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The Influence of Nitrogen Fertilizer Application on Yields and Nitrogen Use Efficiencies of *Solanum macrocarpon* and *Solanum scabrum* in Southwest Nigeria

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Abstract

Solanum macrocarpon and *Solanum scabrum* are good sources of vitamin, minerals, protein, anti-oxidants and fiber in southwest Nigeria. The study examined the effects of nitrogen fertilizer application on yields and nitrogen use efficiencies of *Solanum macrocarpon* and *Solanum scabrum* in Iwaro-Oka, Ondo State in southwest Nigeria in 2014 and 2015. The experiment was a 4 × 4 factorial arranged into a randomized complete block design with four rates of urea-N drilled at 0, 40, 80 and 160 kg/ha and replicated four times. Each plot was 3 m × 2 m with space of 1 m between plots. Vegetable seeds were planted by drilling. Fresh shoot and dry matter yields were determined. Nitrogen content and uptake were determined, and nitrogen use efficiency estimated. The result showed that average dry matter weight for *S. macrocarpon* was 228 kg/ha and *S. scabrum* was 6116 kg/ha. Average nitrogen uptake was 5.90 kg/h and 158.60 kg/ha for *S. macrocarpon* and *S. scabrum,* respectively. Nitrogen use efficiencies were 6.48 kg/ha, 0.15 kg/ha and 0.1 kg/ha for *S. macrocarpon* and 87.33 kg/ha, 26.14 kg/ha and 24.35 kg/ha for *S. scabrum* at 40, 80 and 160 kg N/ha, respectively. Negative values were obtained for N-recovery for *S. macrocarpon* while *S. scabrum* gave 5.85%, 2.10% and 1.44% at 40, 80 and 160 kg N/ha, respectively. The study concluded that *S. scabrum* had higher nitrogen use efficiency in the soil than *S. macrocarpon* and that highest NUE and N recovery were obtained at 40 kg N/ha.

Keywords

Underutilized Vegetables, Soil Fertility, Plant Moisture Content

1. Introduction

African eggplant (*Solanum macrocarpon*) and African nightshades (*Solanum scabrum*) are very important underutilized vegetables of southwest Nigeria and other countries of Africa [1] [2]. The vegetables are good sources of vitamin C, riboflavin, folic acid, carotenes, protein, iron, vitamin A, iodine, calcium, potassium and zinc [3] [4]. Good consumption of the vegetables could contribute to healthy diets in the face of the current COVID-19 pandemic. Nitrogen is the most essential element for plant nutrition and the most limiting nutrient for crop growth and yield [5]. It is important for chlorophyll formation, protein synthesis and coenzyme. Nitrogen content of savanna soil of Nigeria is low because of wide C/N ratio, which greatly affects N availability compared with forest soil. Limited soil water and nitrogen are major factors militating against crop production in the region. Climatic factors, temperature and moisture also have profound effect on N availability through their effects on N mineralization, transformation and movement. Approximately 50% of total N fertilizer applied was being taken up by the crop. Vegetable crops require high amount of nitrogen; however, research attention on indigenous vegetables has over the years focused on diversity, production and marketing, role in poverty alleviation, nutritional quality, processing techniques, livelihood diversification studies and fertilizer requirement.

Little information is available on nitrogen uptake and nitrogen use efficiency of indigenous underutilized vegetables of southwest Nigeria [6]. Genotypical differences in nutrient efficiency are related to differences in efficiency in acquisition by the roots, or in utilization by the plants or both. Efficiency in acquisition is frequently defined in terms of total uptake per plant or specific uptake rate per unit root length, and efficiency in utilization (nutrient use efficiency) as dry matter production per unit nutrient in the dry matter. For a given genotype, nutrient efficiency is reflected by the ability to produce a high yield in a soil that is limiting in one or more mineral nutrients for a standard genotype. According to [7], N use efficiency is the result of two main components: N uptake efficiency, which is the ability of crops to take up N from the soil and use efficiency with which crops use the absorbed N to grow and give yield. These efficiencies may differ within the same crop because they depend on different organs and mechanisms and on different environmental factors as well. At application of large amount of nutrients for plants with lower nutrient use efficiency, a luxury consumption may occur [8].

Since leafy vegetables have high demand for nitrogen, intensive production of vegetable in order to provide balanced nutrition for rapidly increasing population in developing countries and reduce environmental pollution, demand for high fertilizer used efficiency. The nitrogen use efficiencies of *Solanum macrocarpon* and *Solanum scabrum* in soils of savanna have not been documented. Understanding plant N uptake dynamics is critical for increase fertilizer N uptake efficiency and minimize the risk of N loss. The aim of the study was to examine the effects of nitrogen fertilizer application on dry matter yields, N uptake, nutrient use efficiencies and N recovery of *Solanum macrocarpon* and *Solanum scabrum* with a view to improving food and nutrition security in Nigeria.

2. Materials and Methods

2.1. Description of the Study Area

The study was carried out in Iwaro Oka, Ondo State, southwest Nigeria in 2013. The study location lies between Latitude 07˚25'25.99"N and Longitude 05˚46'29.14"E with elevation ranging between 350 and 353 m above sea level. The area climatic region was characterized by alternating wet and dry season and underlain by the Precambirian Basement complex [9].

2.2. Soil Sampling, Preparation and Analysis

Bulk surface soil samples (0 - 15 cm) were collected from unfertilized plots from Obafemi Awolowo University, Teaching and Research Farm, Ile-Ife. Soils at the sampling site have been classified as Iwo series (the local name) [10] and Typic Paleustult (the international name) [11]. Soil samples were air dried, crushed in agate mortar, passed through a 2-mm sieve, and analyzed for following properties. Particle size distribution was determined by the modified hydrometer method [12] using 0.2 M NaOH solution as the dispersing agent. Soil pH was determined using a glass electrode pH meter in both distilled water and 0.01 M $CaCl_2$ solution, using mass ratio for 1:2 soil:$CaCl_2$ solution as described by [13]. Soil organic carbon was determined by the chromic acid digestion method of [14]. The total N concentration was determined by macro-Kjeldahl method according to [15], and the available P was extracted by Bray-1 method as described by [16] and determined using Spectrometer (Model 721 Visible Spectrophotometer, Axiom Mediral LMD. UK). Exchangeable K, Ca, Na and Mg were extracted with neutral (pH 7) solution of 1 N NH_4OAc. K, Ca and Na were determined using the flame photometer (flame photometer model 2655-00 Digital Flame Analyzer, Cole-Parmer Instrument Company, Chicago, Illinois 60061) and Mg by the atomic absorption spectrophotometer (PG-900 Atomic Absorption Spectrophotometer Model, PG-instrument Ltd. United Kingdom).

2.3. Experimental Design

The experiment was arranged into a Completely Randomized Design with N at 0, 40, 80 and 160 kg/ha^{-1} applied as urea fertilizer and replicated four times, as previously described by [3].

A plot was 2 m × 3 m with 1 m between the plots. Planting method was by drilling and control of weeds and pests were as previously described by [3]. Fertilizer was applied at two weeks after planting and immediately after the first and second harvest.

2.4. Data Collection

2.4.1. Shoot Fresh and Dry Matter Weight

Solanum scabrum shoot was harvested at six weeks after planting (WAP) whereas *Solanum macrocarpon* shoot was harvested at eight WAP. The shoots of all vegetable plants on each plot were harvested by cutting the stem at 4 cm above the soil surface and the weight recorded. Shoot subsample was collected in polyethylene bag and immediately transported to the Soil Testing Unit of the Department of Soil Science and Land Resources Management, Obafemi Awolowo University, Ile-Ife. Leaves and succulent stem of the sub-sample were collected and dried in oven at 65˚C until a constant weight was obtained. The dry weight was determined.

The shoot dry matter weight was estimated using the following expressions

Oven dry weight of shoot per plot (kg):

$$\frac{\text{Oven dry weight of subsample}(\text{g})}{\text{Fresh weight subsample}(\text{g})} \times \frac{\text{Fresh weight of shoot per plot }(\text{kg})}{1}$$

$$\text{Total shoot dry matter weight}\left(\text{kg/ha}^{-1}\right) = \frac{\text{Oven dry weight of shoot per plot }(\text{kg}) \times 10,000\text{ m}^2}{\text{Area of land of plot }\left(6\text{ m}^2\right)}$$

2.4.2. Determination of Nitrogen Composition

Plant tissue N content was determined using micro-Kjeldahl method.

2.4.3. Determination of Shoot Dry Matter Yield, N Uptake, N Use Efficiency and N-Recovery

N uptake, NUS and N-recovery were estimated using the following expressions

$$\text{Determination of tissue N uptake}\left(\text{kg/ha}^{-1}\right) = \frac{\text{Total shoot dry matter weight }\left(\text{kg/ha}^{-1}\right)}{1} \times \frac{\text{Nitrogen content }(\%)}{100}$$

$$\text{Nitrogen Use Efficiency }(\text{NUE})\left(\text{ton ha}^{-1}\right) = \left(Y_N - Y_0\right)/N_r$$

where N_r is the amount of N applied (kg·N·ha^{-1}), Y_N is the dry yield with applied N, and Y_0 is the dry yield without N applied. To further explore the response to applied N, the NR was calculated using the following equation

$$N - \text{recovery }\% = \left(U_N - U_0\right)/N_r \times 100$$

where N_r is the amount of N applied (kg·N·ha^{-1}), U_N is the plant N uptake (ton N·ha^{-1}) with applied N and U_0 is the plant N uptake (ton N·ha^{-1}) without applied N [17].

2.4.4. Data Analysis

Data collected were subjected to analysis of variance (ANOVA) to assess treatment effects and when it was significant means were separated using Fisher's Least Significant Difference at 5% level of probability using SAS 9.1 [18].

3. Results and Discussion

3.1. Growth of the Vegetables

Plate 1(a) & Plate 1(b) show the photographs of *Solanum macrocarpon and Solanum scabrum*. *Solanum macrocarpon* has broad, thicker leaves and more drought tolerant compared with *Solanum scabrum*. The vegetables were planted under rainfed.

3.2. Characteristics of the Soil Used for the Study

The native soil used for growing the vegetables were loamy sand, slightly acidic, medium to low in organic matter and high available P but low exchangeable cations and cation exchange capacity CEC (Table 1). Total N was also low for vegetable production [3].

3.3. Effects of N Fertilizer Application on Dry Matter Yields and N Uptake of the Vegetables

The result showed a significant ($p < 0.05$) increase in dry matter yield only at 160

(a) (b)

Plate 1. Photo of (a) *Solanum macrocarpon* and (b) *Solanum scabrum* at the experimental station.

Table 1. Properties of the soil (air dried) used for the experiment at 0 - 15 cm depth.

Soil properties	*S. macrocarpon*	*S. scabrum*
Textural class	Loamy sand	Loamy sand
Sand g/kg	723	733
Silt g/kg	140	130
Clay g/kg	130	128
pH	6.3	6.3
Organic matter g/kg	197	150
Total N g/kg	0.9	0.8
Available P mg/kg	63	68
Exch. Ca cmol/kg	2.5	2.7
Exch. Mg cmol/kg	1.4	1.3
Exch. K cmol/kg	0.2	0.3
Exch. Na cmol/kg	0.1	0.1
CEC cmol/kg	5.0	5.5

kg N/ha compared with control, which was similar with what was observed at 40 and 80 kg N/ha for *S. macrocarpon* whereas application at 40 kg N/ha and higher rates were markedly ($p < 0.05$) increased the yield compared with the control for *S. scabrum* (**Figure 1(a)** & **Figure 1(b)**). The average dry matter weight at 40 kg N/ha was 93% and 9.2% higher than the values for the control for *S. scabrum* and *S. macrocarpon,* respectively. The values obtained for nitrogen content at applied N were lower that the control due to dilution effect (**Figure 1(c)** & **Figure 1(d)**) [5]. The average nitrogen uptake was 10 kg/ha and 240 kg/ha for *S. macrocarpon* and *S. scabrum,* respectively. The result showed that *S. scabrum* had ability for nutrient acquisition [8].

3.4. Effects of N Fertilizer Application on N Use Efficiency and N-Recovery

Negative values for nitrogen use efficiencies were obtained for N-recovery for *S. macrocarpon* while 40 kg N/ha gave the highest value (87.33 kg/ha), which decreased consistently at 80 kg·N·ha^{-1} and 160 kg N/ha for *S. scabrum* (**Table 2**).

The nitrogen content required for optimal growth varies between 2% to 5% of the plant dry matter weight depending on the plant species, development stage and organ [5] [8]. An increase in the nitrogen supply not only delays senescence and stimulate growth but also changes plant morphology in a typical manner, particularly if the nitrogen availability is high in the rooting medium during the early growth.

The results of our study showed 9% and 93% increase in dry matter weight at

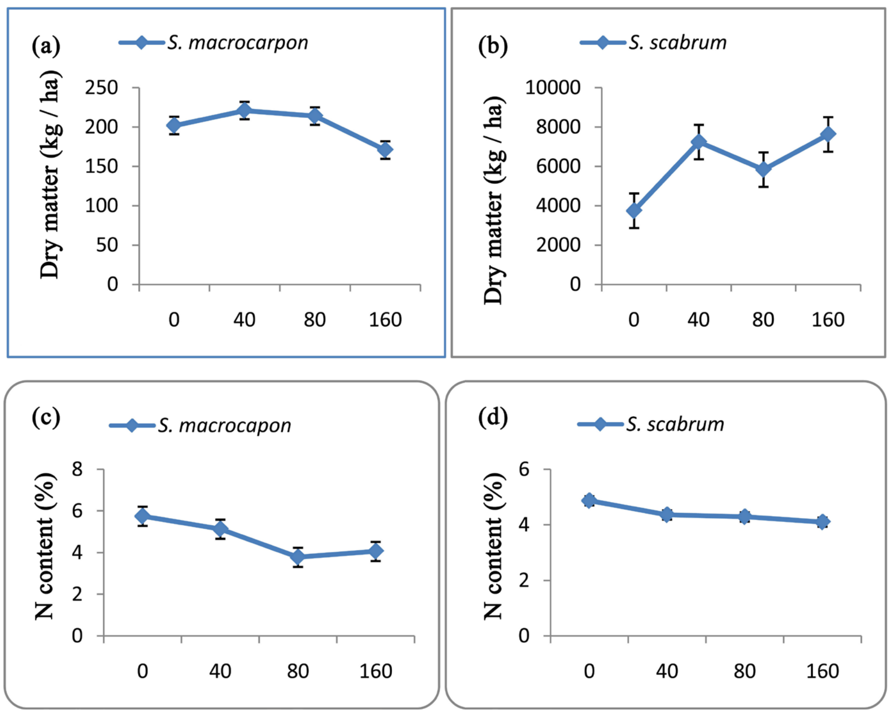

Figure 1. Effects of nitrogen fertilizer application on (a) & (b) shoot dry matter and (c) & (d) N uptake of *S. macrocarpon* and *S. scabrum.*

Table 2. Effects of nitrogen fertilizer application on (a) N use efficiencies (NUE) and (b) N-recovery of *S. macrocarpon* and *S. scabrum.*

Applied N kg/ha	*S. macrocarpon*			*S. scabrum*		
	N uptake kg/ha	NUE kg/ha	N-recovery %	N uptake kg/ha	NUE kg/ha	N-recovery %
0	12	-	-	82	-	-
40	11	0.48	-0.03	316	87.33	5.85
80	8	0.15	-0.05	250	26.14	2.10
160	9	0.10	-0.02	312	24.25	1.44

application of 40 kgN/ha, which were not significantly different from the values obtained at 80 kgN/ha and 160 kgN/ha for *S. macrocarpon* and *S. scabrum*, respectively, showing a luxury consumption. These observation confirmed the previous finding of [8] on luxury consumption of nutrient and nutrient use efficiency at high nutrient availability There was a wide difference in the use of nitrogen take up between *S. macrocarpon* and *S. scabrum*. The high dry matter weight produced by *S. scabrum* at 40 kgN/ha could be explained by the report of earlier study by [19] that photosynthesis of C_4 plant species of tropical origin have high photosynthetic rates and produce large amounts of dry matter. The C_4 mechanism enables plants to utilize both CO_2 and water more efficiently. *S. scabrum* gave highest % N-recovery (5.85%) at 40 kgN/ha while negative values were obtained for *S. macrocarpon*.

4. Conclusion

The study concluded that *S. scabrum* had higher nitrogen uptake and nitrogen use efficiency in the soil compared with *S. macrocarpon* and that highest NUE and N recovery were obtained at 40 kgN/ha. There is a need for further studies on N use efficiency of indigenous underutilized vegetables of Africa in order to achieve their potentials for improved nutrition security.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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