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EFFECTS OF GREEN MANURES AND NPK FERTILIZER ON SOIL PROPERTIES, TOMATO YIELD AND QUALITY IN THE FOREST-SAVANNA ECOLOGY OF NIGERIA

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SUMMARY

Green manures (GM) as an alternative to inorganic fertilizer offer considerable potential as a source of plant nutrients and organic matter (OM). Hence, field experiments were carried out during 2015 and 2016 cropping seasons to compare impacts of GM and NPK (15:15:15) fertilizer on soil properties, growth, fruit yield, mineral, lycopene and vitamin C contents of tomato (*Lycopersicon esculentum* Mill). GMs were composed by green tender stems and leaves of pawpaw (*Carica papaya* L.), neem (*Azadirachta indica* A. Juss.), moringa (*Moringa oleifera* Lam.) or gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) and applied at 5 Mg ha^{-1}, whereas NPK was applied at 300 kg ha^{-1} and there was a no fertilizer plot (control). Application of GMs reduced soil bulk density and increased soil OM, N, P, K, Ca, Mg, growth, number of fruits and fruit yield of tomato compared with the control. NPK fertilizer had no effect on soil bulk density and soil OM, but it increased soil fertility and tomato yield as compared with the control. When comparing treatments, the highest tomato yield and best cost:benefit ratio were obtained with gliricidia as GM. The GMs and NPK fertilizer increased mineral, lycopene and vitamin C contents in tomato fruits and the highest K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents in tomato fruits were found with moringa as GM. Our results revealed that GM has potential to improve soil properties, tomato yield and quality, being an alternative for cropping management.

INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill) is a source of vitamin C (Ilupeju *et al.*, 2015) and its consumption has been associated with prevention of cardiovascular disease, cancers and several other diseases due to the antioxidant compounds such as ascorbic acid, carotenes, lycopene and phenols (Sharoni and Levi, 2006; Willcox *et al.*, 2003). Average tomato yield in Nigeria is low, about 10 Mg ha^{-1} (FAO, 1993), owing to low native soil fertility status among other factors. Low, and declining, soil fertility is

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a major concern in many African smallholder farms and has been exacerbated by continuous cultivation without adequate soil fertility enhancement (Nandwa, 2001). Use of inorganic fertilizers can improve crop yields, but its use is limited due to high cost, scarcity during planting, soil acidity and nutrient imbalance.

Maintenance of soil organic matter (OM) is the basis of sustainable crop production in tropical countries. With continuous cultivation, soil OM content declines and nutrients are leached from the root zone. One way of restoring fertility, and increasing soil OM content of tropical soils, is with use of green manure (Ali, 1999). Although the use of green manure as a way to improve soil structure and fertility is not a common practice among tomato growers in the tropics, green manure plants are non-polluting and biodegradable with no hazardous residues in soil, water and air. They are environmentally safe and generally do not leave residue in stored food product.

Neem (*Azadirachta indica* A. Juss.), gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.), moringa *(Moringa oleifera* Lam.) and pawpaw (*Carica papaya* L.) can be used as green manure, but use of their leaves for tomato production has not been investigated. For instance, application of fresh neem leaves at 5 Mg ha^{-1} or dry neem leaves at 1.25 Mg ha^{-1} and urea caused higher N recovery and N response compared to application of urea alone (Santhi and Palaniappan, 1986). As another alternative, incorporation of moringa shoots as green manure increased fertility of agricultural soils (Fahey, 2005). Gliricidia has been used to improve quality of soils and as a potential source of N (Makumba *et al.*, 2006). Plant materials used as green manure differ in chemical composition, rate of decomposition and nutrient elements released to the soil, affecting nutrient uptake by crops. Then, the nutritional effect of green manure on crops depends on its residue quality. While high-quality materials improve plant nutrition by releasing nutrients, low-quality residues have relatively weak direct nutritional effect on crops.

As there is a need to study the potential of plant materials as green manure and their effects on soil chemical properties and mineral composition of crops (Adekiya *et al.*, 2017), this study was undertaken to compare the impact of green manures and NPK fertilizer on soil properties, growth, yield, minerals, lycopene and vitamin C composition of tomato. It was hypothesized that soil properties and tomato growth, yield and quality will react differently to the use of green manures and NPK fertilizer.

MATERIAL AND METHODS

Site description and treatments

Field experiments were carried out at the Teaching and Research Farm, Rufus Giwa Polytechnic, Owo, Ondo State, Nigeria, during the 2015 and 2016 cropping seasons (7°12′N 5°35′E, 348 m asl). The area is located in the forest-savanna transition zone of Nigeria and soil is an Alfisol classified as Oxic Tropuldalf or Luvisol (Soil Survey Staff, 2014) derived from quartzite, gneiss and schist. The soil was sandy loam in texture with 753, 127 and 120 g kg^{-1} sand, silt and clay, respectively. Bulk density was 1.65 Mg m^{-3}. The values for OM, total N, available P, exchangeable K, Ca, Mg and pH (water) were 2.24%, 0.18%, 9.5 mg kg^{-1}, 0.14 cmol kg^{-1}, 1.4 cmol

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Table 1. Chemical composition of green tender stems and leaves of various green manures used.

Green manure	OC (%)	N (%)	C:N	P (%)	K (%)	Ca (%)	Mg (%)
Neem	40a	1.30d	30.8a	0.83a	1.67c	0.77d	0.75a
Pawpaw	35b	1.40c	25.0b	0.42b	1.51d	1.60b	0.48c
Moringa	36b	2.56b	14.1c	0.43b	2.04b	2.62a	0.56b
Gliricidia	41a	3.26a	12.6d	0.41b	2.76a	1.08c	0.36d

Values followed by similar letters under the same column are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

kg^{-1}, 0.56 cmol kg^{-1} and 5.8, respectively. According to these data, the soil was high in bulk density, acidic, low in OM, total N, available P, exchangeable K and Ca and adequate in Mg, when considering the critical levels of 3.0% OM, 0.20% N, 10.0 mg kg^{-1} available P, 0.16–0.20 cmol kg^{-1} exchangeable K, 2.0 cmol kg^{-1} exchangeable Ca and 0.40 cmol kg^{-1} exchangeable Mg, recommended for crop production in ecological zones of Nigeria (Akinrinde and Obigbesan, 2000). Such poor soil fertility is unable to sustain crop yield without the addition of external input. There are two rainy seasons at the location, from March to July and from mid-August to November. Average annual rainfall varies from 1000 to 1400 mm, mean annual air temperature is about 32 °C. The soil at the site had been under rotational cropping for at least 8 years before being cleared for use. The predominant weeds at the site were Siam weed (*Chromolaena odorata* L. King and Robinson), Haemorrhage plant (*Aspilia africana* Pers. Adams) and Goat weed (*Ageratum conyzoides* L.).

The experiment consisted of green manure composed by green tender stems and leaves of pawpaw, neem, moringa and gliricidia. NPK (15:15:15) was used as inorganic fertilizer and there was a control treatment with no green manure or fertilizer. The chemical composition of green manures was relatively high in N, P, K, Ca and Mg and organic carbon (OC) required for the growth of tomato (Table 1). Gliricidia had the highest N and K concentrations and moringa had the highest Ca concentration, while neem was highest in P and Mg (Table 1). The treatments were arranged in a randomized complete block design with four replications. Each block comprised of six plots, each of which measured 4 × 3 m. Blocks were 2 m apart, and plots were 1 m apart. The same site was used in both years.

Land preparation and crop establishment

The soil was prepared by plowed and disked. The green manure was harvested from nearby sites. Green tender stems and leaves were chopped and incorporated at 5 Mg ha^{-1} based on recommendation (Santhi and Palaniappan, 1986) to a depth of about 10 cm, using hoes. The NPK and control plots were prepared the same way as those of green manures, but without incorporation of green manure. Plots were left for 2 weeks before transplanting seedlings to allow for decomposition of green manures.

Seeds of tomato cultivar Owo local (*Lycopersicon esculentum* Mill.) were sown into a rich loamy soil in raised beds outdoors and mulched immediately using dry grasses. The seeds were treated with a seed-dressing fungicide (Apron plus 50 DS) against

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seed-borne or soil-borne pathogens before sowing. Water was applied daily using a watering can with fine rose. Seedlings emerged 5–8 days after sowing and mulched materials were removed after seedling emergence to harden the plants. When the tomato seedlings were 4 weeks old, they were transplanted into a previously ploughed and harrowed field on 3 April 2015 and 5 April 2016. The seedlings were removed singly with ball of earth to reduce damage to the roots. One tomato seedling was transplanted per hole at an inter-row spacing of 50 cm and a 50 cm intra-row spacing providing 48 plants per plot, which is equivalent to a plant population of 40 000 plants ha^{-1}.

Owo local cultivar has a wide range of adaptability and can survive in a wide range of conditions. It gives medium to large sized reddish fruits that are solid and flat-shaped. This cultivar is an indeterminate type of tomato that matures between 72 and 100 days and it continues to set and ripen fruits throughout the growing season (i.e. it gives a slow and steady supply of tomatoes, rather than one large harvest). At 2 weeks after transplanting (WAT), 300 kg ha^{-1} of NPK (15:15:15) was applied to NPK fertilizer treatment based on general fertilizer recommendation for tomato plant in southwest Nigeria (FPDD, 1990). The NPK fertilizer was applied manually by ring method at 10 cm away from the base of each tomato plant. Manual weeding with hoes was done three times beginning at 2 WAT and repeated at a 3 weeks interval. Insect pests were controlled by application of cypermethrin (3 mL L^{-1}) at a 2 weeks interval starting from 2 WAT. Plants were individually staked with 1 m stake at 4 and 5 WAT. No irrigation water was applied throughout the cropping seasons; however, the fields received about 523 mm of rainfall in 2015 and 536 mm in 2016 during the crop cycle.

Growth and yield parameters

Ten plants were randomly selected per plot for evaluations of plant height, number of leaves and leaf area at the mid-flowering stage in each year. Plant height was measured from the base of the plant (ground level) to the shoot apex using a ruler. Number of leaves was measured by counting manually and leaf area (A) was estimated using the mathematical model developed by Lyon (1948). It was computed by squaring the length (L) and multiplying by constant $K = 0.1551$ ($A = KL^2$). The number of fruits and fruit yield were evaluated between 72 and 90 days after transplanting. Fruit yields were evaluated based on the cumulative harvests per plot. Fruits were counted and fresh weight obtained with a top loading balance.

Soil physical and chemical properties

Before the start of the experiment, soil bulk density was determined as described by Campbell and Henshall (1991). Soil samples were also randomly collected at a depth of 0–15 cm and bulked to make a composite soil sample and evaluate particle-size and chemical composition. Particle-size analysis was done using the hydrometer method (Gee and Or, 2002). Textural class was determined using a textural triangle (Brady and Weil, 1999; Hunt and Gilkes, 1992). Four weeks after incorporation of green manure leaves, determination of bulk density in all plots was started and repeated

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after 6, 8, 10 and 12 weeks. Five soil samples were collected at 0–15 cm depth from the centre of each plot and 10 cm away from each tomato plant using steel core sampler. At the end of the experiment each year, soil samples were collected from each plot for chemical analysis. The soil samples collected were air dried, ground and passed through a 2 mm sieve. The sieved soil samples were taken to the laboratory for chemical analysis, as described by Carter and Gregorich (2007). Soil OC was determined by the procedure of Walkley and Black using the dichromate wet oxidation method (Nelson and Sommers, 1996). OM was estimated by multiplying carbon (C) by 1.724. Total N was determined by micro-Kjeldahl digestion and distillation techniques (Bremner, 1996), and available P was extracted using Bray-1 solution and determined by molybdenum blue colorimetry (Frank *et al.*, 1998). Exchangeable K, Ca and Mg were extracted using ammonium acetate 1 N (Reeuwijk, 2002). Thereafter, K was determined using a flame photometer, and Ca and Mg were determined by the EDTA titration method (Hendershot *et al.*, 2008). Soil pH was determined in 1:2 soil–water medium (Ibitoye, 2006).

Analyses of green manure and tomato fruits

Just prior to incorporation of green manure to plots, tender stem and leaf samples were collected randomly from each green manure, oven-dried for 24 h at 80 °C and ground in a Willey mill. The samples were analysed for leaf N, P, K, Ca and Mg as described by Tel and Hagarty (1984). Leaf N was determined by the micro-Kjeldahl digestion method. Ground samples were digested with nitric-perchloric-sulphuric acid mixture for determination of P, K, Ca and Mg. Phosphorus was determined colorimetrically using the vanadomolybdate method, K was determined using a flame photometer and Ca and Mg were determined by the EDTA titration method (Horwitz and Latimer, 2005). The percentage of OC in the green manure leaves was determined by the Walkley and Black procedure using the dichromate wet oxidation method (Nelson and Sommers, 1996).

At harvest, 10 tomatoes of uniform ripening were randomly collected from each plot in each year and analysed for mineral, lycopene and vitamin C contents. The fruits were homogenized in a micro-hammer stainless mill (Wiley, Philadelphia, Pennsylvania). Mineral elements of tomato fruit were determined according to methods recommended by the Association of Official Analytical Chemists (AOAC, 2006). 1 g of each sample was digested using 12 mL of the mix of HNO_3, H_2SO_4 and $HCLO_4$ (7:2:1 v/v/v). Contents of K, Ca, Fe, Zn and Cu were determined by atomic absorption spectrophotometry and vitamin C content was determined using the indophenol dye method (Singh *et al.*, 2007). Lycopene content was determined by grinding 20 mL of homogenized pulp in 25 mL hexane and the absorbance was read at 501 nm using a colorimeter (AOAC, 2006).

Statistical analysis

Data collected from each experiment were subjected to analysis of variance (ANOVA) using the Genstat statistical package (GENSTAT, 2005). If the treatment

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Table 2. Effect of various green manures and NPK fertilizer on soil bulk density and soil chemical properties.

Year	Fertilizer	Bulk density (Mg m^{-3})	pH (water)	OM (%)	N (%)	P (mg kg^{-1})	K (cmol kg^{-1})	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})
2015	Control	1.55a	5.74a	1.69d	0.11d	7.9e	0.13f	1.09d	0.49e
	Moringa	1.23b	5.58b	2.57c	0.16b	10.4d	0.27d	2.16b	0.73b
	Pawpaw	1.23b	5.42c	3.67a	0.16b	13.0b	0.30c	2.20b	0.85a
	Gliricidia	1.23b	5.42c	3.56a	0.18a	14.9a	0.38a	2.59a	0.72b
	Neem	1.25b	5.42c	2.87b	0.16b	12.5b	0.33b	2.13b	0.61c
	NPK 15-15-15 fertilizer	1.52a	5.24d	1.72d	0.13c	11.8c	0.23e	1.35c	0.51d
2016	Control	1.50a	5.72a	1.53d	0.09d	7.3e	0.11f	0.97d	0.31e
	Moringa	1.12b	5.56b	2.89c	0.20b	13.8c	0.33d	2.70b	0.91b
	Pawpaw	1.13b	5.40c	3.99a	0.20b	16.4b	0.36c	2.74b	1.03a
	Gliricidia	1.14b	5.40c	3.88a	0.22a	18.3a	0.44a	3.27a	0.90b
	Neem	1.15b	5.40c	3.19b	0.20b	15.9b	0.39b	2.67b	0.79c
	NPK 15-15-15 fertilizer	1.48a	5.22d	1.58d	0.11c	11.4d	0.21e	1.25c	0.45d
	P								
	Year (Y)	0.136	0.324	0.256	0.127	0.045	0.037	0.456	0.521
	Fertilizer (F)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Y × F	1.02	0.999	0.994	0.763	0.989	0.995	0.998	0.993

P – probability of *F* statistic from ANOVA; means in column for each effect followed by similar letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

by year interaction was significant, it was used to explain the results. If the interaction was not significant, means were separated using Duncan's multiple range test. A cost:benefit analysis was done to determine relative economic returns using 2015 and 2016 annual market prices. Total yield and cost:benefit analyses were determined using the harvest from the central bed (1 m^2) of each plot. Costs of farm services were from Oja Oba market in Owo Local Government Area of Ondo State, Nigeria (Agbede *et al.*, 2014).

RESULTS

Incorporation of green manures and NPK fertilizer influenced soil bulk density and chemical properties in both years (Table 2). Higher bulk density was found in 2015 than in 2016 (Table 2). Incorporation of green manure leaves reduced soil bulk density significantly compared with the NPK fertilizer and the control and there were no significant differences in bulk density among moringa, pawpaw, gliricidia and neem treatments (Table 2). There were no differences between NPK fertilizer and the control in terms of soil bulk density. Averaged over cropping seasons, the green manures (moringa, pawpaw, gliricidia and neem) reduced soil bulk density by 27% compared with NPK fertilizer and the control.

Higher soil OM, N, P, K, Ca and Mg concentrations were found in 2016 as compared to 2015 (Table 2). There were no significant differences in pH between the

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Table 3. Effect of various green manures and NPK fertilizer on plant height, number of leaves, leaf area, number of fruits and fruit yield of tomato.

Year	Fertilizer	Fruit yield (Mg ha^{-1})	Number of fruits per plant	Plant height (m)	Number of leaves per plant	Leaf area (m^2)
2015	Control	8.6e	17e	0.39e	27e	0.17e
	Moringa	12.2d	26d	0.53d	54d	0.21d
	Pawpaw	13.2c	30c	0.59c	59c	0.25c
	Gliricidia	15.8a	39a	0.75a	86a	0.32a
	Neem	14.4b	34b	0.67b	70b	0.28b
	NPK 15-15-15 fertilizer	12.1d	25d	0.53d	53d	0.21d
2016	Control	6.9f	15f	0.31f	23f	0.15f
	Moringa	14.7d	32d	0.57d	56d	0.25d
	Pawpaw	15.8c	36c	0.63c	71c	0.29c
	Gliricidia	18.6a	45a	0.79a	98a	0.36a
	Neem	16.9b	40b	0.71b	80b	0.32b
	NPK 15-15-15 fertilizer	11.3e	23e	0.47e	49e	0.19e
	P					
	Year (Y)	0.004	0.003	0.426	0.024	0.031
	Fertilizer (F)	0.000	0.000	0.000	0.000	0.000
	Y × F	0.012	0.017	0.013	0.022	0.025

p – probability of *F* statistic from ANOVA; means in column for each effect followed by similar letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

first and second years. Among fertilizers, incorporation of green manures increased soil OM, N, P, K, Ca and Mg compared with the NPK fertilizer and the control. NPK fertilizer increased soil N, P, K, Ca and Mg compared with the control, while OM was similar in NPK treatment and the control. There were no differences in soil pH among the various green manures (except moringa) and it was significantly lower in NPK when compared with other treatments. In both years, Gliricidia increased soil N, P, Ca and K significantly compared with other green manures, whereas pawpaw had the highest OM and Mg values (Table 2). Incorporation of green manures increased soil nutrient status, while NPK fertilizer and the control decreased nutrient status over time.

Application of green manures and NPK fertilizer influenced growth, number of fruits and fruit yield of tomato in both years (Table 3). Number of leaves, leaf area, number of fruits and fruit yield of tomato were higher in 2016 (second crop) than in 2015 (first crop). The green manures and NPK fertilizer increased fruit yield, number of fruits, plant height, number of leaves and leaf area of tomato significantly compared with the control (Table 3, Figure 1). Gliricidia and other green manures caused higher growth, number of fruits and fruit yield of tomato as compared with NPK fertilizer. Decreasing order for treatments leading to high fruit yield, number of fruits, plant height, number of leaves and leaf area of tomato was gliricidia > neem > pawpaw > moringa > NPK fertilizer > control (Table 3, Figure 1). In the first year (2015)

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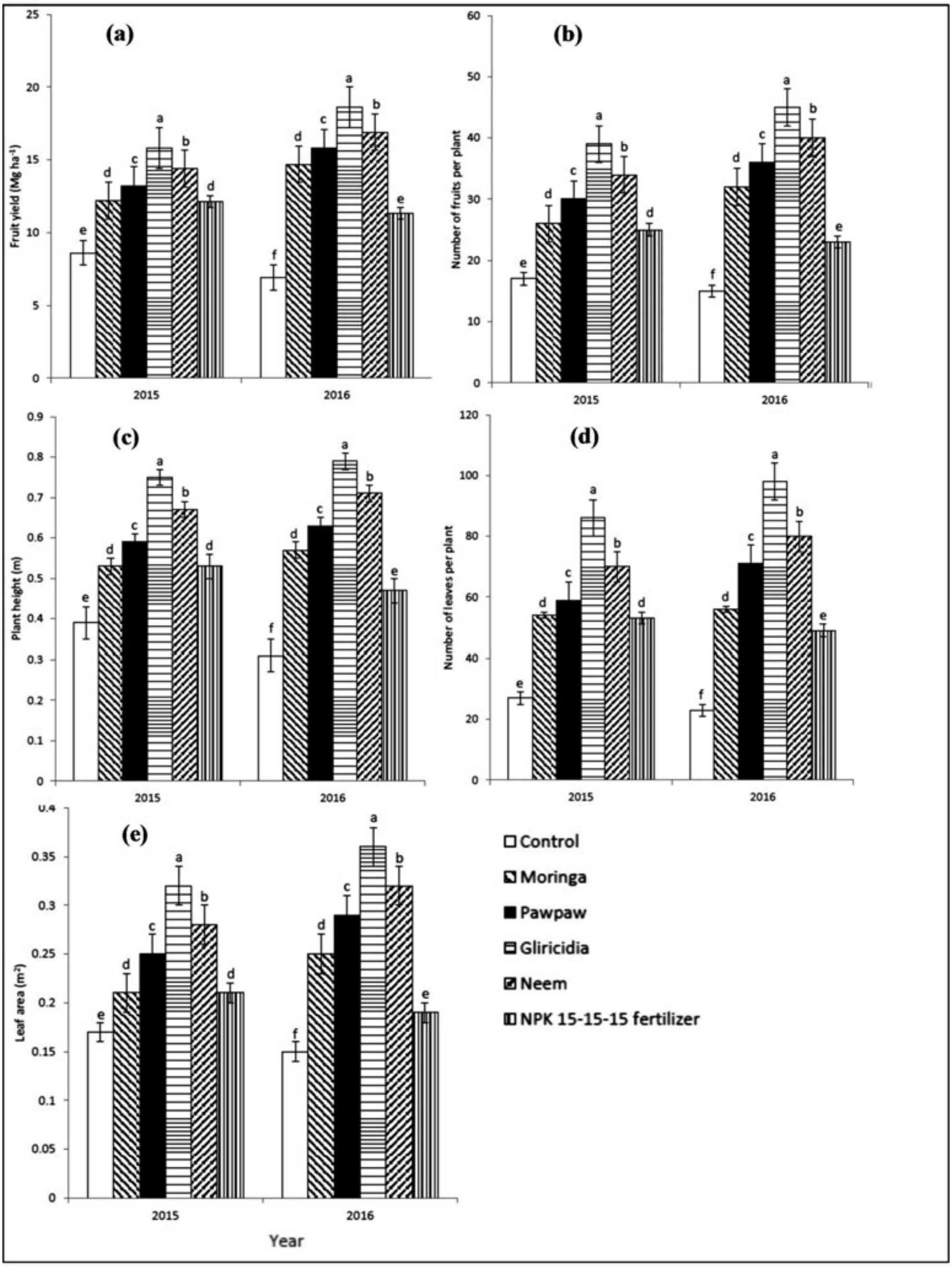

Figure 1. Effect of various green manures and NPK 15-15-15 fertilizer on fruit yield (a), number of fruits per plant (b), plant height (c), number of leaf per plant (d) and leaf area (e) of tomato in 2015 and 2016. Letters show Duncan's multiple range test and vertical bars show standard errors.

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Table 4. Effect of various green manures and NPK fertilizer on mineral, lycopene and vitamin C contents of tomato fruits.

Year	Fertilizer	K (mg 100^{-1} g)	Ca (mg 100^{-1} g)	Fe (mg 100^{-1} g)	Zn (mg 100^{-1} g)	Cu (mg 100^{-1} g)	Lycopene (mg 100^{-1} g)	Vita min C (mg 100^{-1} g)
2015	Control	334.3d	32.0d	0.23d	0.12d	0.06d	0.33e	10.9d
	Moringa	472.9a	53.3a	0.50a	0.24a	0.15a	0.62a	16.5a
	Pawpaw	362.3c	31.2c	0.45b	0.18b	0.11c	0.40c	13.1b
	Gliricidia	364.5c	31.7c	0.31c	0.17bc	0.11c	0.51b	10.8c
	Neem	418.2b	44.4b	0.44b	0.18b	0.13b	0.50b	12.4b
	NPK 15-15-15 fertilizer	365.0c	31.1c	0.30c	0.18b	0.13b	0.35d	12.6b
2016	Control	286.1d	25.6d	0.19d	0.10d	0.04d	0.29e	7.9d
	Moringa	521.1a	59.7a	0.54a	0.26a	0.17a	0.66a	20.7a
	Pawpaw	410.5c	37.6c	0.47b	0.20b	0.13c	0.44c	17.3b
	Gliricidia	412.7c	38.1c	0.35c	0.19bc	0.13c	0.55b	15.0c
	Neem	466.4b	50.8b	0.48b	0.20b	0.15b	0.54b	16.6b
	NPK 15-15-15 fertilizer	413.2c	37.5c	0.34c	0.20b	0.15b	0.39d	16.8b
	P							
	Year (Y)	0.259	0.346	0.418	0.421	0.587	0.675	0.634
	Fertilizer (F)	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Y × F	0.999	0.998	0.997	0.993	0.898	0.693	1.000

P – probability of *F* statistic from ANOVA; means in column for each effect followed by similar letter are not significantly different at $P = 0.05$ according to Duncan's multiple range test.

and compared with control, gliricidia, neem, pawpaw, moringa and NPK fertilizer increased fruit yield of tomato by 84%, 67%, 53%, 42% and 41%, respectively. In the second year (2016), gliricidia, neem, pawpaw, moringa and NPK fertilizer increased fruit yield of tomato by 170%, 145%, 129%, 113% and 64%, respectively. Averaged over 2 years and compared with control, gliricidia, neem, pawpaw, moringa and NPK fertilizer increased fruit yield of tomato by 121%, 101%, 86%, 73% and 50%, respectively. In relation to NPK treatment and averaged over 2 years, gliricidia, neem, pawpaw and moringa increased fruit yield of tomato by 47%, 34%, 24% and 15%, respectively.

K, Ca, Fe, Cu, lycopene and vitamin C contents of tomato fruits were higher in 2016 than in 2015 (Table 4). There were no significant differences in Zn content of tomato fruits in both years. The various green manures and the NPK fertilizer increased K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents of tomato fruits significantly compared with the control (Table 4). Moringa caused the highest K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents of tomato fruits compared with other treatments. While there were no differences in Zn content of tomato fruits among pawpaw, gliricidia, neem and NPK treatments, green manures caused higher lycopene content than NPK fertilizer.

Cost of purchasing fertilizer was higher than the cost of cutting and transporting green manure (Table 5). Use of gliricidia produced the highest gross return

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Table 5. Economics of producing tomato under green manures and NPK fertilizer tested in the first year (2015) and second year (2016).

Treatment	Monetary gain ($ ha^{-1})	Production increase value ($ ha^{-1})	Production increase (%)	Cost of cutting and transporting of green manures/cost of NPK fertilizer ($ ha^{-1})	Net return over each fertilization ($ ha^{-1})	Return rate or value/cost ratio of each fertilization
Control	33 540	–		–	–	–
Moringa	58 050	24 510	73.08	145	24 365	168.03
Pawpaw	62 350	28 810	85.90	145	28 665	197.69
Gliricidia	73 960	40 420	120.51	145	40 275	277.76
Neem	67 510	33 970	101.28	145	33 825	233.28
NPK 15-15-15 fertilizer	50 310	16 770	50.00	250	16 520	66.08

Notes: In the first year of 2015, the price of fruit yield of tomato was $4.25 kg^{-1}; NPK 15-15-15 fertilizer was $41.67 per 50 kg bag. In the second year of 2016, the price of fruit yield of tomato was $4.34 kg^{-1}; NPK 15-15-15 fertilizer was $41.67 per 50 kg bag.

($73 960 ha^{-1}) and net return ($40 275 ha^{-1}) followed by neem with a gross return of $67 510 ha^{-1} and net return of $33 825 ha^{-1}, the lowest gross return ($33 540 ha^{-1}) was from the control. All green manures and the NPK fertilizer produced higher net profit than the control (Table 5). The economic returns and net benefits from all green manures were higher than for the NPK treatment. The gliricidia treatment was more cost effective and profitable in production of tomato than all other treatments, as indicated by its high return rate or value/cost ratio of 277.76.

DISCUSSION

The soil analysis clearly showed that the nutrient status of the soil was low, except for Mg, which was adequate (as described in Materials and Methods section). Therefore, it is expected that the crops should respond to fertilizer application. The poor soil fertility status could be attributed to nature and continuous cultivation over the years without addition of manure or fertilizer inputs. The green manures used for the study were rich in major nutrients and decomposed rapidly. That incorporation of green manure reduced soil bulk density compared with the control and NPK fertilizer (Table 2) could be due to increased soil OM from decomposed manures. Presence of green manures should have increased activities of beneficial soil fauna and then OM decomposition, which could lead to enhanced soil porosity and reduced soil bulk density (Salahin *et al.*, 2013). Incorporation of gliricidia, moringa, pawpaw and neem increased soil OM, N, P, K, Ca and Mg concentrations (Table 2), indicating that nutrients in plant tissues were released into the soil. As expected, NPK fertilizer did not increase soil OM because it did not contain OM (Table 2). The slightly lower soil pH in plots incorporated with green manure leaves compared with the initial soil pH may be explained by the production of CO_2 and organic acids during decomposition of incorporated green manure. Salahin *et al.* (2013) also observed reduced soil pH and changes in soil properties after incorporation of green manure crops. On the

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other hand, the significant decrease in soil pH of the plots treated with NPK fertilizer compared with green manures and the control could be due to its acidic nature.

Our data revealed that the use of green manures as fertilizers are cumulative and extend considerably beyond the year of application as OM, N, P K, Ca and Mg were significantly affected (Table 2). This might be due to the slow release patterns of their nutrients as the cumulative agronomic values of some organic compounds applied to agricultural soils could be more than five times greater in the post application period than the values realized during the year of application (Adeleye and Ayeni, 2010; Colacico, 1982). As there is an association between soil OM and bulk density (Adekiya *et al.*, 2016), the significant effect of fertilizer treatments with green manure for bulk density could be related to the increase in soil OM in the second year as a result of the residual effect of manures.

Incorporation of green manures increased soil OM and nutrients, fruit yield, number of fruits, plant height, number of leaves and leaf area of tomato and such effects differed between cropping seasons (Tables 2 and 3, Figure 1). The high concentrations of OM, N, P, K, Ca and Mg in the second cropping season than in the first season can be attributed to improved soil OM status of the organic materials, since soil OM is a natural source of nutrients and improves cation exchange capacity. This implies that organic materials can be used beneficially to increase productivity of agricultural soils. The improved growth performance of tomato crops in the second year compared with the first year could be attributed in part to the increased plant nutrients availability due to residual concentration from the first cropping season and the subsequent application of the organic manure in the second year.

Incorporation of green manures and NPK fertilizer increased growth, number of fruits and fruit yield of tomato compared with the control. The increase in the performance of tomato as a result of green manure could be due to reduced soil bulk density and increased availability of soil OM, N, P, K, Ca and Mg concentrations from the manures. The increase in the performance of tomato as a result of green manure compared with the NPK fertilizer could be due to reduced soil bulk density and increased availability of soil OM, N, P, K, Ca and Mg concentrations from the manures. In fact, reduced soil bulk density enhances root growth and water and nutrient uptake and yield (Lampurlanes and Cantero-Martinez, 2003). Then, the better performance of tomato under NPK fertilizer plots compared with the control might be due to availability of essential nutrient elements (N, P and K) from the inorganic fertilizer, which are absorbed by the tomato plants.

Incorporation of gliricidia increased performance of tomato compared with NPK fertilizer and other green manures due to availability of N, Ca, K and P in the soil (Table 2). Adams *et al.* (1978) and Adams (1986) reported that N, Ca, K and P are the four major elements that are particularly critical in production of tomato. Application of optimum N-fertilizer to the soil produces high tomato fruit yield and improves fruit quality (Adams *et al.*, 1978). Potassium maintains the ionic balance and water status within the tomato plant. It is involved in the production and transport of sugars in the plant, enzyme activation and synthesis of proteins. Potassium is also required in pigment synthesis in tomato fruit, notably lycopene (Adams, 1986). The lower

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performance of tomato under NPK fertilizer compared with gliricidia, neem, pawpaw and moringa leaves might be due to leaching and erosion.

That green manures and NPK fertilizer increased mineral, lycopene and vitamin C contents in tomato fruits compared with the control was attributed to increased availability of nutrients in soil as a result of the mineralization of the manures leading to increased uptake by tomato plants. Except for moringa having the highest values, there were no consistent variation between other green manures in terms of mineral, lycopene and vitamin C contents of tomato fruits. Green manures caused higher values of lycopene content compared with NPK fertilizer. Ilupeju *et al.* (2015) found higher content of lycopene in organically grown tomato compared with conventionally grown tomato, with no significant difference observed in vitamin C content. The slightly lower soil pH of other green manures and especially NPK fertilizer apart from moringa could have prevented nutrient uptake due to acidity and injury to roots (Undie *et al.*, 2013). Soil OM is a source of oxalate, malate, citrate and tartarate acids (Tsado *et al.*, 2008), aside from the fact that these acids can neutralize cations, they can increase soil acidity thereby injuring roots and reducing nutrients uptake. In strongly acidic soils, availability of macronutrients (Ca, Mg, K, P, N and S) is curtailed (Brady and Weil, 1999). This present study indicated that gliricidia, neem, pawpaw and moringa could be used as green manure on any acidic tropical soil for sustainable soil and crop productivity without worsening its acidity. The results of this study provided evidence that these locally available plant species can be used as green manure to improve soil and crop quality.

CONCLUSION

Green manures can serve as alternative source of soil OM and nutrients, replacing inorganic fertilizers with beneficial effects on soil fertility and nutrient release and increasing tomato yield and quality. While gliricidia is recommended as green manure for increasing tomato yield, moringa is recommended for improving tomato growth and quality.

REFERENCES

Adams, P. (1986). Mineral nutrition. In *The Tomato Crop: A Scientific Basis for Improvement*, 281–334 (Eds J. G. Atherton and J. Rudich). New York: Chapman & Hall.

Adams, P., Graves, C. J. and Winsor, G. W. (1978). Tomato yields in relation to the nitrogen, potassium and magnesium status of the plants and of the peat substrate. *Plant and Soil* 49(1):137–148.

Adekiya, A. O., Agbede, T. M., Aboyeji, C. M., Dunsin, O. and Ugbe, J. O. (2017). Green manures and NPK fertilizer effects on soil properties, growth, yield, mineral and vitamin C composition of okra (*Abelmoschus esculentus* (L.) Moench). *Journal of the Saudi Society of Agricultural Sciences* https://doi.org/10.1016/j.jssas.2017.05.005 (Article in press).

Adekiya, A. O., Agbede, T. M. and Ojeniyi, S. O. (2016). **T**he effect of three years of tillage and poultry manure application on soil and plant nutrient composition, growth and yield of cocoyam. *Experimental Agriculture* 52(3):466–476.

Adeleye, E. O. and Ayeni, L. S. (2010). Enhancing soil nutrient status and maize yield through organic wastes on an Alfisol in southwest Nigeria. *Nigerian Journal of Soil Science* 20(1):79–85.

Agbede, T. M., Adekiya, A. O. and Ogeh, J. S. (2014). Response of soil properties and yam yield to *Chromolaena odorata* (Asteraceae) and *Tithonia diversifolia* (Asteraceae) mulches. *Archives of Agronomy and Soil Science* 60(2):209–224.

https://doi.org/10.1017/S0014479718000376 Published online by Cambridge University Press

Akinrinde, E. A. and Obigbesan, G. O. (2000). Evaluation of the fertility status of selected soils for crop production in five ecological zones of Nigeria. In *Proceedings of the 26th Annual Conference of the Soil Science Society of Nigeria*, 279–288 (Ed. O. Babalola), 30 Oct–3 Nov, Ibadan, Nigeria.

Ali, M. (1999). Evaluation of green manure technology in tropical lowland rice systems. *Field Crops Research* 61(1):61–78.

AOAC (2006). *Official Methods of Analysis of the Association of Official Analytical Chemists. AOAC International*, 18th edn. 2005 (Eds W. Horwitz and G. W. Latimer). Gaithersburg, MD: AOAC International.

Brady, N. C. and Weil, R. R. (1999). *The Nature and Properties of Soils*, 12th edn. Upper Saddle River, New Jersey: Prentice-Hall.

Bremner, J. M. (1996). Nitrogen-total. In *Methods of Soil Analysis. Chemical Methods, Part 3*, 2nd edn, 1085–1121 (Ed D. L. Sparks). SSSA Book Series No. 5, Madison, WI, USA: ASA and SSSA.

Campbell, D. J. and Henshall, J. K. (1991). Bulk density. In *Physical Methods of Soil Analysis*, 329–366 (Eds K. A. Smith and C. E. Mullin). New York: Marcel Dekker.

Carter, M. R. and Gregorich, E. G. (2007). *Soil Sampling and Methods of Analysis*, 2nd edn., 1264. Canadian Society of Soil Science, Boca Raton, FL: CRC Press and Taylor & Francis Group, USA.

Colacico, D. (1982). Economic aspects of composting. *Biocycle* 31(10):68–73.

Fahey, J. W. (2005). *Moringa oleifera*: A review of the medical evidence for its nutritional, therapeutic, and prophylactic properties. Part 1. *Trees for Life Journal* 1:5 http://www.tfljournal.org

FAO (1993). *Year Book of Production*. Rome, Italy: Food and Agriculture Organization of the United Nations.

FPDD (1990). Summary of fertilizer recommendations for fruits and vegetables in southwestern nigeria. Literature Review on Soil Fertility Investigation in Nigeria. Fertilizer Procurement Division and Distribution, Federal Ministry of Agriculture and Natural Resources, Lagos, Nigeria.

Frank, K., Beegle, D. and Denning, I. (1998). Phosphorus. In *Recommended Chemical Soil Test Procedures for the North Central Region*, 21–26 (Ed J. R. Brown). Columbia, MO, USA: North Central Regional Research Publication No. 221 (revised) Missouri Agric. Exp. Stn.

Gee, G. W. and Or, D. (2002). Particle-size analysis. In *Methods of Soil Analysis. Part 4. Physical Methods*, 255–293 (Eds J. H. Dane and G. C. Topp). Madison, WI, USA: Soil Science Society of America Book Series No. 5.

GENSTAT (2005). *Genstat*, 8th edn. Release 8.1. Oxford, UK: VSN International Ltd.

Hendershot, W. H., Lalande, H. and Duquette, M. (2008). Ion exchange and exchangeable cations. In *Soil Sampling and Methods of Analysis*, 2nd edn, 173–178 (Eds M. R. Carter and E. G. Gregorich). Canadian Society of Soil Science, Boca Raton, FL: CRC Press and Taylor & Francis Group, USA.

Horwitz, W. and Latimer, G. W. Editors (2005). *Official Methods of Analysis of the Association of Official Analytical Chemists International*, 16th edn. Gaithersburg, Maryland, USA: AOAC International.

Hunt, N. and Gilkes, R. (1992). *Farm Monitoring Handbook*. Nedlands, WA: The University of Western Australia.

Ibitoye, A. A. (2006). *Laboratory Manual on Basic Soil Analysis*, 2nd edn., 82. Akure, Ondo State: Foladaye Publishing Company.

Ilupeju, E. A. O., Akanbi, W. B., Olaniyi, J. O., Lawal, B. A., Ojo, M. A. and Akintokun, P. O. (2015). Impact of organic and inorganic fertilizers on growth, fruit yield, nutritional and lycopene contents of three varieties of tomato [*Lycopersicon esculentum* (L.) Mill] in Ogbomoso, Nigeria. *African Journal of Biotechnology* 14(31):2424–2433.

Lampurlanes, J. and Cantero-Martinez, C. (2003). Soil bulk density and penetration resistance under different tillage and crop management systems and their relationship with barley root growth. *Agronomy Journal* 95:526–536.

Lyon, C. J. (1948). A factor method for the leaf area of tomato leaves. *Plant Physiology* 23(4):634–635.

Makumba, W., Janssen, B., Oenema, O., Akinnifesi, F. K., Mweta, D. and Kwesiga, F. (2006). The long-term effects of a gliricidia-maize intercropping system in Southern Malawi, on gliricidia and maize yields, and soil properties. *Agriculture, Ecosystems and Environment* 116(1–2):85–92.

Nandwa, S. M. (2001). Soil organic carbon (SOC) management for sustainable productivity of cropping and agro-forestry systems in Eastern and Southern Africa. *Nutrient Cycling in Agroecosystems* 61(1–2):143–158.

Nelson, D. W. and Sommers, L. E. (1996). Total carbon, organic carbon and organic matter. In *Methods of Soil Analysis. Part 3. Chemical Methods*, 2nd edn., 961–1010 (Ed D. L. Sparks). SSSA Book Series No. 5, Madison, WI, USA: ASA and SSSA.

Reeuwijk, L. P. van Editor, (2002). *Procedures for Soil Analysis. Technical Paper 9*, 6th edn. Wageningen, The Netherlands: International Soil Reference and Information Centre (ISRIC) & Food and Agriculture Organization of the United Nations (FAO).

https://doi.org/10.1017/S0014479718000376 Published online by Cambridge University Press

Salahin, N., Alam, Md. K., Islam, Md. M., Naher, L. and Majid, N. M. (2013). Effects of green manure crops and tillage practice on maize and rice yields and soil properties. *Australian Journal of Crop Science* 7(12):1901–1911.

Santhi, S. R. and Palaniappan, S. P. (1986). Effect of Neem leaf (*Azadirachta indica* L.) on growth and yield of low land rice. *Journal of Agronomy and Crop Science* 157(2):114–117.

Sharoni, Y. and Levi, Y. (2006). Cancer prevention by dietary tomato lycopene and its molecular mechanisms. In *Tomatoes, Lycopene and Human Health*, 111–125 (Ed A. V. Rao). Barcelona, Spain: Caledonian Science Press Ltd.

Singh, J., Upadhyay, A. K., Prasad, K., Bahadur, A. and Rai, M. (2007). Variability of carotenes, vitamin C, E and phenolics in Brassica vegetables. *Journal of Food Composition and Analysis* 20(2):106–112.

Soil Survey Staff. (2014). *Keys to Soil Taxonomy*, 12th edn. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service.

Tel, D. A. and Hagarty, M., Eds. (1984). *Soil and Plant Analysis*, 277. Nigeria, Guelph, Ontario, Canada: International Institute of Tropical Agriculture (IITA), University of Guelph, Ibadan.

Tsado, P. A., Agbenin, J. O., Osunde, A. O., Bala, A. and Odofin, A. J. (2008). The effect of some selected organic acids on phosphorus sortion in an Alfisol in Minna, North Central Nigeria. In *Proceedings of the 32nd Conference of the Soil Science Society of Nigeria*, 276–283 (Eds L. Singh, B. H. Usman, A. M. Saddiq, H. Musa and S. O. Ojeniyi), March 10–14th, Yola, Nigeria.

Undie, U. L., Kekong, M. A. and Ojikpong, T. O. (2013). Moringa (*Moringa oleifera* Lam.) leaves effect on soil pH and garden egg (*Solanum aethiopicum* L.) yield in two Nigeria agro-ecologies. *European Journal of Agriculture and Forestry Research* 1(1):17–25.

Willcox, J. K., Catignani, G. L. and Lazarus, S. (2003). Tomatoes and cardiovascular health. *Critical Reviews in Food Science and Nutrition* 43(1):1–18.

https://doi.org/10.1017/S0014479718000376 Published online by Cambridge University Press