.56*	2.54
DF	2	4	8	28

MSV = mean square of variety, MSP = mean square of phosphorus, MSV*P = mean square of variety by P rate interaction, MSE = mean square error, VL = vine length, VIL = vine internodes length, VD = vine diameter, VN = vine number, NRP = number of roots per plant, SRL = storage root length, SRD = storage root diameter, SRW = storage root dry weight, RDW = root dry weight, MY = marketable yield, TY = total yield, and DF = degree of freedom.

return (MRR %) = $\Delta NR/\Delta TVC \times 100$, which is the marginal net benefit (i.e., the change in net benefit) divided by the marginal cost (i.e., the change in cost).

2.6. Statistical Data Analysis. Data was subjected to analysis of variance (ANOVA) using Statistical Analysis Software (SAS) version 9.2 [18] (SAS, 2009). Significantly differing means with respect to the effect of P rates, varieties, and their interaction were separated using the least significant difference (LSD) test at 5% level of significance as described by Gomez and Gomez [19].

3. Results and Discussion

3.1. Physicochemical Properties of the Experimental Site Soil. The soil analysis results showed that the soil was moderately acidic, sandy loam in texture, low in AP and TN, and moderate in CEC (Table 1). This result indicated that the soil requires external nutrient sources such as farmyard manure, inorganic fertilizers, and crop residues for enhancing growth and yield of the crop.

3.2. Above Ground Growth of Sweet Potato. Sweet potato varieties varied significantly ($P < 0.05$) on their vine length, vine internodes length, vine diameter, and vine number, while P had no significant effect on these parameters (Tables 2 and 3). The local variety had the longest vine length (149.94 cm) and vine internode length (4.49 cm) while the shortest length of the indicated parameters was observed from Kulfo (Table 2). Similarly, the highest vine diameter (3.5 cm) and vine number (16.77) were recorded from Awassa-83 and Kulfo, respectively, while the lowest one for the respective parameters (2.61 cm and 9.1) was obtained from Kulfo and local varieties, respectively (Table 2). The current study results indicated that the local variety had better growth performance than the other varieties. This variability might be attributed to their genetic difference on growth traits. This indicates that local varieties can be used as a good vine source especially where production is aimed at producing sweet potato vines. The vines can also be used as forage for the feeding of ruminants since the vines are rich in their protein and mineral contents were needed in livestock feed [20]. Similar to the current study result, Kathabwalika et al. [21] and Rahman et al. [22] reported that a significant difference was observed on vine length among sweet potato varieties that were evaluated. Furthermore, Berhanu and Beniam [23] reported similar results. The results also indicate that P level had no significant effect on the above ground growth parameters. This may be due to the low availability of P in the soil and its fixation (Table 1). Rashid and Waithaka [24] reported that phosphorus nutrition did not significantly increase vine production of sweet potato. On the other hand, Hassan et al. [7] and El-Sayed et al. [25] stated that application of 20 kg P ha^{-1} on sweet potato plants resulted in significantly superior vine length, number of branches per plant, and leaf area per plant as compared with control treatment. This difference may be due to the effective absorption of available phosphorus in the soil.

3.3. Number of Roots per Plant. Number of roots per plant showed significant ($P < 0.05$) variation only with variety difference (Table 3). The highest (6.49) and lowest (2.39) number of roots per plant was noted from Awassa-83 and Kulfo varieties of sweet potato, respectively (Table 4).

The Awassa-83 variety showed the highest NRRP (6.43) compared to Kulfo and local varieties. The variation among varieties in the number of roots may be attributed to their genetic difference since variability in genetic makeup in turn expressed on their growth performance [26]. Egbe et al. [27] reported that sweet potato varieties showed significant variation in their root number.

Table 4: Effect of varieties and P rates on the number of roots per plant of sweet potato at Tadissa, Boloso Sore District, Southern Ethiopia, 2016.

Varieties	NRPP	P rates (kg ha^{-1})	NRPP
Awassa-83	6.49[a]	0	4.83
Kulfo	2.39[b]	10	5.01
Local	6.32[a]	20	5.08
		30	5.39
		40	5.01
LSD (0.05)	0.46	LSD	NS
CV (%)	12.15	CV (%)	12.15

Means followed by the same letters are not significantly different at the 5% level of significance. LSD = least significant difference, CV = coefficient of variation, and NRPP = number of roots per plant.

3.4. Storage Root Length and Diameter. The interaction effects of P rate and variety significantly ($P < 0.05$) influenced root length and diameter (Table 3). The longest (23.22 cm) and shortest (10.11 cm) storage root lengths were recorded from Awassa-83 variety at P rate of 30 kg ha^{-1} and Kulfo with 10 kg P ha^{-1}, respectively (Figure 1).

Similarly, the highest (23.31 cm) and lowest (11.81 cm) root diameters were observed from the local variety at P rate of 10 kg ha^{-1} and Kulfo at P rate of 40 kg ha^{-1}, respectively (Figure 2).

The variation on storage root growth parameter of sweet potato with their convulsive to P rates might be related to their inherent variability to use nutrients like P. Berhanu and Beniam [23] stated that sweet potato varieties varied on their root growth in response to P fertilizer rates.

3.5. Root Dry Weight. Interaction effect of P rates and varieties was significant ($P < 0.05$) on storage root dry weight (Table 3). The highest storage root dry weight (18.12 t ha^{-1}) was obtained from AW-83 variety at P rate of 20 kg ha^{-1} followed by the same variety at P rate of 30 kg ha^{-1} with a mean storage root dry weight of 14.67 t ha^{-1} (Table 4). The lowest storage root dry weight (0.64 t ha^{-1}) was obtained from a variety of Kulfo at 0 kg P ha^{-1} (Table 5).

This result indicated that varieties of sweet potato showed variation on their storage root dry weight as P rates increase which might be attributed to the fact that crop varieties show variation on their resource utilization which in turn expressed on assimilates allocation and biomass formation [28]. The variation might be related to the genetic formation of the genotypes which may influence the strength of their biomass production and the partitioning of assimilate to different parts of the plant. Similarly, Belanger [29] reported that variations on tuber growth and biomass partitioning of two potato cultivars were observed as a result of different fertilization rates and irrigation treatments.

3.6. Marketable and Total Root Yield. The highest marketable root yield (30.22 t ha^{-1}) was obtained from a variety of AW-83 at P rate of 30 kg ha^{-1} followed by the same variety at P rate of 40 kg h $^{-1}$ with a mean marketable yield of 29.13 t

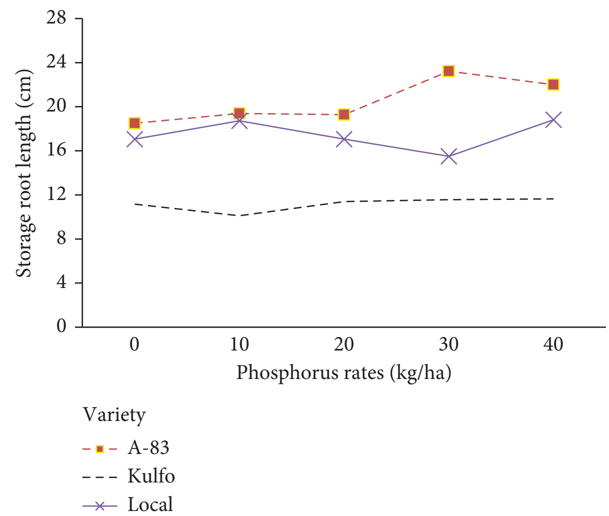

Figure 1: Effect of P rates on storage root length of sweet potato varieties at Tadissa, Boloso Sore District, Southern Ethiopia. A-83 = Awassa-83.

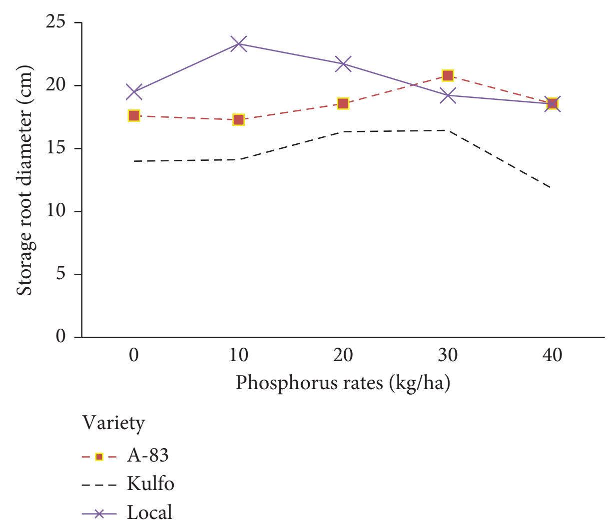

Figure 2: Effect of P rates on storage root diameter of sweet potato varieties at Tadissa, Boloso Sore District, Southern Ethiopia. A-83 = Awassa-83.

Table 5: Effect of variety and P rates on storage root dry weight (t ha^{-1}) of sweet potato at Tadissa, Boloso Sore District, Southern of Ethiopia.

Varieties	P rates (kg ha^{-1}) 0	10	20	30	40	Mean
Awassa-83	8.77[c]	13.87[b]	18.12[a]	14.67[b]	13.06[b]	13.7
Kulfo	0.64[e]	0.69[e]	0.85[e]	0.92d[e]	0.74[e]	0.77
Local	3.76[d]	8.62[c]	7.84[c]	7.54[c]	7.33[c]	7.02
Mean	4.39	7.73	8.94	7.71	7.05	7.16
LSD (0.05), V*P = 2.95				CV = 24.6		

Means followed by the same letters are not significantly different at the 5% level of significance. AW-83 = sweet potato variety named as Awassa-83, LSD = least significant difference at 5% probability level, CV = coefficient of variation, and V*P = LSD value for interaction of variety by P rates.

Table 6: Interaction effect of variety and P rates on marketable root yield (t ha^{-1}) of sweet potato at Tadissa, Boloso Sore District, Southern Ethiopia.

Varieties	P rates (kg ha^{-1})					Mean
	0	10	20	30	40	
Awassa-83	11.75^{h}	$22.33d^{e}$	27.6^{bc}	30.22^{a}	29.13^{ab}	24.2
Kulfo	6.57^{i}	12.7^{gh}	14.88^{fg}	16.96^{f}	14.99^{fg}	13.22
Local	11.33^{h}	20.48^{e}	23.54^{d}	26.26^{c}	23.63^{d}	21.05
Mean	9.88	18.5	22	24.48	22.59	19.49
	LSD (0.05), $V^{*}P = 2.32$				CV (%) 7.1	

Means with the same letters are not significantly different at the 5% probability level. CV = coefficient of variation, AW-83 = sweet potato variety named as Awassa-83, LSD = least significant difference at 5% level of significance, and $V^{*}P$ = LSD value for interaction of variety by P rate.

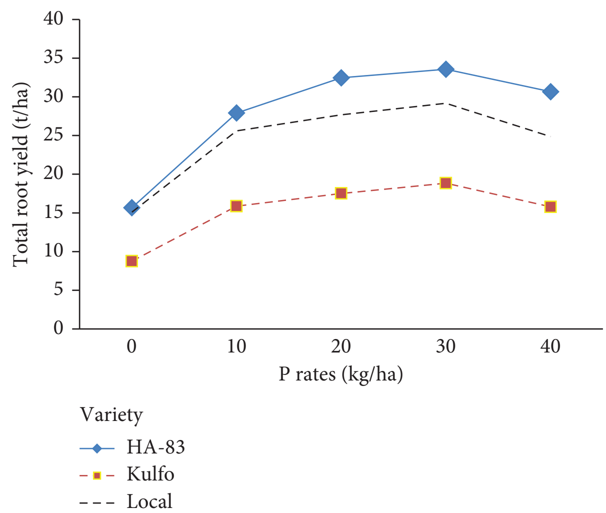

Figure 3: Total root yield of sweet potato varieties in response to P rates at Tadissa, Boloso Sore District, Southern Ethiopia. A-83 = Awassa-83.

Table 7: Partial budget analysis of P fertilizer application on sweet potato at Tadissa, Boloso Sore District, Southern Ethiopia.

Varieties	P rates (kg ha^{-1})	AJMY (t ha^{-1})	TR (ETB)	TVC (ETB)	NR (ETB)	MRR (%)	BCR
Awassa-83	0	10.58	15,870	2,167	13,703	0	0
	10	20.1	30,150	4,229	25,921	592.53	18.16
	20	24.84	37,260	5,522	31,738	452.4	10.76
	30	27.2	40,800	6,471	34,329	273.02	8.21
	40	26.22	39,330	7,019	$32,311^{D}$	−368.25	5.56
Kulfo	0	5.91	8,865	1,476	7,387	0.00	0
	10	11.43	17,145	3,025	14,120	434.54	8.04
	20	13.39	20,085	4,026	16,059	193.71	5.17
	30	15.26	22,890	4,998	17,892	188.58	4.18
	40	13.49	20,235	5,530	$14,705^{D}$	−599.06	2.18
Local	0	10.2	15,300	2,110	13,190	0.00	0
	10	18.43	27,645	3,998	23,647	553.87	12.48
	20	21.19	31,785	5,048	26,737	294.29	8.08
	30	23.63	35,445	6,031	29,414	272.33	6.45
	40	21.27	31,905	6,439	$25,466^{D}$	−967.65	3.66

AJMY = adjusted marketable yield, TR = total revenue, TVC = total variable cost, NR = Net revenue, AW-83 = sweet potato variety named as Awassa-83, MRR = marginal rate of return, D = dominated (having treatments with higher cost and lower net benefit than the previous successive treatments), BCR = benefit to cost ratio, ETB = Ethiopia birr, one dollar = 22.085 ETB, and field price of root yield = 150.00 Birr/100 kg of root yield.

ha^{-1} (Table 5). The lowest marketable root yield (6.57 t ha^{-1}) was obtained from a variety of Kulfo at P rate of 0 kg ha^{-1} (Table 6).

The results indicate that marketable root yield of the three sweet potato varieties significantly increased with increasing P rates up to 30 kg ha^{-1} and then showed a declining trend. These increments might be related to the important role of phosphorus as an essential component of many organic compounds in the plant such as phosphor-proteins, phospholipids, nucleic acids, and nucleotides that indirectly reflected on yield [30]. The declining of marketable root yield with application of P after 30 kg ha^{-1} might be attributed to the overdose effect of P that induces deficiency of micronutrient [31, 32]. Similar results were reported by Hassan et al. [7] who reflected that P fertilization of sweet potato plants cause significant increases in total and marketable yield. Additionally, [6] indicated that root yield and yield components of sweet potato were increased by increasing rate of P from 6.5 to 20 kg ha^{-1}.

The variety AW-83 gave the highest total root yield (33.57 t ha^{-1}) at P rate of 30 kg ha^{-1} while the lowest total root yield (8.76 t ha^{-1}) is obtained from the variety of Kulfo at P rate of 0 kg ha^{-1} (Figure 3). Furthermore, total root yield of the three sweet potato varieties significantly increased with increasing P rates up to 30 kg ha^{-1} and then shows declining trends. The variability of sweet potato varieties on their root yield in response to P rates might be related to their differences on root yield attributes and their inherent variation on capturing environmental resources and later on root yields formation. The reduction of root yield after application of P over the optimum rate might induced deficiency of micronutrients especially zinc as a result of high P build-up in the soil [31, 32]. Similarly, Hameda et al. [6] report that the increase of P from 0 to 20 kg ha^{-1} increased root yield, but the increase of P from 20 to 40 kg ha^{-1} decreased root yield.

3.7. Economic Profitability. The partial budget analysis showed that the highest net income was found with the dose of 30 kg P ha^{-1} (34 329 birr) followed by 40 kg P ha^{-1} (32 311 birr) of the same variety, Awassa-83 (Table 7). The lowest net income (7,387 birr) occurred when no P was applied on the Kulfo variety.

The highest marginal rate of return (592.53%) was achieved with the Awassa-83 variety at a P rate of 10 kg ha^{-1}. The phosphorus rate of 40 kg/ha was rejected because the treatments with higher cost and lower net benefit than previous successive treatments were considered dominated [17]. The highest cost-benefit ratio (18.16) is found with the AW-83 variety at a P rate of 10 kg ha^{-1} and the lowest Kulfo at a P rate of 40 kg ha^{-1}. Therefore, the combination of 10 kg P ha^{-1} with the Awassa-83 variety is profitable and is recommended for farmers in the study area and other areas with similar agroecological conditions.

4. Conclusion

The combined effect of varietal performance and P rates significantly influence sweet potato growth and yield. The Awassa-83 variety shows the best performance in most of the parameters measured with respect to the local and Kulfo varieties. The Asawa-83 variety with P at a rate of 10 kg ha^{-1} contributes the greatest economic benefit in this study.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Mesfin Dawit collected, analyzed, and interpreted the data. Abera Habte drafted and edited the manuscript. All authors read and approved the final manuscript.

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