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Research Article

Nutrient Uptake and Efficiencies of Orange-Fleshed Sweet Potato (*Ipomoea batatas* L.) Varieties under Different Rates of Nitrogen and Phosphorus Fertilizers

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Sweet potatoes serve as a staple food and animal feed in Africa and serve as a source of raw materials for the food, feed, pharmaceutical, cosmetic, chemical, and energy industries. The yield of orange-fleshed sweet potatoes is increased when nitrogen (N) and phosphorus (P) are added to low-fertility soils. The objective of this study was to evaluate the nutrient uptake and use efficiency of orange-fleshed sweet potato varieties under applied N and P. The experiment was conducted for two growing seasons (2019 and 2020) under rain-fed conditions in the field. The study included five orange-fleshed sweet potato varieties (Kulfo, Kabode, Alamura, Dilla, and NASPOT-12), three N levels (0, 23, and 46 $kg{\cdot}N{\cdot}ha^{-1}$), and two levels of P (0 and 46 kg $P_2O_5{\cdot}ha^{-1}$) fertilizers designed in $5 \times 3 \times 2$ with α-lattice design in factorial arrangement using 3 replications. The interaction effect of variety, N, and P fertilizers affected nutrient uptake, physiological efficiency, and agronomic efficiency of sweet potatoes. NASPOT-12 was the better variety in nutrient uptake but poor in apparent recovery at all levels of N and P. The highest nutrient uptake, agronomic efficiency, and physiological efficiency were observed on NASPOT-12 when subjected to 23 kg $N{\cdot}ha^{-1}$ and 46 kg $P_2O_5{\cdot}ha^{-1}$. Overall, NASPOT-12 with 23 $kg{\cdot}N{\cdot}ha^{-1}$ and 46 kg $P_2O_5{\cdot}ha^{-1}$ could be recommended for its high nutrient uptake, agronomic, and physiological efficiencies.

1. Introduction

One of the minerals that sweet potatoes most frequently take up is nitrogen [1]. Its availability, whether through mineral fertilizer or green manure, is crucial to promoting crop production and productivity. Nitrogen plays a significant role in the creation and growth of sweet potato storage roots, the accumulation of dry matter, the absorption of phosphorus and potassium, and other processes [2, 3]. Nitrogen is also one of the most critical elements influencing sweet potato shoot morphogenesis and root yield [3, 4]. Since it affects how dry matter accumulates and is distributed throughout the plant [5], nitrogen treatment causes plants to develop more quickly, which raises their need for other nutrients [6]. Even on marginal terrain, the sweet potato (*Ipomoea batatas* L.) yields a lot of roots per unit of time and space [3, 7]. However, sweet potato has significant nutritional requirements starting with the store's basic bulking stage until the completion of the sweet potato growing cycle [1, 8]. The outcome is that the sweet potato crop absorbs a lot of nutrients from the soil [1].

In the later growth season, when the crop is expanding quickly, the majority of nitrogen is absorbed by crops [4, 9]. The danger of losing nitrogen to volatilization, immobilization, denitrification, and/or leaching increased as a result of this [10]. It goes without saying that applying a lot of nitrogen fertilizer before transplanting causes a poor harmonization between the farm's nitrogen application and the plant's need, leading to a high concentration of mineral nitrogen present on earth before the quick plant uptake of nitrogen occurs [4, 9]. This increased the likelihood of nitrogen losses and caused a significant drop in nitrogen use efficiency [11, 12].

A significant factor limiting crop productivity has been identified as phosphorus (P). Despite the fact that phosphorus remains fairly plentiful on numerous earths, that one is typically inaccessible to plants because that one creates an unsolvable set of buildings by means of cations in both acidic and alkaline environments [13–16]. Potato is one crop that is predominantly vulnerable to phosphorus-lacking earth, demonstrating the poor phosphorus absorption effectiveness [17–20]. Its tiny root structure by comparison with extra plants like mueslis and leguminous plants is most likely the cause of this [21]. However, certain patterns suggest that efforts to increase phosphorus usage effectiveness (PUE) by this plant will be driven by the realization that phosphate rock availability will decline significantly over the next 50 to 100 years [22]. In the last 40 years, no investigations on the phosphorus nutrition of sweet potatoes have proven any of these established pathways for phosphorus absorption or phosphorus use efficiency [23, 24]. Numerous studies conducted under low phosphorus circumstances on sweet potato cultivars have revealed considerable variations in growth and production. Phosphorus concentrations, biomass, and phosphorus distribution variations in cultivars have all been linked to variations in phosphorus use efficiency (PUTE) [25–27].

Appropriate P application helps to develop a root system, promote the synthesis, transportation, and storage of carbohydrates, increase the starch content of storage roots, and increase the yield [28]. However, excessive application of phosphorus fertilizer leads to the reduction of phosphorus fertilizer utilization rate and the increase of environmental load in the current season, which is not conducive to the increase of yield and even leads to its reduction of yield. Therefore, it is of great significance to explore the appropriate amount of P fertilizer to achieve the balance between sweet potato yield and the utilization rate of P fertilizer.

Increased phosphorus absorption and greater yield result from a synergistic interaction between nitrogen and phosphorus [6]. Owing to alterations by soil pH, nitrogen application might also promote or reduce the uptake of micronutrients depending on its type (NH4+ or NO3−) [6]. Additionally, variations in the energy cost of biomass synthesis may account for variations in the phosphorus utilization efficiency of different crops (PUTE). Previous research has demonstrated that cereals, followed by legumes and oilseed crops, have the highest nutrient utilization rates [29, 30]. Rare information exists regarding how applied nitrogen and phosphorus affect varieties specific sweet potato uptake and subsequent yield improvement. Furthermore, it has not been looked at how much nutrition sweet potatoes need when grown in succession under certain nitrogen and phosphorus fertilizer supply conditions. So, based on fertilizer administration, we expected that the sweet potato varieties would differ in nutrient uptake and productivity. The ability of varieties to absorb and use nutrients depends on the nutrient's availability and their genetic makeup. In accordance with this, the objective of the current investigation was to determine the nutrient uptake, physiological efficiency, and agronomical use efficiency (nitrogen and phosphorus) of orange-fleshed sweet potatoes in response to fertilization with nitrogen and phosphorus.

2. Materials and Methods

2.1. Description of the Study Area. The experiment was carried out for 2 successive cropping years (2019 and 2020 April to October) at Hawassa, Southern Agricultural Research Institute (SARI), at an altitude of 1708 m.a.s.l. in the Sidama Regional State of Ethiopia, and Hawassa Research Center situated at 7°3′54″ N and 38°28′59″ E. The location of the site is 275 kilometers south of Addis Abeba [31].

2.2. Description of Experimental Materials. Five varieties of orange-fleshed sweet potatoes that had been released four domestically and one imported from Uganda were used as the experimental materials. The name of the varieties is Kulfo (LO-323), Kabode (SPK 004/6/6), Alamura (Ukr/Eju-10), Dilla (Ukr/Eju-13), and NASPOT-12. All were taken from the Hawassa Agricultural Research Center of the South Agricultural Research Institute (SARI).

2.3. The Treatment and Experimental Design. The experiment contained five different varieties of orange-fleshed sweet potatoes (listed above), three rates of N (0, 23, and 46 kg $N \cdot ha^{-1}$), and two rates of P (0 and 46 kg $P_2O_5 \cdot ha^{-1}$). They were all organized in a $5 \times 3 \times 2$ with α-lattice design with three replications.

2.4. Experimental Procedure. The experimental land was prepared ahead of planting. The land was plowed three times and made fine tilth. The size of each plot was 2.4 by 2.4 m or 4.8 m^2. Row and plant spacing were set to be 60 cm and 30 cm, respectively. In every plot, there were four rows with eight plants each, totaling 32 plants. The space between blocks and plots was 2 m and 1 m, respectively. Planting was done using 30 cm-long young vine cuttings from each variety. At the time of vine planting, half of the N and full dosages of P (as per treatments) were applied. Half of the remaining N was applied forty-five days later. The fertilizers were placed beneath the cutting just immediately before planting. The fertilizers were covered with soil to avoid direct contact with the vine cutting. The experiments were conducted under rain-fed conditions in both years. Weeding, intertillage, and earthing-up were all carried out in accordance with the Ethiopian Agricultural Research Organization's recommendations [32].

2.5. Soil Sampling and Analysis. Before implanting, soil samples were taken by auger from 9 different places over the entire investigational field at a deepness of 0–30 cm and combined to form one sample. Zigzag patterns were used to collect the soil samples. Similar to this, soil samples were composed shortly after harvest from 3 places from each plot at the same depth. The samples were mixed in every plot. The samples were dried out and sieved using a two-millimeter filter prior to research laboratory evaluation. Soil samples were tested on behalf of relevant strictures at the SARI soil laboratory. Before planting, measurements were made of the soil's texture, pH, organic matter, total nitrogen, and available phosphorus. After harvest, soil samples were taken, and the total nitrogen and available phosphorus were assessed. Through a glass electrode pH meter, the soil pH standards were obtained in a 1 : 2.5 soil water suspension [33]. Hydrometrically, the particle size distribution (texture) was determined [34]. Walkely's and Black's procedures, correspondingly, were used to calculate the amount of organic matter grounded on the oxidization of OC by acid potassium dichromate [33]. Total N was determined as described in [35]. According to Olsen and Sommer [36], available P was determined.

2.6. Analysis of Plant Tissue. At harvest maturity, samples of the shoots and roots from three plants of each plot were collected. To make drying easier, the roots were sliced into little pieces. To analyze the tissue's N and P contents, the plant tissues were oven-dried at 80°C until a constant weight was reached. According to Jackson [37], modified Kjeldahl procedures were used to evaluate the total N content of the shoot and root. Similarly, the plants' dry and ground branches were ashed at 480 degrees Celsius. A solution of 1 volume nitric acid (HNO3) diluted in three volumes of distilled water was used to treat the ashed plant material. P content was evaluated calorimetrically using the vanado-molybdate method [38] at Hawassa University soil laboratory.

2.7. Calculation of Plant Nutrient Uptake and Use Efficiencies. The shoot and root yields were multiplied to get the whole taken up of nitrogen and phosphorus (kg·ha^{-1}), with the nitrogen and phosphorus concentrations (%) of every treatment being like this:

$$
\begin{aligned}
&\text{a. N uptake of root or shoot (kg ha} - 1) = \frac{\text{Yield of root or shoot (kg ha} - 1)x\ N \text{ concentration of root or shoot (\%)}}{100},\\
&\text{b. P uptake of root or shoot (kg ha} - 1) = \frac{\text{Yield of root or shoot (kg ha} - 1)\text{x P concentration of root or shoot (\%)}}{100},\\
&\text{c. Whole N taken up} = \text{N taken up of root} + \text{N taken up of shoot},\\
&\text{d. Whole P taken up} = \text{P uptake of root} + \text{P taken up of shoot}.
\end{aligned} \tag{1}
$$

The efficiency of nutrient utilization was calculated using the following formulas [39, 40]. AE stands for the additional economical yields/applied entity of nutrients.

$$
\begin{aligned}
&\text{Agronomic efficiency } (N \text{ and } P) = \frac{\text{Yield of the fertilized plot (kg)} - \text{yield of the unfertilized plot (kg)} = \text{kg ha} - 1}{\text{quantity of nutrient applied (kg)}},\\
&\text{Physiological efficiency } (N \text{ and } P)\text{: PE} = \frac{(\text{Yf} - \text{Yu})}{(\text{Ntf} - \text{Ntu})},\\
&\text{Apparent recovery } (N \text{ and } P)\text{: PE} = \frac{(\text{Nf} - \text{Nu})}{(\text{Na})} x100.
\end{aligned} \tag{2}
$$

2.8. Data analysis. Data analysis was performed using SAS software version 9.2's PROC MIXED method [41]. The normality of the distribution and homogeneity of the variance assumptions of the ANOVA were verified. For analysis, the data from the two years were combined. We regarded N, P, and varieties as fixed effects. Year, block nested in year, the interaction of each of the major plot components (N treatment, P, and varieties) with year, and the two-way and three-way interactions of main plot factors with year were all judged to be random. Interactions between the major effects (varieties × N, varieties × P, N × P, and three-way interaction varieties × N × P) were presented only when statistically significant. Mean standard deviations were given in the results tables.

3. Results and Discussion

3.1. Physicochemical Properties of the Experimental Soil before Planting. The soil analysis result showed that the experimental site had 56, 21, and 26% sand, silt, and clay, in that order. In general, loamy surfaced topsoil is thought to be productive and has the capacity on the way to store enough readily available water. This outcome is consistent with Tantowojiyo's and Fliert's [42] research, which showed that these kinds of soils are typically found in hilly areas and are good for growing sweet potatoes. According to Landon [43], the soil reaction is classified as somewhat acidic (Table 1). Before planting, the analysis of the research farm found less in organic carbon, moderate in total N, and less in available P according to the same author's evaluation for tropical soils (Table 1). The soil pH and available P of the research area were reported by ATA [44] to be similar to those reported by Landon [43], although Hazelton and Murphy [45] classified OC values between 2.00 and 2.99 as very high.

3.2. Concentration of N and P in Soils after Harvest

3.2.1. Total N Concentration in Soil. Total N concentration (%) in the soil significantly differed ($P \leq 0.05$) as a result of the interaction between fertilizers types, N, P, and varieties (Table 2). Total N in the soil after harvest was higher by 35% due to the application of 46 kg N·ha^{-1} and 46 kg P_2O_5·ha^{-1} which was also far greater than N concentration of control after harvest. This indicated that P fertilizer increased the availability of N from the soil pool. The lowest N concentration of soil was recorded from control treatments. Among tested varieties, NASPOT-12 had a higher N concentration at 46 kg N·ha^{-1} with 46 kg P_2O_5·ha^{-1} than other varieties at all rates of N and P in the soils. This outcome is consistent with that reported by Lemineh et al. [46]. The author claimed that the quantitative maximum N content in the soils was achieved by applying N at a level of 100 kg·ha^{-1} with 70 kg·P_2O_5·ha^{-1}. Preplanting N levels in the soil (0.166%) were decreased by 44.35% compared to the control and in plots treated with nitrogen and phosphorus after harvesting it ranged from 0.115% to 0.177%. The crop might have used up the available N since no N or P fertilizer was applied to the farm before harvest in the control plot. The plant's consumption demand may be responsible for the decrease in total N in the farm of harvested plots.

3.2.2. Available P Concentration in Soils. The interactions of variety, N, and P fertilizers indicated the presence of significantly different ($P \leq 0.05$) values of available P (ppm). Numerically, the highest available P of the soil was recorded in the plots of variety Alamura treated with 46 kg·N·ha^{-1} and 46 kg·P_2O_5·ha^{-1} and Dilla treated with 23 kg·N·ha^{-1} and 46 kg·P_2O_5·ha^{-1}. Variety Dilla left better P in the soil at the control plots as compared to the other varieties. This indicated that the genetic variation has shown different responses to different levels of P fertilizer. The lowest available P of soil was recorded from a variety of Kulfo with control treatments. According to Demis and Boru et al. [28, 46], growing plants in the soil reduced the available P content of the soil where the control treatment had the lowest soil P levels. It was indicated that available P concentration in the topsoil usually declines due to uptake and/or adsorption by soil colloids unless P fertilizer is added Benhua et al. [47].

3.3. Nutrient Accumulation of N and P in Plant Tissues and Their Uptake of Orange-Fleshed Sweet Potato Plants

3.3.1. Nitrogen Concentration in Plant Tissues. Variety, N, and P fertilizer interactions significantly ($P \leq 0.05$) affected the N concentration of shoot and root. N uptake of plant per hectare and P uptake of plant per hectare were also affected by the interaction (Table 3). Applications of 46 kg N and 46 kg P_2O_5·ha^{-1} on variety Kabode plots enhanced the N concentration of shoot by 34% as compared to the control plot of the same variety. These findings are in line with those of Yitages [48], who reported that increasing the applications of N from 0 to 90 kg N·ha^{-1} significantly improved the shoot N concentration by 40.71%. The amount of N in the leaves improved to 197 and 200 kg N·ha^{-1} after fertilization of N [49]. Also, Busha [50] reported that increasing initial N rates from 45 to 90 kg N·ha^{-1} and P levels from 25 to 75 kg P_2O_5·ha^{-1} resulted in a significant increase in N (mg/g dm) concentration of shoot. Again, Getu [51] reported a higher N concentration of haulms in response to N application. According to Tsegaye [52] in comparison to the 0 kg N·ha^{-1} and 0 kg P_2O_5·ha^{-1}, the plots applied with suggested NP reported considerably higher values of total N. This is due to the fact that an increased concentration of N fertilizer can increase the N uptake, and this increase has a positive effect on chlorophyll concentration, photosynthetic rate, leaf expansion, total number of leaves, and dry matter accumulation.

The concentration of N in the orange-fleshed sweet potato root was significantly affected by the interaction of variety, N, and P fertilizers (Table 3). Dilla variety's root N concentration increased by nearly 18% after receiving treatment of 23 kg N and 46 kg P_2O_5·ha^{-1} as compared to control with the same variety. However, the current result was statistically not significantly different from Kulfo with 23 kg N·ha^{-1} and 0 kg P_2O_5·ha^{-1}, 46 kg N·ha^{-1} and 0 kg P_2O_5·ha^{-1}, from Kabode with all combinations except 23 kg N·ha^{-1} and 0 kg P_2O_5·ha^{-1}, and control from Alamura with all combinations except 46 kg N·ha^{-1} and 46 kg P_2O_5·ha^{-1} and control from Dilla with 0 kg N·ha^{-1} and 46 kg P_2O_5·ha^{-1},

Table 1: Selected soil physicochemical properties of the experimental area before planting.

						Texture of the soil			
Soil depth (cm)	pH(H_2O) 1 : 2.5	Total N%	Available P (ppm)	OC%	OM%	Clay%	Silt%	Sand%	Classes
0–30	5.79	0.166	7.69	1.87	5.31	27	18	59.5	Sandy clay loam

Table 2: Interaction effect of nitrogen and phosphorus fertilizers on the concentration of total nitrogen (%) and available phosphorus in the soil after harvest in 2019/2020.

Variety	Nitrogen (kg·ha^{-1})	Phosphorus (P_2O_5 kg·ha^{-1})	Total N (%)	Available P (ppm)
Kulfo	0	0	0.115^{ef}	4.26^{r}
		46	0.171^{a-d}	7.64^{no}
	23	0	0.117^{def}	9.79^{h}
		46	0.174^{abc}	12.91^{b}
	46	0	0.159^{a-e}	8.58^{klm}
		46	0.135^{a-e}	9.75^{hi}
Kabode	0	0	0.162^{a-e}	9.28^{hij}
		46	0.172^{a-e}	8.16^{mn}
	23	0	0.169^{a-e}	7.66^{no}
		46	0.173^{a-d}	9.37^{hij}
	46	0	0.145^{a-e}	12.26^{cde}
		46	0.167^{a-e}	12.85^{bc}
Alamura	0	0	0.146^{a-e}	5.60^{q}
		46	0.161^{a-e}	9.17^{ij}
	23	0	0.156^{a-e}	11.10^{g}
		46	0.175^{a-d}	11.54^{fg}
	46	0	0.172^{a-e}	12.15^{de}
		46	0.132^{bf}	13.68^{a}
Dilla	0	0	0.117^{c-f}	11.79^{ef}
		46	0.149^{a-e}	12.24^{de}
	23	0	0.134^{a-e}	12.57^{bcd}
		46	0.159^{a-e}	13.52^{a}
	46	0	0.117^{c-f}	5.98^{q}
		46	0.131^{b-e}	9.01^{jkl}
NASPOT-12	0	0	0.152^{a-e}	6.79^{p}
		46	0.176^{ab}	7.36^{op}
	23	0	0.159^{a-e}	8.16^{mn}
		46	0.131^{a-e}	9.17^{ijk}
	46	0	0.147^{a-e}	8.55^{lm}
		46	0.177^{a}	7.93^{no}
SE±			**0.011**	0.58

Means following identical columns with the same letter (s) do not substantially differ from one another. This is the standard error of the means. It indicates the deviation of the values of the observations in different replications.

46 kg N·ha^{-1} and 46 kg P_2O_5·ha^{-1} from NASPOT-12 with 23 kg N·ha^{-1} and 46 kg P_2O_5·ha^{-1}. A positive interaction between N and P leads to an increase in P uptake and a higher yield. The current result was confirmed by White et al. [53] found that adding N fertilizer to the soil increases the concentration of N in potato tubers. Similar to this, increasing N application from 0 to 90 kg N·ha^{-1} and increasing P application from 0 to 75 kg P_2O_5·ha^{-1} both significantly improved the root N concentration of sweet potatoes by 18.89% and 44.44%, respectively [48].

On the NASPOT-12 variety, the application of 46 kg N·ha^{-1} and 46 kg P_2O_5·ha^{-1} resulted in the maximum N uptake (184.65), which was 75.42% more advanced than the control on the same variety. The current result demonstrated that the variety NASPOT-12 had shown a good potential for N uptake using all rates of N and P fertilizer combination than the other varieties. Orange-fleshed sweet potatoes' ability to absorb nutrients was influenced by a variety of genetics. The current result is similar to previous reports of Flore-Anne [54] that showed the treatment of N significantly increased the N uptake of the sweet potato plant. Advanced N uptake resulted in plants applying high amounts of N which ranged from 138.64 to 162.27 g per plant. Depending upon the rate of N and potato varieties, Banerjee et al. [55] reported comparable total N (foliage and tuber) uptake of greater than 2-3 folds. The quantity of nutrients absorbed by a potato plant is directly connected to production, according to a similar result reported by Haifa [56]. More interestingly, different P uptakes were revealed for the combination of variety, N, and P treatment (Table 3), suggesting important variations in P uptake. The result showed that the same level of N application varieties differed greatly in P uptake, which

Table 3: Interaction effect of variety, nitrogen (N), and phosphorus (P) fertilizers on N concentrations and uptake of N and P in orange-fleshed sweet potato grown at Hawassa in 2019 and 2020 cropping seasons.

Variety	N ($kg{\cdot}ha^{-1}$)	P (P_2O_5 $kg{\cdot}ha^{-1}$)	N concentration shoot (%)	N concentration root (%)	N uptake of plant ($kg{\cdot}ha^{-1}$)	P uptake of plant ($kg{\cdot}ha^{-1}$)
Kulfo	0	0	0.50^{a-d}	0.88^{kln}	88.17^{h-k}	112.47^{b-f}
		46	0.47^{b-e}	0.89^{j-n}	82.51^{ijk}	118.48^{b-f}
	23	0	0.53^{a-d}	0.96^{a-j}	94.60^{f-k}	89.23^{c-f}
		46	0.54^{abc}	0.92^{g-n}	93.40^{f-k}	160.94^{a-f}
	46	0	0.55^{ab}	0.98^{a-g}	120.70^{cde}	112.47^{b-f}
		46	0.48^{b-e}	0.93^{d-m}	97.08^{f-j}	65.76^{c-f}
Kabode	0	0	0.44^{de}	0.90^{i-n}	89.56^{h-k}	168.38^{a-f}
		46	0.48^{b-e}	0.97^{a-j}	91.13^{h-k}	144.70^{a-f}
	23	0	0.47^{b-e}	0.92^{e-l}	95.41^{f-k}	170.87^{a-e}
		46	0.51^{bcd}	0.97^{a-h}	110.97^{def}	144.19^{b-f}
	46	0	0.49^{b-e}	0.94^{a-k}	98.86^{f-i}	119.14^{b-f}
		46	0.59^{a}	0.94^{a-l}	91.62^{g-k}	71.92^{c-f}
Alamura	0	0	0.52^{a-d}	0.92^{f-l}	98.87^{f-i}	40.43^{def}
		46	0.49^{b-e}	0.94^{a-k}	94.64^{f-k}	163.76^{a-f}
	23	0	0.54^{abc}	0.96^{a-j}	95.43^{f-k}	149.86^{a-f}
		46	0.55^{ab}	0.99^{abc}	119.31^{de}	215.00^{abc}
	46	0	0.52^{a-d}	0.99^{a-e}	125.03^{cd}	200.13^{a-d}
		46	0.45^{de}	0.87^{ln}	79.15^{jkl}	73.99^{c-f}
Dilla	0	0	0.41^{e}	0.85^{n}	63.18^{l}	29.99^{ef}
		46	0.48^{bcd}	0.97^{a-i}	90.01^{h-k}	125.77^{b-f}
	23	0	0.54^{ab}	0.93^{b-l}	89.83^{h-k}	40.62^{f}
		46	0.55^{ab}	1.00^{a}	95.26^{f-j}	143.21^{a-f}
	46	0	0.48^{b-e}	0.92^{g-l}	77.97^{kl}	133.81^{b-f}
		46	0.53^{a-d}	0.99^{a-f}	105.19^{e-h}	40.76^{f}
NASPOT-12	0	0	0.46^{b-e}	0.91^{h-n}	105.26^{e-h}	182.95^{a-e}
		46	0.48^{b-e}	0.92^{f-l}	123.30^{cd}	274.49^{ab}
	23	0	0.45^{de}	0.92^{g-n}	137.83^{bc}	207.95^{a-d}
		46	0.54^{ab}	0.99^{abd}	151.79^{b}	304.56^{a}
	46	0	0.52^{a-d}	0.93^{c-m}	109.62^{d-g}	202.22^{a-d}
		46	0.49^{b-e}	0.93^{e-l}	184.65^{a}	259.85^{ab}
SE±			**0.036**	**0.015**	**7.95**	**35.85**

Means following identical columns with the same letter (s) do not substantially differ from one another. These are standard errors of the means. Each indicates the deviation of the values of the observations in different replications.

suggests that there is an important variation in P uptake. P uptake of orange-fleshed sweet potato per hectare was significantly differing by variety NASPOT-12 that received 23 kg $N{\cdot}ha^{-1}$ and 46 kg $P_2O_5{\cdot}ha^{-1}$. Similar results were found by Tsegaye [52], who found that applying organic (FYM) and blended fertilizer over the control on various genotypes increased the amount of P uptake by shoots and roots by twofold. This variation in P uptake is caused by the application of nutrients, the availability of P from amendments, and/or the differences in the varieties [56–58]. According to research, manure and inorganic fertilizers in the soil promoted plants' uptake of P. Thus, P is important for physiological and biochemical processes such as photosynthesis, character transmission, and the conversion of sugar to starch in plants [59].

3.3.2. Phosphorus Concentration in Plant Tissues. Interaction between varieties, N, and P fertilizer considerably ($P < 0.05$) affected the P concentration in the orange-fleshed sweet potato shoot and root. Treatment of 46 kg $N{\cdot}ha^{-1}$ and 46 kg $P_2O_5{\cdot}ha^{-1}$ increased P concentration in the shoot as compared to the control on two varieties (Dilla and NASPOT-12). The concentration of P in the shoot varied from 0.10% (variety Dilla) to 0.90% (variety NASPOT-12) at different N and P applications (Table 4). The other three varieties remained not influenced using the various rates of N and P. The significant response among varieties for P concentration in the shoot may be due to genetic variability. This result is in line with other reports that indicated increasing N and P application increased P concentration of shoots [48, 50, 52]. Results also confirmed that for potato, cabbage, and carrot, the shoot P concentration of plants grown without P supply was significantly lower than that of plants grown with P supply [60].

The concentration of P in the root was significantly increased for variety Alamura with 23 kg $N{\cdot}ha^{-1}$ and 46 kg $P_2O_5{\cdot}ha^{-1}$ by 197.44% as compared to the control on the same variety (Table 4). The significant differences among the varieties for P concentration in root may be due to genetic variability at the same N and P applications. The current result is similar to previous reports stating that the maximum (0.96%) and minimum (0.66%) root P concentrations

Table 4: Interaction effect of variety, nitrogen, and phosphorus (P) fertilizers on P concentrations in shoots and roots grown at Hawassa in 2019 and 2020 cropping seasons.

Variety	Nitrogen (kg·ha^{-1})	Phosphorus (P_2O_5 kg·ha^{-1})	P concentration shoot (%)	P concentration root (%)
Kulfo	0	0	0.74^{abc}	0.89^{abc}
		46	0.65^{abc}	0.80^{abc}
	23	0	0.50^{abc}	0.66^{abc}
		46	0.53^{abc}	0.85^{abc}
	46	0	0.65^{abc}	0.90^{abc}
		46	0.37^{abc}	0.53^{abc}
Kabode	0	0	0.84^{ab}	0.99^{abc}
		46	0.72^{abc}	0.99^{abc}
	23	0	0.87^{ab}	1.03^{abc}
		46	0.74^{abc}	0.89^{abc}
	46	0	0.61^{abc}	0.76^{abc}
		46	0.38^{abc}	0.54^{abc}
Alamura	0	0	0.84^{ab}	0.39^{bc}
		46	0.86^{ab}	1.01^{abc}
	23	0	0.81^{abc}	0.96^{abc}
		46	0.23^{bd}	1.16^{a}
	46	0	0.86^{ab}	1.01^{abc}
		46	0.39^{abc}	0.55^{abc}
Dilla	0	0	0.10^{cd}	0.25^{c}
		46	0.24^{abc}	0.93^{abc}
	23	0	0.78^{abc}	0.26^{c}
		46	0.11^{cd}	0.39^{abc}
	46	0	0.81^{abc}	0.96^{abc}
		46	0.74^{abc}	0.89^{abc}
NASPOT-12	0	0	0.80^{abc}	0.96^{abc}
		46	0.88^{ab}	1.03^{ab}
	23	0	0.80^{abc}	0.9567^{abc}
		46	0.89^{ab}	1.05^{ab}
	46	0	0.87^{ab}	1.03^{ab}
		46	0.90^{ab}	1.05^{ab}
SE±			**0.15**	**0.15**

Means following identical columns with the same letter (s) do not substantially differ from one another. These are standard errors of the means. Each indicates the deviation of the values of the observations in different replications.

were found at 0/75 and 0/0 of N or P kg/ha applications, respectively [48].

3.4. Nitrogen and Phosphorus Uptake by Shoot, Root, and Whole Plant. Nitrogen and phosphorus have a strong main effect on the uptake of N by the shoots of orange-fleshed sweet potatoes (Table 5). However, the varieties and all interaction effects (two-way or three-way) were not significant. The result showed that treatment of 46 kg·N·ha^{-1} increased nitrogen taken up of shoot and however statistically did not different in N uptake of shoot from 23 kg·N·ha^{-1} application. The outcome demonstrated that the applied 46 kg·P_2O_5·ha^{-1} was effective in improving the N uptake of shoot by 6.4% as related to the 0 kg·P_2O_5·ha^{-1}. The results agreed with Yitages [48] who found that increasing the treatment of N from 0 to 90 kg·ha^{-1} significantly improved the shoot N uptake from 320.20 to 462.59 g shoot^{-1}. Increasing N application causes an increase in N uptake because N application causes excessive aerial part growth, which in turn causes an increase in leaves' and stems' dry weight due to higher N uptake [61].

The main effects of variety, N, and P considerably influenced the N uptake of orange-fleshed sweet potato root and whole plant. For the varieties response, NASPOT-12 had greater N uptake than Kulfo, Kabode, Alamura, and Dilla (Table 5). Treatment of N and P had an impact on N uptake as well. Treatment of 23 kg·N·ha^{-1} resulted in 9.6% and 7.4% N absorption of root and whole plant, respectively, over the control. P application improved N uptake of orange-fleshed sweet potato root and whole plant (Table 5). This finding is confirmed by Zabihi-e-Mahmoodabad et al. [61] and Haase et al. [62], and the authors showed that tuber N has taken up raised by increasing N treatment. Depending on the degree of N and potato cultivars, Banerjee et al. [55] discovered the same whole N (foliage and tuber) taken up greater than 2-3 times. The quantity of nutrients absorbed by means of a potato plant is directly connected to production, according to a similar finding recorded by Haifa [56].

3.5. Phosphorus Uptake by Shoot, Root and Whole. The uptake of P in orange-fleshed sweet potato shoots showed variation among varieties, N and P application (Table 5).

Table 5: Effect of variety, nitrogen (N), and phosphorus (P) application on N and P uptake of orange-fleshed sweet potato grown in Hawassa in 2019 and 2020 cropping seasons.

	N ($kg{\cdot}ha^{-1}$) uptake			P ($kg{\cdot}ha^{-1}$) uptake		
	Shoot	Root	Total	Shoot	Root	Total
Variety						
Kulfo	16.65^{a}	96.08^{b}	112.73^{bc}	19.62^{ab}	118.68^{bc}	138.30^{bc}
Kabode	15.19^{a}	96.26^{b}	111.46^{c}	22.19^{ab}	136.53^{bc}	158.73^{b}
Alamura	20.45^{a}	102.08^{b}	122.52^{b}	26.82^{a}	140.53^{b}	167.34^{b}
Dilla	19.97^{a}	86.91^{c}	106.88^{c}	19.19^{b}	72.36^{c}	91.55^{c}
NASPOT-12	15.26^{a}	135.41^{a}	150.67^{a}	23.58^{ab}	238.67^{a}	262.25^{a}
SE±	**3.75**	**7.46**	**9.79**	**5.43**	**22.95**	**26.14**
N ($kg\ ha^{-1}$)						
0	16.87^{b}	98.18^{b}	115.84^{b}	18.84^{b}	122.70^{a}	141.53^{b}
23	17.66^{a}	107.56^{a}	124.42^{a}	23.43^{ab}	143.52^{a}	166.95^{ab}
46	17.99^{a}	104.31^{a}	122.30^{a}	24.57^{a}	157.85^{a}	182.41^{a}
SE±	**3.54**	**7.33**	**9.67**	**5.29**	**20.92**	**24.99**
P_2O_5 ($kg\ ha^{-1}$)						
0	17.45^{b}	100.16^{b}	117.62^{b}	19.36^{b}	129.91^{b}	149.26^{b}
46	18.56^{a}	106.53^{a}	124.09^{a}	25.19^{a}	152.80^{a}	178.00^{a}
SE±	**3.37**	**7.29**	**9.60**	**5.22**	**19.21**	**24.39**

Means following identical columns with the same letter (s) do not substantially differ from one another. These are standard errors of the means. Each indicates the deviation of the values of the observations in different replications.

Shoot P uptake among Alamura, Kabode, Kulfo, and NASPOT-12 was similar (Table 5). All varieties varsities mentioned above showed higher shoot P uptake than Dilla varieties. Application of N (23 or 46 $kg{\cdot}N{\cdot}ha^{-1}$) results in greater shoot P uptake as compared to the control treatment (Table 5). The outcome demonstrated the applied 46 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$ was effective in improving the P uptake of orange-fleshed sweet potato shoots by 30% than the control. A similar finding was reported by Yitages [48] who indicated that increasing the main effect of P from 0 to 75 $kg{\cdot}ha^{-1}$ was found to be highly significant in increasing P uptake of shoot from 1.81 to 2.93 g $shoot^{-1}$.

Varieties and P had a significant effect on the P uptake of sweet potato root, whereas the influence of N was not significant (Table 5). NASPOT-12 variety showed the best P uptake by the root. Applied 46 $kg{\cdot}P_2O_5$ fertilizer resulted in better P uptake than the control. Varieties, N and P considerably influenced P uptake of the whole plant (Table 5). The highest whole plant P uptake was observed from NASPOT-12 as compared to the other varieties considered. Dilla variety had lower P uptake than other varieties for the whole plant P uptake. N and P application in particular increased whole plant P uptake of sweet potato (Table 5). The source of P as of the alterations and/or the differences in the varieties was shown in the reports to be the cause of the variations in P uptakes [56–58].

3.6. Agronomic Efficiency of Nitrogen and Phosphorus. The result showed significant differences in the agronomic efficiency in response to the interaction effect of variety, N, and P fertilizers. The highest agronomic efficiency was observed on NASPOT-12 when subjected to 23 $kg{\cdot}N{\cdot}ha^{-1}$ and 46 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$ (Table 6). The current study demonstrated that N application at 23 $kg{\cdot}N{\cdot}ha^{-1}$ and P application with 46 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$ were beneficial in improving the agronomic efficiency by more than eight-fold as compared to 46 $kg{\cdot}N{\cdot}ha^{-1}$ and 0 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$ (Table 6) for NASPOT-12 variety. Another report that demonstrated an interaction between fertilizer and variety revealed that the variety Kasinia treated with Farm Yard Manure (7500 kg/ha) had maximum agronomic effectiveness of 228.46 Masibuka [63]. According to Banerjee et al. [55], agronomic efficiency was not affected by higher levels of fertilizers as compared to lower levels. This is due to the fact that the input-output relationship follows the law of diminishing returns when it comes to the relationship between N and yield, [64]. In this regard, the efficiency of the variety to use the nutrient and the economical application of N fertilizers are critically important. Excess application wastes fertilizers without the benefit of the plant. The current result demonstrated the requirement of selecting genotypes that are more efficient in the use of nutrients for economical yield [65]. Additionally, the balance between the doses and the utilization capacity of the crops should be maintained. Such practice can reduce cost and environmental pollution while attaining maximum benefit from the fertilizers.

3.7. Physiological Efficiency of Nitrogen and Phosphorus. Variety by N and P treatment significantly ($P < 0.05$) influenced the physiological efficiency of orange-fleshed sweet potato (Table 7). Varieties Dilla and NASPOT-12 performed poorly at higher N combined with no P fertilizer (Table 7). NASPOT-12 increased physiological efficiency more than three-fold as compared to the Alamura variety. Application of combined 23 $kg{\cdot}N{\cdot}ha^{-1}$ and 46 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$ fertilizer improved mean physiological efficiency more than 100% comparable with 46 $kg{\cdot}N{\cdot}ha^{-1}$ and 0 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$. Physiological efficiency was reduced on NASPOT-12 at higher N but with no P fertilizer (N 46 $kg{\cdot}N{\cdot}ha^{-1}$ with 0 $kg{\cdot}P_2O_5{\cdot}ha^{-1}$). It implies that the supply of N alone at higher rates causes limited uptake of nutrients that influence physiological functions. The efficiency through a crop usage

Table 6: Interaction effect of variety, nitrogen, and phosphorus on agronomic efficiency of orange-fleshed sweet potato in 2019 and 2020 cropping seasons.

		Agronomic efficiency kg·ha^{-1}					
Variety		Kulfo	Kabode	Alamura	Dilla	NASPOT-12	Mean
Fertilizer Nitrogen (kg·ha^{-1})	P_2O_5 (kg·ha^{-1})						
0	0	—	—	—	—	—	
	46	13.59^{jkl}	60.38^{fg}	28.96^{ijk}	32.39^{hij}	176.61^{b}	**62.39**
23	0	102.50^{cd}	56.61^{fgh}	44.46$^{f–i}$	35.06$^{g–j}$	152.42^{b}	**78.21**
	46	116.51^{cd}	91.83^{de}	124.26^{c}	110.08^{cd}	208.30^{a}	**130.19**
46	0	16.61^{jkl}	9.43^{jkl}	20.18$^{i–l}$	12.57^{jkl}	12.89^{kl}	**14.34**
	46	33.53^{hij}	35.22$^{g–j}$	28.94^{ijk}	13.52^{jkl}	70.18^{ef}	**36.28**
Mean		**56.55**	**50.69**	**49.36**	**40.72**	**124.08**	
SE±							**4.86**

Means following identical columns with the same letter (s) do not substantially differ from one another. These are standard errors of the means. Each indicates the deviation of the values of the observations in different replications. However, the means are just to show the differences of each mean from the overall mean.

Table 7: Interaction effect of variety, nitrogen, and phosphorus on physiological efficiency (kg ha^{-1}) of orange-fleshed sweet potato 2019 and 2020 cropping seasons.

		Physiological efficiency (kg·ha^{-1})					
Variety		Kulfo	Kabode	Alamura	Dilla	NASPOT-12	Mean
Fertilizer N (kg·ha^{-1})	P_2O_5 (kg·ha^{-1})						
0	0	—	—	—	—	—	
	46	7766.69^{bc}	15630^{abc}	6653.16^{bc}	13172^{abc}	49929^{ab}	**18,630.17**
23	0	11594^{abc}	6708.42^{abc}	1441.83^{bc}	33367^{abc}	31426^{abc}	**16,907.45**
	46	7241.86^{bc}	5574.00^{bc}	12710^{abc}	29044^{abc}	53665^{a}	**21,646.97**
46	0	17248^{abc}	24113^{abc}	9295.63^{abc}	454.61^{bc}	815.84^{c}	**10,385.42**
	46	15888^{abc}	3531.44^{c}	3027.30^{c}	8101.34^{bc}	26357^{abc}	**11,381.02**
Mean		**11,947.71**	**11,111.34**	**6,625.58**	**16,827.79**	**32,438.56**	**15,790.20**
SE±							

Means following identical columns with the same letter (s) do not substantially differ from one another.

Table 8: Interactions effect of variety, nitrogen, and phosphorus on apparent recovery (%) of orange-fleshed sweet potato 2019 and 2020 cropping seasons.

		Apparent recovery (%)				
Variety		Kulfo	Kabode	Alamura	Dilla	NASPOT-12
Fertilizer N (kg·ha^{-1})	P_2O_5 (kg·ha^{-1})					
0	0	—	—	—	—	—
	46	1.99$^{a–d}$	2.03$^{a–d}$	2.98$^{a–d}$	1.24^{cd}	0.45^{d}
23	0	1.97$^{a–d}$	4.66^{abc}	5.72^{a}	4.69^{ab}	0.67^{d}
	46	0.93^{bcd}	1.71^{bcd}	0.59^{d}	1.24^{cd}	0.45^{d}
46	0	2.23$^{a–d}$	1.89$^{a–d}$	3.21^{abcd}	3.04$^{a–d}$	0.55^{d}
	46	0.67^{d}	0.72^{d}	1.73^{bcd}	1.52^{bcd}	0.31^{d}
SE±						**0.73**

Means following identical columns with the same letter (s) do not substantially differ from one another. This is the standard error of the means. It indicates the deviation of the values of the observations in different replications.

of every single component of N obtained from fertilizer application is known as physiological efficiency. Related research on potatoes by Banerjee et al. [55] revealed that the physiological efficiency reduced at increased N absorption. According to Fageria et al. [66], efficiency in utilizing nutrients to produce a great harvest by little nutrient absorption in a soil is affeted by genotype, nutrient availability and other environmental factors. Physiological and genetic nutrient use efficiencies are complex traits. A better understanding of the physiological behavior of germplasm in relation to nutrient use efficiency is of prime importance for the improvement of nutrient management [67].

3.8. Apparent Recovery of Nitrogen and Phosphorus. The interaction between variety and fertilizers significantly affected the apparent recovery of nutrients (Table 8). Generally, apparent recovery was higher in plots where either N or P was not applied across all varieties (Table 8). This may indicate the need to balance the N and P applications together in order for the plant to use for its growth and development thereby increasing productivity. Variety NASPOT-12 showed the same response for all combinations of treatments and was lower as compared to other varieties for apparent recovery at all treatments of fertilizers. This variety (NASPOT-12) has better variety in nutrient use and uptake efficiency as indicated in the previous results. This suggests that the high apparent recovery is probably due to the inefficiency of the varieties and the effectiveness of the applied fertilizer. The current result is in conformity with Darwish et al. [68], who revealed that lower rates of N considerably increased N recovery as compared to higher N rates. Kadiyala et al. [69], who conducted a field investigation on rice, reported that the apparent N recovery was reduced with higher rates of N treatment.

4. Conclusion

Generally, N and P fertilizer applications would be preferred for orange-fleshed sweet potato production. Varieties showed a wide difference in agronomic use efficiency, nutrient uptake, and physiological use efficiency with respect to nitrogen and phosphorus applications. The choice of the right variety and the correct doses of these fertilizers are crucial for the cultivation efficiency of orange-fleshed sweet potato. Overall, NASPOT-12 with application of $23\,\mathrm{kg{\cdot}N{\cdot}ha^{-1}}$ and $46\,\mathrm{kg{\cdot}P_2O_5{\cdot}ha^{-1}}$ could be recommended for its high nutrient uptake and agronomic and physiological efficiencies.

Data Availability

All the data collected are included in the manuscript.

Disclosure

The work was part of the duty of the researchers.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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