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Responses of Soil Exchangeable properties, Growth and Yield of Orange-Fleshed Sweet Potato (*Ipomoea batatas* (L) Lam) to the application of N, P, and K fertilizer combination rates at Ikwo, Abakaliki Nigeria

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ABSTRACT

This study was carried out on a degraded Ultisol at Teaching and Research Farm, Faculty of Agriculture, Alex Ekwueme Federal University, Ndufu-Alike (AEFUNAI), Abakaliki Ebonyi state during the 2022 and 2023 planting seasons, to assess the responses of soil exchangeable properties, growth and yield of orange-fleshed sweet potato (OFSP) to the application of N, P and K fertilizer rates at Ikwo, Abakaliki Nigeria. The treatments were Nitrogen fertilizer at four levels; 0, 45, 90, and 135 kg/ha; Phosphorus fertilizer at four levels; 0, 15, 30, and 45kg/ha and Potassium fertilizer at four levels; 0, 20, 40, and 60 kg/ha. The experiment was a factorial experiment arranged in a Randomized Complete Block Design (RCBD) with three (3) replications. Growth and yield data were collected on OFSP. Soil samples were collected with a soil auger at a depth of 0 to 20cm at the end of the experiment for soil exchangeable properties determination. All data collected were subjected to ANOVA for a factorial experiment in RCBD at 5% probability level. The results showed that different combined rates of NPK fertilizers significantly ($P < 0.05$) improved soil exchangeable properties and growth and yield parameters of orange-fleshed sweet potato compared to the control in the two years of the experiment. However, the application of N, P and K at the rate of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest number of OFSP leaves, number of branches, vine length, weight of OFSP storage root and total storage root yield in 2022 and 2023.

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INTRODUCTION

Sweet potato is the 6th most valuable crop in the world (CIP, 2018). With an expected yearly output of 4.45 million metric tons, Nigeria ranks second in Sub-Saharan Africa after Malawi and third globally after China and Uganda (FAOSTA, 2021). Sweet potatoes are vital crops for the survival of Nigeria's resource-poor farmers because of their high yield per unit area and time, which increases their ability to reduce poverty and ensure food security (NRCRI, 2009). Essential nutrients such as vitamins, minerals, proteins, and carbohydrates are found in sweet potatoes (Stathers et al., 2005). 25–30% of its store roots are carbohydrates, 2.5–7.5% is protein, Potassium (K) 200–300 mg 100 g-1, iron (Fe) 0.8 mg 100 g-1, and calcium (Ca) 11 mg 100 g-1 and 20-30 mg 100 g-1 of vitamin C in its dry matter (Çalifikan et al., 2007), along with pro-vitamin A, copper, zinc, manganese, and vitamins B2, B6, and E are also from the orange-fleshed sweet potato storage roots (Neela and Fanta 2019). According to Duvernaya et al. (2013), it can also be utilized as starch, natural coloring, and fermented products such as butanol, lactic acid, ethanol, wine, and acetone. In low-income households, orange-fleshed sweet potatoes (OFSP) are receiving a lot of attention as a way to help with frequent health issues linked to vitamin A deficiency. This is because beta-carotene, a precursor to the synthesis of vitamin A, has a significant nutritional value (Ukpabi et al., 2012). Orange-fleshed sweet potato varieties are high in micronutrients, especially β-carotene, which is a precursor to vitamin A, and their consumption helps fight vitamin A deficiency and are also a good source of energy, calcium, iron, vitamins, and some minerals (Low et al., 2009). It also has potent antioxidants that help prevent cancer, along with natural sugar. Stems are utilized as planting material, stored roots are boiled or roasted, and sweet potato leaves are commonly eaten as vegetables (Low et al., 2009).

Orange-fleshed sweet potato production in Nigeria still faces several challenges such as low yield. The average yield of the crop is still in a very low range of 4.0 t/ha compared to the average yield values of 15 to 30 t/ha obtained in other sweet potato-producing countries of the world such as China (Odebode, 2004). High-yielding orange-fleshed sweet potato varieties are sensitive to fertilizers (Nedunchezhiyan et al., 2010). Applying fertilizer is a crucial option that farmers have for increasing production in the majority of soil types. Due to the sweet potato's potential as a cash crop, commercial growers now need fertilizer recommendations to boost root yield. To prevent adverse ecological effects and unfavorable effects on the sustainability of agricultural systems, fertilization must be done sensibly. Additionally, it is economically wasteful to apply fertilizers excessively. Nitrogen (N) is one of the most essential nutrients for sweet potatoes. It is essential to the development, yield, and quality of storage roots primarily because it affects the production and distribution of dry matter (DM) in plants (Okpara et al., 2009; Ukom et al., 2009).

Adequate N supply improves stem development and increases leaf area index, promoting sweet potato plant photosynthesis and carbohydrate and protein synthesis (Okpara et al., 2009; Ukom et al., 2009). Phosphorus (P) is one of the most important soil nutrients after nitrogen, which plants need in large quantities. It is an important element in providing the cellular energy needed for plant biochemical synthesis (Cruz et al., 2016). It is essential for root development and tuber formation (Agri-Farming, 2023). Potassium (K) is also an important nutrient that sweet potatoes require for enzyme activation, carbohydrate formation, and starch conversion, in addition to acting in the transport of photo-assimilates from leaves to organs of storage (Okpara et al., 2009). Thus, K acts positively on storage root size and flavor, improving product quality, and market value (Marschner, 2012) and increasing the carotenoid content of cultivars of orange sweet potato (Okpara et al., 2004).

Soil fertility is one of the main biophysical factors influencing food quantity and quality (Panpatte and Jhala, 2019). According to Bekunda et al. (1997), increased deficiencies of N, P, and other nutrients can be expected as a result of intensive cultivation and unbalanced fertilizer use. Nutrient depletion in soils adversely affects soil quality, reduces crop yield and consequently pose a potential threat to global food security and agricultural sustainability. Restoration of the nutrients can be accomplished by application of fertilizers.

However, some results showed that the application of N, P, and K fertilizers, alone or in combination, can improve soil exchangeable properties, growth and yield of sweet potatoes, but few or no studies have evaluated the responses of soil exchangeable properties, growth and yield of orange-fleshed sweet potatoes (*Ipomoea batatas*). (L) Lam) to the application of N, P, and K fertilizers combinations in Ikwo, Abakaliki Nigeria.

MATERIAL AND METHODS

Experimental site

The field experiments were carried out in 2022 and 2023 planting seasons at the Teaching and Research Farm, Faculty of Agriculture, Alex Ekwueme Federal University, Ndufu-Alike (AEFUNAI), Abakaliki Ebonyi state, located at approximately Latitudes 06˚ 07' 34'' N and 06˚ 07' 40'' N and Longitudes 08˚ 08' 09'' E and 08˚ 08' 14'' E with altitude of 142 m. The climate is mainly humid tropical with a total precipitation of 2168 mm per year, an average annual temperature of about 27 °C, and an annual relative humidity between 60 and 80%. The rainfall regime is bimodal: a long wet season from April to July is interrupted by a brief "August break" followed by another short rainy season from September to October or early November. The dry season lasts from early November to March (AE-FUNAI

Meteorology station, 2020). The soil of the experimental area is a well-drained sandy soil. These are Ultisol and usually strongly weathered acidic soil with low cation exchange capacity, low base saturation, low organic matter content, and low total nitrogen content (Federal Department of Agriculture and Soil Resources, 1985).

Experimental layout

A total area of land of 2,726m^2 (58m by 47m) was used for the experiment in 2022 and 2023. The field was mechanically cleared, plowed, harrowed, and ridged with a tractor. The ridges were made at 1m intervals in a 3m by 3m plot with a furrow of 0.5 m. The experiment was a factorial experiment laid out in a Randomized Complete Block Design (RCBD) with three (3) replications. Each plot measures 3m by 3m with a furrow of 0.5m separating the plots and 1m separating the replicate from another.

The experimental treatments

The treatments comprised of Nitrogen fertilizer (Urea with 45% N) applied at four levels namely 0, 45, 90, and 135 kg/ha; Phosphorus fertilizer (Triple Super Phosphate with 20% P) applied at four levels namely 0, 15, 30, and 45kg/ha and Potassium fertilizer (Muriate of Potash with 50% K) applied at four levels namely 0, 20, 40, and 60 kg/ha, which were sourced from the Ebonyi state Fertilizer and Chemical company Abakaliki, Ebonyi state. The treatments were combined to give 64 treatment combinations with three (3) replicates.

Planting Material and Treatment Application

The experimental test crop is Orange Flesh Sweet Potato (UMUSPO 3) commonly called Mother Delight which was obtained from The National Root Crop Research Institute, Umudike, Abia state. The treatments were applied 4 weeks after planting the Orange Flesh Sweet Potatoes vines. The vine cuttings of 20cm in length were planted at a spacing of 1m by 0.3m along the crest of the ridge, given a total plant population of 40 plants per plot and 33,333 plants per hectare. Supplying was done two weeks after planting (WAP). Weeding was done manually with a hoe at 6 and 10 weeks after planting (WAP). The ridges were earthed up to avoid exposure to the orange flesh sweet potato roots.

Data Collection

Orange flesh sweet potato growth and data were collected as follows: (a) Vine length was taken at 4, 8, and 12 weeks after treatment application with a measuring tape from the base of the plant vine to the tip of the vine. (b) The number of leaves was taken at 4, 8, and 12 weeks after treatment application by counting (c) The number of branches was taken at 4, 8, and 12 weeks after treatment application by counting (d) The weight of storage root/plot (kg/plot) at harvest were taken with a scale, and (f) Total storage root yield (t/ha) at harvest were taken with a scale.

Soil Sample Collection and Analysis

A composite soil sample was collected prior to treatment application for the characterization of the experimental site. Soil samples were collected using a soil auger at a depth of 0 to 20 cm at the end of the experiment for chemical analysis. The soil samples were air-dried at room temperature and sieved through a 2mm sieve. The following soil exchangeable properties were determined: Exchangeable cations such as K+, $Ca^{2+,}$ $Mg^{2+,}$ and Na+ were analyzed according to the method of Summer and Miller (1996); Exchangeable Acidity was determined following the method of McLean (1965); Effective Cation Exchange Capacity (ECEC) was calculated as follows: Cation Exchange Capacity. CEC = K + Ca + Na + Mg + EA, and Percent Base Saturation (%BS) was computed using this formula: %BS = $\underline{TEB}$ × 100

Data Analysis

All collected data were subjected to Analysis of variance (ANOVA) for a factorial experiment in Randomized Complete Block Design (RCBD) using GenStat statistical package 17th Edition (GenStat, 2014), and Fisher's Least Significant Different (FLSD) was used to separate the treatment means at 5% probability level.

RESULTS AND DISCUSSION

Physico-Chemical Properties of the Soil Used For the Experiment

Table 1. Some physico-chemical properties of the soil before treatment application

Soil Properties	2022	2023
Sand (%)	59.60	60.00
Silt (%)	20.10	20.00
Clay (%)	20.30	20.00
Textural class	Sandy-loam	Sandy loam
Soil pH (water)	5.92	5.97
Soil pH ($CaCl_2$)	5.08	5.22
Organic carbon (%)	0.69	0.72
Organic matter (%)	1.18	1.24
Total nitrogen (%)	0.16	0.18
C: N ratio	4.31	4.0
Available phosphorus (mg kg^{-1})	28.20	28.30
Ca^{2+} ($cmol^{-1}$ kg^{-1})	1.65	1.7
Mg^{2+} ($cmol^{-1}$ kg^{-1})	0.88	0.92
K^{+} ($cmol^{-1}$ kg^{-1})	0.112	0.124
Na^{+} ($cmol^{-1}$ kg^{-1})	0.225	0.251
Total Exchangeable bases (TEB) ($cmol^{-1}$ kg^{-1})	2.867	2.995
Exchangeable acidity ($cmol^{-1}$ kg^{-1})	2.64	2.38
Effective cation exchange capacity (ECEC) ($cmol^{-1}$ kg^{-1})	5.507	5.375
Percentage base saturation (%)	52.06	55.72

The experimental soil properties showed that the soil is sandy loam, slightly acidic, and poor in organic carbon, nitrogen, available phosphorus, and exchangeable bases as shown in Table 1. This implies that the fertility of the soil is low.

Growth Responses Of Orange-Fleshed Sweet Potato (OFSP) To The Application Of N, P, And K Fertilizer Combinations

Effect of NPK fertilizer on the Number of leaves at 4, 8, and 12 weeks after treatment application (WATA) in 2022 and 2023 planting season

The effect of NPK fertilizer on the number of OFSP leaves at 4, 8, and 12 WATA in the 2022 and 2023 planting seasons is shown in Tables 2, 3, and 4. The various rates of NPK fertilizer applied significantly ($P < 0.05$) recorded a higher number of OFSP leaves over control at 4, 8, and 12 WATA in the 2022 and 2023 planting seasons. The application of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest number of OFSP leaves at 4 WATA (192.3 and 184.3), 8 WATA (292.3 and 315.0) and 12 WATA (374.3 and 388.0) in 2022 and 2023 respectively.

The increased number of OFSP leaves might be a result that N aids in the development of leaf tissues and cell multiplication, P plays a critical role in leaf initiation and K increases photosynthetic activity in OFSP plants. The observed significant positive performance in the number of OFSP leaves with the application of NPK fertilizer could also be a result of the rapid release of essential nutrient elements supplied, which resulted in increased photosynthetic efficiency.

Similar findings were found by Sowley et al. (2015) who stated that fertilizers increase the number of sweet potato leaves with an increased level of fertilization; Nmor and Okobia (2017), who claimed that the amount of available phosphorous, potassium, and nitrogen in the soil determines crop yield and the effectiveness of mineral fertilization; Dennis (2018) reported that NPK blended fertilizer may have affected both the chemical and microbial transformation of soil nutrient elements, enhancing the metabolism activity of the plants and this increased rate of growth; El-Hlamy (2011) reported a significant increase in the number of leaves of OFSP with mineral fertilizer application, and Olatunji and Adeyongu (2021) also noted that a sufficient supply of nutrients to plants boosts vegetative growth and yield.

Also, application of fertilizer beyond the rate of 90kgN-45kgP_2O_5-60kgK_2O showed a reduction in the number of OFSP leaves at 4, 8, and 12 WATA in both the 2022 and 2023 planting seasons. This might be due to the quantity of fertilizer applied being beyond the optimum level resulting in toxicity in the plant, thereby decreasing OFSP foliage production. This aligned with the report of Havlin et al. (2005) who found that when plant nutrients are applied above the optimum level, the plants absorb more of the nutrients than they require for growth and development. This can lead to toxicity in the plants, which may result in decreased growth or even plant death.

Table 2. Effect of NPK fertilizer on number of leaves at 4 WATA in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	15.3	30.3	32.3	37.3	28.8	32.0	43.0	47.0	52.0	43.4
	15	46.3	46.0	65.3	69.0	53.8	55.0	56.0	59.0	63.0	58.2
	30	72.0	74.7	75.7	78.0	72.6	67.0	75.0	79.0	82.0	75.7
	45	82.0	88.0	92.0	96.7	89.6	86.0	89.0	96.0	98.0	92.2
45	0	102.1	105.0	105.3	106.3	104.5	109.5	111.0	115.0	119.0	113.9
	15	105.7	108.0	109.0	111.0	108.4	120.0	123.0	126.0	128.0	124.2
	30	115.7	117.7	116.7	117.0	116.7	129.0	128.0	131.0	132.0	130.0
	45	124.3	124.0	128.0	134.0	127.6	131.0	134.0	135.0	138.0	134.5
90	0	137.0	137.0	147.0	147.0	142.0	141.0	143.0	148.0	149.0	145.2
	15	151.0	166.0	172.0	179.0	164.1	153.0	158.0	163.0	166.0	160.0
	30	178.7	185.3	187.0	189.0	185.0	169.0	173.0	175.0	179.0	174.0
	45	191.3	191.3	191.3	192.3	191.3	181.0	182.0	184.0	184.3	182.7
135	0	148.0	139.7	146.0	169.3	150.8	132.0	136.0	139.0	141.0	137.0
	15	148.0	148.0	152.3	149.0	149.3	145.7	146.3	149.0	152.0	148.2
	30	157.3	152.0	159.7	168.3	159.4	154.0	157.0	159.0	162.0	158.0
	45	150.0	172.3	160.0	173.7	163.9	164.0	167.0	168.0	173.0	168.0
Mean		120.0	124.1	126.6	131.7		123.1	126.7	129.6	132.4	
LSD (0.05) for N = 2.715							LSD (0.05) for N = 0.2038				
LSD (0.05) for P = 2.715							LSD (0.05) for P = 0.2038				
LSD (0.05) for K = 2.715							LSD (0.05) for K = 0.2038				
LSD (0.05) for N*P = 5.431							LSD (0.05) for N*P = 0.4076				
LSD (0.05) for N*K = 5.431							LSD (0.05) for N*K = 0.4076				
LSD (0.05) for P*K = 5.431							LSD (0.05) for P*K = 0.4076				
LSD (0.05) for N*P*K = 10.87							LSD (0.05) for N*P*K = 0.8160				

Table 3. Effect of NPK fertilizer on number of leaves at 8 WATA in 2022 and 2023 planting seasons

K (kg/ha)		**0**	**20**	**40**	**60**	**Mean**	**0**	**20**	**40**	**60**	**Mean**
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	60.3	83.3	88.3	93.7	81.3	68.7	87.0	91.0	97.7	86.0
	15	97.0	101.0	104.7	109.0	102.9	102.3	104.3	108.3	113.0	107.0
	30	112.7	119.0	121.3	123.3	119.1	117.0	117.0	123.0	125.0	120.5
	45	126.7	129.7	133.7	136.0	131.5	132.0	136.0	138.0	148.0	138.5
45	0	169.8	174.5	179.3	181.7	176.5	189.1	192.0	197.0	199.0	194.5
	15	189.0	192.0	195.3	201.3	194.4	210.0	218.0	224.0	232.0	221.0
	30	204.3	209.3	213.7	220.3	211.9	236.0	238.0	242.0	245.0	240.2
	45	224.3	227.7	233.0	236.0	230.2	248.0	250.0	256.0	257.0	252.7
90	0	243.7	248.0	251.0	256.7	249.8	259.0	263.0	265.0	278.0	266.2
	15	260.7	262.0	266.3	268.0	264.2	282.0	285.0	288.0	290.0	286.2
	30	272.7	276.0	279.0	281.7	277.3	295.0	297.0	302.0	306.0	300.0
	45	284.7	288.0	289.7	292.3	288.6	309.0	312.0	313.0	315.0	312.2
135	0	230.3	232.3	237.3	241.0	235.2	238.0	243.0	246.0	247.0	243.5
	15	248.3	251.3	253.3	257.7	252.7	250.0	251.0	254.0	257.0	253.0
	30	256.0	266.3	270.3	275.0	266.9	259.0	267.0	272.0	276.0	268.5
	45	278.7	278.3	281.0	283.3	280.3	282.0	285.0	287.0	290.0	286.0
Mean		203.7	209.6	212.3	216.1		217.3	222.2	225.4	229.7	
LSD (0.05) for N = 3.805							LSD (0.05) for N = 1.011				
LSD (0.05) for P = 3.805							LSD (0.05) for P = 1.011				
LSD (0.05) for K = 3.805							LSD (0.05) for K = 1.011				
LSD (0.05) for N*P =7.612							LSD (0.05) for N*P = 2.022				
LSD (0.05) for N*K =7.612							LSD (0.05) for N*K = 2.022				
LSD (0.05) for P*K = 7.612							LSD (0.05) for P*K = 2.022				
LSD (0.05) for N*P*K =15.24							LSD (0.05) for N*P*K = 4.044				

Table 4. Effect of NPK fertilizer on number of leaves at 12 WATA in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	P (kg/ha)	2022 planting season					2023 planting season				
0	0	73.7	88.3	93.0	98.3	88.3	86.0	94.0	101.0	104.0	96.2
	15	104.7	107.7	110.7	114.0	109.2	109.0	113.0	114.0	117.0	113.2
	30	117.7	124.7	129.3	135.7	126.8	119.0	126.0	137.0	142.0	131.0
	45	138.7	143.7	148.3	157.3	147.0	148.0	156.0	159.0	168.0	157.7
45	0	201.0	209.0	214.0	219.7	211.2	225.2	232.0	238.0	242.0	234.5
	15	225.3	229.7	236.3	241.7	233.2	245.0	248.0	251.0	256.0	250.0
	30	249.7	254.0	257.7	259.7	255.2	259.0	272.0	278.0	283.0	272.9
	45	266.7	278.3	282.3	287.7	278.7	287.0	291.0	296.0	299.0	293.2
90	0	291.7	296.3	313.0	318.3	304.8	304.0	312.0	323.0	327.0	316.5
	15	321.7	326.3	329.7	331.3	327.2	332.0	336.0	339.0	346.0	338.2
	30	335.3	342.3	347.7	354.7	345.0	348.0	354.0	358.0	367.0	356.7
	45	358.3	366.3	370.7	374.3	367.5	371.0	376.0	382.0	388.0	379.2
135	0	277.7	281.3	288.3	291.7	284.7	306.0	310.0	315.0	322.0	313.2
	15	296.0	298.0	301.3	303.7	299.7	327.0	328.0	335.0	338.0	332.0
	30	307.3	310.7	315.7	317.7	312.8	342.0	347.0	352.0	359.0	350.0
	45	319.7	322.0	326.3	329.7	324.4	363.0	368.0	373.0	379.0	370.7
Mean		242.8	249.5	254.1	258.5		260.7	267.2	271.9	277.3	
LSD (0.05) for N = 0. 0.5098							LSD (0.05) for N = 0.3061				
LSD (0.05) for P = 0.5098							LSD (0.05) for P = 0.3061				
LSD (0.05) for K = 0.5098							LSD (0.05) for K = 0.3061				
LSD (0.05) for N*P =1.019							LSD (0.05) for N*P = 0.6122				
LSD (0.05) for N*K =1.019							LSD (0.05) for N*K = 0.6122				
LSD (0.05) for P*K = 1.019							LSD (0.05) for P*K = 0.6122				
LSD (0.05) for N*P*K = 2.041							LSD (0.05) for N*P*K = 1.2244				

Effect of NPK fertilizer on the Number of branches at 4, 8, and 12 weeks after treatment application (WATA) in 2022 and 2023 planting season

The effect of NPK fertilizer on the number of OFSP branches at 4, 8, and 12 WATA in the 2022 and 2023 planting seasons is shown in Tables 5, 6, and 7. The various rates of NPK fertilizer applied significantly ($P < 0.05$) recorded a higher number of OFSP branches over control at 4, 8, and 12 WATA in both the 2022 and 2023 planting seasons. The application of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest number of OFSP branches at 4 WATA (11.333 and 14), 8 WATA (17.33 and 19) and 12 WATA (19 and 20.33) in 2022 and 2023 respectively.

The numerical growth of OFSP branches could be due to the improved metabolic processes due to the optimal nutrients provided by NPK fertilizers. The increase in the number of branches of OFSP may also be due to the adequate supply of N, P, and K which promotes higher photosynthetic activity, vigorous vegetative growth, and chances of emergence of new vines. The increased number of OFSP branches in response to the application of NPK fertilizers can be attributed to an increased concentration of nutrients in the soil, which could have increased the uptake of nutrients by the roots, which could have resulted in a greater concentration of the chlorophyll in the leaves, the higher the rate of photosynthesis, a high rate of leaf expansion, increase in the number of leaves, increase in the number of branches and accumulation of dry matter.

Similar results were obtained from Zalalem et al. (2023) who reported an increase in the number of OFSP branches from the higher application of NPSB blended fertilizer and varieties of sweet potato; Getachew (2019) reported a higher photosynthetic activity and vigorous plant growth and development due to the application of adequate NPK fertilizer; Rijal et al. (2023) reported an increase in the number of sweet potato branches with the application of Different Fertilizers in the Eastern Midhill of Nepal; Thomas et al. (2023) observed an increase in the number of branches with 400 kg/ha NPK 15:15:15 fertilizer in Obio Akpa; and Uwah et al. (2013) who reported an increase in the number of OFSP branches with different rates of potassium fertilizer in Calabar, Nigeria.

Table 5. Effect of NPK fertilizer on number of branches at 4 WATA in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	2.667	5.000	6.000	6.000	4.905	3.33	5.67	7.00	7.67	5.90
	15	6.667	6.667	6.667	7.667	6.917	8.33	8.33	8.67	8.67	8.50
	30	6.667	7.667	7.333	7.333	7.245	9.00	9.33	9.00	9.33	9.16
	45	7.333	6.667	8.000	7.667	7.420	9.67	9.67	10.00	10.00	9.83
45	0	7.999	8.000	8.000	8.333	8.090	10.50	11.00	11.33	11.33	11.04
	15	9.000	9.000	9.000	9.000	9.000	11.67	11.67	11.67	11.67	11.67
	30	8.667	8.667	9.000	9.000	8.833	11.67	12.00	12.33	12.33	12.08
	45	9.667	10.000	10.000	10.000	9.915	12.67	12.67	12.67	12.67	12.67
90	0	10.000	10.333	10.333	11.000	10.415	12.67	12.67	12.67	13.00	12.75
	15	11.000	11.000	11.000	11.000	11.000	13.00	13.33	13.67	13.67	13.41
	30	11.333	11.333	11.333	11.333	11.333	13.67	13.67	13.67	13.67	13.67
	45	11.333	11.333	11.333	11.333	11.333	13.67	13.67	13.67	14.00	13.75
135	0	10.667	10.000	10.000	10.333	10.253	13.67	12.00	10.67	10.67	11.76
	15	11.000	11.000	11.000	11.000	11.000	11.00	11.33	11.67	11.67	11.41
	30	11.000	11.000	11.000	11.000	11.000	11.67	11.67	11.67	11.67	11.67
	45	11.000	11.000	11.000	11.000	11.000	11.67	11.67	12.00	12.33	11.92
Mean		9.125	9.319	9.500	9.500		11.11	11.36	11.40	11.50	
LSD (0.05) for N =0.1788							LSD (0.05) for N = 0.3642				
LSD (0.05) for P =0.1788							LSD (0.05) for P = 0.3642				
LSD (0.05) for K =0.1788							LSD (0.05) for K = 0.3642				
LSD (0.05) for N*P = 0.3576							LSD (0.05) for N*P = 0.7284				
LSD (0.05) for N*K = 0.3576							LSD (0.05) for N*K =0.7284				
LSD (0.05) for P*K = 0.3576							LSD (0.05) for P*K = 0.7284				
LSD (0.05) for N*P*K = 0.7160							LSD (0.05) for N*P*K = 1.458				

Also, the application of fertilizer beyond the rate of 90kgN-45kgP_2O_5-60kgK_2O showed a reduction in the number of OFSP branches at 4, 8, and 12 WATA in both the 2022 and 2023 planting seasons. This might be due to the quantity of fertilizer applied being beyond the optimum level resulting in toxicity in the plant, thereby decreasing OFSP number of branches. This is consistent with Havlin et al., (2005) who found that when plant nutrients are applied above the optimum level, the plants absorb more of the nutrients than they require for growth and development. This can lead to toxicity in the plants, which may result in decreased growth or even plant death.

Table 6. Effect of NPK fertilizer on number of branches at 8 WATA in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	**P (kg/ha)**	2022 planting season					2023 planting season				
0	0	4.33	8.67	8.67	8.67	7.56	5.00	9.00	9.00	10.00	8.23
	15	8.67	8.67	9.33	9.67	9.08	10.00	10.00	10.00	10.00	10.00
	30	9.67	10.33	10.33	10.33	10.16	10.00	12.00	12.00	13.00	11.74
	45	10.33	10.67	10.67	10.67	10.58	13.00	13.00	13.00	13.00	13.00
45	0	12.02	12.00	12.33	12.33	12.19	13.00	13.00	13.00	14.00	13.27
	15	12.33	13.00	13.00	13.00	12.83	14.00	14.00	14.00	15.00	14.25
	30	13.00	13.67	13.67	14.00	13.58	15.00	15.00	15.00	15.00	15.00
	45	14.00	14.00	14.00	14.00	14.00	15.00	16.00	16.00	16.00	15.74
90	0	14.00	14.67	15.33	14.67	14.66	16.00	16.00	16.00	16.00	16.00
	15	14.67	15.33	15.67	16.33	15.50	16.00	16.00	16.00	17.00	16.25
	30	17.00	16.67	17.00	17.00	17.08	17.00	18.00	18.00	18.00	17.74
	45	17.00	17.00	17.00	17.33	17.08	18.00	18.00	18.00	19.00	18.25
135	0	13.67	13.67	14.00	14.67	14.00	15.00	15.00	15.00	15.00	15.00
	15	14.67	14.67	14.67	14.33	14.58	16.00	16.00	16.00	17.00	16.25
	30	14.33	14.67	15.00	15.00	14.75	17.00	17.00	17.00	17.00	17.00
	45	14.33	14.33	15.00	15.00	14.67	17.00	17.00	17.00	17.00	17.00
Mean		12.10	13.00	13.89	14.08		14.19	14.79	14.75	15.12	

LSD (0.05) for N =0.2901	LSD (0.05) for N = 0.3102
LSD (0.05) for P =0.2901	LSD (0.05) for P = 0.3102
LSD (0.05) for K =0.2901	LSD (0.05) for K = 0.3102
LSD (0.05) for N*P = 0.5801	LSD (0.05) for N*P = 0.6204
LSD (0.05) for N*K = 0.5801	LSD (0.05) for N*K = 0.6204
LSD (0.05) for P*K = 0.5801	LSD (0.05) for P*K = 0.6204
LSD (0.05) for N*P*K =1.161	LSD (0.05) for N*P*K = 1.2408

Table 7. Effect of NPK fertilizer on number of branches at 12 WATA in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	P (kg/ha)	2022 planting season					2023 planting season				
0	0	6.33	12.00	12.00	12.33	10.64	6.33	12.00	12.00	12.33	10.64
	15	12.67	13.00	12.33	13.33	12.83	14.33	14.33	14.33	14.67	14.42
	30	13.33	14.00	14.33	14.33	14.00	14.67	14.67	15.00	15.67	15.00
	45	14.33	14.33	14.33	14.33	14.33	15.67	15.67	15.67	15.67	15.67
45	0	14.29	15.00	15.00	15.00	14.80	15.56	16.00	16.33	16.33	16.00
	15	16.00	16.33	16.33	17.00	16.67	17.00	17.00	17.00	17.67	17.17
	30	17.00	17.00	17.00	17.00	17.00	17.67	17.67	17.67	18.33	17.83
	45	17.33	17.33	17.33	17.33	17.33	18.67	18.67	18.67	18.67	18.67
90	0	17.67	17.67	17.67	17.67	17.67	19.00	19.00	19.00	19.00	19.00
	15	17.67	17.67	18.67	18.67	18.17	19.00	19.67	20.00	20.00	19.66
	30	18.87	18.67	18.67	18.67	18.75	20.00	20.00	20.00	20.00	20.00
	45	18.67	18.67	18.67	19.00	18.67	20.00	20.00	20.00	20.33	20.08
135	0	15.67	15.67	16.00	15.67	15.75	17.00	17.00	17.33	17.00	17.08
	15	16.00	16.00	16.33	16.33	16.17	17.33	16.67	17.00	17.00	17.00
	30	16.33	16.67	16.67	17.33	16.75	17.00	17.33	18.00	18.00	17.58
	45	17.33	17.67	17.00	17.33	17.33	18.00	18.33	18.00	18.00	18.08
Mean		15.64	16.15	16.15	16.31		16.70	17.21	17.21	17.20	
LSD (0.05) for N = 0.2186							LSD (0.05) for N = 0.2244				
LSD (0.05) for P = 0.2186							LSD (0.05) for P = 0.2244				
LSD (0.05) for K = 0.2186							LSD (0.05) for K = 0.2244				
LSD (0.05) for N*P =0.4372							LSD (0.05) for N*P = 0.4488				
LSD (0.05) for N*K =0.4372							LSD (0.05) for N*K = 0.4488				
LSD (0.05) for P*K = 0.4372							LSD (0.05) for P*K = 0.4488				
LSD (0.05) for N*P*K = 0.8752							LSD (0.05) for N*P*K = 0.8983				

Effect of NPK fertilizer on vine length at 4, 8, and 12 weeks after treatment application (WATA) in 2022 and 2023 planting season

The effect of NPK fertilizer on the vine length of OFSP at 4, 8, and 12 WATA in the 2022 and 2023 planting seasons is shown in Tables 8, 9, and 10. The various combined rates of NPK fertilizer applied significantly ($P < 0.05$) recorded higher vine length of OFSP over control in both the 2022 and 2023 planting seasons. The application of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest vine length of OFSP at 4 WATA (128.7cm and 126.7cm), 8 WATA (319.3cm and 337.7cm) and 12 WATA (457.0cm and 444.7cm) in 2022 and 2023 respectively.

The increase in the vine length of the OFSP could be due to an adequate supply of N, P, and K from the applied fertilizers, which resulted in high photosynthetic activity and vigorous vegetative growth, thus increasing the length of the internode. In addition, the greater vine length observed may be due to the application of adequate amounts of N, P, and K, which resulted in better vegetative growth, greater photosynthetic assimilation, photosynthetic activation, and metabolic processes of organic compounds in plants for the production of increasing the length of the vine. The increase in the duration of the pine vines may be due to the increase in cell division and elongation, which resulted in greater canopy development and a better utilization of NPK fertilizers applied.

Similar findings were reported by Bekele et al. (2020), who found that the application of chemical fertilizer types and rates on Ethiopian potato yield and quality resulted in improved plant cellular growth and development; Singh and Rangav (2020) who reported a notable increase in plant height due to increased NPK fertilizer; Thomaset al., (2023) observed an increase in OFSP vine length with 400 kg/ha NPK 15:15:15 fertilizer in Obio Akpa; and Rijal et al. (2023) that reported increased vine length of sweet potato due to the fast release of nutrients by the applied NPK fertilizers in the Eastern Midhill of Nepal.

Table 8: Effect of NPK fertilizer on vine length (cm) at 4 WATA in 2022 and 2023 planting seasons

K (kg/ha)		**0**	**20**	**40**	**60**	**Mean**	**0**	**20**	**40**	**60**	**Mean**
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	24.0	37.3	41.3	53.3	38.9	67.0	74.7	79.3	82.7	75.9
	15	52.0	55.3	57.3	60.3	56.2	82.7	86.7	88.7	88.7	86.6
	30	61.3	66.3	64.7	72.0	66.1	91.7	93.7	95.7	99.7	95.2
	45	71.3	71.7	77.3	84.7	76.2	101.7	106.0	106.7	110.7	106.2
45	0	101.1	104.0	105.0	107.0	104.3	121.9	125.0	126.7	128.7	125.6
	15	107.0	106.7	104.0	102.7	105.1	130.7	134.7	135.0	139.7	135.0
	30	106.3	111.7	117.3	115.3	112.6	142.3	148.0	153.0	158.0	150.3
	45	117.3	118.7	117.3	120.7	118.5	162.3	164.3	168.0	169.3	166.0
90	0	123.3	124.0	125.0	125.7	124.5	173.3	174.7	175.7	179.3	175.7
	15	125.0	125.7	126.7	127.0	126.1	182.3	183.7	188.0	193.0	186.7
	30	125.7	126.0	126.0	127.3	126.2	197.3	199.0	203.3	206.3	201.5
	45	126.3	127.0	128.0	128.7	127.5	208.0	210.7	213.7	216.7	212.2
135	0	126.3	124.0	125.7	124.7	125.2	172.0	174.7	176.7	179.7	175.7
	15	124.3	127.0	125.0	124.0	125.1	183.3	184.0	187.3	189.0	185.9
	30	126.3	126.3	125.3	126.0	126.0	191.7	194.7	197.7	200.0	196.0
	45	126.7	126.0	126.3	126.7	126.4	202.7	172.7	208.3	212.0	199.1
Mean		102.8	104.9	105.8	107.9		150.7	152.3	156.5	159.6	
LSD (0.05) for N = 0.7268							LSD (0.05) for N = 3.047				
LSD (0.05) for P = 0.7268							LSD (0.05) for P = 3.047				
LSD (0.05) for K = 0.7268							LSD (0.05) for K = 3.047				
LSD (0.05) for N*P =1.453							LSD (0.05) for N*P = 6.094				
LSD (0.05) for N*K =1.453							LSD (0.05) for N*K = 6.094				
LSD (0.05) for P*K = 1.453							LSD (0.05) for P*K = 6.094				
LSD (0.05) for N*P*K =2.910							LSD (0.05) for N*P*K = 12.20				

Also, application of fertilizer beyond the rate of 90kgN-45kgP_2O_5-60kgK_2O showed a reduction in the vine length of OFSP at 4, 8, and 12 WATA in both the 2022 and 2023 planting seasons. This might be due to the quantity of fertilizer applied being beyond the optimum level resulting in toxicity in the plant, thereby affecting the OFSP vine length. . This is consistent with Havlin *et* al. (2005) who found that when plant nutrients are applied above the optimum level, the plants absorb more of the nutrients than they require for growth and development. This can lead to toxicity in the plants, which may result in decreased growth or even plant death.

Table 9. Effect of NPK fertilizer on vine length at 8 WATA in 2022 and 2023 planting seasons

K (kg/ha)		**0**	**20**	**40**	**60**	**Mean**	**0**	**20**	**40**	**60**	**Mean**
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	68.3	108.7	122.7	126.3	106.3	99.3	144.7	148.0	151.3	135.6
	15	131.7	137.3	139.7	145.7	138.6	160.7	165.0	170.3	174.3	167.6
	30	148.7	150.7	154.3	157.7	152.8	178.3	181.0	183.3	187.3	182.5
	45	163.3	173.3	177.7	182.0	174.0	191.3	194.7	199.0	202.0	196.7
45	0	196.3	201.0	203.7	210.0	202.9	219.1	230.0	225.7	230.0	225.8
	15	214.0	217.3	218.3	223.3	218.2	236.0	241.3	244.3	249.0	242.6
	30	224.7	230.7	239.0	244.0	234.6	252.3	256.3	259.0	262.3	257.5
	45	250.7	253.3	256.7	261.0	255.4	266.7	270.0	273.3	280.3	272.6
90	0	262.7	269.3	274.7	281.3	272.0	284.7	288.0	291.3	295.0	289.7
	15	284.0	286.0	291.7	293.3	288.7	299.0	302.3	307.0	310.7	304.7
	30	294.3	295.7	297.3	299.3	296.7	315.0	319.0	454.7	324.7	353.3
	45	305.7	310.7	316.7	319.3	313.1	329.7	332.0	334.7	337.7	333.5
135	0	263.3	268.0	268.0	270.0	267.3	287.3	289.3	289.3	292.3	289.6
	15	276.7	277.3	284.0	288.0	281.5	295.7	296.3	300.0	302.0	298.5
	30	292.0	296.0	297.0	299.0	311.2	304.7	307.7	310.3	316.0	309.7
	45	304.0	310.0	314.0	317.0	296.0	315.0	316.7	320.7	323.7	319.0
Mean		230.0	237.3	241.0	244.8		252.2	259.0	269.4	264.9	
LSD (0.05) for N = 0.6505							LSD (0.05) for N = 6.098				
LSD (0.05) for P = 0.6505							LSD (0.05) for P = 6.098				
LSD (0.05) for K = 0.6505							LSD (0.05) for K = 6.098				
LSD (0.05) for N*P = 1.301							LSD (0.05) for N*P = 12.19				
LSD (0.05) for N*K = 1.301							LSD (0.05) for N*K = 12.19				
LSD (0.05) for P*K = 1.301							LSD (0.05) for P*K = 12.19				
LSD (0.05) for N*P*K =2.605							LSD (0.05) for N*P*K = 24.42				

Table 10. Effect of NPK fertilizer on vine length at 12 WATA in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	P (kg/ha)	2022 planting season					2023 planting season				
0	0	157.0	209.0	212.6	217.3	198.6	188.0	245.0	250.3	255.3	234.4
	15	222.6	226.6	230.3	234.6	228.5	259.3	262.3	266.3	269.3	264.3
	30	238.3	242.6	248.3	253.6	245.7	271.3	273.7	276.3	278.3	274.9
	45	256.6	260.6	265.6	267.6	262.6	279.0	279.3	280.0	282.0	280.1
45	0	280.3	297.0	295.3	302.3	293.3	301.9	317.0	309.0	313.7	309.7
	15	306.3	316.0	323.0	328.0	318.2	316.7	321.7	331.7	331.7	325.4
	30	335.0	339.6	344.3	349.3	342.0	341.0	344.3	350.3	358.0	348.4
	45	353.3	358.0	361.0	363.6	358.9	360.7	363.7	370.7	373.0	367.0
90	0	367.6	371.3	376.6	381.6	374.3	379.7	384.7	388.7	357.3	377.6
	15	385.6	390.3	393.6	397.0	391.6	393.7	395.7	400.7	404.7	398.7
	30	402.6	406.3	415.6	433.0	414.3	408.7	413.7	418.7	427.7	417.1
	45	438.0	444.3	452.3	457.0	447.8	435.7	438.7	441.7	444.7	440.2
135	0	360.6	363.3	369.0	367.0	365.0	377.7	379.7	382.7	385.7	381.4
	15	377.3	377.0	374.6	382.6	377.9	389.7	390.7	393.7	394.7	392.2
	30	385.3	392.6	397.3	390.3	391.4	398.7	402.7	405.0	409.7	404.0
	45	406.0	434.0	443.0	456.0	432.6	412.3	416.7	423.0	428.0	420.0
Mean		329.1	339.7	343.4	346.2		344.6	352.6	355.5	357.1	

LSD (0.05) for N = 3.385	LSD (0.05) for N = 4.429
LSD (0.05) for P = 3.385	LSD (0.05) for P = 4.429
LSD (0.05) for K = 3.385	LSD (0.05) for K = 4.429
LSD (0.05) for N*P =6.771	LSD (0.05) for N*P = 8.857
LSD (0.05) for N*K =6.771	LSD (0.05) for N*K = 8.857
LSD (0.05) for P*K = 6.771	LSD (0.05) for P*K = 8.857
LSD (0.05) for N*P*K =13.57	LSD (0.05) for N*P*K = 17.73

Ield Responses of Orange-Fleshed Sweet Potato to the Application of N, P, And K Fertilizer Combinations

Effect of NPK fertilizer on the weight of storage root (kg/plot) of Orange Flesh Sweet Potato in 2022 and 2023 planting season

Table 11 shows the effect of NPK fertilizer on the weight of OFSP storage roots in the 2022 and 2023 planting seasons. The various rates of NPK fertilizer applied significantly ($P < 0.05$) recorded higher weight of OFSP storage roots over control in both the 2022 and 2023 planting seasons. The application of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest weight of OFSP storage root in 2022 (3.07kg) and (3.5kg) in 2023. This might be because the applied N enhanced the photosynthetic activity and prolonged the vegetative growth of the OFSP plant, P aids in cell division and promotes root development of OFSP while K helps in the transfer of photo-assimilates, activates enzymes involved in photosynthesis, carbohydrate metabolism and aids in the movement of carbohydrates from leaves to the root, resulting in increased weight of OFSP storage root. It could also be due to the direct access of N, P, and K nutrient elements from the applied fertilizer by OFSP plants.

Adequate N supply improves shoot development, favoring the photosynthetic activity of sweet potato plants and carbohydrate synthesis; P facilitates cell division and encourages root development; and K stimulates the formation, transformation, and movement of photoassimilates from leaves to roots, thus resulting in increased weight of OFSP root.

Similar findings were reported by Israel et al. (2012), who found that the interaction of N, P, and K significantly influenced the root weight of potatoes positively; Singh and Rangav (2020), who reported a significant increase in potato yield due to increased NPK fertilizer; and Bekele et al. (2020), who reported enhanced plant cellular growth and development with the application of chemical fertilizer types and rates on potato yield and quality in Ethiopia.

Table 11. Effect of NPK fertilizer on weight of storage root (kg/plot) of Orange Flesh Sweet Potato in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	P (kg/ha)	2022 planting season					2023 planting season				
0	0	0.867	1.333	1.600	1.700	1.373	1.000	1.600	1.800	2.000	1.597
	15	1.900	1.950	1.950	1.950	1.937	2.500	2.550	2.550	2.550	2.537
	30	1.980	1.987	2.033	2.067	2.017	2.600	2.600	2.700	2.700	2.650
	45	2.067	2.083	2.097	2.097	2.086	2.700	2.750	2.750	2.750	2.737
45	0	2.135	1.800	2.133	2.133	2.074	2.750	2.750	2.800	2.800	2.777
	15	2.167	2.167	2.183	2.217	2.183	2.800	2.800	2.850	2.850	2.825
	30	2.217	2.217	2.217	2.217	2.217	2.850	2.850	2.850	2.850	2.850
	45	2.233	2.300	2.300	2.300	2.283	2.900	2.900	2.900	2.900	2.900
90	0	2.433	2.467	2.467	2.533	2.475	2.900	3.000	3.000	3.000	2.974
	15	2.567	2.700	2.733	2.733	2.683	3.100	3.100	3.200	3.200	3.150
	30	2.867	2.867	2.907	2.917	2.894	3.200	3.220	3.240	3.250	3.227
	45	2.967	3.067	3.067	3.070	3.041	3.300	3.350	3.350	3.500	3.449
135	0	2.433	2.533	2.533	2.533	2.508	3.100	3.200	3.200	3.200	3.174
	15	2.533	2.533	2.633	2.633	2.583	3.200	3.200	3.300	3.300	3.250
	30	2.663	2.683	2.767	2.817	2.732	3.330	3.350	3.400	3.450	3.382
	45	2.817	2.833	2.867	2.867	2.846	3.450	3.500	3.500	3.500	3.487
Mean		2.303	2.358	2.405	2.424		2.855	2.933	2.971	2.987	

2022	2023
LSD (0.05) for N = 0.04719	LSD (0.05) for N = 0.05230
LSD (0.05) for P = 0.04719	LSD (0.05) for P = 0.05230
LSD (0.05) for K = 0.04719	LSD (0.05) for K = 0.05230
LSD (0.05) for N*P = 0.09436	LSD (0.05) for N*P = 0.1460
LSD (0.05) for N*K = 0.09436	LSD (0.05) for N*K = 0.1460
LSD (0.05) for P*K = 0.09436	LSD (0.05) for P*K = 0.1460
LSD (0.05) for N*P*K = 0.1889	LSD (0.05) for N*P*K = 0.2920

The weight of OFSP roots decreased in both the 2022 and 2023 planting seasons when fertilizer was applied at rates higher than 90kgN-45kgP_2O_5-60kgK_2O. This could be as a result of the high N fertilizer treatments inhibiting the storage root development. Similar results were reported by Fernandes and Ribeiro (2020), Ukom *et al.*,(2009), and Ambecha (2011) who reported that excess nitrogen can stimulate increased foliage production at the expense of tubers and may also lead to tuber cracking. This might also be due to the quantity of fertilizer applied being beyond the optimum level resulting in toxicity to the plant. This aligned with the findings of Havlin *et al.,* (2005) who found that when plant nutrients are applied above the optimum level, the plants absorb more of the nutrients than they require for growth and development. This can lead to toxicity in the plants, which may result in decreased growth or even plant death.

Effect of NPK fertilizer on the Total Storage Root Yield (t/ha) of Orange Flesh Sweet Potato in the 2022 and 2023 planting season

Table 12 shows the effect of NPK fertilizer on OFSP total storage root yield in the 2022 and 2023 planting seasons. The various rates of NPK fertilizer applied significantly ($P < 0.05$) recorded higher weight of OFSP storage roots over control in both the 2022 and 2023 planting seasons. The application of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest OFSP total storage root yield in 2022 (3.255t/ha) and (3.88t/ha) in 2023.

This increase in yield may be due to the photosynthetic capacity of the leaf canopy and the ability of the plant to move the photo-assimilates from the leaf to the root. Therefore, it is possible that the assimilation of photosynthesis moved to the roots contributes to the high yields of the treatment of mineral fertilizers. An adequate supply of N improves shoot development and promotes sweet potato plant photosynthesis and carbohydrate synthesis, P facilitates cell division and promotes root development, while K stimulates photosynthesis and synthesis of high molecular weight substances in storage organs that may contribute to the rapid growth of swollen roots, resulting in root growth. The increase in the yield of sweet potato with cabbage leaves can be due to the readily available macronutrients that lead to the synthesis of more photosimilates, which are used in the accumulation of dry matter in the roots of sweet potato with cabbage leaves with the application of N., P and K. fertilizers.

Similar results were reported by Israel et al. (2012) who stated that the interaction of N, P, and K had a positive and significant impact on potato root yield; Bekele et al. (2020) who reported an increased growth and development of plant cells with the application of types and rates of chemical fertilizers on the yield and quality of potato in Ethiopia; Singh and Rangav (2020) who reported a significant increase in potato yield due to increased NPK fertilizers; and Asa et al (2021) reported that the application of NPK fertilizers has resulted in balanced management of nutrients that lead to an increase in the amount of sweet potato root yield.

In addition, the application of fertilizers beyond the norm of 90kgN-45kgP_2O_5-60kgK_2O showed a reduction in the total yield of sweet potatoes during the 2022 and 2023 planting seasons. This could be a result of the high N fertilizer treatments inhibiting the storage root development. Similar results were reported by Fernandes and Ribeiro (2020), Ukom et al. (2009), and Ambecha (2011) who reported that excess nitrogen can stimulate increased foliage production at the expense of tubers and may also lead to tuber cracking. This might also be due to the quantity of fertilizer applied being beyond the optimum level resulting in toxicity to the plant. This aligned with the findings of Havlin et al. (2005) who found that when plant nutrients are applied exceeds the optimum level, the plants absorb more of the nutrients than they require for growth and development. This can lead to toxicity in the plants, which may result in decreased growth or even plant death.

Table 12. Effect of NPK fertilizer on the Total Storage Root Yield (t/ha) of Orange Flesh Sweet Potato in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	0.880	1.330	1.660	1.720	1.395	1.110	1.770	2.000	2.220	1.772
	15	1.770	1.830	1.830	1.830	1.815	2.770	2.830	2.830	2.830	2.815
	30	1.850	1.860	1.880	1.940	1.882	2.880	2.880	3.000	3.000	2.940
	45	1.940	1.940	1.960	1.960	1.950	3.000	3.050	3.050	3.050	3.037
45	0	1.990	1.990	1.990	1.990	1.990	3.060	3.060	3.110	3.110	3.087
	15	2.050	2.050	2.050	2.110	2.065	3.110	3.110	3.160	3.160	3.135
	30	2.110	2.110	2.110	2.110	2.110	3.160	3.160	3.160	3.160	3.160
	45	2.110	2.220	2.220	2.220	2.192	3.220	3.220	3.220	3.220	3.220
90	0	2.440	2.440	2.440	2.550	2.468	3.220	3.330	3.330	3.330	3.302
	15	2.550	2.770	2.900	3.000	2.804	3.440	3.440	3.550	3.550	3.495
	30	3.000	3.000	3.000	3.200	3.050	3.550	3.570	3.590	3.610	3.580
	45	3.200	3.250	3.250	3.250	3.237	3.660	3.880	3.880	3.880	3.824
135	0	2.200	2.200	2.200	2.200	2.200	3.440	3.550	3.550	3.550	3.522
	15	2.333	2.367	2.500	2.500	2.425	3.550	3.550	3.660	3.660	3.605
	30	2.500	2.550	2.600	2.600	2.562	3.700	3.720	3.770	3.830	3.755
	45	2.700	2.800	3.000	3.000	2.874	3.830	3.880	3.880	3.880	3.867
Mean		2.226	2.301	2.349	2.386		3.169	3.254	3.296	3.315	
LSD (0.05) for N = 0.004158							LSD (0.05) for N = 0.0044				
LSD (0.05) for P = 0.004158							LSD (0.05) for P = 0.0044				
LSD (0.05) for K = 0.004158							LSD (0.05) for K = 0.0044				
LSD (0.05) for N*P = 0.008316							LSD (0.05) for N*P = 0.0088				
LSD (0.05) for N*K = 0.008316							LSD (0.05) for N*K = 0.0088				
LSD (0.05) for P*K = 0.008316							LSD (0.05) for P*K = 0.0088				
LSD (0.05) for N*P*K = 0.01665							LSD (0.05) for N*P*K = 0.0176				

Responses of Soil Exchangeable Properties to The Application of N, P, And K Fertilizer Combinations

Effect of N, P, and K fertilizer combinations on Soil Exchangeable Acidity, Total Exchangeable Bases, Effective Cation Exchange Capacity, and % Base Saturation

The result of the study on the effect of N, P, and K fertilizer rates on soil exchangeable acidity, total exchangeable bases, effective cation exchange capacity and % base saturation are presented in Tables 13, 14, 15, and 16. These results show a decrease in soil exchangeable acidity and an increase in total exchangeable bases, effective cation exchange capacity, and percentage base saturation in treated plots compared to control plots during both the 2022 and 2023 planting seasons. Specifically, soil exchangeable acidity was significantly ($P<0.05$) reduced, while total exchangeable bases, effective cation exchange capacity, and percentage base saturation increased significantly ($P<0.05$) in the plots treated with various rates of N, P, and K fertilizers relative to the control.

In 2022, the soil exchangeable acidity in treated plots was lower (1.36 $cmol^{-1}$ kg^{-1}) than in 2023 (1.48 $cmol^{-1}$ kg^{-1}) with the application of 20 kg/ha K_2O. The highest total exchangeable base (TEB) values were obtained from applying 135kgN-45kgP_2O_5-60kgK_2O in 2022 resulted 7.124 $cmol^{-1}$ kg^{-1} while the application of 90kgN-45kgP_2O_5-0kgK_2O recorded 7.169 $cmol^{-1}$ kg^{-1} in 2023. The highest effective cation exchange capacity (ECEC) values were also achieved with the application of 135kgN-45kgP_2O_5-60kgK_2O yielding 9.711 $cmol^{-1}$ kg^{-1} in 2022 and 9.949 $cmol^{-1}$ kg^{-1} in 2023. Additionally, the highest percentage base saturation (%BS) values were found with the application of 90kgN-15kgP_2O_5-60kgK_2O in 2022 at 73.97% and 73.34% in 2023.

The reduction in soil exchangeable acidity is likely attributed to potentiality of Potassium fertilizer to increase and saturate the soil with bases, thus helping to lower soil acidity. Additionally, high soil organic matter content from plant residues contributes to this effect. The increase in soil exchangeable properties may result from enhanced soil organic matter (SOM) due to increased microbial activity and the accumulation of organic materials such as decaying roots, litter, and crop residues along with the applied fertilizers.

Similar findings were reported by Simiyu (2018) and Omenda et al. (2021), who noted decreased soil exchangeable acidity following chemical fertilizer application in Kenya and the acidic soils of Kakamega in Western Kenya, respectively. Additionally, Ubi et al. (2013) and Onwumere (2023) found increases in TEB and %BS due to rising levels of soil organic matter with higher NPK fertilizer application rates in the coastal plain sands of Akpabuyo, Cross River State, and Ikwo, Nigeria, respectively. Furthermore, Phares et al. (2022) reported an improvement in ECEC following the application of 90:60:60 kg NPK per hectare in Kade, Ghana.

Table 13. Effect of NPK fertilizer on Soil Exchangeable Acidity (Conc. mol^{-1} kg^{-1}) in 2022 and 2023 planting seasons

K (kg/ha)		**0**	**20**	**40**	**60**	**Mean**	**0**	**20**	**40**	**60**	**Mean**
N (kg/ha)	**P (kg/ha)**		**2022 planting season**					**2023 planting season**			
0	0	2.680	1.360	1.360	1.380	1.345	2.840	1.400	1.440	1.480	1.424
	15	1.400	1.440	1.440	1.440	1.567	1.460	1.480	1.520	1.520	1.500
	30	1.480	1.480	1.480	1.520	1.865	1.520	1.520	1.540	1.540	1.530
	45	1.520	1.520	1.520	1.540	2.250	1.560	1.560	1.600	1.600	1.580
45	0	1.545	1.560	1.560	1.600	1.430	1.610	1.640	1.680	1.680	1.653
	15	1.600	1.600	1.640	1.680	1.630	1.680	1.700	1.720	1.720	1.705
	30	1.680	1.680	1.700	1.720	1.925	1.760	1.800	1.840	1.840	1.810
	45	1.720	1.760	1.800	1.840	2.435	1.840	1.880	1.900	1.900	1.880
90	0	1.840	1.840	1.880	1.900	1.490	1.920	1.920	1.960	1.960	1.940
	15	1.900	1.920	1.920	1.960	1.695	2.000	2.060	2.060	2.100	2.055
	30	1.960	2.000	2.060	2.060	2.020	2.100	2.100	2.100	2.200	2.125
	45	2.100	2.100	2.100	2.100	2.510	2.200	2.300	2.300	2.400	2.299
135	0	2.200	2.200	2.300	2.300	1.525	2.400	2.460	2.480	2.500	2.460
	15	2.400	2.400	2.460	2.480	1.780	2.507	2.513	2.520	2.560	2.525
	30	2.500	2.500	2.520	2.520	2.100	2.560	2.590	2.620	2.650	2.605
	45	2.560	2.560	2.600	2.600	2.580	2.690	2.720	2.760	2.780	2.737
Mean		1.855	1.877	1.896	1.915		1.948	1.987	2.003	2.027	
LSD (0.05) for N = 0.0006213							LSD (0.05) for N = 0.001495				
LSD (0.05) for P = 0.0006213							LSD (0.05) for P = 0.001495				
LSD (0.05) for K = 0.0006213							LSD (0.05) for K = 0.001495				
LSD (0.05) for N*P = 0.001242							LSD (0.05) for N*P = 0.00299				
LSD (0.05) for N*K = 0.001242							LSD (0.05) for N*K = 0.00299				
LSD (0.05) for P*K = 0.001242							LSD (0.05) for P*K = 0.00299				
LSD (0.05) for N*P*K = 0.002488							LSD (0.05) for N*P*K = 0.00598				

Table 14. Effect of NPK fertilizer on soil Total Exchangeable Bases ($cmol^{-1}$ kg^{-1}) in 2022 and 2023 planting seasons

K (kg/ha)		**0**	**20**	**40**	**60**	**Mean**	**0**	**20**	**40**	**60**	**Mean**
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	2.293	2.524	2.732	2.775	2.580	2.376	2.605	3.410	3.616	3.001
	15	2.978	2.978	3.600	3.609	3.393	3.624	3.634	3.637	3.646	3.635
	30	3.614	3.624	3.627	3.636	3.625	3.652	3.660	3.666	4.066	3.761
	45	3.646	3.649	4.060	4.061	3.854	4.069	4.073	4.079	4.079	4.075
45	0	4.071	4.074	4.075	4.075	4.074	4.089	4.089	4.093	4.093	4.091
	15	4.084	4.084	4.088	4.093	4.087	4.095	4.105	4.510	4.514	4.306
	30	4.095	4.095	4.505	4.505	4.398	4.516	4.520	4.522	4.526	4.521
	45	4.512	4.515	4.521	4.525	4.518	4.531	4.531	4.931	4.940	4.733
90	0	4.526	4.926	4.926	4.935	4.826	4.946	5.347	5.347	5.356	5.247
	15	5.338	5.339	5.344	5.349	5.342	5.362	5.366	5.373	5.778	5.470
	30	5.349	5.353	5.762	5.768	5.558	5.781	5.789	5.794	5.806	5.792
	45	5.771	5.776	5.786	5.786	5.780	5.806	6.218	6.224	6.231	6.118
135	0	6.194	6.196	6.206	6.212	6.202	6.631	6.637	6.640	6.642	6.637
	15	6.624	6.627	6.633	6.635	6.630	6.670	6.670	6.687	6.701	6.682
	30	6.642	6.645	6.645	7.073	6.751	7.106	7.109	7.117	7.123	7.114
	45	7.073	7.100	7.111	7.124	7.102	7.129	7.147	7.162	7.169	7.152
Mean		3.363	4.273	5.377	6.671		3.618	4.420	5.657	6.896	
LSD (0.05) for N = 0.007502							LSD (0.05) for N = 0.01585				
LSD (0.05) for P = 0.007502							LSD (0.05) for P = 0.01585				
LSD (0.05) for K = 0.007502							LSD (0.05) for K = 0.01585				
LSD (0.05) for N*P = 0.01500							LSD (0.05) for N*P = 0.03169				
LSD (0.05) for N*K = 0.01500							LSD (0.05) for N*K = 0.03169				
LSD (0.05) for P*K = 0.01500							LSD (0.05) for P*K = 0.03169				
LSD (0.05) for N*P*K = 0.03004							LSD (0.05) for N*P*K = 0.06346				

Table 15. Effect of NPK fertilizer on Soil Effective Cation Exchange Capacity (cmol^{-1} kg^{-1}) in 2022 and 2023 planting seasons

K (kg/ha)		**0**	**20**	**40**	**60**	**Mean**	**0**	**20**	**40**	**60**	**Mean**
N (kg/ha)	**P (kg/ha)**	**2022 planting season**					**2023 planting season**				
0	0	4.973	3.884	4.092	4.155	3.924	5.216	4.045	4.850	5.096	4.425
	15	4.378	4.835	5.040	5.049	4.823	5.104	5.114	5.137	5.166	5.130
	30	5.094	5.104	5.107	5.156	5.115	5.172	5.180	5.206	5.606	5.291
	45	5.166	5.166	5.580	5.601	5.378	5.629	5.633	5.679	5.679	5.655
45	0	5.616	5.634	5.635	5.675	5.640	5.699	5.729	5.773	5.773	5.745
	15	5.684	5.684	5.728	5.773	5.717	5.775	5.805	6.230	6.234	6.011
	30	5.775	6.175	6.205	6.225	6.093	6.276	6.320	6.362	6.366	6.331
	45	6.232	6.275	6.321	6.365	6.298	6.371	6.411	6.831	6.840	6.613
90	0	6.366	6.766	6.806	6.835	6.691	6.371	7.267	7.307	7.316	7.187
	15	7.238	7.259	7.264	7.309	7.267	7.362	7.426	7.433	7.878	7.524
	30	7.309	7.353	7.822	7.828	7.578	7.881	7.889	7.894	8.006	7.917
	45	7.871	7.876	7.886	7.886	7.880	8.006	8.518	8.524	8.631	8.417
135	0	8.394	8.396	8.506	8.512	8.452	9.031	9.097	9.120	9.142	9.097
	15	9.024	9.027	9.093	9.115	9.065	9.171	9.207	9.207	9.261	9.202
	30	9.142	9.145	9.165	9.593	9.261	9.666	9.699	9.737	9.773	9.719
	45	9.633	9.660	9.700	9.711	9.679	9.819	9.867	9.922	9.949	9.889
Mean		6.656	6.789	6.873	6.924		6.971	7.102	7.201	7.295	

LSD (0.05) for N = 0.0008003	LSD (0.05) for N = 0.001245
LSD (0.05) for P = 0.0008003	LSD (0.05) for P = 0.001245
LSD (0.05) for K = 0.0008003	LSD (0.05) for K = 0.001245
LSD (0.05) for N*P = 0.001600	LSD (0.05) for N*P = 0.002490
LSD (0.05) for N*K = 0.001600	LSD (0.05) for N*K = 0.002490
LSD (0.05) for P*K = 0.001600	LSD (0.05) for P*K = 0.002490
LSD (0.05) for N*P*K = 0.003205	LSD (0.05) for N*P*K =0.004986

Table 16. Effect of NPK fertilizer on Soil %Base Saturation in 2022 and 2023 planting seasons

K (kg/ha)		0	20	40	60	Mean	0	20	40	60	Mean
N (kg/ha)	P (kg/ha)	2022 planting season					2023 planting season				
0	0	46.18	64.98	64.98	66.79	65.67	45.55	64.40	70.31	70.96	67.40
	15	68.02	70.22	71.43	71.48	70.28	71.00	71.06	70.80	70.58	70.86
	30	70.95	71.00	71.02	70.52	70.87	70.61	70.67	70.42	72.53	71.06
	45	70.58	70.59	72.76	72.50	71.61	72.29	72.31	71.83	71.83	72.06
45	0	72.49	72.31	72.32	71.81	72.23	71.75	71.37	70.90	70.90	71.22
	15	71.83	71.85	71.37	70.90	71.49	70.90	70.77	72.39	72.41	71.62
	30	70.90	72.80	72.60	72.37	72.16	71.96	71.52	71.08	71.10	71.42
	45	72.40	71.95	71.52	71.09	71.74	71.12	70.68	72.19	72.22	71.55
90	0	71.10	72.80	72.38	72.20	72.11	72.04	73.58	73.18	73.21	72.99
	15	73.75	73.55	73.57	73.97	73.71	72.83	72.26	72.29	73.34	72.68
	30	73.18	72.80	73.66	73.68	73.33	73.35	73.38	73.40	72.52	73.16
	45	73.32	73.34	73.37	73.37	73.35	73.50	73.00	73.02	72.19	72.94
135	0	73.79	73.80	72.97	72.98	73.38	73.43	72.97	72.80	72.65	72.96
	15	73.41	73.41	72.95	72.79	73.14	72.70	72.69	72.63	72.36	72.60
	30	72.65	72.66	72.50	73.73	72.88	73.52	73.30	73.09	72.88	73.20
	45	73.42	73.50	73.22	73.27	73.35	72.60	72.43	72.18	72.06	72.32
Mean		71.62	71.97	72.15	72.09		70.35	71.46	72.94	72.77	

2022	2023
LSD (0.05) for N = 0.007502	LSD (0.05) for N = 0.01585
LSD (0.05) for P = 0.007502	LSD (0.05) for P = 0.01585
LSD (0.05) for K = 0.007502	LSD (0.05) for K = 0.01585
LSD (0.05) for N*P = 0.01500	LSD (0.05) for N*P = 0.03170
LSD (0.05) for N*K = 0.01500	LSD (0.05) for N*K = 0.03170
LSD (0.05) for P*K = 0.01500	LSD (0.05) for P*K = 0.4076
LSD (0.05) for N*P*K = 0.03004	LSD (0.05) for N*P*K = 0.06346

CONCLUSION

Based on increased growth and root yield, this study has shown that the application of NPK fertilizer improved the performance of orange-fleshed sweet potatoes. The growth and yield parameters of OFSP were significantly ($P<0.05$) higher than control in both the 2022 and 2023 planting seasons due to the different rates of NPK fertilizer applied. The findings demonstrated that all growth and yield parameters of orange-fleshed sweet potatoes were significantly ($P<0.05$) boosted by the different combined rates of N, P, and K fertilizers and improved the soil exchangeable properties such as Soil Exchangeable Acidity, Total Exchangeable Bases, Effective Cation Exchange Capacity, and % Base Saturation in comparison to the control. Additionally, the 2023 planting season had better results than the 2022 planting season. However, the application of NPK at the rate of 90kgN-45kgP_2O_5-60kgK_2O recorded the highest number of OFSP leaves at 4 WATA (192.3 and 184.3), 8 WATA (292.3 and 315.0) and 12 WATA (374.3 and 388.0), number of branches at 4 WATA (11.333 and 14), 8 WATA (17.33 and 19) and 12 WATA (19 and 20.33), vine length at 4 WATA (128.7cm and 126.7cm), 8 WATA (319.3cm and 337.7cm) and 12 WATA (457.0cm and 444.7cm), weight of OFSP storage root (3.070kg/plot) and (3.5kg/plot) and total storage root yield (3.255t/ha) and (3.88t/ha) in 2022 and 2023 respectively. For orange-fleshed sweet potato production in the research region, NPK fertilizer treatment at a rate of 90kgN-45kgP_2O_5-60kgK_2O seems suitable for the highest yield and is thus advised.

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Conflict of interest statement

The authors have not declared any conflict of interest.

Author's contribution

ISC executed the study, discussed the results and compiled the work and DOA and EO supervised the experiment and read the manuscript

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