Original Research Article

Potential of *Tithonia diversifolia* Residue as a Sustainable Alternative for Inorganic Fertilizers to Improve Soil Fertility and Production of African Nightshade (*Solanum nigrum* L.)

ABSTRACT

Poor soil fertility is a major constraint for crop production that is corrected with fertilizers, but high fertilizer costs with environmental and human health concerns have necessitated alternative soil amendment strategies. Hence, *Tithonia* residue was assessed as a sustainable alternative resource to improve the fertility of volcanic soils for production of African nightshade. A field experiment was setup as randomized complete block design with four treatments (Control – No fertilizer, Urea, NPK and Tithonia) and four replications, to evaluate their impact on soils and the performance of *Solanum nigrum*. Soil available phosphorus ranged from 10.3–16.3 mg kg^{-1} and differed significantly across treatments, with the highest in Tithonia and NPK treatments that differed significantly ($P < 0.05$) from urea and control. Compared 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. Yield of African nightshade ranged from 8.6–14.9 t ha^{-1} fresh and 1.5–2.5 t ha^{-1} dry biomass across treatments, with the highest in NPK treatment that differed significantly ($P < 0.05$) from control. Both fresh and dry biomass yields correlated significantly ($P < 0.05$) with treatments and soil phosphorus. Plant height ranged from 24.6–33.2 cm and differed significantly ($P < 0.05$)

across treatments, with the highest in NPK that differed significantly ($P < 0.05$) from the other treatments. The number of leaves ranged from 80–117 per plant and differed significantly ($P < 0.05$) across treatments, with the highest in NPK that differed significantly ($P < 0.05$) from urea. Both Tithonia and inorganic fertilizers increased performance of *Solanum nigrum* compared to the control, but their comparable performance demonstrates the potential of Tithonia as a sustainable alternative resource for soil fertility management.

Keywords: *African nightshade, Fertilizers, Leafy vegetables, Soil fertility, Sunflower.*

1. INTRODUCTION

Sub-Saharan Africa (SSA) accounts for about 9% of the global population with 40% under malnutrition [1]. Vegetables are the most affordable and accessible source of micronutrients, vitamins and health-promoting secondary metabolites [2,3]. Indigenous African leafy vegetables such as African nightshade (e.g. *Solanum scabrum*) 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 declining soil fertility resulting from continuous cultivation is a major constraint to 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]. Inorganic fertilizers are commonly used to improve soil fertility and plant nutrition, but their enduring use eventually damages the soil [9,10]. According to The Economist [11], 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 [11]. Meanwhile, high cost of fertilizers and the need for resource conservation has led to renewed interest in alternative nutrient resources for soil fertility management [12].

Alternatively, organic inputs enhance soil organic matter and nutrients with improved soil structure, aeration, moisture holding capacity and infiltration [9,10,13]. Plant residues have demonstrated efficacy for use as mulch to improve soil health and foster sustainable development [14,15]. However, reliance on plant residues for soil fertility management largely depends on the residue quality and availability. Mexican sunflower (*Tithonia diversifolia*) is abundant in Buea Cameroon and rich in essential elements, with demonstrated potential to improve soil fertility and tomato production [16]. Tithonia residue 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 assess the potential of Tithonia as a sustainable alternative for inorganic fertilizer to improve production of African nightshade on volcanic soils of Buea Cameroon. It was hypothesized that Tithonia residue will enhance soil status leading to a greater performance of African nightshade as compared to the inorganic fertilizer amendments.

2. MATERIALS AND METHODS

2.1 Experimental site

This experiment was conducted at the teaching and research farm of the Faculty of Agriculture and Veterinary Medicine, University of Buea. The site is located at Bulu Mile 16–Buea, situated 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].

2.2 Experimental setup

The experiment was conducted from April to August 2018, and layout 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. 1-m buffer zone the experimental plots from each other and surrounding areas. The four treatments used in this experiment were Control – No fertilizer, and three fertilizer amendments (Urea, NPK and Tithonia). Urea and NPK fertilizers are commonly used in this study area for cultivation of *Solanum* *nigrum*, while *Tithonia diversifolia* (Mexican sunflower) was considered for use as cost-effective and environmentally friendly organic alternative to inorganic fertilizers. The field site was manually cleared using a cutlass and tilled at about 15 cm depth using a hoe.

2.3 Crop cultivation

Seeds of the traditional African leafy vegetable (African nightshade – *Solanum nigrum* L.) were purchased from the local market and pre-germinated on nursery beds before transplanting on the experimental plots. The nursery comprised three (1×10 m each) raised-beds produced by tilling at about 15 cm depth using a hoe. 0.2 kg of MOCAP (active ingredient as Ethoprop: O-EthylmS, S-Dipropyl Phosphorodithioate; Amvac®, USA) was broadcasted on nursery plots to control nematodes and insect pests. *Solanum nigrum* seeds were planted at about 1 cm soil depth, covered lightly with soil and mulch. Depending on rainfall regime, the nursery was watered twice a day in the morning and evening for three weeks, starting on the day of sowing. After three weeks, watering was reduced to once a day or once in two days depending on the frequency of local rainfall. Vigorous *Solanum nigrum* seedlings were transplanted to the experimental plots after four weeks in the nursery. Seedlings were planted at 40×40 cm spacing between and within rows, giving a total of 81 plants on each experimental plot. The seedlings that did not survive after transplanting were immediately replaced with supplies from the nursery.

2.4 Fertilizer amendments

A total of 1.5 kg (0.5 kg per bed) inorganic fertilizer NPK 20:10:10 + CaO (ADER® Cameroon) was applied on the three nursery beds (83.3 t ha^{-1}). Tithonia biomass was broadcasted on the respective plots two weeks before seedlings were transplanted. The inorganic urea and NPK 20:10:10 + CaO (ADER® Cameroon) fertilizers were broadcasted on respective plots after seedlings were transplanted. Both inorganic (Urea and NPK) and organic (Tithonia) amendments were applied at the rate of 312.5 kg ha^{-1} (e.g. 0.5 kg per plot). Urea and NPK fertilizers were purchased from a local agro-shop, while Tithonia biomass (leaves and stems) were harvested from roadsides within the university of Buea and sun-dried for two weeks.

2.5 Crop protection

The African nightshade seedlings were protected against nematodes and insect pests in the nursery by broadcasting a mixture of 2 kg wood ash and 0.2 kg MOCAB (ingredient as Ethoprop: O-EthylmS, S-Dipropyl Phosphorodithioate; Amvac®, USA) while dry grass was used as mulch. The nursery plants were protected against snails with Mocid (active ingredient as Metaldehyde; SAVANA-Horizon Phyto Plus®, Cameroon) broadcasted thrice with 0.1 kg every two weeks (i.e. total of 0.3 kg). Meanwhile, a total of 1 kg Mocid was broadcasted four times to protect plants at experimental site against snails, with 0.25 kg every two weeks. For pest and disease control, 40 ml K-Optimal (active ingredient Lambda-cyhalothrine 15g/l plus Acetamipride 20g/l; SCPA SIVEX International®, France) was mixed in 16L water and applied on plants using a knapsack sprayer. This was performed on all experimental plots one week after seedlings were transplanted. The experimental plots and alleys were regularly monitored for weed emergence and weeded manually using a hoe.

2.6 Sampling and data collection

One day after the experimental site was cleared, five soil sub-samples were collected at 0–15 cm depth in 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. Plant girth was measured using a rope wrapped round the plant stem at 5 cm from the soil surface and the rope stretched on a 30 cm ruler to record the girth. Three manual harvests were conducted using a sharp knife every two weeks over four weeks to determine the cumulative yield of *S. nigrum*. Harvesting was done by cutting the main stem at about 6 cm from the soil surface and the primary branches were cut at about 3 cm from the main stem. The three harvests of *S. nigrum* 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.

2.7 Statistical analysis

Data sets were subjected to statistical analyses using STATISTICA 9.1 for Windows [31]. Dependent variables as performance of *S. nigrum* (e.g. 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 tillage and application of treatments indicates that 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 (ANOVA: $F_{3,15} = 21.17$, $P < 0.001$; Fig. 1) significantly 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 (Turkey's HSD, $P < 0.05$; Fig. 1) significantly from urea and control, but urea and control did not differ (Turkey's HSD, $P > 0.05$; Fig. 1) significantly. The soil available phosphorus correlated significantly ($P < 0.05$) with the fresh ($r = 0.67$) and dry yield ($r = 0.75$) of African nightshade. 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). Meanwhile, all the other soil parameters that were assessed (including macronutrients – nitrogen and potassium) did not differ significantly across treatments ($P > 0.05$; Table 1B).

3.2 Impact of treatments on performance of *Solanum nigrum*

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. The fresh biomass yield differed (ANOVA: $F_{3,14}$ = 4.53, P < 0.05; Fig. 3a) significantly across treatments, with the highest in NPK treatment that differed (Turkey's HSD, P < 0.05) significantly from the control. Similarly, the dry biomass yield differed (ANOVA: $F_{3,14}$ = 4.34, P < 0.05; Fig. 3b) significantly across treatments, with the highest in NPK treatment that differed (Turkey's HSD, P < 0.05) significantly from the control. Moreover, the fresh biomass yield correlated significantly (P < 0.05) with the treatments (r = 0.68) and soil available phosphorus (r = 0.67). Similarly, the dry biomass yield correlated significantly (P < 0.05) with the treatments (r = 0.72) and soil available phosphorus (r = 0.75).

The average 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 that differed (Turkey's HSD, P < 0.05) significantly from the other treatments. The number of leaves ranged from 80–117 per plant that differed (ANOVA: $F_{3,15}$ = 4.09, P < 0.05; Table 2) significantly across treatments, with the highest in NPK that differed (Turkey's HSD, P < 0.05) significantly from the urea treatment. The number of branches ranged from 11–15 per plant, but did not differ (P > 0.05; Table 2) significantly across treatments. The stem girth ranged from 1.4–2.1 cm per plant, but did not differ (P > 0.05; Table 2) significantly across treatments.

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 residue, 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 residue in the present study with high clay content of 47.19%. Ngosong et al. [16] reported 0.55% phosphorus content in Tithonia residues 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. Lower phosphorus content observed in the control and urea treatment is likely due to high phosphorus sorption capacity of the highly acidic tropical soil in this study area with 47.19% clay composition, since clay particles were strongly correlated to phosphorus sorption [36]. The increased soil available phosphorus recorded for Tithonia compared to the other treatments might be as a result of increase in the labile pools of soil phosphorus by Tithonia [21]. Net phosphorus mineralization rate increased because of the concentration of phosphorus in residues in relation to critical levels required for mineralization of soil organic phosphorus to inorganic phosphorus [37–39]. The low phosphorus content in the control soil is likely due to high phosphorus sorption capacity of the tropical acidic soil in this study area with 47.2% clay composition, since clay particles were strongly correlated to phosphorus sorption [36]. Accordingly, the interaction of phosphorus sources and different soil types reportedly influenced phosphorus availability [40]. However no significant differences were observed in the other soil parameters in all the treatments.

4.2 Impact of treatments on performance of African nightshade

The low yield of African nightshade recorded in control demonstrates the lack of soil essential nutrients for optimum crop performance, while the highest yields in Tithonia and inorganic fertilizer treatments is likely due to enhanced nutrient supply that favoured plant growth and yield. The similarity in *Solanum nigrum* yield for Tithonia and inorganic fertilizers does not support the hypothesis of this study, which advocated greater performance for Tithonia than inorganic fertilizers. However, the similarity in *Solanum nigrum* 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 residue that is comparable to NPK treatment can be attributed to high nutrient status of Tithonia, fast decomposition and nutrient release [22,37]. In addition, Tithonia residue might have created a favourable soil environment with constant nutrient supply that probably favoured root growth and nutrient acquisition [41]. Moreover, application of higher amounts of Tithonia residues might have increased the performance of *Solanum nigrum* more than the inorganic fertilizers as reported by other studies [16,42]. Hence, similarity in *Solanum nigrum* yield for Tithonia and inorganic fertilizers compared to higher performance of Tithonia reported by other studies is likely because of the lower amount of Tithonia residue used in this study [16,42]. Meanwhile, the release of readily available and balanced macronutrients in the NPK fertilizer likely stimulated the growth and yield of *Solanum nigrum* [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 performance of *Solanum nigrum* as compared to the control. The comparable performance of Tithonia and inorganic fertilizers demonstrate the potential of Tithonia as a sustainable alternative for inorganic fertilizers to improve the fertility of volcanic soils and enhance the production of *Solanum nigrum*. The results strongly indicate the need for fertilizer inputs to improve soil fertility, which highlights the need for cost-effective and sustainable alternative resources in arable systems.

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Table 1. A – Baseline soil properties of the experimental site before tillage and application of treatments. B – Effect of treatments (Control – No fertilizer, Urea, NPK and Tithonia) on soil properties at crop harvest (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 (Tukey's HSD, $P < 0.05$).

Table 2. Effect of treatments (Control – No fertilizer, Urea, NPK and Tithonia) on the growth parameters of African nightshade (Mean ± SD).

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

Values within columns with different letters are significantly different (Tukey's HSD, $P < 0.05$).

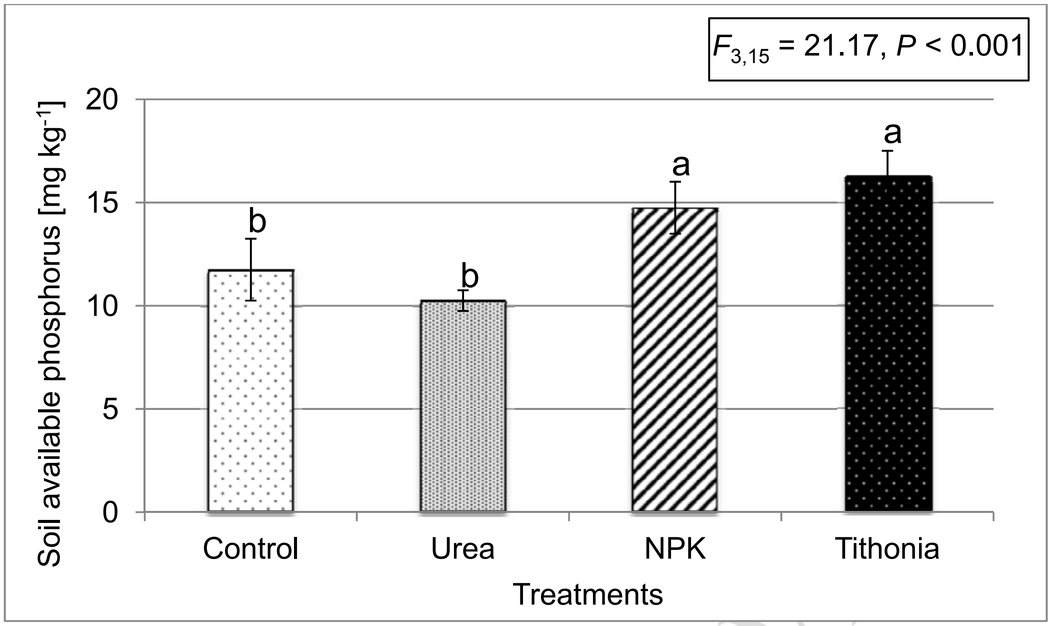

Fig. 1 Effect of treatments (Control – No fertilizer, Urea, NPK and Tithonia) on soil available phosphorus (mg kg^{-1}, Mean ± SD). Values with different letters are significantly different (Tukey's HSD, $P < 0.05$).

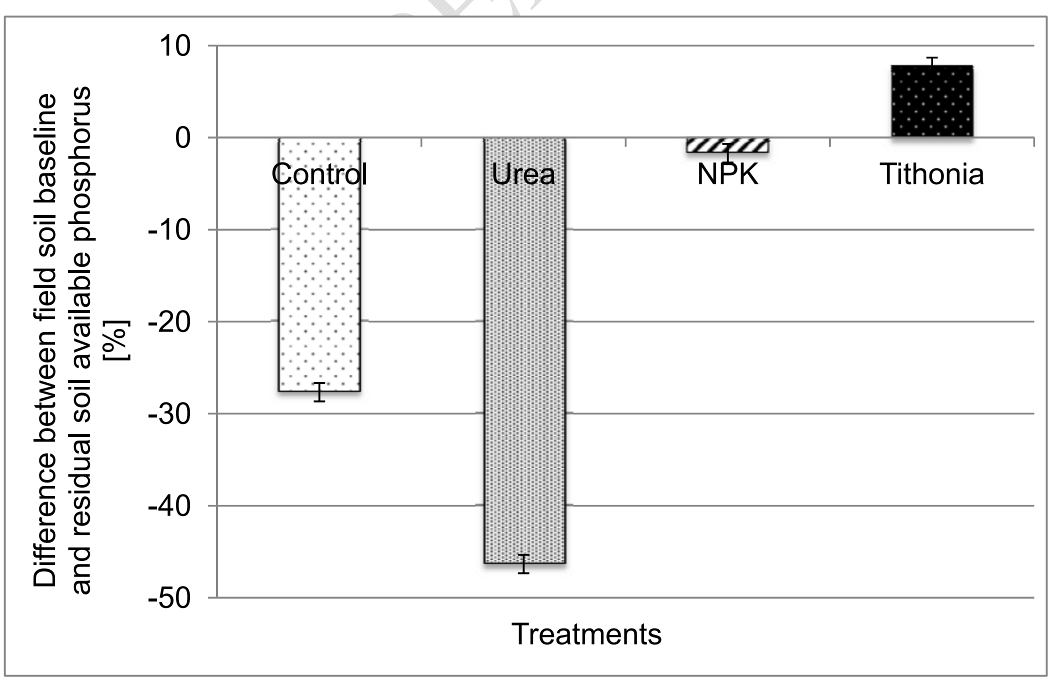

Fig. 2 Percentage [%] difference (increase or decrease) between field soil baseline and residual soil available phosphorus after treatments.

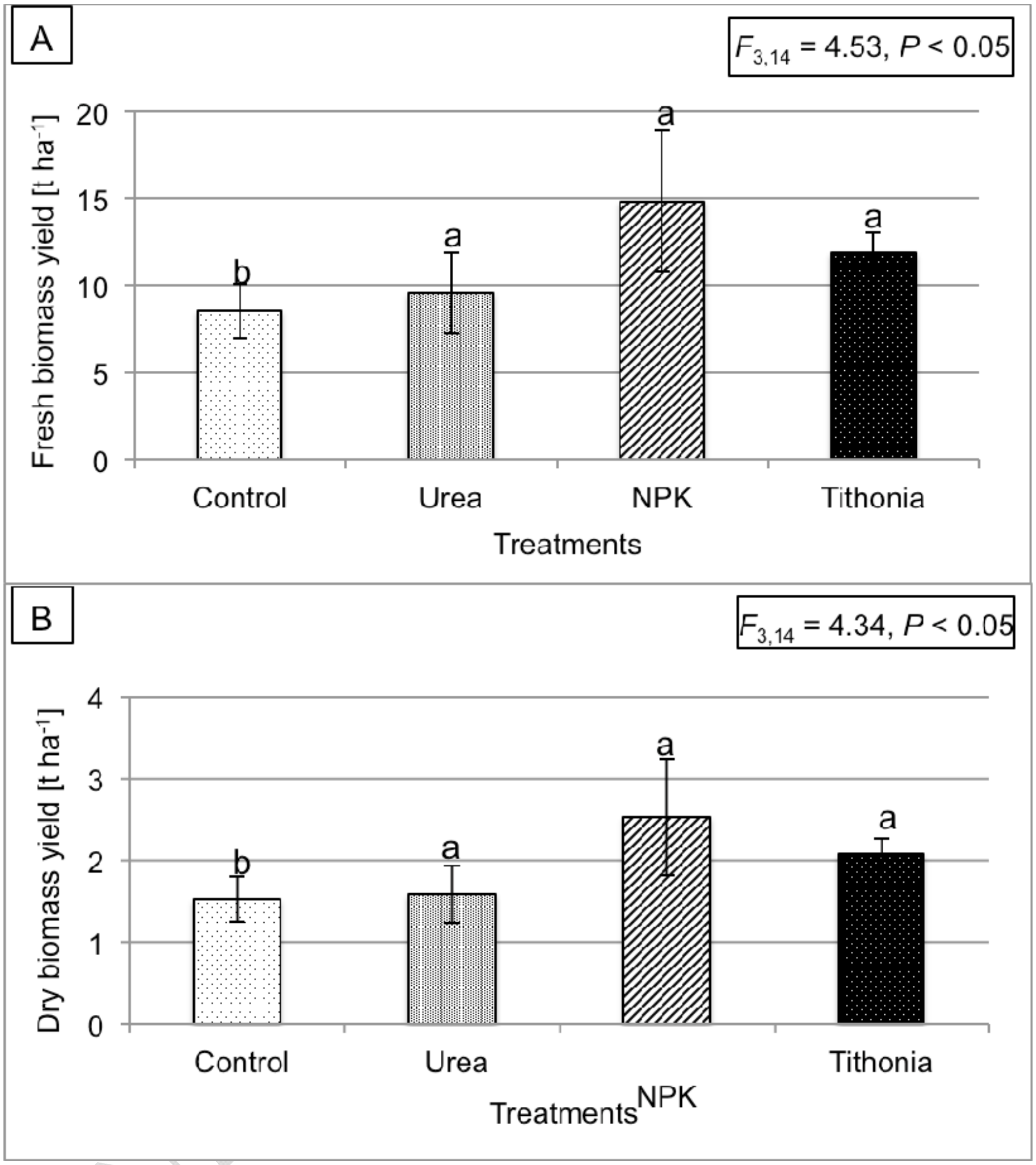

Fig. 3 Impact of treatments (Control – No fertilizer, Urea, NPK and Tithonia) on the biomass yield of African nightshade (t ha^{-1}, Mean ± SD); A – Fresh biomass, B – Dry biomass. Values with different letters are significantly different (Tukey's HSD, P < 0.05).