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EFFECTS OF FERTILIZER MICRODOSING ON SOIL PHOSPHORUS AND SULPHUR AVAILABILITY TO *SOLANUM MACROCARPON* IN SOUTHWEST NIGERIA

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Abstract: This present study aimed at evaluating the effect of fertilizer rate and time of application on yield, and determined the availability of soil P and S to *S. macrocarpon*. The experiment was conducted in the derived savanna (Ogbomoso) and the rainforest (Ilesha) in southwest Nigeria. The treatments were arranged in a factorial combination and laid out in a split-plot design with four replicates. The main plots were the fertilizer rates of 0, 20, 40, 60, and 80 kg N ha $^{-1}$ (without organic fertilizer), with the time of urea application (at planting and two weeks after planting) as a sub-plot. *S. macrocarpon* was the test crop. Plant fresh weight, P, and S uptake were determined at the first harvest. The results showed that a fertilizer rate of 20 kg N ha $^{-1}$ produced significantly higher yields and uptake of P and S in the derived savanna (4.2 ha $^{-1}$) and in the rainforest (1.2 t ha $^{-1}$). Application at two weeks after planting (2 WAP) produced higher yields (3.3 t ha $^{-1}$) in the derived savanna, while the application at planting (AAP) produced the highest yield (1.2 t ha $^{-1}$) in the rainforest. Although the time of fertilizer application did not affect fresh yields and nutrient availability, this study concluded that 60 kg N ha $^{-1}$ plus 5 tons ha $^{-1}$ was the optimum fertilizer combination for *S. macrocarpon* production in southwest Nigeria.

Key words: *Solanum macrocarpon*, phosphorus, sulfur, fresh weight, fertilizer, microdosing.

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Introduction

Solanum macrocarpon contains essential macro and micronutrients, vitamins, and considerable amounts of protein, making it economically, nutritionally, and medicinally important. The roots, leaves, and fruit of *S. macrocarpon* possess medicinal qualities. In Nigeria, the fruit is used as a laxative and to treat cardiac diseases, while the flowers are chewed on to clean the teeth. In Sierra Leone, the leaves are used to ease throat pain. In Kenya, the roots are boiled, and the juice is then consumed to eliminate hookworms in the stomach (Plant Resources of Tropical Africa – PROTA, 2004). The root is also used for bronchitis, body aches, asthma, and to accelerate wound healing. It contains high levels of Ca, Mg, and Zn (Idowu et al., 2014; NICANVEG, 2014).

Nitrogen (N), phosphorus (P), and sulphur (S) are essential nutrients needed for high yields and quality of vegetables. For example, N is vital for the photosynthetic activity, and both vegetative and reproductive metabolisms; P is involved in energy storage needed for physiological processes and photosynthetic reactions, while S is an important component of chlorophyll, certain vitamins, and proteins in plants (Adepetu et al., 2014). These nutrients have specific functions and synergistic relationships; therefore, it is expedient that they are supplied to the plant in sufficient quantities at the right time (Omotoso and Akinrinde, 2013). The effective placement and timing of fertilizers maximize both yield and nutrient use efficiency (Jones and Jacobsen, 2009), increase net returns for vegetable farmers, and reduce environmental pollution from fertilizers. Although vegetables respond positively to organic and/or inorganic fertilizer application in Nigeria (Idowu, 2010; Ajibola et al., 2015; Ehigiator et al., 2015), the cost of these fertilizers is unaffordable by resource poor farmers in Southwest Nigeria (Adebisi-Adelani et al., 2011; FEPSAN, 2014), and they lack adequate knowledge of fertilizer application or recommended rates. Consequently, the nutritional, medicinal, and economic benefits of these vegetables are forfeited.

Fertilizer microdosing involves the application of relatively small quantities of fertilizer at sowing or shortly after sowing, substantially reducing the recommended fertilizer rates that subsistence farmers need to apply while giving plants enough nutrients for optimal growth (ICRISAT, 2009). The implementation of this technology has resulted in greater nutrient use efficiency and positive responses of increased production of crops such as maize and pearl millet in some African countries (Twomlow et al., 2010; Bagayoko et al., 2011). It also permits a more precise and better-timed fertilizer placement, resulting in improved fertilizer management (Sanginga and Woomer, 2009). However, there is limited information on the effects of urea and organic fertilizer application under microdosing on the yield and uptake of P and S in the selected vegetable crops, which is the focus of this study.

The specific objectives of this research were to examine the effects of fertilizer rate and application timing on yield and soil P and S availability to *S. macrocarpon*, with the aim of establishing the optimum fertilizer application for vegetable production in southwest Nigeria.

Material and Methods

The study was conducted in two locations: the rainforest zone (Ilesha, Osun State) and the derived savannah (Ogbomoso, Oyo State). These zones were part of the Nigeria-Canada-Vegetable/Micro-Veg project sites and had been under vegetable cultivation for 3 years. The experiment was conducted in 2015 at the experimental fields. Ogbomoso is located at latitude 8^0 6' 35" N and longitude 4^0 18' 41" E in Oyo State with a bimodal rainfall pattern that ranges between 1296 mm and 1306 mm. Ilesha is located at latitude 7^0 38' 36" N and longitude 4^0 45' 40" E in Osun State, with a bimodal rainfall pattern varying between 1600 and 2000 mm.

Bulk surface soil samples were randomly collected at a 0–15-cm depth from the unfertilized plots for routine analysis. Soil samples were air-dried, crushed in an agate mortar, and passed through a 2-mm sieve to remove roots, stones, and other debris. The fraction that passed through the sieve was kept in an air-tight container and analyzed for the following properties. Particle size distribution was determined by the modified hydrometer method (Bouyoucous, 1962) using 0.2 M NaOH solution as the dispersing agent. Soil pH was determined using a glass electrode pH meter in 0.01 M $CaCl_2$ solution, using a 1:2 soil: $CaCl_2$ solution (Thomas, 1996). Soil organic carbon was determined by the chromic acid digestion method (Walkey and Black, 1934). The total N concentration was determined by the macro-Kjeldahl method (Bremner, 1996), available S was extracted using KH_2SO_4 and was determined using the turbidimetric method (Tabatabai, 1974). The available P was extracted by the Bray-1 method (Kuo, 1996) and determined using a spectrometer (Model 721 Visible Spectrophotometer, Axiom Mediral LMD U.K.). Exchangeable Ca, Mg, K, and Na were extracted with a neutral (pH 7) solution of 1N NH_4OAc. Potassium, Ca, and Na were determined using a flame photometer (Model 2655-00 Digital Flame Analyzer, Cole-Parmer Instrument Company, Chicago, Illinois 60061), and Mg was determined by the atomic absorption spectrophotometry (PG-900 Atomic Absorption Spectrophotometer Model, PG-instrument Ltd., United Kingdom).

The experimental plots measured 3 m × 2 m, with 1-m spacing within a total area of 29 m × 15 m. The treatment consisted of a factorial combination of five nitrogen levels (0, 20, 40, 60, and 80 kg N ha^{-1}, without organic fertilizer), two urea application times (at planting and two weeks after planting). Organic fertilizer (3.5% N, 1% P, and 1.2% K) was applied at 5 tons ha^{-1} as a basal fertilizer one week before urea application, with the exception of 80 kg N ha^{-1}. All the treatments were replicated four times.

Solanum macrocarpon shoots were harvested at seven weeks after planting (WAP). The shoots were harvested by cutting the stem at about 8 cm above the soil surface. Subsequent harvests were conducted every two weeks; the fresh weight of the harvested edible shoots was measured per plot and immediately transported to the Soil Science Laboratory at Obafemi Awolowo University, Ile-Ife, Nigeria. The vegetable leaf samples were randomly collected from each harvested shoot. The vegetable samples were dried in a draft oven set at 70˚C in the laboratory, and 0.5 g of the dried vegetable tissue was digested using the wet ashing method (Piper, 1944). The ash was extracted with 2 ml of 6 N H_2SO_4, and the extract was quantitatively transferred to a 50 ml volumetric flask and made up to the mark. Appropriate dilutions were prepared, and the elements were analyzed against their standards. All the samples were analyzed along with a blank solution. Phosphorus content was determined using the vanadomolybdate method (Kuo, 1996), and absorbance was measured using a visible spectrophotometer at 440 nm wavelengths, while S content was determined using the turbidimetric method (Tabatabai, 1974), with absorbance measured at 420 nm wavelength using the visible spectrophotometer. Standard solutions of P and S at different concentrations were also measured. A standard curve was plotted with the concentrations of the standards against the absorbance readings, and this was used to determine the concentrations of P and S in the samples.

Data collected was subjected to analysis of variance (ANOVA) to assess treatment effects and time of application on fresh yield and the uptake of phosphorus and sulphur by the vegetable. Means were separated using Duncan's multiple range test at the 5% level of probability (SAS 9.1).

Results and Discussion

The soils (Table 1) were strongly acidic (pH 5.4) in the rainforest (Ilesha) and moderately acidic (pH 5.70) in the derived savanna (Ogbomoso) when measured in 0.01 M $CaCl_2$. The textural classification of the soil for both locations was loamy sand. The organic carbon and total N contents of the soils in the rainforest zone (8.4 and 2.3 g kg^{-1}) and the derived savanna (16.6 and 1.8 g kg^{-1}) were within the medium fertility class (Sobulo and Adepetu, 1987; Adepetu, 1990). The available P was high in the rainforest and medium in the derived savanna. The available S in both agro-ecologies was low (Adetunji and Adepetu, 1987). Exchangeable Ca, Mg, K, and Na were above the critical levels (0.03 cmol kg^{-1}) established for maize in the region (Adepetu et al., 2014).

Table 1. The physical and chemical properties of the soil (0–15 cm) used for the experiment.

Soil properties	RAINFOREST	DERIVED
Sand ($mgkg^{-1}$)	760	820
Silt "	90	50
Clay "	150	130
Textural class	Loamy sand	Loamy sand
pH (0.01M $CaCl_2$)	5.4	5.7
Total N (gkg^{-1})	2.3	1.8
Organic C (gkg^{-1})	16.6	8.45
Available P ($mgkg^{-1}$)	24	19
Available S ($mgkg^{-1}$)	3.59	3.31
Exchangeable Ca ($cmolkg^{-1}$)	1.78	1.30
" Mg "	0.49	0.43
" K "	0.48	0.40
" Na "	0.11	0.10

Table 2 shows that the fertilizer treatment using microdosing technology had a significant effect on the fresh yield of *S. macrocarpon.* The application of organic and inorganic fertilizer at rates of 20, 40 and 60 kg N ha^{-1} significantly increased yields, although these were not significantly different from the yields obtained with 80 kg N ha^{-1}, compared to the control. This result is in line with Akintoye et al. (2006), who found that the use of inorganic fertilizer alone supports the production of *S. macrocarpon*. Furthermore, this result substantiates the findings of Ncube et al. (2007), who reported that larger average gains could be obtained by combining nitrogen fertilizer with a basal application of manure. Twomlow et al. (2010) also reported significant increases in cereal grain yield with 17 kg N ha^{-1} (approximately 25% of recommended levels) compared to recommended rates of 55 kg ha^{-1} under microdosing.

In this study, significant increases in the yield of the vegetables with 20 kg N ha^{-1} were observed compared to the recommended rates of Nafiu et al. (2011), who have established that 30 kg N is optimum for *S. macrocarpon* production. Although the time of application did not have a significant effect on the yields of *S. macrocarpon*, it was observed that application at 2 WAP was more favorable in the derived savanna, while the application at AAS was favorable in the rainforest. This result is in line with the findings of Hayashi et al. (2008).

Fertilizer treatments at both locations had no significant effect on the uptake of phosphorus as shown in Table 3. Following the same trend with yield, a fertilizer rate of 20 kg N ha^{-1} resulted in the highest uptake. The highest P uptake was also observed in the derived savanna compared to the rainforest. This can be attributed to the fact that soils in the rainforest are richer in nutrients compared to those in the derived savanna, which are fragile and low in organic matter content (Abiala et al., 2014). Hence, there was a higher response to fertilizer treatments in the derived savanna compared to the rainforest zone. Although the two fertilizer application times showed no significant differences, application at 2 WAP was favorable for higher P uptake in the derived savanna, while AAS was favorable in the rainforest. This can be attributed to the varying climatic conditions that exist across ecological zones.

Table 2. Effect of time and fertilizer rates on fresh yield of *Solanum macrocarpon* at the two agroecologies.

	DERIVED SAVANNA			RAINFOREST		
Fertilizer rate (kg ha^{-1})	T1 →	T2 kg ha^{-1}	Mean ←	T1 →	T2 kg ha^{-1}	Mean ←
0	333b	1750b	1042	604b	417b	511
20	4583a	3792ab	4188	1104ab	1229ab	1167
40	1417ab	3458ab	2438	1833a	750ab	1292
60	1333ab	4750a	3042	1771ab	1292ab	1532
80	2167ab	2625ab	2396	775ab	1708a	1242
Mean	1967	3275	2621	1218	1079	1149
LSD	3137	2142	-	1038	1140	-

Means with the same letters are not significantly different from each other at $p \leq 0.05$. LSD – least significant difference, where: 0 – organic fertilizer (OF) only, 20 – OF + 20 kg N ha^{-1}, 40 – OF + 40 kg N ha^{-1}, 60 – OF + 60 kg N ha^{-1}, 80 – 80 kg N ha^{-1} only. T 1 – fresh yield at planting, T 2 – fresh yield at 2 WAP.

A slight decline in P uptake was also observed at both locations. This is in line with Agbede et al. (2010), who found that the combined application of mineral and organic manure at suboptimal rates ensured greater availability of major nutrients in the soil and increased yam leaf nutrient concentration, growth, and tuber yield compared with full rates of mineral fertilizer or organic manure alone. Ogbodo (2009) has further explained that organic matter releases organic acids, which increases the rate of P desorption and thus improves its availability and other nutrients in the soil.

Although the time of fertilizer application had no significant effect on P uptake, higher uptake, attributed to well-established root hairs and well-decomposed organic material, was observed in the derived savanna with the application at 2 WAP while higher P uptake was obtained at AAS in the rainforest zone, owing to higher precipitation and soil type.

Table 3. The effect of fertilizer rate and time of application on the availability of soil P to *S. macrocarpon*.

Fertilizer rate (kg ha^{-1})	DERIVED SAVANNA T1	DERIVED SAVANNA T2 (kg ha^{-1})	DERIVED SAVANNA Mean	RAINFOREST T1	RAINFOREST T2 (kg ha^{-1})	RAINFOREST Mean
0	0.02a	0.64a	0.33	0.05a	0.03a	0.04
20	3.50a	2.21a	2.85	0.13a	0.27a	0.20
40	0.32a	1.45a	0.88	0.38a	0.08a	0.23
60	0.33a	2.44a	1.38	0.36a	0.16a	0.26
80	0.56a	0.80a	0.67	0.11a	0.30a	0.21
Mean	0.95	1.51	1.23	0.21	0.17	0.19
LSD	3.30	1.86		0.34	0.33	

Means with the same letter are not significantly different from each other at $p \leq 0.05$, where: 0 – organic fertilizer (OF) only, 20 – OF + 20 kg N ha^{-1}, 40 – OF + 40 kg N ha^{-1}, 60 – OF + 60 kg N ha^{-1}, 80 – 80 kg N ha^{-1} only; T 1 – phosphorus availability at planting, T 2 – phosphorus availability at 2 WAP.

Table 4 shows the effect of fertilizer rate and time of application on the availability of soil S to *S. macrocarpon*. The fertilizer rate had no significant effect on S uptake by the vegetable. Sulphur uptake increased with increasing fertilizer rate, but the highest uptake occurred at 20 kg N ha^{-1}, while the control had the lowest uptake by *S. macrocarpon*.

Table 4. The effect of fertilizer rate and time of application on the availability of soil S to *S. macrocarpon*.

Fertilizer rate (kg ha^{-1})	DERIVED SAVANNA T1	DERIVED SAVANNA T2 (kg ha^{-1})	DERIVED SAVANNA Mean	RAINFOREST T1	RAINFOREST T2 (kg ha^{-1})	RAINFOREST Mean
0	0.11b	0.49b	0.30	0.18a	0.07ab	0.12
20	1.26a	1.30a	1.28	0.32 a	0.37ab	0.35
40	0.52ab	1.00ab	0.76	0.51 a	0.21ab	0.36
60	0.45ab	1.33a	0.89	0.47 a	0.31ab	0.39
80	0.65ab	0.68ab	0.66	0.23 a	0.43a	0.33
Mean	0.60	0.96	0.57	0.34	0.28	0.31
LSD	0.82	0.65		0.33	0.31	

Means with the same letters are not significantly different from each other at $p \leq 0.05$, where: 0 – organic fertilizer (OF) only, 20 – OF + 20 kg N ha^{-1}, 40 – OF + 40 kg N ha^{-1}, 60 – OF + 60 kg N ha^{-1}, 80 – 80 kg N ha^{-1} only; T 1 – sulphur availability at planting, T 2 – sulphur availability at 2 WAP.

The time of fertilizer application had no significant effect on the uptake of S at either location. The application at 2 WAP was favorable for S uptake in the derived savanna, while AAS was favorable for the uptake of S in the rainforest. A slight decline in S uptake, similar to P uptake, was observed with the application of 80 kg N ha^{-1}, though this was not significantly different from 60 kg N ha^{-1}. This result is in line with the findings of Islam et al. (2011), who observed that higher nutrient uptake (N, P, K and S) by radish-stem-amaranth was significantly influenced by the integrated treatment of organic and inorganic fertilizers. Moreover, Wilkinson et al. (2000) and Fageria (2009) explained that the addition of nitrogen can increase P concentration in plants by increasing root growth and by increasing the ability of roots to absorb and translocate P. Additionally, the acidifying effect of N fertilizers could enhance N concentration in plants (Malhi et al., 1988) and P solubility in soil (Power and Prasad, 1997), which improves photosynthetic efficiency and nitrogen metabolism by enhancing the synthesis of new chloroplast thylakoids (Menghini et al., 1998). These effects result in increased assimilation of P and S (Osman, 2013).

Conclusion

This study concluded that using microdosing technology, a fertilizer rate of 20 kg N ha^{-1}, was optimal for *Solanum macrocarpon* production and the uptake of P and S in southwest Nigeria. The time of fertilizer application had no significant effect on yield or uptake of P and S by *T. occidentalis*. This study demonstrated that combination of fertilizer microdosing with the application of organic fertilizer was a more sustainable alternative for achieving optimal yield of fluted pumpkin and sustainable fluted pumpkin production, in contrast to the excessive use of fertilizers by farmers. Further research is required on other underutilized indigenous vegetables in Africa to establish the effectiveness of microdosing for all such crops.

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UTICAJI MIKRODOZA ĐUBRIVA NA DOSTUPNOST FOSFORA I SUMPORA U ZEMLJIŠTU ZA *SOLANUM MACROCARPON* U JUGOZAPADNOJ NIGERIJI

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R e z i m e

Ovo istraživanje imalo je za cilj da proceni uticaj doze đubriva i vremena primene na prinos, kao i da utvrdi dostupnost fosfora (P) i sumpora (S) u zemljištu u usevu *S. macrocarpon*. Eksperiment je sproveden u zoni savane (Ogbomoso) i kišne šume (Ileša) u jugozapadnoj Nigeriji. Tretmani su bili raspoređeni u kombinaciji faktora i postavljeni po dizajnu podeljenih parcela (engl. *split-plot design*) sa četiri ponavljanja. Glavne parcele činile su doze đubriva od 0, 20, 40, 60 i 80 kg N ha^{-1} (bez organskog đubriva), dok je vreme primene uree (pri sadnji i dve nedelje nakon sadnje) predstavljalo potparcele. Testirani usev bio je *S. macrocarpon*. Sveža masa biljaka, kao i usvajanje P i S, određivani su pri prvoj berbi. Rezultati su pokazali da je doza đubriva od 20 kg N ha^{-1} dovela do statistički značajno viših prinosa i većeg usvajanja P i S u zoni savane (4,2 t ha^{-1}) i kišne šume (1,2 t ha^{-1}). Primena dve nedelje nakon sadnje dala je veće prinose (3,3 t ha^{-1}) u zoni savane, dok je primena pri sadnji dala najviši prinos (1,2 t ha^{-1}) u zoni kišne šume. Iako vreme primene đubriva nije imalo uticaja na prinos sveže mase i dostupnost hranljivih materija, istraživanjem se zaključilo da je kombinacija 60 kg N ha^{-1} uz 5 t ha^{-1} optimalna kombinacija đubriva za proizvodnju *S. macrocarpon* u jugozapadnoj Nigeriji.

Ključne reči: *Solanum macrocarpon*, fosfor, sumpor, sveža masa, đubrivo, mikrodoza.

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