Potential of *Tithonia diversifolia* Biomass as Alternative for Inorganic Fertilizer to Improve Production of African Nightshade (*Solanum nigrum* L.)

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Authors' contributions

This work was carried out in collaboration between all authors. CMJ, CN and AST designed the experiment. CMJ established the experiment and collected data. LTN and AST conducted soil analysis. CMJ, CBT and CN processed data performed statistics. CN wrote the first manuscript draft. All authors read and approved the final manuscript.

ABSTRACT

Poor soil fertility is a major constraint for crop production that is commonly corrected with inorganic fertilizers, but their high cost or environmental and health effects have necessitated alternative management strategies. Hence, the biomass of Mexican sunflower (*Tithonia diversifolia*) was evaluated as a sustainable alternative resource to improve soil fertility and production of African nightshade (*Solanum nigrum* L.) A field experiment was laid out as randomized complete block design with four treatments (Control – no fertilizer, urea, NPK and *Tithonia*) and four replications. Soil available phosphorus ranged from 10.3–16.3 mg kg^{-1} and differed significantly ($P < 0.05$) across treatments, with the highest in *Tithonia* and NPK as compared to urea and control. In comparison to the baseline soil, residual soil phosphorus increased by 7.7% for *Tithonia*, but decreased by 1.7% for NPK, 27.7% for control, and 46.3% for urea. The yield of African nightshade correlated significantly ($P < 0.05$) with the content of soil available phosphorus, and ranged from 8.6–14.9 t ha^{-1} fresh and 1.5–2.5 t ha^{-1} dry biomass that differed significantly ($P < 0.05$) across treatments, with the highest in NPK as compared to control. Plant height ranged from 24.6–33.2 cm and differed significantly ($P < 0.05$) across treatments, with the highest in NPK. The number of leaves ranged from 80–117 per plant and differed significantly ($P < 0.05$) across treatments, with the highest in NPK as compared to urea. *Tithonia* and fertilizers increased yield comparatively, which demonstrates the potential of *Tithonia* biomass as a sustainable alternative resource for soil fertility management.

Keywords: *Fertility, leafy vegetables, NPK, sunflower, urea.*

1. INTRODUCTION

Sub-Saharan Africa (SSA) accounts for about 9% of the global population with 40% under malnutrition [1]. Vegetables are considered as the most affordable and accessible source of micronutrients, vitamins and health-promoting secondary metabolites [2,3]. Indigenous African leafy vegetables such as African nightshade (*Solanum spp.*) are important for food and nutrition security, but the method of cultivation and processing influences their nutritional value and health-promoting potential [4]. However, poor and soil fertility resulting from continuous crop cultivation is one of the main constraints of crop production in SSA, with nitrogen and phosphorus as the most limiting elements [5,6]. This is exacerbated by low fertilizer inputs that result in low productivity with huge gaps of over 30% between actual production and the attainable potential [7,8]. SSA accounts for only 0.1% of global mineral fertilizer production and 1.8% of global mineral fertilizer use, which is less than 10 kg ha^{-1} fertilizer use compared to 87 kg ha^{-1} for some developed nations [9]. Inorganic fertilizers are commonly used to improve soil fertility and plant nutrition, but their enduring use eventually damages the soil [10,11]. According to The Economist [12], simply using more fertilizers to produce more food is not sustainable for the feeding of about nine billion people on earth by 2050. This requires gains from narrowing the yield gaps through sustainable cost-effective techniques [12]. Meanwhile, high cost of fertilizers and the need for resource conservation has led to renewed interest in alternative nutrient resources for soil fertility management.

Alternatively, organic inputs enhance soil organic matter and nutrients with improved soil structure, aeration, water holding capacity and infiltration [10,11,13]. Plant biomasses have demonstrated efficacy as mulch to improve soil health and foster sustainable development [14,15]. However, reliance on plant biomass for soil fertility management largely depends on the quality and availability. *Tithonia diversifolia* (Hemsley) is abundant in Buea Cameroon and rich in essential elements, with demonstrated potential to improve soil fertility and tomato production [16]. *Tithonia* biomass possesses both fertilizer attributes and allelopathic or phytotoxic growth inhibiting qualities [17,18]. *Tithonia* has high biomass with nutrient contents of about 3.5% nitrogen, 0.4% phosphorus and 4.1% potassium [19,20]. *Tithonia* also contains low recalcitrant compounds with 6.5% lignin and 1.6% polyphenol [21]. *Tithonia* demonstrated strong potential for soil rejuvenation and crop protection due to sesquiterpene lactones (tagitinins-terpene) and other antimicrobial substances against pests and diseases [20,22]. Hence, this study was conducted to evaluate the potential of *Tithonia* as a sustainable alternative for inorganic fertilizer to improve soil fertility and performance of African nightshade *Solanum nigrum* L. (Solanaceae). It was hypothesized that *Tithonia* biomass will enhance soil fertility and yield of African nightshade as compared to inorganic fertilizers.

2. MATERIALS AND METHODS

2.1 Experimental site and setup

This experiment was conducted from April–August 2018 at the research and teaching farm of the Faculty of Agriculture and Veterinary Medicine, University of Buea. The site is located at Bulu Mile 16–Buea between latitudes 4º3'N and 4º12'N and longitudes 9º12'E and 9º20'E. The soil is derived from weathered volcanic rocks dominated by silt, clay and sand [23,24]. Buea has mono-modal rainfall regime with less pronounced dry season and 86% relative humidity. The dry season starts from November to March, with mean annual rainfall of 2800 mm and monthly air temperature ranging from 19−30 °C. Soil temperature at 10 cm depth decreases from 25−15 °C with increasing elevation from 200−2200 m, respectively, above sea level [23,25,26].

The experiment was laid out as a randomized complete block design with four treatments each replicated four times, giving a total of 16 experimental plots measuring 4×4 m each. The experimental plots and surrounding areas were separated from each other by 1 m buffer zone. This experiment comprised four treatments including a control – no fertilizer, two inorganic (urea and NPK) and organic (*Tithonia diversifolia* – Mexican sunflower) fertilizers. Both urea and NPK fertilizers are commonly used in vegetable production systems, while *Tithonia* biomass was used as a cost-effective and environmentally friendly alternative. The field site was manually cleared using a cutlass and tilled at about 30 cm depth using a hoe.

2.2 Crop cultivation

Seeds of the African nightshade leafy vegetable (*Solanum nigrum* L.) were purchased from an agro-shop and pre-germinated on nursery beds before they were transplanted on the experimental plots. The nursery comprised three (1×10 m each) raised-beds produced by tilling at about 30 cm depth using a hoe. The African nightshade seeds were planted at about 1 cm soil depth and covered lightly with soil and dry grass mulch. Depending on rainfall regime, the nursery was manually irrigated twice a day (morning and evening), starting on the day of sowing. After three weeks, irrigation was reduced to once a day or after two days depending on the frequency of rainfall. Vigorous African nightshade seedlings of approximately same sizes were transplanted to experimental plots after four weeks in the nursery. The seedlings were planted at 40×40 cm spacing between and within rows, giving a total of 81 plants per plot. Seedlings that did not survive after transplanting were immediately replaced with supplies from the nursery in order to maintain uniform field capacity.

2.3 Fertilizer resources and crop protection

A total of 1.5 kg inorganic fertilizer NPK 20:10:10 + CaO (ADER® Cameroon) was applied on the 30 m^2 nursery beds. *Tithonia* biomass (leaves and stems) were harvested from roadsides within the university of Buea and sun-dried for two weeks, and spread on respective plots two weeks before African nightshade seedlings were transplanted. The inorganic urea and NPK 20:10:10 + CaO (ADER® Cameroon) fertilizers were purchased from a local agro-shop and broadcasted on respective plots after African nightshade seedlings were transplanted. Both inorganic (urea and NPK) and organic (*Tithonia*) amendments were applied at the rate of 312.5 kg ha^{-1}.

A mixture of 2 kg wood ash and 0.2 kg MOCAB (ingredient as ethoprop: o-ethylms, s-dipropyl phosphorodithioate; Amvac®, USA) was spread in the nursery to protect African nightshade seedlings against insect pests. MOCID (active ingredient as metaldehyde; SAVANA-Horizon Phyto Plus®, Cameroon) was broadcast in the nursery (total of 0.3 kg at the rate of 0.1 kg every two weeks) and experimental site (total of 1 kg at the rate of 0.25 kg every two weeks) for protection against snails. For control of insect pests and diseases, 40 ml K-Optimal (active ingredient lambda-cyhalothrine 15g/l plus acetamipride 20g/l; SCPA SIVEX International®, France) was mixed in

16L water and a knapsack sprayer was used to spray plants one week after seedlings were transplanted. Experimental plots and alleys were regularly monitored for weed emergence and weeded manually using a hoe.

2.4 Sampling and data collection

One day after the experimental site was cleared, five soil sub-samples were collected at 0–15 cm depth in randomized distribution (Z-form) using 3.5 cm diameter auger and bulked to form a composite baseline sample. Sampling at crop maturity was conducted two days before the first crop harvest (64 and 50 days after application of *Tithonia* and inorganic fertilizers, respectively). Five sub-soil samples were randomly collected at 0–15 cm depth (using 3.5 cm diameter auger) and bulked together to form a composite sample for each experimental plot, giving a total of 16 soil samples. The soil samples were air-dried and sieved using a 2-mm sieve, and the soil particle size was determined using the pipette method with sodium hexametaphosphate as the dispersing agent [27]. Soil pH was determined potentiometrically in both water (H_2O) and one molar potassium chloride (1 M KCl) solutions after 24 hours in soil suspension (soil/liquid = 1/2.5 w/v). Exchangeable bases were extracted with neutral ammonium acetate solution. Calcium (Ca) and magnesium (Mg) were determined by atomic absorption spectrophotometry while potassium (K) and Sodium (Na) were determined by flame photometry [28]. Exchangeable acidity was determined by KCl extraction method [28]. Total nitrogen was determined by macrokjeldahl digestion method [29], while available phosphorus (P) was determined by Bray II method [28]. Soil organic carbon was determined by Walkley-Black method [30].

During the experimentation, five plants were randomly selected from each treatment replicate and tagged for assessment of growth parameters at three to five weeks after transplanting. Plant height (cm) was measured from the soil surface to the apical tip of the plant using a measuring tape. The number of fully developed leaves on the nodes of the main stem and the number of branches were visually observed and counted per plant. Stem girth was measured with a vernier calliper at 5 cm from soil surface to the nearest cm. Three manual harvests were conducted using a sharp knife every two weeks over four weeks to determine the cumulative yield. Plants were harvested by cutting the main stem at 6 cm from soil surface, and primary branches cut at 3 cm from the main stem and considered as marketable yield. The three harvests of African nightshade were weighed using a top-loading balance and the data reported in tons per hectare fresh and dry (after oven-drying at 60 ^{0}C for 72 hours) weights.

2.5 Statistical analysis

Data sets were subjected to statistical analyses using STATISTICA 9.1 for Windows [31]. Dependent variables as performance of African nightshade (yield, plant height, stem girth, number of leaves or branches) were subjected to univariate analysis of variance (ANOVA, $P < 0.05$) to test effects of treatments (n=4) as categorical predictors. Significant data means were compared by Tukey's HSD ($P < 0.05$). Where applicable, Spearman Rank Correlation ($P < 0.05$) was performed to determine the degree of association between dependent variables and categorical predictors.

3. RESULTS

3.1 Influence of treatments on soil properties

Soil texture at the experimental site before application of treatments indicated that the site is dominated by clay (47.19%), silt (44.44%) and sand (8.37%). The soil was highly acidic and ranged from 4.1–5.4, but soil pH was not affected by the different treatments (Table 1A,B). The content of soil available phosphorus differed significantly (ANOVA: $F_{3,15} = 21.17$, $P < 0.001$; Fig. 1) across treatments, ranging from 10.3–16.3 mg kg^{-1}. The highest soil available phosphorus occurred in the *Tithonia* and NPK treatments, which differed significantly ($P < 0.05$; Fig. 1) from urea and control, but urea and control did not differ significantly ($P > 0.05$; Fig. 1). Compared to the baseline soil phosphorus (Table 1A), the residual soil phosphorus (Fig. 1) increased by 7.7% for *Tithonia* plots, but decreased by 1.7% for NPK, 27.7% for control and 46.3% for urea after treatments were applied (Fig. 2).

3.2 Impact of treatments on yield and vegetative parameters

The yield of African nightshade ranged from 8.6–14.9 t ha^{-1} fresh biomass (Fig. 3a) and 1.5–2.5 t ha^{-1} dry biomass (Fig. 3b) across treatments. Fresh biomass yield differed significantly (ANOVA: $F_{3,14} = 4.53$, $P < 0.05$; Fig. 3a) across treatments, with the highest in NPK as compared to the control. Similarly, dry biomass yield differed significantly (ANOVA: $F_{3,14} = 4.34$, $P < 0.05$; Fig. 3b) across treatments, with the highest in NPK as compared to the control. The content of soil available phosphorus influenced the yield of African nightshade as demonstrated by the significant ($P < 0.05$) positive correlation of fresh ($r = 0.67$) and dry ($r = 0.75$) biomass yield with soil phosphorus. The plant height ranged from 24.6–33.2 cm and differed significantly (ANOVA: $F_{3,15} = 7.77$, $P < 0.01$; Table 2) across treatments, with the highest in NPK as compared to the other treatments. The number of leaves ranged from 80–117 per plant and differed significantly (ANOVA: $F_{3,15} = 4.09$, $P < 0.05$; Table 2) across treatments, with the highest in NPK as compared to urea. The stem girth ranged from 1.4–2.1 cm per plant while the number of branches ranged from 11–15 per plant across treatments, but did not differ ($P > 0.05$; Table 2).

4. DISCUSSION

4.1 Effect of treatments on soil properties

According to the guidelines for tropical soils elaborated by Landon [32], high, medium and low soil contents correspond to >10, 4–10 and <4% for organic carbon; >0.5, 0.2–0.5 and <0.2% for total nitrogen; 10–15, 5–10 and 0–5 cmol/kg for phosphorus; >0.4–0.8, 0.2–0.4 and <0.03–0.2 cmol/kg for potassium. Therefore, organic carbon and total nitrogen contents were low in this study, while phosphorus was high and potassium was medium [32]. Meanwhile, the observed highly acidic soil pH corresponds to the standard tropical acid soil pH range [33]. Liasu et al. [34] reported high nutrient contents in *Tithonia* biomass, but the ability to exert effects on soil fertility depends on the quantity of material used and the rate of decomposing and mineralization. Therefore, the low amount of *Tithonia* used did not adequately supply the essential nutrients as compared to Ngosong et al. [16] who reported an increase in soil fertility and tomato yield for *Tithonia* than NPK. In addition, Odhiambo [35] reported reduced nitrogen mineralization in high clay soils, which might have influenced the mineralization of *Tithonia* biomass in the present study with high clay content of 47.19%. Ngosong et al. [16] reported 0.55% phosphorus content in *Tithonia* biomass from Buea, which means that by applying 312.5 kg ha^{-1} *Tithonia*, the total phosphorus input was only 1.72 kg ha^{-1} as compared to the 78.13 kg ha^{-1} phosphorus supplied by the 312.5 kg ha^{-1} NPK fertilizer applied. This suggests that much of the phosphorus from NPK fertilizer was either leached or adsorbed by the highly acidic tropical soil [6]. The two highest peaks of phosphorus fixation occur in the acid range of pH 4 and 5.5, where phosphorus precipitates with iron and aluminium. Also the clay fraction of the soil (47.19%) is likely to be the main site of phosphorus fixation. Low phosphorus content observed in control and urea treatments is likely due to high P–sorption capacity of the highly acidic tropical soil in this study area with 47.19% clay composition, since clay particles correlate strongly with P–sorption [36]. The high soil available phosphorus recorded for *Tithonia* treatment might be due to increase in labile pools of soil phosphorus [21]. Net phosphorus mineralization likely increased because of the concentration of phosphorus in the biomass, in relation to the critical P–levels required for mineralization of soil organic–P to inorganic–P [37–39]. Accordingly, the interaction of phosphorus sources and different soil types reportedly influenced the availability of soil phosphorus [40]. However, this result does not support the hypothesis and *Tithonia* and NPK recorded similar contents of soil available phosphorus.

4.2 Impact of treatments on crop yield

The low yield recorded in control demonstrates lack of essential soil nutrients, while the high yield recorded for *Tithonia* and inorganic fertilizers reflects high nutrient supply that favoured plant growth. However, the similarity in yield for *Tithonia* and inorganic fertilizers does not support the hypothesis of this study that advocated greater yield for *Tithonia*. Nonetheless, the similarity in yield for *Tithonia* and inorganic fertilizers indicates strong potential of *Tithonia* as a sustainable alternative amendment for soil fertility management. The high yield recorded for *Tithonia* biomass that is comparable to NPK treatment can be attributed to high nutrient status of *Tithonia*, fast decomposition and nutrient release [22,37]. In addition, the *Tithonia* biomass might have created a favourable soil environment that probably enhanced root growth and nutrient acquisition [41]. Moreover, the application of higher amounts of *Tithonia* biomass might have increased crop growth more than the inorganic fertilizers [16,42]. Hence, the similarity in yield for *Tithonia* and inorganic fertilizers compared to higher performance of *Tithonia* reported by other studies is likely because of the low amount of *Tithonia* biomass used in this study [16,42]. Meanwhile, the release of readily available and balanced macronutrients in the NPK fertilizer probably stimulated the crop growth and yield [43]. Overall, the observed yield is consistent with the report of Yengoh [44] that nutrient inputs and farm management are important determinants of yield differences in small-scale food crop farming systems in Cameroon.

5. CONCLUSION

Tithonia and inorganic fertilizers increased the growth and yield of African nightshade as compared to the control. However, the comparable crop yield for *Tithonia* and inorganic fertilizers demonstrate the potential of *Tithonia* as a sustainable alternative for inorganic fertilizers to improve soil fertility and crop production. The results highlight the importance of fertilizers to improve soil fertility and vegetable production, which emphasizes the need for more cost-effective and sustainable alternative resources for soil fertility management.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Table 1. A – baseline soil physicochemical properties of the experimental site before treatments; B – effect of treatments (control – no fertilizer, urea, NPK and *Tithonia*) on soil physicochemical properties (Mean ± SD).

A

	Moisture [%]	Organic carbon [%]	Total nitrogen [%]	C/N	pH [H_2O]	pH [KCl]	Sodium [cmol/kg]	Potassium [cmol/kg]	Magnesium [cmol/kg]	Calcium [cmol/kg]	Aluminium [cmol/kg]	ECEC [cmol/kg]	Available phosphorus [mg/kg]
Baseline soil	9.5	2.0	0.14	14.0	5.4	4.5	0.33	0.22	1.5	4.0	0.32	6.4	15.0

B

Treatments	Moisture [%]	Organic carbon [%]	Total nitrogen [%]	C/N	pH [H_2O]	pH [KCl]	Sodium [cmol/kg]	Potassium [cmol/kg]	Magnesium [cmol/kg]	Calcium [cmol/kg]	Aluminium [cmol/kg]	ECEC [cmol/kg]
Control	17.2 ± 1.8a	2.5 ± 0.3a	0.14 ± 0.02a	18.3 ± 3.8a	4.9 ± 0.5a	4.4 ± 0.2a	0.19 ± 0.11a	0.52 ± 0.22a	1.6 ± 0.5a	4.5 ± 1.0a	0.56 ± 0.37a	7.3 ± 1.2a
Urea	16.3 ± 1.8a	2.8 ± 0.4a	0.13 ± 0.02a	22.3 ± 4.8a	4.5 ± 0.2a	4.1 ± 0.1a	0.11 ± 0.11a	0.30 ± 0.13a	1.4 ± 0.3a	3.4 ± 1.4a	1.13 ± 0.47a	6.3 ± 1.5a
NPK	16.4 ± 1.3a	2.4 ± 0.2a	0.14 ± 0.01a	17.3 ± 4.1a	4.6 ± 0.3a	4.2 ± 0.1a	0.21 ± 0.12a	0.49 ± 0.13a	1.9 ± 0.9a	4.7 ± 1.3a	0.92 ± 0.51a	8.3 ± 1.6a
Tithonia	15.5 ± 0.5a	2.4 ± 0.3a	0.16 ± 0.01a	15.0 ± 2.7a	4.8 ± 0.4a	4.3 ± 0.1a	0.23 ± 0.14a	0.36 ± 0.10a	1.7 ± 0.6a	4.7 ± 1.1a	0.71 ± 0.39a	7.8 ± 1.2a

Values within columns with the same letters are not significantly different ($P < 0.05$).

Table 2. Effect of treatments (control – no fertilizer, urea, NPK and *Tithonia*) on the growth parameters of African nightshade (Mean ± SD).

Treatments	Plant height [cm]	Number of leaves	Stem girth [cm]	Number of branches
Control	27.6 ± 0.7b	90 ± 12ab	1.8 ± 0.3a	12 ± 1a
Urea	24.6 ± 2.4b	80 ± 12b	1.4 ± 0.3a	11 ± 3a
NPK	33.2 ± 2.2a	117 ± 21a	2.1 ± 0.5a	15 ± 4a
Tithonia	26.6 ± 4.1b	83 ± 20ab	1.9 ± 0.2a	13 ± 4a

Values within columns with different letters are significantly different ($P < 0.05$).

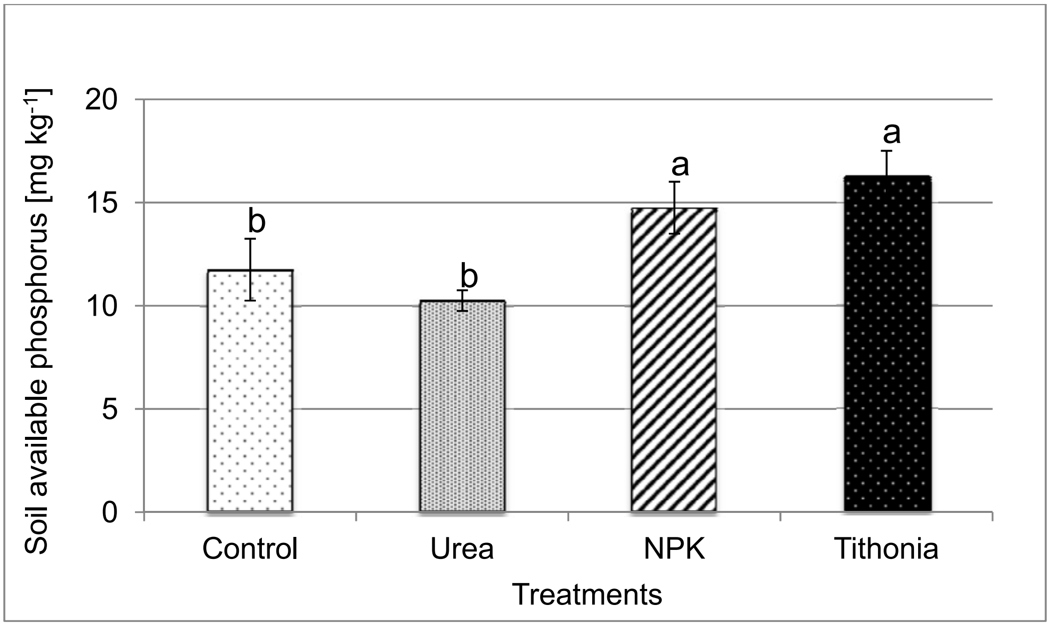

Fig. 1 Effect of treatments (control – no fertilizer, urea, NPK and *Tithonia*) on soil available phosphorus (mg kg^{-1}, Mean ± SD). Values with different letters are significantly different ($P < 0.05$).

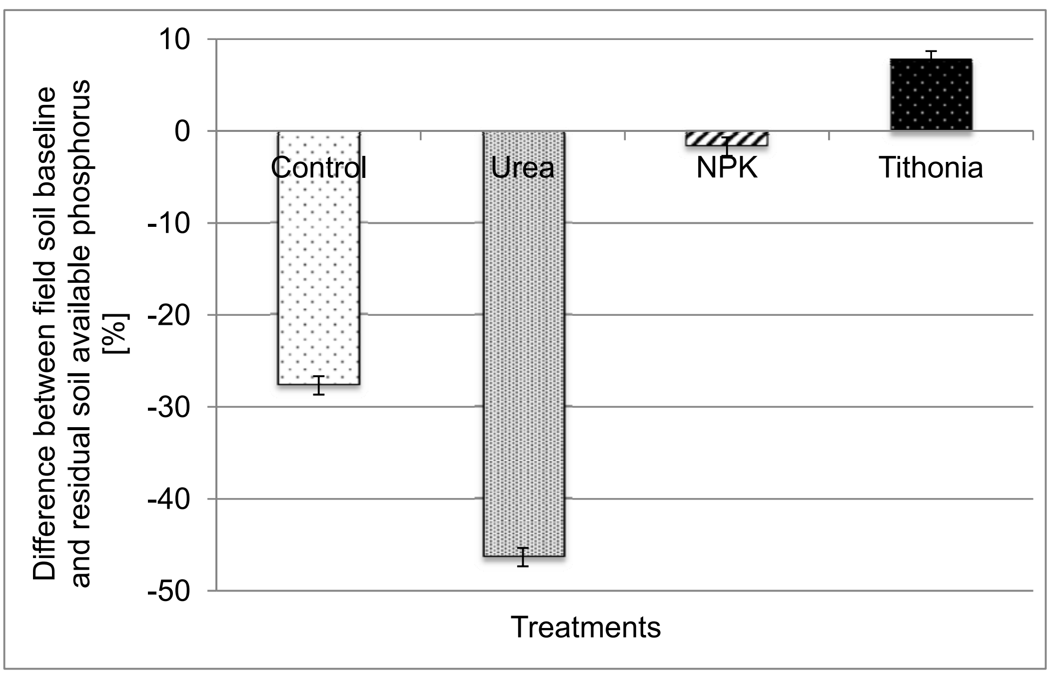

Fig. 2 Percentage difference (% increase or decrease) between field soil baseline and residual soil available phosphorus after treatments.

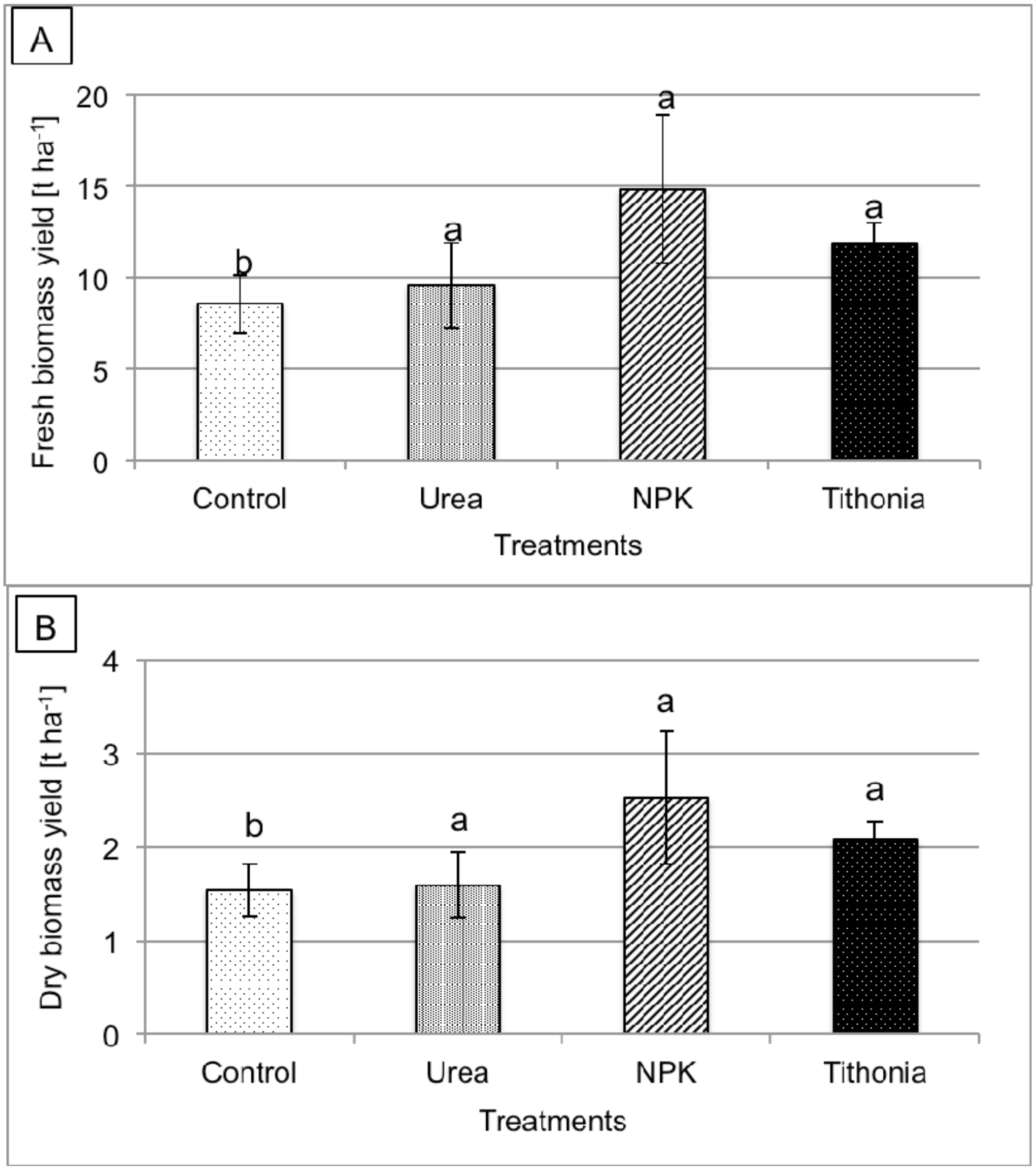

Fig. 3 Impact of treatments (control – no fertilizer, urea, NPK and *Tithonia*) on yield of African nightshade (t ha^{-1}, Mean ± SD); A – fresh biomass, B – dry biomass. Values with different letters are significantly different ($P < 0.05$).