Soil Properties, Growth, Fruit Yield, Mineral, Lycopene and Vitamin C Contents of Tomato (*Lycopersicon esculentum* Mill) Grown with Green Manures and NPK Fertilizer

Taiwo Michael AGBEDE [1(✉)]
Aruna Olasekan ADEKIYA [2]
Monday Olatunbosun ALE [3]
Ehiokhilen Kevin EIFEDIYI [4]
Christy Adebukola OLATUNJI [5]

Summary

Green manures as an alternative to inorganic fertilizer offer considerable potential as a source of plant nutrients and organic matter. Hence, field experiments were carried out during 2015 and 2016 cropping seasons to compare impacts of green manures (GM) and NPK 15-15-15 fertilizer on soil properties, growth, fruit yield, mineral, lycopene and vitamin C contents of tomato (*Lycopersicon esculentum* Mill). The GM from green tender stems and leaves of: Pawpaw (*Carica papaya* L.), Neem (*Azadirachta indica* A. Juss.), Moringa (*Moringa oleifera* Lam.) and Gliricidia (*Gliricidia sepium* (Jacq.) Kunth ex Walp.) were applied at 5 t ha^{-1}, and the NPK fertilizer was applied at 300 kg ha^{-1}. Plots without fertilizer were used as a control. Application of GMs reduced soil bulk density and increased soil organic matter (OM), N, P, K, Ca, Mg, growth and fruit yield of tomato compared with the control. The NPK fertilizer had no effect on soil bulk density and soil OM, and increased soil N, P, K, Ca, Mg, growth and fruit yield of tomato compared with the control. Gliricidia increased growth and fruit yield of tomato compared with NPK fertilizer and other GMs. The GMs and NPK fertilizer increased mineral, lycopene and vitamin C contents in the tomato fruits compared with the control. Moringa produced higher K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents compared with other GMs and NPK fertilizer. Use of GM has potential to improve soil properties, and growth, fruit yield and nutritional contents of tomato than does NPK fertilizer. The Gliricidia treatment best improved soil properties and tomato productivity as indicated by the benefit-cost ratio. For those growing tomato for fruit quantity Gliricidia is recommended as green manure. For those that desire fruit quality Moringa is recommended as green manure.

Key words

Azadirachta indica, *Carica papaya*, *Gliricidia sepium*, *Lycopersicon esculentum*, *Moringa oleifera*

[1] Department of Crop, Soil and Pest Management Technology, Rufus Giwa Polytechnic, P.M.B. 1019, Owo, Ondo State, Nigeria
✉ e-mail: agbedetaiwomichael@yahoo.com
[2] College of Agricultural Sciences, Landmark University, P.M.B. 1001, Omu-Aran, Kwara State, Nigeria
[3] Department of Agricultural and Bioenvironmental Engineering Technology, Rufus Giwa Polytechnic, P.M.B. 1019, Owo, Ondo State, Nigeria
[4] Department of Agronomy, University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria
[5] Department of Hospitality Management Technology, Rufus Giwa Polytechnic, P.M.B. 1019, Owo, Ondo State, Nigeria

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Introduction

Tomato (*Lycopersicon esculentum* Mill) is a good provider of vitamin C (Ilupeju et al., 2015). Consumption of tomatoes has been associated with prevention of cardiovascular disease, cancers and several other diseases mainly due to the content of antioxidants including ascorbic acid, carotenes, lycopene and phenolic compounds (Willcox et al., 2003; Sharoni and Levi, 2006).

Average tomato yield in Nigeria is low, approximately 10 t ha^{-1} (FAO, 2001), owing to low native soil fertility status among other factors. Low, and declining, soil fertility is a major concern in many African small holder 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). Use of green manure as a source of soil fertility is not a common practice among tomato growers in the tropics. Green manure use can increase production of tomato under tropical conditions by maintaining soil density, soil fertility and productivity. Green manure plants are non-polluting, less toxic and biodegradable with no hazardous residues in soil, water and air. They are environmentally safe and generaly 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. It was reported that application of fresh neem leaves at 5 t ha^{-1} or dry neem leaves at 1.25 t ha^{-1}, used in conjunction with urea, resulted in higher N recovery percent and N response ratio compared to application of urea alone (Santhi and Palaniappan, 1986). Moringa is an underutilized tropical crop. Incorporation of Moringa shoots as green manure increased fertility level of agricultural soils (Fahey, 2005). Gliricidia has been used to improve quality and as a potential source of N (Makumba et al., 2006).

Plant materials used as green manure differ in chemical composition, rate of decomposition, nutrient elements released to the soil, and nutrient uptake by crops planted with green manures. The nutritional effect of green manure on crop plants depends on residue quality. High quality materials improve plant nutrition by releasing nutrients. Low quality residues have relatively weak direct nutritional effect.

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 planted in each green manure. The 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.

Material and methods

Site description and treatments

Field experiments were carried out at the Teaching and Research Farm, Rufus Giwa Polytechnic, Owo (7°12'N, 5°35'E), Ondo State, Nigeria, during the 2015 and 2016 cropping seasons. It is located in the forest-savanna transition zone of Nigeria. The soil at Owo is in the Okemesi Series and is an Alfisol classified as Oxic Tropuldalf or Luvisol (Soil Survey Staff, 2014) derived from quartzite, gneiss and schist. 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 temperature is about 32°C. The soil at the site had been under rotational cropping for at least eight 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 from leaves of: Pawpaw, Neem, Moringa, Gliricidia, and NPK 15-15-15 fertilizer and a control with no green manure or fertilizer. The treatments were arranged in a randomized complete block design with four replications. Each block comprised of six 4 × 3 m^2 plots. 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 plowing and disking. The green manures used for the experiments were harvested from nearby sites and were comprised of green tender stems and leaves of the plants. Green tender stems and leaves were chopped and incorporated at 5 t ha^{-1} based on recommendation (Santhi and Palaniappan, 1986) to a depth of about 10 cm using hoes. The NPK and control treatments plots were prepared the same way as those of green manures plots, but without incorporation of green manure. Plots were left for two weeks before transplanting seedlings to allow for decomposition of green manures.

To produce Owo local tomato transplants, seeds were sown into a rich loamy soil in outdoors raised beds. Water was applied daily using a watering can with fine rose. Four-week-old seedlings were transplanted on 3 April 2015 and 5 April 2016. One tomato seedling was transplanted per hole at a 50 cm inter-row spacing and a 50 cm intra-row spacing providing 48 plants per plot, which is equivalent to a plant population of 40,000 plants per hectare. At two weeks after transplanting (WAT), 300 kg ha^{-1} of NPK fertilizer 15:15:15 was applied based on general fertilizer recommendation for tomato plant in southwest Nigeria (FPDD, 1990). Manual weeding, using hoes, was done three times beginning at two WAT and repeated at a three week interval. Insect pests were controlled by application of cypermethrin, 3 mL L^{-1} of water at a two week interval starting from two WAT. Plants crops were individually staked with 1 m stake at four and five WAT.

Determination of growth and yield parameters

Ten plants per plot were randomly selected and growth and yield data were obtained. Growth parameters (plant height, number of leaves and leaf area) were determined at the mid-flowering stage in each year. Fruit yields were evaluated between 72 and 90 days after transplanting.

Determination of 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 for determination of particle-size and chemical analysis. Particle-size analysis was done using the hydrometer method.

Four weeks after incorporation of green manure leaves, determination of bulk density in all plots was started and repeated at 6, 8, 10 and 12 weeks after green manure incorporation. Five soil samples were collected at 0-15 cm depth from the center of each plot and 10 cm away from each tomato plant using steel core sampler. Samples were used to evaluate bulk density as before. 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 (1993). Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation method. Organic matter (OM) was deduced by multiplying carbon (C) by 1.724. Total N was determined by micro-Kjeldahl digestion and distillation techniques; available P was extracted using Bray-1 solution and determined by molybdenum blue colorimetry. Exchangeable K, Ca and Mg were extracted using 1 N ammonium acetate. Additional samples were analyzed for K using a flame photometer and Ca and Mg by the EDTA titration method. Soil pH was determined in 1:2 soil-water medium.

Analysis of green manure leaves and tomato fruits

Just prior to incorporation of green manure leaves to plots, green tender stems and leafs 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 analyzed 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. The percentage of organic carbon (OC) in the green manure leaves was determined by the Walkley and Black procedure using the dichromate wet oxidation method.

At harvest, 10 tomato fruits of uniform ripening were randomly collected from each plot in each year and analyzed for mineral, lycopene and vitamin C contents. The fruits were homogenized in a Micro-hammer stainless mill (Wiley, Philadelphia, Pennsylvania). Mineral elements of tomato fruits were determined according to methods recommended by the Association of Official Analytical Chemists (AOAC, 2006). One gram of each sample was digested using 12 cm^{-3} 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.

Statistical analysis

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

Results

Physical characteristics and chemical analyses of the site before the start of the experiment in 2015 indicated the soil deficient in organic matter (OM) and other nutrients (Table 1). The soil was sandy loam in texture, high in bulk density and acidic. The soil was low in OM, total N, available P, exchangeable K and Ca and adequate in Mg according to the critical level 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), indicating poor soil fertility. It will therefore be unable to sustain crop yield without the addition of external input.

Table 1. Mean ± standard deviation of soil physical and chemical properties of the experimental site before experimentation in 2015

Soil property	Value
Sand (g kg^{-1})	753 ± 2.5
Silt (g kg^{-1})	127 ± 0.5
Clay (g kg^{-1})	120 ± 0.6
Textural class	Sandy loam
Bulk density (Mg m^{-3})	1.65 ± 0.02
pH (water)	5.8 ± 0.05
Organic matter (%)	2.24 ± 0.01
Total N (%)	0.18 ± 0.01
Available P (mg kg^{-1})	9.5 ± 0.5
Exchangeable K (cmol kg^{-1})	0.14 ± 0.01
Exchangeable Ca (cmol kg^{-1})	1.4 ± 0.02
Exchangeable Mg (cmol kg^{-1})	0.56 ± 0.01

The chemical composition of green manure was relatively high in N, P, K, Ca and Mg and organic carbon required for the growth of tomato (Table 2). The chemical analysis of the green manures had no consistent pattern in the concentration of nutrients in the tissues. Gliricidia had the highest organic C, N and K values, and Moringa had the highest Ca values. Neem was the highest in P and Mg (Table 2). Application of green manures and NPK fertilizer in the short term is expected to benefit the crop and soil.

Incorporation of green manures and NPK fertilizer influenced soil bulk density and chemical properties (Figure 1 and Table 3). The first year (2015) had significantly higher bulk density compared with the second year (2016) (Table 3). Incorporation of green manure significantly reduced soil bulk density compared with the NPK fertilizer and the control (Figure 1, Table 3). There were no significant differences in bulk density between Moringa, Pawpaw, Gliricidia and Neem leaves used as green manure (Figure 1, Table 3). There were no differences between NPK fertilizer and the control in term of soil bulk density. Application of NPK fertilizer did not influence soil bulk density compared with green manures. 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. When studied as individual factors, year (Y) and fertilizer (F) were significant for bulk density (Table 3). The Y × F interaction was also significant for bulk density.

Table 2. Chemical composition of various green manures used

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

Table 3. Effect of various green manures and NPK fertilizer on soil bulk density and soil chemical properties

Effect	Bulk density ($Mg\ m^{-3}$)	pH (H_2O)	OM (%)	N (%)	P ($mg\ kg^{-1}$)	K ($cmol\ kg^{-1}$)	Ca ($cmol\ kg^{-1}$)	Mg ($cmol\ kg^{-1}$)
Year								
2015	1.34a	5.50a	2.73a	0.14b	11.3b	0.27b	1.95b	0.67b
2016	1.25b	5.41a	2.78a	0.17a	14.3a	0.30a	2.21a	0.71a
Fertilizer								
Control	1.52a	5.73a	1.61d	0.10d	7.6e	0.12f	1.03d	0.40e
Moringa leaves	1.18b	5.57b	2.73c	0.18b	12.1c	0.30d	2.43b	0.82b
Pawpaw leaves	1.18b	5.41c	3.83a	0.18b	14.7b	0.33c	2.47b	0.94a
Gliricidia leaves	1.19b	5.41c	3.72a	0.20a	16.6a	0.41a	2.86a	0.81b
Neem leaves	1.20b	5.41c	3.03b	0.18b	14.2b	0.36b	2.40b	0.70c
NPK 15-15-15	1.50a	5.23d	1.65d	0.12c	11.6cd	0.22e	1.30c	0.48d
P								
Year (Y)	0.000	0.083	0.520	0.000	0.000	0.000	0.000	0.000
Fertilizer (F)	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Y x F	0.000	0.747	0.000	0.000	0.000	0.000	0.000	0.000

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

The second year (2016) significantly had higher soil N, P, K, Ca and Mg compared with the first year (2015) (Table 3). There were no significant differences in pH and OM between the first year (2015) and the second year (2016). 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. The OM of NPK fertilizer treated soil was similar to the control. There were no differences in pH between the various green manures except Moringa, but pH of NPK fertilizer was significantly lower compared with other treatments. In both years, Gliricidia leaves incorporated as green manure increased soil N, P, Ca and K significantly compared with other green manures. Pawpaw had the highest OM and Mg values (Table 3). Incorporation of leaves of green manures increased soil nutrient status over time, while NPK fertilizer and the control decreased nutrient status over time. When studied as individual factors, year (Y) was significant for soil N, P, K, Ca and Mg, but not for soil pH and OM; fertilizer (F) was significant for soil pH, OM, N, P, K, Ca and Mg (Table 3). The interaction of Y × F were significant for soil OM, N, P, K, Ca and Mg, but not for soil pH.

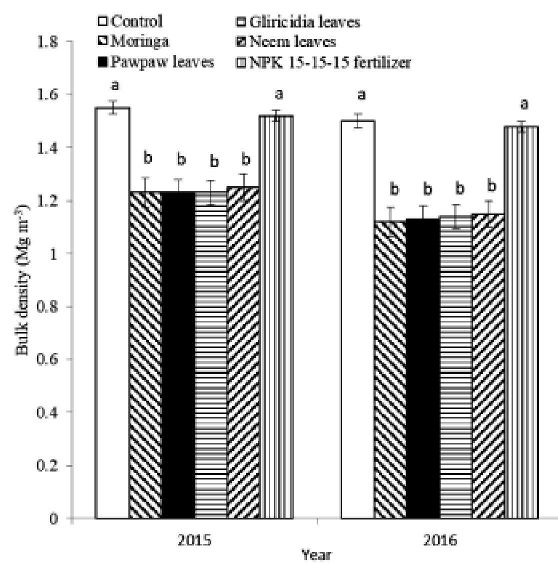

Figure 1. Effect of various green manures and NPK 15-15-15 fertilizer on soil bulk density in 2015 and 2016

Application of green manures and NPK fertilizer influenced growth and fruit yield of tomato (Table 4). Year 2016 (second crop) significantly increased number of leaves, leaf area and fruit yield of tomato compared with year 2015 (first crop). There were no differences in plant height in both years. The green manures and NPK fertilizer significantly increased plant height, number of leaves and fruit yield of tomato compared with the control (Table 4). Gliricidia and other green manures significantly increased growth and fruit yield of tomato compared with NPK fertilizer. In all cases of growth (Table 4) and fruit yield (Figure 2, Table 4) decreasing order was: Gliricidia > Neem > Pawpaw > Moringa > NPK fertilizer > control. Averaged over two 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. Averaged over two years and compared with NPK fertilizer, Gliricidia, Neem, Pawpaw and Moringa increased fruit yield of tomato by 47, 34, 24 and 15%, respectively. When studied as individual factors, year (Y) affected number of leaves, leaf area and fruit yield of tomato,

Table 4. Effect of various green manures and NPK fertilizer on growth and fruit yield of tomato

Effect	Fruit yield, (t ha^{-1})	Plant height, (m)	Number of leaves per plant	Leaf area, (m^2)
Year				
2015	12.7b	0.58a	59.2b	0.24b
2016	14.0a	0.58a	61.7a	0.26a
Fertilizer				
Control	7.8f	0.35f	25f	0.16f
Moringa leaves	13.5d	0.55d	55d	0.23d
Pawpaw leaves	14.5c	0.61c	65c	0.27c
Gliricidia leaves	17.2a	0.77a	92a	0.34a
Neem leaves	15.7b	0.69b	75b	0.30b
NPK 15-15-15 fertilizer	11.7e	0.50e	51e	0.20e
P				
Year (Y)	0.000	0.847	0.000	0.024
Fertilizer (F)	0.000	0.000	0.000	0.000
Y x F	0.000	0.000	0.000	0.000

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

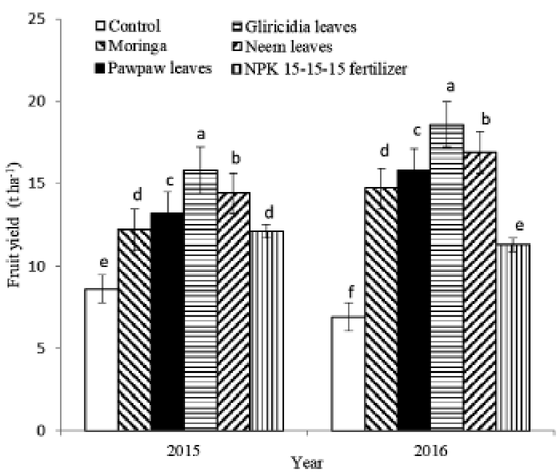

Figure 2. Effect of various green manures and NPK 15-15-15 fertilizer on fruit yield of tomato in 2015 and 2016

but not plant height; fertilizer (F) affected number of leaves, plant height, leaf area and fruit yield of tomato (Table 4). The interaction of Y × F affected plant height, number of leaves, leaf area and fruit yield of tomato.

The second year (2016) significantly increased K, Ca, Fe, Cu, lycopene and vitamin C contents compared with the first year (2015) (Table 5). There were no significant differences in Zn content in both years. The various green manures and the NPK fertilizer significantly increased K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents compared with the control (Table 5). Moringa had the highest K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents compared with other treatments. There were no differences in Zn content between Pawpaw, Gliricidia, Neem and NPK fertilizer. Moringa, Pawpaw, Gliricidia and Neem had higher content of lycopene than NPK fertilizer. When studied as individual factors, year (Y) was significant for K, Ca, Fe, Cu, lycopene and vitamin C contents, but not for Zn content; fertilizer (F) was significant for K, Ca, Fe, Zn, Cu, lycopene and vitamin C contents (Table 5). The interaction of Y × F was significant for K, Ca, Fe, Cu, lycopene and vitamin C contents, but not for Zn content.

Table 5. Effect of various green manures and NPK fertilizer on mineral, lycopene and vitamin C contents of tomato fruits

Effect	K	Ca	Fe	Zn	Cu	Lycopene	Vitamin C
	mg 100^{-1} g						
Year							
2015	366.1b	35.6b	0.35b	0.18ab	0.11b	0.43b	13.1b
2016	438.5a	43.2a	0.41a	0.19a	0.13a	0.51a	15.3a
Fertilizer							
Control	310.2d	28.8d	0.21d	0.11d	0.05d	0.31e	9.4d
Moringa leaves	497.0a	56.5a	0.52a	0.25a	0.16a	0.64a	18.6a
Pawpaw leaves	386.4c	34.4c	0.46b	0.19bc	0.12c	0.42c	15.2b
Gliricidia leaves	388.6c	34.9c	0.33c	0.18c	0.12c	0.53b	12.9c
Neem leaves	442.3b	47.6b	0.46b	0.19bc	0.14b	0.52b	14.5b
NPK 15-15-15	389.1c	34.3c	0.32c	0.19bc	0.14b	0.37d	14.7b
P							
Year (Y)	0.001	0.000	0.000	0.053	0.002	0.000	0.001
Fertilizer (F)	0.000	0.000	0.000	0.041	0.000	0.000	0.000
Y x F	0.000	0.000	0.000	0.055	0.031	0.000	0.000

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

Table 6. 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 leaves	58,050	24,510	73.08	145	24,365	169.03
Pawpaw leaves	62,350	28,810	85.90	145	28,665	198.69
Gliricidia leaves	73,960	40,420	120.51	145	40,275	278.76
Neem leaves	67,510	33,970	101.28	145	33,825	234.28
NPK 15-15-15	50,310	16,770	50.00	250	16,520	67.08

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.

Cost of purchasing of fertilizer was higher than the cost of cutting and transporting each green manure treatment (Table 6). Use of Gliricidia produced the highest gross return ($73,960 ha^{-1}) and net return ($40,275 ha^{-1}) followed by Neem treatment 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. The economic returns and net benefits from all green manures were higher than from the NPK fertilizer 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 278.76.

Discussion

The soil analysis clearly showed that the nutrient status of the soil was low except Mg, which was adequate. Therefore, it is expected that the crops should response to fertilizer application. The poor soil fertility status could be attributed to nature and continuous cultivation over the years. The green manures used for the study were rich in supplying the major nutrients and decomposed rapidly.

That incorporation of green manure reduced soil bulk density compared with the control and NPK fertilizer could be due to increased soil OM from degraded green manures. Presence of green manures should have increased activities of beneficial soil fauna in organic matter decomposition that could lead to enhanced soil porosity and reduced soil bulk density (Salahin et al., 2013). Incorporation of Gliricidia, Moringa, Pawpaw and Neem leaves increased soil OM, N, P, K, Ca and Mg concentrations, which indicate that nutrients in the plant tissues are released into the soil. NPK fertilizer did not increase soil OM because it did not contain organic matter. The slightly lower soil pH in plots incorporated with green manure leaves compared with the initial soil pH may be connected to production of CO_2 and organic acids during decomposition of incorporated green manure leaves (Salahin et al., 2013). The authors observed changes in soil properties and reduction in soil pH after incorporation of green manure crops. The significant decrease in pH of the plots treated with NPK fertilizer compared with organic manures and the control could be due to its acidic nature.

Incorporation of green manures increased soil nutrients, growth and fruit yield of tomato in the second cropping season more than in the first cropping season. Higher concentrations of nutrients (N, P, K, Ca and Mg) in the second cropping season than in the first one can be attributed to improved soil organic matter status, since soil organic matter is a natural source of nutrients and cation exchange capacity. This implies that organic materials can be used beneficially to increase productivity of agricultural soils. It also implies that the values of organic materials as fertilizers are cumulative and extend considerably beyond the year of application. This might be due to the slow release patterns of their nutrients. It has been reported that the cumulative agronomic values of some organic wastes 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). 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 and fruit yield of tomato compared with the control. The increase in the performance of tomato as a result of green manure compared with the NPK fertilizer and the control could be due to reduced soil bulk density and increased availability of soil OM, N, P, K, Ca and Mg contents from the manures (Figure 1, Table 3). Reduced soil bulk density enhances root growth and water and nutrient uptake and yield (Lampurlanes and Cantero-Martinez, 2003). 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 that 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 3).

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 required in lycopene synthesis in tomato fruit (Adams, 1986). The lower performance of tomato under NPK fertilizer compared with Gliricidia, Neem Pawpaw and Moringa leaves might be due to leaching and erosion (Adekiya et al., 2017).

That green manures and NPK fertilizer increased mineral, lycopene and vitamin C contents in tomato fruit 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 term of mineral, lycopene and vitamin C contents of tomato fruits. Green manures had 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 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, malates, 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 organic matter and nutrients, or a replacement for inorganic fertilizers, with beneficial effects on soil fertility improvement and nutrient release for optimum tomato yield and quality. For those that desire high yielding Gliricidia is recommended as green manure, while for those desiring good quality tomatoes Moringa is recommended as green manure.

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