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Effects of plant spacing and rates of NPK application on the growth and yield of sweetpotato var NSIC SP30

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ABSTRACT

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Sweetpotato yield may be increased through effective crop management practices including plant spacing and fertilization. This study was conducted in an alluvial soil (Inceptisol) to evaluate the effects of plant spacing and rates of NPK application on the growth and yield of NSIC Sp30 sweetpotato. The experiment was laid out in a split plot arranged in RCBD with three replications. Three plant spacing treatments were designated as the main plot D_1(75cmx25cm), D_2(100cmx25cm), and D_3(100cmx50cm). The rates of NPK application were designated as the subplot: F_0(no NPK), F_1(40-40-60kg ha^{-1} NPK), F_2(60-60-90kg ha^{-1} NPK), and F_3(80-80-120kg ha^{-1} NPK).

Plant spacing significantly affected the number of lateral vines, weight of marketable roots, number of marketable roots, root length, and the total root yield of NSIC Sp30 sweetpotato. An interaction effect was observed between the plants spaced at 100cmx50cm with NPK application resulting in more medium-sized roots. Plants spaced at 75cmx25cm produced the highest total root yield of 7.67t ha^{-1}.

Application of NPK significantly influenced the length of main vines, fresh herbage yield, the weight of marketable roots, number of marketable roots, root length, root diameter, total root yield, LAI and HI. A higher yield of marketable roots 7,208.85kg ha^{-1} and a total root yield of 8.51t ha^{-1} were observed for plants applied with 40-40-60 kg ha^{-1} NPK. The growth and yield performance of NSIC Sp30 is better when plants are spaced at 75cmx25cm with 53,333 plants ha^{-1} and fertilized with 40-40-60kg ha^{-1} of NPK.

Keywords: NPK fertilization, NSIC Sp30, plant spacing, plant population

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INTRODUCTION

In the Philippines, sweetpotato is a very common crop. It can be seen growing cultivated or not in marginal areas, on sloping or flat lands, on coastal farms, on patches of unutilized land, and sometimes on polluted soils. Farmers grow sweetpotato either as a commercial or subsistence crop that is grown either on a large scale or just for home consumption. The role of sweetpotato in the human diet demonstrates its potential as a value-added product in the human food system (Bovell-Benjamin 2007). It is often considered inferior to cereals (de Vries et al 1967) however when compared on an equal energy basis it has a comparable protein concentration with that of rice (O'Sullivan et al 1997). It produces more edible energy compared to any other major food crop (Woolfe 1992, Mukhopadhyay 2011).

This crop is gaining popularity as a health food. Not only is it packed with many health benefits making it a promising crop in the lowering of the risk of cardiovascular diseases, obesity, and type 2 diabetes mellitus (Trinidad et al 2013), it is also a source of bioactive compounds, which are naturally occurring in sweetpotato roots (de Albuquerque et al 2019). Sweetpotato roots are a rich source of carbohydrates, minerals, and vitamins (O'Sullivan et al 1997). They are also a good source of calcium, vitamin C, and beta-carotene. The yellow to orange-fleshed varieties contain higher levels of carotenoids, an unsurpassed source of beta-carotene which is a good source of vitamin A (Woolfe 1992, Laurie et al 2012). The purple-fleshed varieties contain anthocyanin with important antioxidants and have anti-inflammatory properties (Mohanraj & Sivasankar 2014).

Sweetpotato has the potential to be an excellent climate-resilient crop. It was one of the lone standing crops during Typhoon Haiyan in 2013, which wreaked havoc on the islands of Leyte and Samar, Philippines (Asio et al 2018). With the threats of climate change and extreme weather events, the Philippines needs sources of carbohydrates, other than rice, that are climate resilient, especially in typhoon-prone regions such as Bicol, Leyte, and Samar.

The establishment of an optimum population per unit area of any crop is important to achieve the crop's maximum yield (Singh & Singh 2002). Liang et al (2023) reported that a plant spacing of 80cmx20cm (62,520 plants ha^{-1}) produced more storage roots than 80cmx25cm (50,025 plants ha^{-1}). This treatment also stimulated the cambium cell differentiation increasing carbohydrate accumulation. However, Bouwkamp and Scott (1980) obtained a high number of storage roots in plants with closer spacing. They also found that small roots with a 2-5.5cm diameter are better for canning. Roots with a 4.5-9cm diameter are preferred for the fresh market and over 9cm diameter is required for processing as diced frozen or as puree.

For sweetpotato, closer spacing is generally recommended to achieve maximum root yield (Nedunchezhiyan et al 2012). In India, plant spacing of 30-60cm between rows and 15-20cm between plants obtained the maximum yield for sweetpotato. A field trial in Hungary was conducted during the main cropping season of 2016, 2017, and 2019 to determine the effect of spacing on sweetpotato productivity (Szarvas et al 2019). They noted the highest sweetpotato yield from plants spaced at 100cmx30cm for the cropping seasons of 2016 and 2017 but for the 2018 cropping season, 80cmx30cm spacing obtained the highest root yield. Some sweetpotato farmers in Korea prefer wider planting densities to obtain large and heavier storage roots while a closer spacing to obtain smaller roots is preferred by some for good eating quality and easy cooking (Lee et al 2015). Adequate spacing is also needed to increase the sweetpotato's ability to photosynthesize which may result in higher root yields (Szarvas et al 2019).

Another factor that is given little attention is sweetpotato's nutrition (O'Sullivan et al 1997). The crop can produce a comparatively good yield under high adverse soil conditions however, fertilization is still a much better option to gain an increased yield. Farmers in the Philippines lack comprehensive knowledge of the nutrient needs of sweetpotato. In addition, the price of inorganic fertilizer is increasing thus it is believed that most farmers are applying more or less than the recommended rates of fertilizers. According to Roa (2007), farmers do not really follow recommended fertilizer use because of capital inadequacy. They usually mix urea and complete fertilizer at 30-70% of the recommended amount and no soil analysis is done as the basis for fertilization.

The goal of this research is to improve the production of NSIC Sp30 by optimizing the plant spacing and NPK application rates. The NSIC Sp30 variety is preferred by consumers because of its good eating quality, high level of dry matter and starch content, brown skin and yellow-orange flesh as well as moderate resistance to sweetpotato weevil (Belen 2005). This is also the preferred variety for making chips and fries. In addition, the yellow-orange color of NSIC Sp30 is a potential source of vitamin A and could address the dietary vitamin A deficiency found in the Cordillera Administrative Region and other regions of the Philippines.

MATERIALS AND METHODS

Site Characteristics

The field experiment was conducted at the experimental area of the Philippine Rootcrops Research and Training Center of Visayas State University (VSU), Baybay, Leyte (Figure 1). It has a latitude of 10°44.84'N and a longitude of 124°47.29'E with an elevation of 5-10m above sea level. The area is an alluvial plain with Umingan clay loam soil classified as Inceptisol (Jahn et al 2006). Before the experiment was conducted, the field was used to grow ubi or yam and cassava and sweetpotato. Baybay, Leyte has a Type IV climate with an annual rainfall of 2,800mm based on the Modified Coronas Classification (MCC).

The highest rainfall of 308.20mm observed during the entire conduct of the experiment was in the first two weeks after transplanting and the average temperature was 25.47°C. Sweetpotato requires an average daytime temperature of more than 18°C and 750-1250mm of rainfall (Rehm & Espig 1991). Although the crop can survive long dry periods, high yields and good root quality require evenly spread rainfall or irrigation throughout the growing period.

Land Preparation and Ridging

An area of 1,017m^2 was plowed twice using a 3-disc plow. Harrowing was done after plowing to incorporate the weeds into the soil. The second plowing was done two weeks after the first followed by a 2nd harrowing to completely pulverize the soil. Ridges were made before transplanting, spaced at 100cm for D_2 and D_3 treatments and 75cm for D_1 treatment.

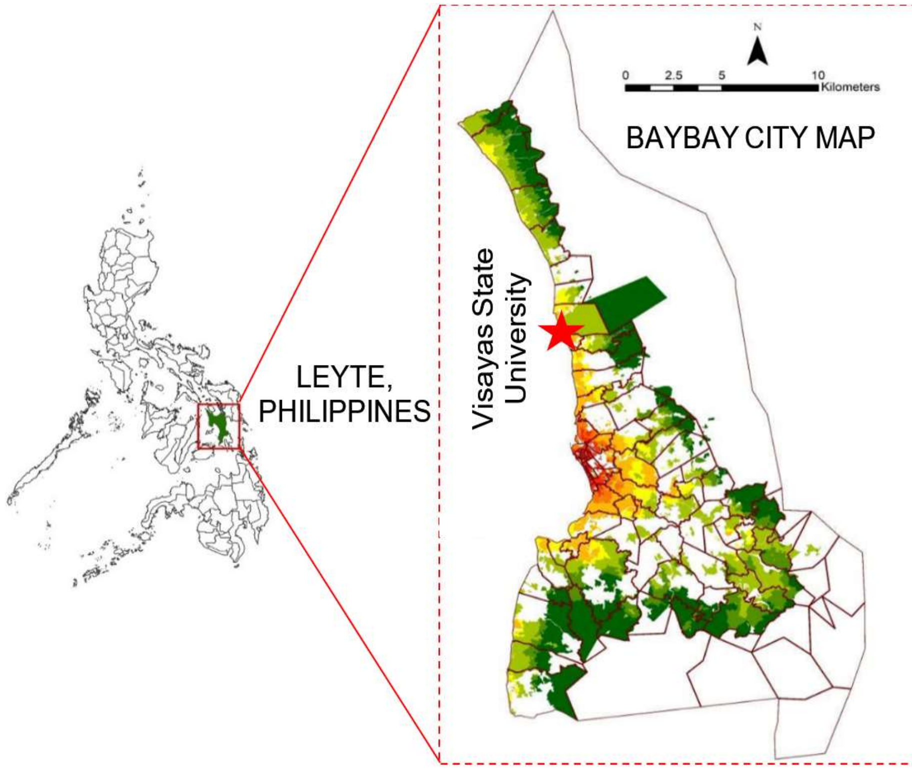

Figure 1. Experimental Site at the Philippine Rootcrops Research and Training Center, Visayas State University, Baybay City, Leyte (Map Source: Bencure et al 2019)

Chemical Analysis of Soil Properties

About 10 soil sub-samples were collected at a 0-20cm depth using an auger. These were mixed and composited to get a 500g sample for soil chemical analysis. The 500g composite sample was air-dried, pulverized, homogenized, and sieved to pass through a 2mm mesh sieve and was submitted to the Central Analytical Service Laboratory (CASL), 2nd Floor Philrootcrops Complex, VSU, for the analysis of the soil pH, Organic Matter, total N, available P and Exchangeable K. After the experiment, more soil samples were collected per treatment per replication using an auger for the final soil chemical analysis. A total of 36 soil samples were collected after harvesting the sweetpotato.

Experimental Design and Field Layout

The field experiment was laid out in a split-plot design arranged in RCBD with three replications. Plant spacing (row distance x plant-to-plant distance) served as the main plot, while the rates of NPK served as the subplot. Alleyways were made at a distance of 1.5m between replications and 1.0m between plots to facilitate farm operations and data gathering. The treatments were as follows:

Plant Spacing

D_1 - 75cmx25cm (53,333 plants ha^{-1})
D_2 - 100cmx25cm (40,000 plants ha^{-1})
D_3 - 100cmx50cm (20,000 plants ha^{-1})

Rates of NPK

F_0 - No NPK (Control)
F_1 - 40-40-60kg ha^{-1} N, P_2O_5, and K_2O
F_2 - 60-60-90kg ha^{-1} N, P_2O_5, and K_2O
F_3 - 80-80-120kg ha^{-1} N, P_2O_5, and K_2O

Preparation of Planting Materials and Transplanting

Apical cuttings of NSIC Sp30 sweetpotato which measured 30cm in length with 8 nodes were used as planting material. Pre-germination was done in a shady place for three days before transplanting (Nedunchezhiyan et al 2012) with one cutting planted per hill. Four nodes were buried and covered with soil and the other four nodes including the shoot were exposed above the soil. Transplanting was done in a slanting position. Missing hills were replaced immediately with pre-rooted cuttings of the same age.

Establishment of Drainage Canal

Drainage canals were established with a depth of 50cm and a width of 30cm between replication plots one week after transplanting. This was done to control the ongoing flooding from the excessive rainfall which occurred two weeks after transplanting.

Application of the Rates of NPK

A complete fertilizer (16-16-16) and muriate of potash (0-0-60) were used to satisfy the NPK rates stipulated in the treatments. Both fertilizers were applied in bands one week after transplanting. The application was done per row and hilling up was employed immediately to cover the fertilizers with soil and prevent fertilizer losses.

Control of Pests, Diseases, and Sweetpotato Weevil

Hand weeding was done twice at one month and two months after transplanting. An insecticide thiamethoxam 12.6%w/w + lambda-cyhalothrin 9.5%w/w was sprayed three months after transplanting (MAT) and three weeks before harvesting. This was done to control the aphids, thrips, and bollworms seen in the area. There were a few rats infecting the border but their population was not critical, however cleaning and removing the weeds of the experimental field was done continuously to control their population.

Six weevil pheromone traps were installed around the experimental field (Vasquez et al 2009) one month after transplanting (MAT).

Harvesting

Storage roots were harvested 120 days after transplanting. Manual harvesting was done using a spading fork by carefully digging so as not to damage the fleshy roots. Storage roots were cleaned of any adherent soil, and placed in a shady area. Roots were sorted by separating the marketable from the non-marketable roots. Marketable roots were classified according to different sizes: small (40-100g), medium (100-200g), and large (>200g) (Hatton 2022, Marston 2022, Richard 2021). Roots below 40g and those damaged by pests were considered non-marketable.

Data Gathered

Agronomic characteristics of NSIC Sp30 such as the length of main vines, number of primary lateral vines, and fresh herbage weight were gathered at harvest. Morphological characteristics such as the Leaf Area Index (LAI) and Harvest Index (HI) were gathered. LAI was determined using a quadrat method with dimensions of 50cmx50cm to obtain a ground area of 2,500cm^2. The total length and width were multiplied by the correction factor (CF) of 0.592 (Amarille 2020). LAI was measured twice at 8 weeks and 16 weeks after transplanting (WAT). The HI was measured by taking the ratio of the economic yield (weight of storage roots) to the biological yield (weight of roots + herbage yield) on a dry weight basis. For the yield and yield components of NSIC Sp30 parameters such as the weight and number of marketable roots, root length and root diameter, and the total root yield were gathered. Meteorological data in the area was also recorded.

Statistical Analysis

Analysis of Variance (ANOVA) of the data collected was analyzed using R package software version 4.3 (R Core Team 2021). And the comparison of treatment means was analyzed using Tukey`s Honestly Significant Difference (HSD) test.

RESULTS AND DISCUSSION

Soil Chemical Analysis

Table 1 shows that before planting, the soil was moderately acidic with a pH of 5.6, very low organic matter (1.42%), low total N (0.13%), sufficient available P (33.57mg kg^{-1}), and sufficient exchangeable K (0.81me 100g^{-1} soil) (Landon 1991). After harvest, the soil pH was slightly acidic in the range of 6.36-6.44, the organic matter content had also increased although it was still very low according to the criteria in Landon (1991). Moreover, the final analysis revealed a very low total N (0.9-0.10%), and high available P in NPK-applied plants ranging from 35.04-39.95mg kg^{-1}. Exchangeable K is sufficient (0.71-0.75me 100g^{-1} soil) but was lower than the initial soil analysis (0.81me 100g^{-1}) (Landon 1991).

Table 1. Initial and final chemical analysis of the soil planted with NSIC Sp30 sweetpotato at various planting densities and rates of NPK application

	pH (1:2.5)	OM (%)	Total N (%)	Avail P (mg kg^{-1})	Exch K (me 100g^{-1} soil)
Initial Soil Analysis					
	5.60	1.42	0.13	33.57	0.81
Final Soil Analysis					
Plant spacing					
D_1:75cmx25cm	6.44	1.91	0.10	39.95	0.72
D_2:100cmx25cm	6.39	1.80	0.09	36.57	0.71
D_3:100cmx50cm	6.36	1.94	0.10	30.25	0.74
F (p)	4.25(0.10)	1.13(0.41)	1.72(0.29)	3.21(0.15)	0.27(0.78)
CV_a (%)	1.12	12.24	11.93	6.42	14.89
Rates of NPK Fertilization					
F_0:Control	6.44	1.88	0.09	32.48	0.73
F_1:40-40-60kg ha^{-1} NPK	6.40	1.92	0.10	37.46	0.72
F_2:60-60-90kg ha^{-1} NPK	6.37	1.89	0.10	35.04	0.75
F_3:80-80-120kg ha^{-1} NPK	6.37	1.84	0.09	37.38	0.71
F (p)	2.42(0.10)	0.19(0.90)	0.23(0.88)	1.19(0.34)	0.58(0.63)
CV_b (%)	1.05	12.33	12.57	13.26	9.60

The total amount of nutrients in the soil does not generally reflect the quantity available for root uptake (O'Sullivan et al 1997). However, soil analysis estimates the potential availability of nutrients that the roots of plants may take up under conditions favorable for root growth (Marschner 1995). Soil analysis could be the basis of whether or not fertilizer is needed before the crop is planted. Soil analysis showed that the soil was deficient in N but had sufficient amounts of P and K.

For optimum sweetpotato production, the optimum NPK concentration in the tissues should be in the range of 4.4–5.0%, 0.26–0.45% and 2.8–6.0% respectively (O'Sullivan et al 1997). Unfortunately, plant analysis was not included in the study thus there is no way to account for whether or not the tissues of NSIC Sp30 were indeed deficient in these mentioned elements.

Agronomic Characteristics of NSIC Sp30

Table 2 shows that only the number of lateral vines of NSIC Sp30 was influenced by plant spacing. Plants spaced at 100cmx50cm (D_3) produced more primary lateral vines of around 4-5 vines followed by plants spaced at 75cmx25cm (D_1) and 100cmx25cm (D_2) with 2-3 vines each. Wider spacing of sweetpotato would result in lateral vining (Lebot 2020). Plants that are widely spaced will have more vines than plants with closer spacing. Closer spacing is generally recommended for sweetpotato to achieve maximum root yield (Nedunchezhiyan et al 2012). In India, according to these authors, a spacing of 30-60cm between rows and 15-20cm between plants gave maximum root yield. However, no specific spacing was followed when sweetpotato were planted in mounds (Nedunchezhiyan et al 2012).

Rates of NPK application significantly affected the length of the main vines and the fresh herbage weight but not the number of primary lateral vines of NSIC Sp30. Plants applied with 60-60-90kg ha^{-1} NPK (F_2) had the longest main vine length of 338.75cm per plant but were not significantly different from plants applied with 80-80-120kg ha^{-1} N, P_2O_5, and K_2O (F_3). While plants applied with 40-40-60kg N, P_2O_5 and K_2O (F_1) produced a shorter main vine length of 280.39cm, which is comparable to plants without NPK (F_0). The high fresh yield herbage was obtained from F_2 with 20.62t ha^{-1} yield but was comparable with F_1 and F_3. The lowest fresh herbage yield was obtained in plants without NPK (F_0).

Sweetpotato is regarded as tolerant to poor soil fertility as it produces yields on soils too low in nutrients for other crops but the yields produced will only be a fraction of the potential yield of the crop (O'Sullivan et al 1997). However, the ratio of NPK is critical in sweetpotato production as it may influence storage roots and herbage production. Bourke (1985), reported that N application influenced the yield by increasing the leaf area duration which increased the mean tuber weight. However, Hartemink et al (2000) found that marketable and non-marketable roots were negatively affected by high N applications, which produced more vines and leaves instead of roots. A similar result was also obtained by Relente and Asio (2020) who reported that increasing the N levels from 80kg ha^{-1} N to 160kg ha^{-1} N resulted in a decline of the root yield.

Results also revealed that although plant spacing and NPK application significantly influenced the number of lateral vines, the length of the main vines, and the fresh herbage, no interaction effects were observed between plant spacing and NPK application (DxF) on the above-mentioned agronomic parameters.

Table 2. Number of lateral vines, length of main vines (cm), and fresh herbage yield (t ha^{-1}) of NSIC Sp30 sweetpotato at various planting densities and rates of NPK application

	Number of Lateral Vines	Length of Main Vines (cm)	Fresh Herbage Yield (t ha^{-1})
Plant Spacing			
D_1:75cmx25cm	2.82^{b}	272.11	17.28
D_2:100cmx25cm	2.99^{b}	286.64	20.21
D_3:100cmx50cm	4.38^{a}	332.01	19.01
F (p)	*45.24(<0.01)	4.63(0.09)	0.76(0.52)
CV_a (%)	12.94	16.94	2.80
Rates of NPK Fertilization			
F_0:Control	3.23	246.30^{c}	16.22^{b}
F_1:40-40-60kg ha^{-1} NPK	3.67	280.39^{bc}	19.26^{ab}
F_2:60-60-90kg ha^{-1} NPK	3.12	338.75^{a}	20.62^{a}
F_3:80-80-120kg ha^{-1} NPK	3.56	322.24^{ab}	19.25^{ab}
F (p)	1.47(0.25)	*8.57(<0.01)	*4.48((<0.01)
CV_b (%)	18.92	14.41	1.52

*Treatment means within the column followed by common letters and those without letter designations are not significantly different at the 5% level, of the HSD test.

Yield and Yield Components

Table 3 shows that the weight of marketable roots and total root yield of NSIC Sp30 was significantly affected by plant spacing and rates of NPK application. Harvested marketable roots were grouped into different sizes small (40-100g), medium (100-200g), and large sizes (>200g). Heavier weights of small and medium-sized roots were obtained from plants spaced at 75cmx25cm (D_1) and 100cmx25cm (D_2) while heavier weights of large roots were obtained from plants spaced at 100cmx50cm (D_3). Lee et al (2015) noted that Korean household consumers prefer small to medium-sized roots for easy cooking, easy steaming, or roasting in a small pan, while industries prefer large root sizes for starch and flour production (Lebot 2020).

Plants spaced at 75cmx25cm (D_1) with 53,333 plants ha^{-1} produced the highest total root yield but were comparable with D_2. The lowest total root yield was from plants spaced at 100cmx50cm (D_3). In the study of Liang et al (2023), appropriate plant spacing is critical in regulating carbohydrate and lignin metabolism affecting storage root formation. They found that a plant population of 62,520 plants ha^{-1} produced more storage roots.

The rates of NPK application significantly influenced the weight of marketable roots and the total root of the NSIC Sp30 sweetpotato variety. Plants applied with 40-40-60kg ha^{-1} NPK (F_1) had the heaviest weight of marketable roots and the highest total root yield but this however was comparable with F_2 and F_3. The lowest total root yield was obtained from plants with no NPK (F_0). F_1 obtained a root yield of 8.51t ha^{-1} followed by F_2 which had a root yield of 7.32t ha^{-1}, F_3 with a root yield of 7.01t ha^{-1}, and F_0 with a root yield of 3.63t ha^{-1}.

Plant spacing is a significant factor in the formation of various sizes of sweetpotato storage roots. Plants at a closer spacing of 75cmx25cm (D_1) produced more small to medium-sized roots followed by D_2 while larger roots (>200g) were obtained from wider-spaced plants at 100cmx50cm (D_3) (Figure 2). However, for medium sized roots an interaction effect was noticed between plant spacing and NPK application (Table 4). It was observed that more medium sized roots were produced in plants spaced at 100cmx50cm applied with NPK compared to no NPK application. On the other hand, the root length of the small-sized roots was longer in D_3 but were comparable with D_1, and D_2(Table 5). For the medium sized roots, longer root lengths were observed in plants with no NPK (F_0) than in NPK-applied plants (F_1, F_2, and F_3) but the root diameters were larger in the NPK-applied plants (F_1, F_2, and F_3) than the plants with no NPK. But root lengths and diameters in F_1, F_2, and F_3 were comparable.

Bhattarai et al (2022) showed that closer plant spacing increased the total root yield per hectare of sweetpotato but reduced the yield per plant. Wees et al (2016) also noticed a reduction in the number of storage roots per plant at wider plant spacing. The yield of sweetpotato is controlled by the number of sweetpotato plants per unit, storage roots per plant and the size of each storage root at harvest. Different plant spacings may not necessarily influence root yield due to factors such as root initiation and development (Shankle & Reddy 2020).

Table 3. Weight of marketable roots, and total root yield of NSIC Sp30 sweetpotato at various planting densities and rates of NPK application

	Weight of Marketable Roots (kg ha^{-1})			Total Root Yield
	Small	Medium	Large	(t ha^{-1})
Plant spacing				
D_1:75cmx25cm	2149.38^a	2346.50^a	1812.35^b	7.67^a
D_2:100cmx25cm	1590.79^a	2011.11^a	1697.69^b	6.41^{ab}
D_3:100cmx50cm	1039.06^b	1101.56^b	2664.58^a	5.78^b
F (p)	*20.68 (<0.01)	*12.50 (<0.01)	*87.14 (<0.01)	*10.25 (0.03)
CV_a (%)	4.11	6.17	1.30	1.92
Rates of NPK Fertilization				
F_0:Control	1126.66^b	941.06^b	891.83^b	3.63^b
F_1:40-40-60kg ha^{-1} NPK	2065.75^a	2489.73^a	2653.37^a	8.51^a
F_2:60-60-90kg ha^{-1} NPK	1502.77^{ab}	2047.43^a	2296.37^{ab}	7.32^a
F_3:80-80-120kg ha^{-1} NPK	1677.13^{ab}	1800.69^{ab}	2391.25^{ab}	7.01^a
F (p)	*3.21 (0.04)	*7.25 (<0.01)	*3.93 (0.02)	*9.74 (<0.01)
CV_b (%)	7.15	7.77	8.88	4.20

*Treatment means within the column followed by common letters and those without letter designations are not significantly different at the 5% level, of the HSD test.

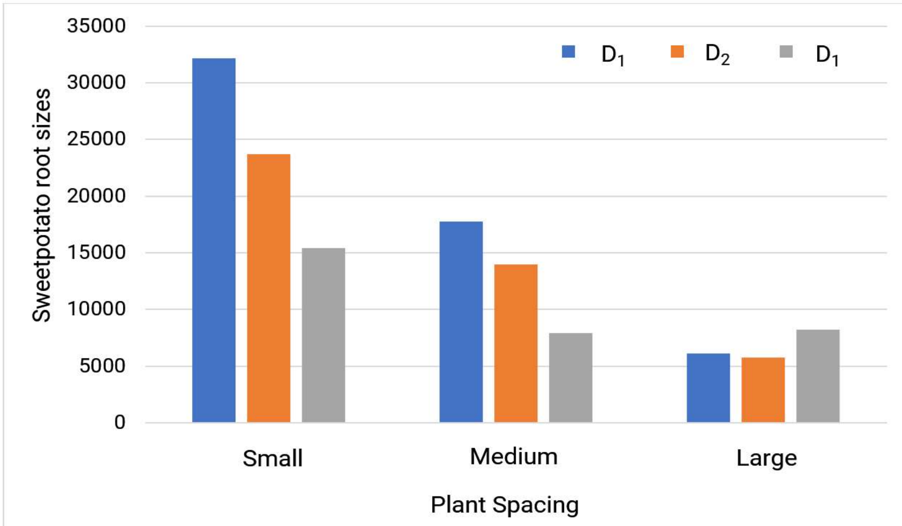

Figure 2. Sweetpotato root sizes as affected by various plant spacing (D_1:75cmx25cm, D_2:100cmx25cm, D_3:100cmx50cm)

Table 4. Interaction effect between plant spacing and NPK fertilization on the medium-sized roots of NSIC Sp30 spaced at 100cmx50cm (D_3)

	Medium Size
D_1 :75cmx25cm	
F_0: Control	50.27[a]
F_1:40-40-60kg ha^{-1} NPK	48.80[a]
F_2:60-60-90kg ha^{-1} NPK	49.99[a]
F_3:80-80-120kg ha^{-1} NPK	50.14[a]
D_2:100cmx25cm	
F_0: Control	44.92[a]
F_1:40-40-60kg ha^{-1} NPK	48.82[a]
F_2:60-60-90kg ha^{-1} NPK	50.25[a]
F_3:80-80-120kg ha^{-1} NPK	51.65[a]
D_3:100cmx50cm	
F_0: Control	42.24[b]
F_1:40-40-60kg ha^{-1} NPK	53.79[a]
F_2:60-60-90kg ha^{-1} NPK	52.43[a]
F_3:80-80-120kg ha^{-1} NPK	51.28[a]
F (p) = 3.05 (0.03)	
CV (%) (D_n) = 8.37	
CV (%) (F_n) = 5.91	

*Treatment means within the column followed by common letters and those without letter designations are not significantly different at the 5% level of the HSD test.

Table 5. Root length and root diameter of NSIC Sp30 sweetpotato at various plant spacing with rates of NPK fertilization

	Root Length (mm)			Root Diameter (mm)		
	Small	Medium	Large	Small	Medium	Large
Planting Density						
D_1:75cmx25cm	103.67^a	126.49	146.47	36.25	49.80	64.67
D_2:100cmx25cm	105.01^{ab}	126.47	149.77	37.00	48.91	63.42
D_3:100cmx50cm	107.42^a	125.36	145.29	35.93	49.94	67.47
F (p)	11.50 (0.02)	0.03 (0.97)	0.15 (0.87)	3.85 (0.12)	0.22 (0.81)	2.53 (0.19)
CV_a (%)	1.84	10.06	14.20	2.66	8.37	6.94
Rates of NPK						
F_0:Control	110.15	139.54^a	142.80	35.22	45.81^b	62.48
F_1:40-40-60kg ha^{-1} NPK	106.02	119.88^b	152.87	36.44	50.47^a	67.04
F_2:60-60-90kg ha^{-1} NPK	102.96	124.20^b	150.22	36.67	50.89^a	63.92
F_3:80-80-120kg ha^{-1} NPK	102.35	120.80^b	142.81	37.24	51.02^a	67.30
F (p)	1.41 (0.27)	10.8(<0.01)	0.85 (0.48)	1.02 (0.41)	6.57 (<0.01)	1.75 (0.19)
CV_b (%)	8.56	6.60	11.40	6.95	5.91	8.23

*Treatment means within the column followed by common letters and those without letter designations are not significantly different at the 5% level of the HSD test.

Morphological Characteristics

Although LAI was higher at 16 WAT than at 8 WAT (Table 6), plant spacing did not significantly influence this parameter but NPK application did affect LAI. An increasing LAI was noticed when rates of NPK were increased from 0 NPK (F_0) to a 60-60-90kg ha^{-2} NPK (F_2) but decreased at 80-80-120kg ha^{-1} NPK (F_3) when the LAI was taken at 16 WAT (Figure 3).

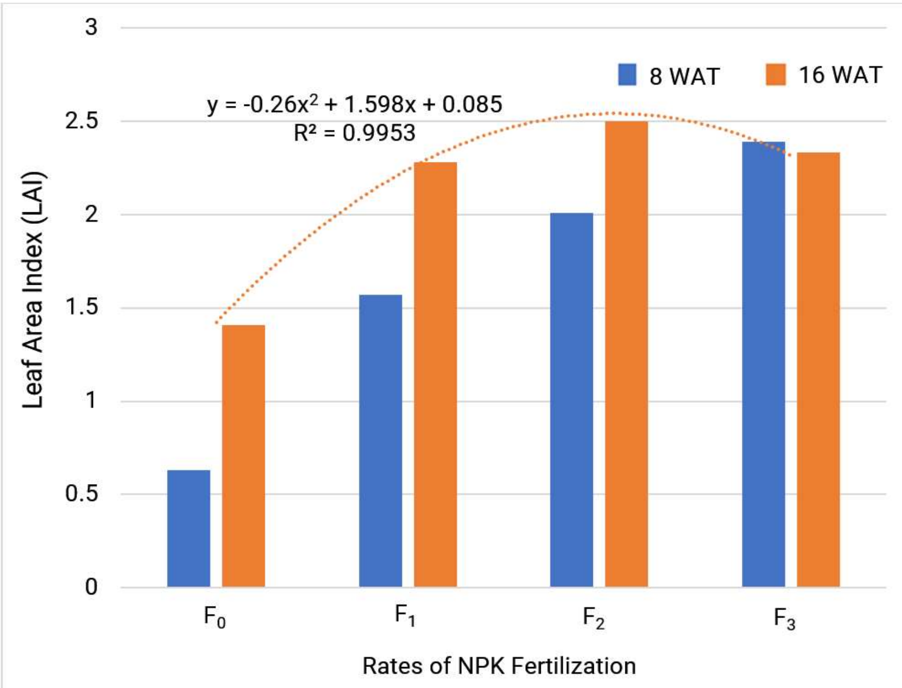

Figure 3. Leaf Area Index (LAI) taken at 8 WAT and 16 WAT affected by rates of NPK fertilization (F_0: no fertilizer, F_1: 40-40-60kg ha^{-1}, F_2 60-60-90kg ha^{-1}, F_3: 80-80-120kg ha^{-1} of NPK)

Positive yield response curves are the result of an increase in LAI (Marschner 1995). The net photosynthesis per unit leaf area and the density of the crop's population are expressed in terms of the LAI. The crop yield increases until an optimum LAI is reached which is dependent on the plant species, light intensity, leaf shape, and leaf angle. At a high LAI leaf shading becomes the main limiting factor due to closer spacing. So the observed decline of LAI in plants applied with 80-80-120kg ha^{-1} NPK (F_3) at 16 WAT was a result of mutual shading.

The harvest index (HI) tells us the partitioning of the dry matter in the harvested parts to the total dry matter production (Marschner 1995). Table 6 shows that planting density did not influence the HI of the NSIC Sp30 sweetpotato but rates of NPK application significantly affected this parameter. Plants applied with 40-40-60kg NPK (F_1) obtained the highest HI of 0.43 but were comparable with the HI of F_3 at 0.39 and F_2 at 0.38. The lowest HI of 0.28 was obtained from the 0 NPK or the control plants (F_0).

Table 6. Leaf Area Index (LAI) and Harvest Index (HI) of NSIC Sp30 sweetpotato at various plant spacing and rates of NPK fertilization

	Leaf Area Index (8 WAT)	Leaf Area Index (16 WAT)	Harvest Index
Plant spacing			
D_1:75cmx25cm	1.65	2.18	0.40
D_2:100cmx25cm	1.76	2.12	0.36
D_3:100cmx50cm	1.54	2.09	0.35
F (p)	1.24 (0.38)	0.13 (0.88)	2.90 (0.17)
CV_a (%)	10.84	12.22	14.40
Rates of NPK Fertilization			
F_0:Control	0.63^c	1.41^b	0.28^b
F_1:40-40-60kg ha^{-1} NPK	1.57^b	2.28^a	0.43^a
F_2:60-60-90kg ha^{-1} NPK	2.01^a	2.50^a	0.38^{ab}
F_3:80-80-120kg ha^{-1} NPK	2.39^a	2.33^a	0.39^{ab}
F (p)	72.71 (<0.01)	20.24 (<0.01)	4.81 (<0.01)
CV_b (%)	9.26	8.27	22.82

*Treatment means within the column followed by common letters and those without letter designations are not significantly different at the 5% level of the HSD test.

According to Marschner (1995), the source-sink relationship is characterized by strong genotype to environment interactions from the source (leaf area) to the sink size (storage roots). Crops with high HI tend to become source limited than crops with low HI. The effect of mineral nutrient supply on the yield response curves often reflects sink limitations imposed by excessive supply or deficiency during certain critical periods of crop growth. For root and tuber crops like sweetpotato, the induction of growth of the storage organ is strongly influenced by environmental factors, ie, fertilizer application. A large and continuous supply of fertilizer specifically N to the roots of sweetpotato delays or prevents tuberization (Relente & Asio 2020). Cessation of storage development with high amounts of N fertilizer induces regrowth of roots or more production of secondary root growth (Marschner 1995).

Bhagsari and Ashley (1990) reported that sweetpotato HI, which ranged from 0.43 to 0.77, resulted in the highest root yield. For this study, the highest HI of 0.43 obtained was in plants applied with 40-40-60kg ha^{-1} NPK which also obtained the highest root yield (Table 6 and Table 3). Darko et al (2020) reported an optimum HI for sweetpotato ranged from 0.3 to 0.6 which are more or less in the same range obtained by Bhagsari and Ashley (1990) and from this study.

Relationship Between Plant Spacing and NPK Application

Figure 4 shows the relationship between plant spacing and NPK application on the total root yield of the NSIC Sp30 sweetpotato variety. An increasing root yield was noticed across planting density when rates of NPK were increased from no NPK (F_0) to a 50% increase of the RR (F_2). However, the root yield in D_1 declined between F_1 (40-40-60kg ha^{-1} NPK) and F_2 (60-60-90kg ha^{-1} NPK) while the root yield in D_2 declined at F_2 (60-60-90kg ha^{-1} NPK). The root yield in D_3 however had a steady increase even at the rate of 80-80-120kg ha^{-1} NPK a 100% increase from the RR (F_3). This suggests that plants spaced at closer densities (D_1 and D_2) require less fertilization per hectare than when plants are spaced at wider densities due to competition between plants. Some nutrients become toxic with excessive application of fertilizer resulting in reduced root production (Singh & Sharma 2014).

For sweetpotato, high amounts of N could cause a reduction of the root yield due to its strong influence on the distribution of dry matter within the plant affecting the root growth relative to shoot growth (O'Sullivan et al 1997). Bourke (1985) reported that in continuous cropping, N had a greater influence on the growth and yield of sweetpotato than K fertilization. N increased the leaf area duration which increased the mean tuber weight thus the root yield. K influenced the tuber yield via an increase in the proportion of the dry matter which diverted into tubers thus increasing the tuber number per plant. Bourke (1985) suggested that K should be applied early in the crop's life.

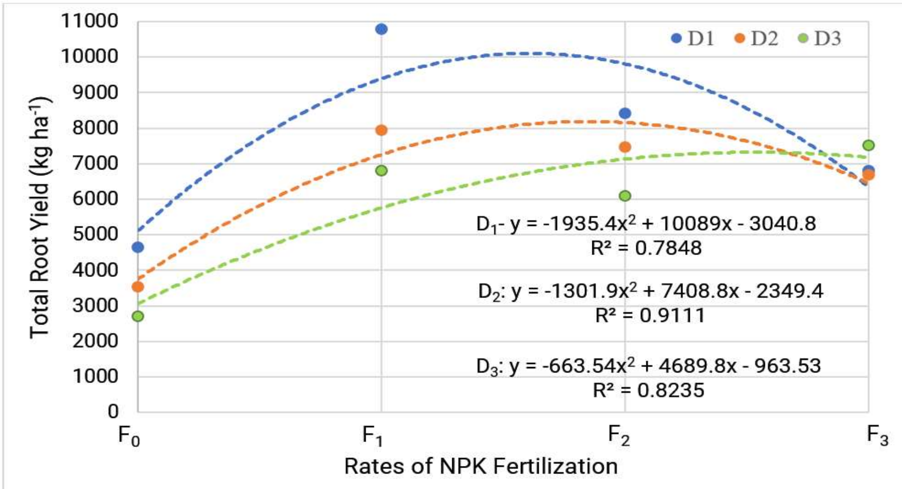

Figure 4. Relationship between various plant spacing (D_1: 75cmx25cm, D_2: 100cmx25cm, D_3: 100cmx50cm) and rates of NPK application (F_0: control, F_1: 40-40-60kg ha^{-1}, F_2: 60-60-90kg ha^{-1}, F_3: 80-80-120kg ha^{-1}) on the total root yield (kg ha^{-1}) of NSIC Sp30 sweetpotato

CONCLUSIONS

In this study, the effect of plant spacing and NPK fertilization of NSIC Sp30 sweetpotato variety was evaluated in terms of its growth responses, yield and yield components. More primary lateral vines were recorded from plants spaced at 100cmx50cm (D_3) while plants spaced at 75cmx25cm (D_1) produced more small and medium-sized roots. Plants spaced at 100cmx50cm produced more large roots. Plants applied with 60-60-90kg ha^{-1} NPK (F_1) produced longer main vines, higher fresh herbage yield, and higher LAI compared to the control but were comparable to the application of 40-40-60 (F_2) and 80-80-120kg ha^{-1} N, P_2O_5, and K_2O (F_3). Comparable HI was noticed in plants with (F_1), (F_2), and (F_3) all of which were superior to the HI of the control plants (F_0). The NPK-applied plants produced shorter roots with bigger root diameters than those not applied with NPK. Highest weights of marketable roots and total root yield were observed in plants applied with 40-40-60kg ha^{-1} NPK but were comparable with those applied with 60-60-90 and 80-80-120kg ha^{-1} NPK.

An interaction effect was noticed between the plants spaced at 100cmx50cm and rates of NPK fertilization. More medium-sized roots at distance D_3 were obtained when applied with 40-40-60, 60-60-90, and 80-80-120kg ha^{-1} NPK. The growth and yield performance of NSIC Sp30 was better when plants were spaced at 75cmx25cm with 53,333 plants ha^{-1} and fertilized with 40-40-60kg ha^{-1} of NPK.

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