Nutrients Uptake and Fruit Yield of Tomato (*Lycopersicon Esculentum* Mill.) Produced Using Home Sorted and Municipal Organic Materials as Nutrient Sources.

Onaolapo, Musiliat Mopelola[1*], Adejuyigbe, Christopher Olu.[1], Olowokere, Florence Alaba [1] & Oyekanmi, Akeem Abdulai.[2]

[1]Department of Soil Science and Land Management,

Federal University of Agriculture, Abeokuta

[2]Department of Plant Physiology and Crop Production,

Federal University of Agriculture, Abeokuta

***Corresponding author**

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ABSTRACT

Tomato (*Lycopersicon esculentum* Mill.) is one of the most popular crops with a unique role in human diets especially in Nigeria. Nutritional quality of fruit is a reflection of uptake by the plant. The study investigated the uptake of Nitrogen, Phosphorus, Potassium, Calcium and Magnesium uptake by tomato with incorporation of home and municipal sorted solid waste. Screenhouse experiment was carried out at the College of Plant Science and Crop Production, while field experiment was conducted at the Directorate of University Farms, Federal University of Agriculture (Latitudes 7°13´N and 7°20´N and Longitudes 3°20´E and 3°28´E) during the early and late seasons of 2019. Roma VF and Ibadan-local varieties as test crop. The screenhouse experiment was factorial in Completely Randomized Design. The treatments were: composted municipal solid waste; composted home sorted waste; pyrolyzed municipal solid waste and pyrolyzed home sorted waste at the rate of 0, 5, 10 and 20 tha^{-1} each. The field experiment was set up in a randomized complete block design with incorporation of waste treatments at 10 t ha^{-1}, all in three replicates. The treatments mentioned above for screenhouse were also used for field experiment. Data collected were subjected to Analysis of Variance and the means were separated using Duncan's Multiple Range Test ($p<0.05$). The study was carried out in the wet and dry seasons. Nutrients (N, P, K, Ca and Mg) uptakes by plants were determined after laboratory analysis using nutrient concentration x dry matter (kg ha^{-1}). Treatments had significant effects on the fruit yield of tomato. Composted home sorted waste at 5 t ha^{-1} resulted in highest uptake of nitrogen (5.32 mg kg^{-1}), phosphorus (2.87 mg kg^{-1}), potassium (26.10 mg kg^{-1}) and magnesium (9.74 mg kg^{-1}) in screenhouse compared with control and other treatments. Pyrolyzed wastes enhanced the fruit yield and nutrient uptake by plant relative to composted wastes in both seasons on the field. Pyrolyzed home sorted waste (PHSW) enhanced nitrogen uptake at early (186 kg ha^{-1}) and late (108 kg ha^{-1}) seasons. Pyrolyzed wastes (PHSW and PMSW) increased phosphorus uptake of 573 kg ha^{-1} and 507 kg ha^{-1} respectively in the early season while the highest phosphorus uptake of 339.6 kg ha^{-1} was observed with PHSW in the late season. Pyrolyzed municipal solid waste (PMSW) increased potassium uptake in both early (22.21 kg ha^{-1}) and late (12.55 kg ha^{-1}) seasons compared to control and other treatments applied. It was concluded that composted and pyrolyzed home sorted wastes improved the fruit yield and nutrient uptake in organic tomato production, and thus recommended for optimal production of tomato.

Keywords: Nutrient uptake, composted waste, pyrolyzed waste, home sorted waste, municipal sorted waste.

INTRODUCTION

Increase in global population accompanied with urbanization and industrial progress has directly increased the generation of complex solid waste [50]. Materials, such as agricultural wastes, municipal solid waste, food and kitchen wastes, garden wastes, agro-industrial wastes, animal wastes, and so on can be generally classified as solid organic wastes comprising of organic biodegradable fraction with moisture content below 85–90 % [35]. Most of the developing countries in the world generate huge quantities of solid waste characterized with poor handling and management amidst lack of waste segregation and proper disposal facilities [40]. The organic portion of municipal solid waste can be processed into organic fertilizer either through compost or pyrolysis.

Organic fertilizer through compost or pyrolysis, a widely accepted technology for organic waste recycling in agriculture, ensures the organic matter stabilization and sanitization of these wastes. This is the method by which nutrients in organic wastes are recycled for crop production in order to reduce volume, particle size and humidity of organic waste, remove the biodegradable parts of organic materials thereby transforming waste into valuable soil conditioner that can be used for agricultural purposes [28]. The growth and development of plants depend on the continuous uptake of essential nutrients found in soil in the form of different mineral compounds, which are used for the synthesis of bio molecules [34]. Among the most important elements for higher plants are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S) [29]. The procuring of nutrients from soil is ensured by specialized transporters and channels situated in roots that are influenced by the environmental factors, the metabolism, the availability of nutrients [20] and water in the soil [6]. During the vegetative period of tomato production, plants require mostly N, followed by K, P, Ca, Mg and S ([47], [46]). In this stage, N is important for chlorophyll formation, which is responsible for root, stalk and leaf development. Nitrogen promotes the growth of plant height, leaf area and the number of flowers. At maturity, excess nitrogen has inhibitory effects, such as decreasing fruit size or delaying ripening. Phosphorus stimulates the growth and development of tomato plants but is also used for flowering because it is responsible, in particular, for flower initiation and fruit ripening [16]. Potassium is equally important for the above ground and underground plant organs, enhancing their growth, Ca stimulates plant growth in height and the number of formed leaves, Mg (like P) accelerates the growth of plants and S is important for ensuring plant vigor [5]. For flowering, tomato plants need large amounts of P (responsible for the number of flowers and buds formed) and K (promotes flower initiation), while during fruiting, K (stimulates flowers to mature and to form fruits) is the most required element [16].

Tomato (*Lycopersicon esculentum* Mill.) is the second most widely consumed vegetable after the potato [33]. Tomatoes are important not only because of the large amount consumed, but also because of their nutrition. In the human diet, it is an important source of micronutrients, certain minerals (notably potassium), carboxylic acids, and carotenoids (in particular lycopene and phenolic compounds) ([13], [24]). Most importantly, tomato consumption has been shown to reduce the risks of cardiovascular disease and certain types of cancer, such as prostate, lung, and stomach [12]. Tomato quality is a function of several factors, including the choice of cultivar, cultural practices, harvest time and method, storage, and handling procedures. Increased interest in organic tomato production has imposed the need to evaluate the quality and nutritional value of organic tomatoes.

MATERIALS AND METHODS

Description of the Study Location

The study was carried out at the Federal University of Agriculture, Abeokuta (FUNAAB), Ogun state, Nigeria, (Latitude 7°13´N and 7°20´N and Longitude 3°20´E and 3°28´E). The university is located in the transition zone between tropical humid and savannah climate, characterized by distinct wet and dry seasons. The mean annual rainfall is 1200 mm with bimodal distribution and the mean annual temperature of about 22.2 ℃.

Experiment 1: Screenhouse Study

This experiment was conducted in the screenhouse at the College of Plant Science and Crop Production (COLPLANT), Federal University of Agriculture, Abeokuta (FUNAAB), Ogun state, Nigeria, (Latitude 7°13’N and 7°20’N and Longitude 3°20’E and 3°28’E).

Experiment 2: Field Trials

Field experiment was carried out at Research Farm of the Directorate of University Farms (DUFARMS) at the Federal University of Agriculture, Abeokuta in the year 2019. Two cropping seasons (early season and late season) were involved.

Waste Collection and Sorting

Home wastes were collected from designated homes where organic materials had been sorted at household level by collecting the organic waste in separate containers. Municipal solid wastes were collected from Johnson landfill site along Baptist boys’ high school, Saje Abeokuta, and sorted to remove non-degradable materials. Both home sorted wastes and municipal solid organic wastes were then composted or pyrolyzed separately.

Compost and Biochar Production

The Indian indore hot heap method was adopted for composting. The two sets of organic wastes (home and municipal-sorted waste) were composted separately. The two sets of waste materials were also pyrolyzed to produce biochar using pyrolyzer. The biochar production was by ignition method. Waste materials were placed in Top-lit Updraft Kiln [41] and ignited for 10 minutes residence time at 450^{o} C. The biochars formed were homogenized and milled to fine texture, stored in labeled air-tight polythene bags. Chemical analyses were carried out on compost and biochar.

For compost samples: the nutrients (organic carbon, nitrogen and phosphorus) were determined using AOAC standard methods. Calcium and magnesium concentrations were determined by EDTA titration [3] while sodium and potassium concentrations were determined by flame photometer.

For pyrolyzed (biochar) sample: Biochar pH was measured using 1:2 (soil: water ratio) after shaking for 30 minutes in de ionized water. Organic Carbon (%) was determined. Total nitrogen content in the biochar was determined by Kjedahl’s method [9]. Phosphorous was determined by the ammonium molybdate method using a spectrophotometer. Calcium and Magnesium concentrations were determined by EDTA (Ethylene diamine tetra acetic acid) titration [3], while sodium and potassium concentrations were determined by flame photometer.

Experiment 1: Screenhouse Study

Experimental design

The experiment was a 4 x 4 x 2 factorial fitted into a Completely Randomized Design (CRD). The factors included four types of amendments: composted municipal solid waste; composted home-sorted waste; pyrolyzed municipal solid waste; pyrolyzed home-sorted waste. Amendments were applied at the rate of 0, 5, 10 and 20 t ha^{-1}. Two varieties of tomato (Roma VF and Ibadan local) were used. All treatments were replicated three times.

Treatment application

Pots were perforated at the base to allow proper drainage and aeration. The base was supported with tray to prevent nutrients from being drained away. The surface soil (0-20 cm) used for the trial was collected from the site where the field experiment was laid, the Federal University of Agriculture, Abeokuta. Five (5) kilograms of soil sample was weighed in each pot and arranged in Completely Randomized Design (CRD). Treatments were incorporated by uniformly spread on the surface of the pot and worked into the soil using a hand trowel at the rate of 0 t ha^{-1} (no application), 5 t ha^{-1} (11.16 g pot^{-1}), 10 t ha^{-1} (22.32 g pot^{-1}) and 20 t ha^{-1} (44.64 g pot^{-1}).

Seedling production and transplanting

Tomato seeds (Roma VF and Ibadan local) which were sourced from the National Horticultural Research Institute (NIHORT) Idi-Isin, Ibadan were raised in the nursery for 4 weeks and one seedling was transplanted into each pot. Transplanting was done manually at 2 weeks after treatment incorporation. Pots were watered to 80 % field capacity.

At 10 weeks after transplanting, data were obtained on each pot for collection of ripped fruit yield of tomato, and this was done every two (2) weeks interval. The total fruit yield harvested was taken per pot and their yield was expressed in g plant^{-1} [43].

Experiment 2 – Field Trial (2019)

Experimental design

Experiment was laid out in a 5 x 2 factorial arranged in Randomized Complete Block Design (RCBD) with 3 replications. Treatments involved were: Composted municipal solid waste, composted home-sorted waste, pyrolyzed municipal solid waste, pyrolyzed home-sorted waste; all at 10 t ha^{-1} and the Control (CTR) (no amendment). Two varieties (Roma VF and Ibadan local) of tomato were used.

Nursery establishment, plot establishment, planting and cultural practices.

Seeds of tomato were established in the nursery separately. Seeds were planted by broadcasting in tray and watered for 4 weeks before transplanting. Experimental site was cleared, ploughed and harrowed. Experimental land size was 806 m^2 plots measuring 4 m x 4 m (16 m^2) was demarcated with 1 m intra and inter row spacing. Treatments at 10 t ha^{-1} were incorporated 2 weeks before transplanting. Seedling transplanting was done manually two weeks after treatment incorporation into the plots. Two seedlings were transplanted per stand at a spacing of 75 cm x 50 cm, planted at a depth of 5 cm; and thinned to one where both survived at one week after transplanting. Weeding was done manually at three (3) weeks interval. The experiment involved two cropping seasons: main cropping (early season: April-August) with treatment application and residual (late season: August-December) without any further treatments application.

Data collection

At 10 weeks after transplanting, five (5) plants were randomly selected at the middle row of each plot for collection of ripped fruit yield of tomato, and this was done every two (2) weeks interval. The cumulative total fruit yield harvested was taken per plot using mettle weighing balance and their yield was expressed in t ha^{-1} [26].

Laboratory Analyses

Pre – and post treatment of screenhouse soil analyses

The surface soil used for the trial was collected from the site where the field experiment was laid at the Federal University of Agriculture Abeokuta (FUNAAB). Soil samples were randomly collected with soil augar from eight different points at the depth of 0-20 cm. These were bulk to form a composite soil sample for laboratory routine analysis. The collected soil samples were air-dried, homogenized, sieved and prepared for analysis. 2.0 mm sieve mesh was used for pH, phosphorus, sodium, potassium, calcium and magnesium while 0.05 mm sieve mesh was used for organic carbon and total nitrogen. Also, post-treatment soil sampling was taken from each experimental pot, air- dried, pulverized and sieved. The samples were analyzed for the following:

The pretreatment soil sample was analyzed for particle size fractions after dispersion with calgon [18]. Soil pH was determined (1:1 Soil: Water ratio) using pH glass electrode meter [37]. Total Nitrogen was analyzed using macro-Kjedahl distillation apparatus [9]. Soil organic carbon was determined by the procedure of Walkley and Black using the dichromate wet oxidation methods [39]. Available phosphorous was extracted with Bray1solution and colorimetrically determined using the vanado-molybdate method [8]. Exchangeable bases were extracted with ammonium Acetate (1N NH_4OAc) buffered at pH 7. Sodium and potassium in the extract were determined by flame photometer while Ca and Mg were determined using Atomic Absorption Spectrophotometer (AAS) following the method of [30].

Plant tissue analysis

Tomato shoot was cut at the soil level from each pot after harvest. The fresh weights were taken using mettler weighing balance. The plants were oven dried to constant weight at $65^{o}C$ and the dry weight also recorded. Plant samples were milled and digested for analysis. Nutrient concentration of N, P, K, Ca and Mg were determined as follows: Nitrogen content was determined by micro-Kjedahl method of [9]. Phosphorus was colorimetrically determined using the vanado-molybdate method [8]. Potassium was determined by flame photometer. Calcium and magnesium were determined using Atomic Absorption Spectrophotometer (AAS).

Total uptake of N, P, K, Ca and Mg were calculated using the formular below:

Nutrient uptake = Nutrient concentration × Dry matter [15]

Pre – and post treatment of field soil analyses

Pre-Treatment Soil Sampling and analysis: Prior to treatment application, initial soil samples (0 – 20 cm depth) were randomly collected at 8 different points with the aid of soil auger on the experimental site, these were bulked, and sub sampled for routine analysis.

Post-Treatment Soil Sampling and Analysis: After harvest, soil samples (0 – 20 cm depth) were randomly collected from each plot with the aid of a soil auger. The samples were bulked per plot and sub sampled for analysis followed same procedure of greenhouse study (2.8.1).

Plant tissue analysis

Five tomato shoots were taken from each experimental plot at 16 weeks after transplanting. The fresh weights were taken using weighing balance. The plants were then oven dried to constant weight at 65 ^{o} C and dry weight was also taken. After oven drying, plant samples were weighed, milled and digested for analysis. Also, nutrients uptake (kg ha^{-1}) were determined followed same procedure of greenhouse study (2.8.2).

Statistical Analysis

All data collected were subjected to Analysis of Variance (ANOVA) using Genstat discovery, 12th Edition. Means were separated using Duncan’s Multiple Range Test (DMRT) at 5 % level of probability.

RESULT AND DISCUSSION

Characterization of Pretreatment Soil used in the Study

Physical and chemical characteristics of the soil used for the field study were presented in Table 1. The soil was sandy loam in texture with 764 g kg^{-1} sand, 13 g kg^{-1} clay and 223 g kg^{-1} silt particles; hence the experimental soil was dominantly sandy, probably due to the nature of the parent material [54]. The soil was neutral with a pH of 6.8 in H_2O. The organic carbon (7.50 g kg^{-1}) and total nitrogen (0.26 g kg^{-1}) were very low [22]. The very low OC and TN status of experimental plot indicates the poor fertility status of the soils. The exchangeable potassium (0.33 cmol kg^{-1}) and exchangeable sodium were moderate (0.47 cmol kg ^{1}). Available phosphorus (Bray 1 P) of the soil was however adequate (24.14 mg kg^{-1}) while exchangeable magnesium (0.37 cmol kg^{-1}) and exchangeable Calcium were low (0.40 cmol kg^{-1}). The poor fertility status of the experimental soil might be due to nature and continuous cultivation of the soil over the years. This corroborate with the research work of [36] that most tropical soils are depleted of nutrients especially when crop demands were high. Most Nigerian soils are deficient in the primary major essential nutrients required by plants [1] and [45]. The sustainability method of improving these soils is by fertilizer application which in this research was organic waste materials.

Characterization of the Amendments Used for The Experiments

Chemical properties of the organic materials used for this study were presented in Table 2. The pH (H_2O) of pyrolyzed home-sorted waste (PHSW), pyrolyzed municipal solid waste (PMSW) and composted home-sorted waste (CHSW) were very strongly alkaline (10.30, 9.40 and 8.30) while that of composted municipal solid waste (CMSW) was moderately alkaline (8.00) and suggesting

Table 1: Properties of the soil used for the experiment

Soil Properties	Unit	Values
Soil pH (H_2O)	1: 2	6.8
Organic Carbon	(g kg^{-1})	7.50
Total Nitrogen	(g kg^{-1})	0.26
Available Phosphorus	(mg kg^{-1})	24.14

Exchangeable Cation		
	Ca (cmol kg^{-1})	0.40
	Mg (cmol kg^{-1})	0.37
	K (cmol kg^{-1})	0.33
	Na (cmol kg^{-1})	0.47
Particle size:	Sand (g kg^{-1})	764
	Clay (g kg^{-1})	13
	Silt (g kg^{-1})	223
Textural class		Sandy loam

Table 2: Chemical properties of the organic waste materials used for the experiment

Properties	Units	PHSW	PMSW	CHSW	CMSW
pH (H_2O) 1:2		10.30	9.40	8.30	8.00
Organic Carbon	(g kg^{-1})	109.7	199.5	48.7	83.5
Total Nitrogen	(g kg^{-1})	2.90	2.70	2.70	2.60
Total Phosphorus	(g kg^{-1})	132.3	121.7	70.00	40.00
Total Potassium	(g kg$^{-1)}$	0.90	3.32	1.80	1.00
Total Calcium	(g kg$^{-1)}$	4.53	5.32	3.56	5.69
Total Magnesium	(g kg$^{-1)}$	3.80	4.00	2.80	4.60
Total Sodium	(g kg$^{-1)}$	1.80	3.70	3.20	4.10

PHSW- Pyrolyzed home-sorted waste; CHSW- Composted home-sorted waste; PMSW- Pyrolyzed municipal solid waste; CMSW – Composted municipal solid waste.

promoting soil pH on application. It has been noted that application of organic fertilizer can improve the soil pH [23]. Organic carbon was found highest in the PMSW amendment (199.5 g kg^{-1}). However the total Nitrogen content of the amendments was found highest with PHSW (2.90 g kg^{-1}), while the potassium was observed highest in PMSW amendments (3.32 g kg^{-1}). Phosphorus was found highest with PHSW having 132.3 g kg^{-1}. Highest magnesium in the amendments was observed in CMSW (4.60 g kg^{-1}). Calcium was found highest with CMSW amendment (5.69 g kg^{-1}).

Effects of Composted and Pyrolyzed Sorted Wastes on The Yield of Tomato in The Screenhouse

The effect of composted and pyrolyzed sorted wastes on the yield of tomato in the screenhouse is shown in Figure 1. Among the treatments, maximum tomato fruit yield of 256.054 g plant^{-1} and 235.594 g plant^{-1} were recorded in treatment receiving pyrolyzed home sorted waste at 10 t ha^{-1} with Roma VF and Ibadan local respectively. This could be attributed to the improved growth characteristics such as height, girth, number of leaves, number of flowers as well as number of fruits from the pyrolyzed amendments as this contains some amount of nutrients, which could have been taken up by the plants for an enhanced biomass partitioning. This was in line with the findings of [27] who reported that application of biochar (pyrolyzed organic materials) to soils boost crop yield and productivity. Lowest tomato fruit yield of 116.084 g plant^{-1} and 82.209 g plant^{-}**1** were observed in control. All the amendments applied at 10 t ha^{-1} increased tomato yield more than 5 and 20 t ha^{-1}. However, varietal response was significant with Roma VF having produced higher yields compared to Ibadan local.

Nutrient (N, P, K, Ca and Mg) Uptake by Tomato Shoot (Plant) in the Screenhouse After Harvest

The effect of composted and pyrolyzed waste on nutrient uptake by plant is shown in Table 3. There were significant differences in nutrients uptake due to amendments incorporation. All the amendments significantly increased nutrients (N, P, K, Ca and Mg**)** uptake above the control.

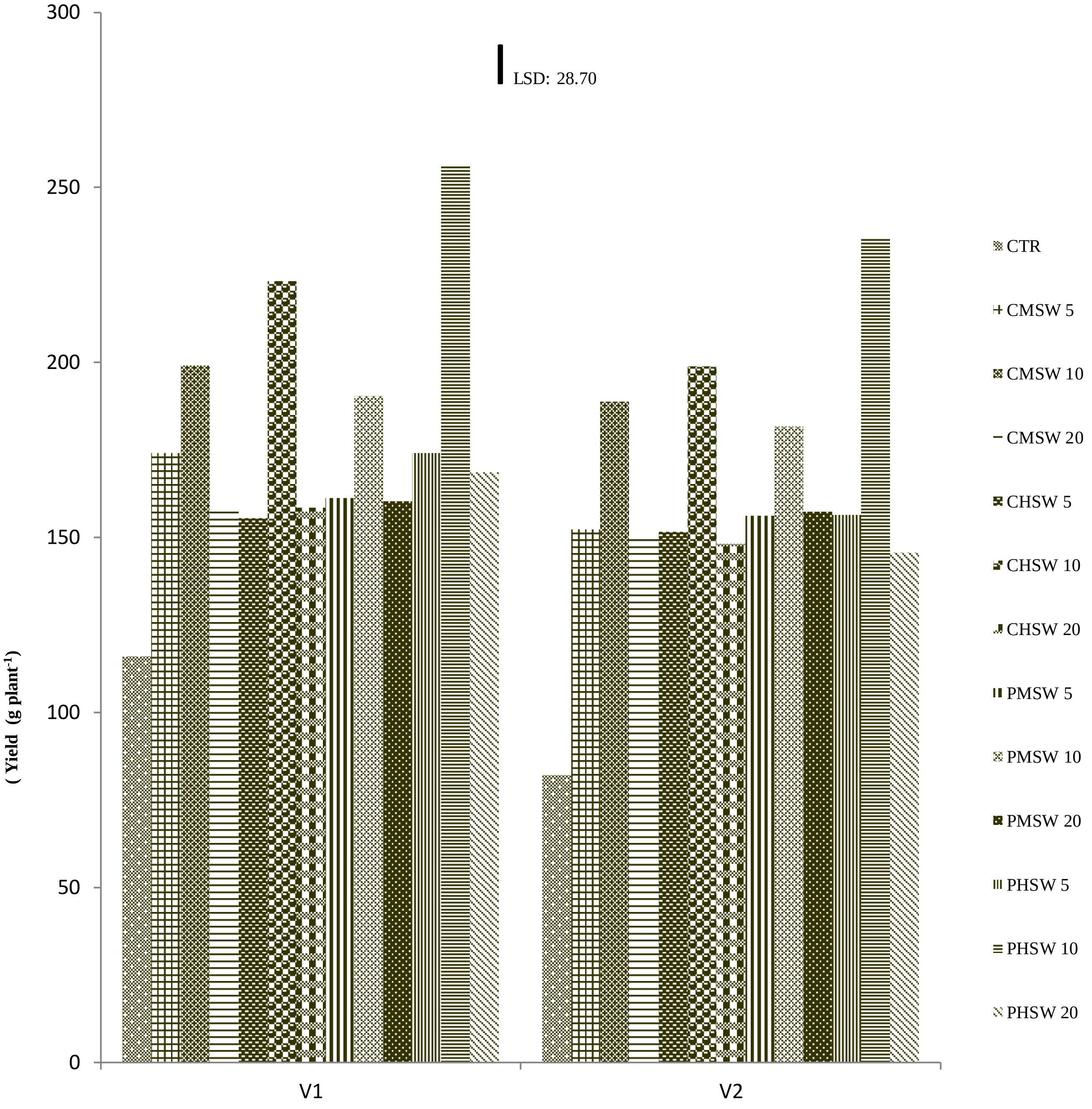

Figure 1: Effects of composted and pyrolyzed sorted wastes on tomato yield in the screenhouse.

Note: **CMSW**– Composted municipal solid waste at 5, 10 and 20 t ha^{-1}; **CHSW**-Composted home-sorted waste at 5, 10 and 20 t ha^{-1}; **PMSW**– Pyrolyzed municipal solid waste at 5, 10 and 20 t ha^{-1}; **PHSW**- Pyrolyzed home-sorted waste at 5, 10 and 20 t ha^{-1}; **CTR-** Control; Roma VF –V1; Ibadan local-V2.

Table 3: Nutrients uptake by tomato shoot (plant) in the screenhouse after harvest

	Nutrient uptake (mg kg^{-1})				
	↔				
Varieties (V)	N	P	K	Ca	Mg
Roma VF	3.71a	0.52a	20.5a	10.2a	8.20a
Ibadan local	3.82a	0.52a	20.3a	10.5a	8.70a
Amendments (A)					
Control	2.0e	1.41d	11.04e	8.64e	6.94d
Composted municipal solid waste at 5 t ha^{-1}	4.20ab	2.32bc	22.90abc	13.31bc	8.81abc
Composted municipal solid waste at 10 t ha^{-1}	4.41ab	2.50ab	22.70abc	13.22bc	9.07ab
Composted municipal solid waste at 20 t ha^{-1}	4.31ab	2.43bc	23.20abc	13.40bc	8.86abc
Composted home sorted waste at 5 t ha^{-1}	5.32a	2.87a	26.10a	11.20cd	9.74a
Composted home sorted waste at 10 t ha^{-1}	3.93bcd	2.54ab	21.60bc	10.42de	8.54cd
Composted home sorted waste at 20 t ha^{-1}	4.10ab	1.53cd	20.50cd	12.06bcd	8.82abc
Pyrolyzed municipal solid waste at 5 t ha^{-1}	3.71bcd	2.51ab	24.60ab	14.41abc	9.02ab
Pyrolyzed municipal solid waste at 10 t ha^{-1}	3.44de	2.04cd	24.30ab	14.41abc	8.78abc
Pyrolyzed municipal solid waste at 20 t ha^{-1}	4.22ab	2.12bc	22.50abc	15.34a	8.82abc
Pyrolyzed home sorted waste at 5 t ha^{-1}	3.74bcde	2.33bc	19.7d	11.35cd	8.65cd
Pyrolyzed home sorted waste at 10 t ha^{-1}	3.70bcde	2.72ab	20.40cd	11.95cd	8.91abc
Pyrolyzed home sorted waste at 20 t ha^{-1}	3.91bcd	2.60ab	20.50cd	11.86cd	9.07ab
V×A	2.04	1.32	NS	NS	NS
A×R	NS	NS	NS	NS	4.28
V×A×R	2.66	1.97	NS	NS	NS

N –Nitrogen; P Phosphorus; K- Potassium; Ca- Calcium; Mg- Magnesium, DMRT ($p < 0.05$)**.** NS-Not significant

Incorporation of composted home sorted waste (CHSW) at 5 t ha^{-1} resulted in highest N (5.32 mg kg^{-1}), P (2.87 mg kg^{-1}), K (26.10 mg kg^{-1}) and Mg (9.74 mg kg^{-1}) uptake among other amendments and rates of incorporation. ([50], [51]) stated that incorporation of organic waste via composting provides soil nutrients, enhances soil organic matter, soil structure improvement and increased nutrient uptake by plants. Composted home-sorted waste however contained nutrients in proportion similar to that which will enhance nutrient balance for uptake by tomato. Composted waste applied at 5 t ha^{-1} enhanced nutrient uptake, though it was comparable to 10 t ha^{-1} and 20 t ha^{-1}. However, municipal waste enhanced Ca uptake compared to home waste while the highest Ca uptake (15.34 mg kg^{-1}) was observed with PMSW at 20 t ha^{-1}. Composted municipal solid waste and pyrolyzed home sorted waste at 5, 10 and 20 t ha^{-1} were notstatistically different from one another.

Chemical properties of screenhouse experiment after harvest

The soil properties at the end of the trial in the screenhouse experiment (Table 4) indicated that pH of the soils ranged from neutral to moderately alkaline. Soils in pots amended with pyrolyzed (biochar) materials

(PHSW and PMSW) were significantly higher in pH than composted materials while the control pot with no treatment application had the lowest pH. This could be as a result of high surface area and porous nature of biochar that increases the cation exchange capacity (CEC) of the soil. Thus, there could be a chance for Al^{3+} and Fe to bind with the exchange site of the soil. There were no significant differences in the exchangeable bases (K and Mg) of the soil across all the treatment. The highest values of organic carbon and total nitrogen were observed in soils amended with pyrolyzed waste (biochar). The increase could be resulted from the presence of high amount of carbon and nitrogen in the pyrolyzed waste materials. The highest values of OC indicate the recalcitrance of C-organic in biochar. High organic carbon in soils treated with biochar was reported by [31]. [53] and [32] also revealed the higher OC and total N at the ancient *terra preta* compared with the adjacent soil. Plot amended with composted waste materials significantly increased P in soil than plot treated with pyrolyzed waste materials while the control pot had the lowest P.

Table 4: Chemical properties of screenhouse soil after harvest

Treatments	pH (H_2O)	OC	T N	P	K	Ca	Mg	Na
		(g kg^{-1})		(mg kg^{-1})	(cmolkg^{-1})			
CTR	6.68c	10.10c	0.57c	0.1c	0.27a	3.98b	1.23a	0.24b
CMSW	7.17b	11.13b	1.20b	8.98a	0.33a	4.90b	1.42a	2.34a
CHSW	7.27b	11.01b	1.19b	9.01a	0.29a	6.33a	1.50a	2.39a
PHSW	8.30a	14.21a	2.25a	7.92b	0.37a	7.32a	1.34a	2.36a
PMSW	8.10a	14.36a	2.24a	7.54b	0.30a	5.31b	1.35a	2.34a

Mean value with same letters along the column are not significantly different by DMRT ($p<0.05$)

Note: CTR- Control; **CHSW**– Composted home sorted waste; **CMSW**– Composted municipal solid waste. **PHSW**– Pyrolyzed home sorted waste; **PMSW**-Pyrolyzed municipal solid waste, OC- Organic Carbon. TN-Total Nitrogen; P- Phosphorus; K- Potassium; Ca- Calcium; Mg- Magnesium and Na- Sodium

According to [4], the effect of compost was significant on phosphorus which is one element whose availability is low due to its fixation by aluminum and iron in the soil. The significant effects of available P in soil with incorporation of CHSW and CMSW after harvest showed that the quality of organic matter in the compost influenced P availability in soil and this was in line with the findings of [44]. Incorporation of home waste enhanced Ca more than municipal waste. Also, all the amendments increased Na above the control plot.

Effects of Composted and Pyrolyzed Sorted Wastes on Yield (T Ha^{-1}) of Tomato on the Field

The effects of composted and pyrolyzed waste on the yield of tomato at early and late seasons are shown in Figure 2. There was significant difference in the yield of tomato due to amendments incorporation at both planting seasons. All the amendments increased the yield above the control. However, incorporation of PHSW produced more yield of tomato at early (1284 t ha^{-1}) and late (1038 t ha^{-1}) seasons than other amendments incorporated. At early season, tomato fruit yield increased in the order PHSW > CHSW > CMSW > PMSW in V1 and PHSW > PMSW > CHSW > CMSW in V2. At late season, PHSW > CHSW > PMSW > CMSW in both V1 and V2. Plot amended with PHSW increased the fruit yield of the Roma VFand Ibadan local in both planting seasons. This may be due to the ability of biochar potential of activating soil micro organisms and increasing the water retention capacity of the soil thereby increasing photosynthetic rate and consequently promoting growth and yield of plants. Pyrolyzed waste materials have been shown to increase plant productivity and yield through several mechanisms: its dark color alters thermal dynamics and facilitates rapid germination, allowing more time for growth compared with controls [20]. [10] also reported that application of pyrolyzed based organic waste improved the yield of tomato. Tomato fruit yield observed in the early planting season was significantly higher than the late season planted tomato. This was due to the fact that nutrients being released have been used up during the early season.

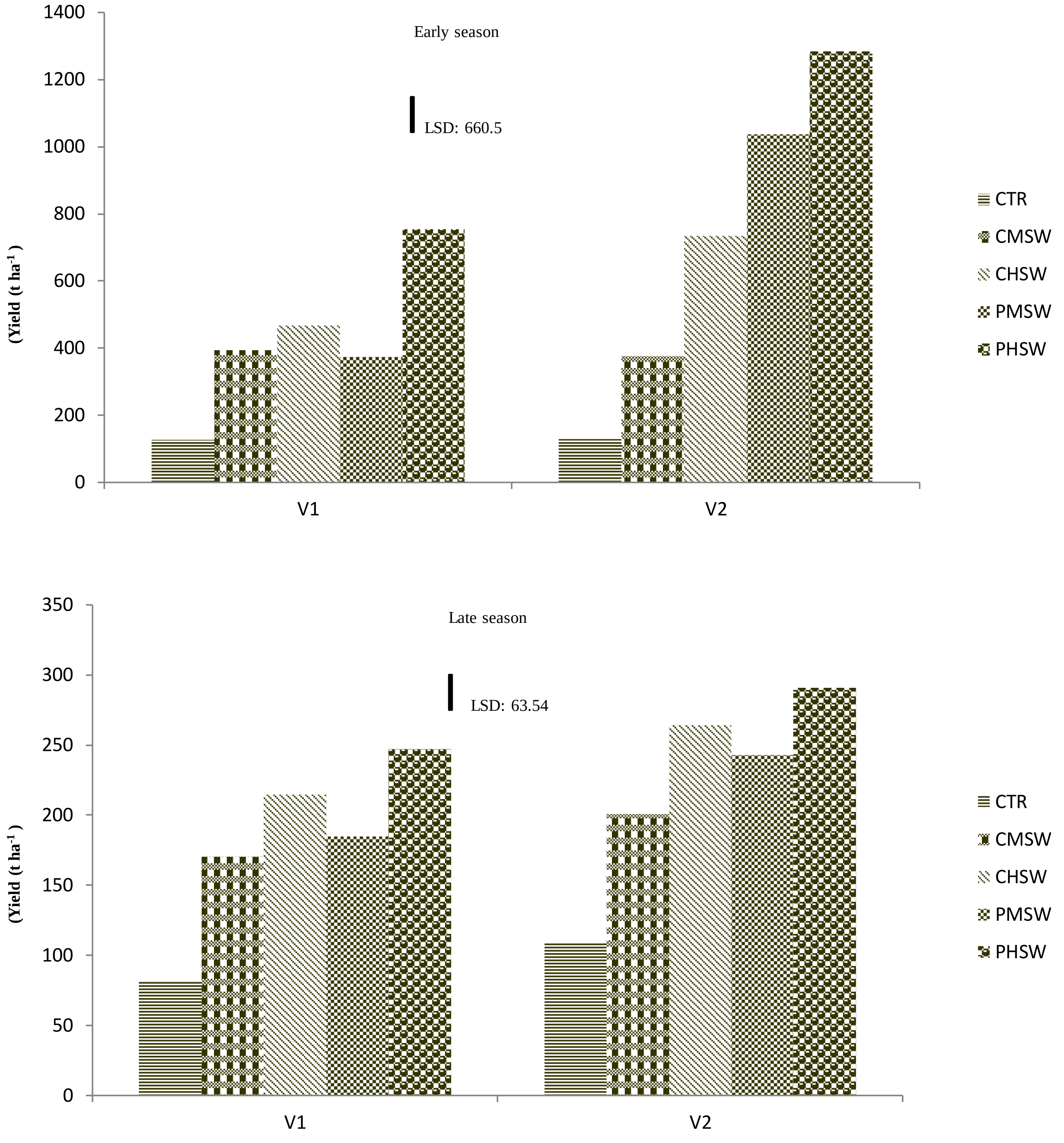

Figure 2: Effects of composted and pyrolyzed sorted wastes on the fruit yield of tomato.

Note: **CMSW**-Composted municipal solid waste; **CHSW**-Composted home-sorted waste; **PMSW**–Pyrolyzed municipal solid waste; **PHSW**-Pyrolyzed home-sorted waste; **V1** – Roma VF; V2 – Ibadan local.

Nutrients (N, P, K, Ca and Mg) Uptake by Tomato Plant (Shoot) on the Field

The effect of composted and pyrolyzed waste on nutrient uptake is shown in Table 5. There was significant difference in N uptake due to amendments incorporation at early and late seasons. At both planting seasons, all the amendments significantly increased N uptake above the control. Incorporation of CMSW, CHSW and PHSW enhanced N uptake more than PMSW at early season. Home waste (CHSW and PHSW) stimulated N uptake than municipal waste (CMSW and PMSW) at late season. However, PHSW significantly increased plant N (186.3 kg ha^{-1} and 108.8 kg ha^{-1}) uptake at early and late seasons respectively. The improved in N uptake in plants on adding pyrolyzed (biochar) waste was also observed by [2]; [11] and [59]. Similar to this finding, [14] also reported high N uptake by radish plants grown in soil amended by biochar. Significant difference in P uptake due to amendments incorporation was only observed at late season. Plot amended with CMSW, PMSW and PHSW increased P uptake more than CHSW while the highest P uptake (339.6 kg ha^{-1}) by plant was also observed with PHSW. Phosphorus uptake by plants may depend on the association between plants and mycorrhizal fungi which secrets extracellular phosphatases and P-solubilizing organic acids making organic P plant available. This was in line with the findings of [56] who reported that biochar encourages mycorrhizal colonization of plant roots by facilitating habitats for them and thereby indirectly promotes P solubility. Similarly, [55] and [57] reported an increase in plant available phosphorus in soil with the application of biochar. Amendments incorporation showed significant effect on potassium uptake at both planting seasons. The soil amended with PMSW enhanced K uptake at both planting seasons compared with control and other amendments applied. This might be ascribed to the presence of potassium rich ash in the pyrolyzed (biochar) municipal waste [58] and [2]. This may also be as a result of biochar ability to increase soil CEC, thereby increase the ability of soil to hold K, store them in the soil and make it available for plant uptake [38]. Similarly, increased in potassium concentration in maize grains with the application of cow manure biochar was reported by [55]. At both planting seasons, there was no significant difference in Ca and Mg uptake due to amendments incorporation.

Table 5: Effects of composted and pyrolyzed sorted wastes on nutrient uptake by tomato shoot (plant) on the field

NUTRIENTS UPTAKE (kg ha^{-1})										
	Nitrogen (N)		Phosphorus (P)		Potassium (K)		Calcium (Ca)		Magnesium (Mg)	
Varieties (V)	Early Season	Late Season	Early Season	Late Season	Early Season	Late Season	Early Season	Late Season	Early Season	Late Season
Roma VF	121.2a	74.5a	330.4a	213a	7.9a	4.6a	3.46a	2.24a	1.86a	1.11a
Ibadan Local	108.5a	64.3a	409.8a	246a	10.9a	5.9a	5.69a	3.15a	1.98a	1.10a
Amendments (A)										
CTR	23.1b	21.62c	74.0a	65.4b	0.55b	0.35b	1.09a	0.50a	0.52a	0.42a
CMSW	134.0a	79.26ab	426.4a	269.3a	10.89ab	6.48ab	3.31a	2.33a	2.16a	1.26a
CHSW	142.3a	91.24a	373.3a	178.7ab	3.22b	1.69b	5.44a	3.41a	1.57a	0.97a
PMSW	88.8ab	46.18bc	507.1a	295.9a	22.21a	12.55a	6.69a	3.65a	2.82a	1.51a
PHSW	186.3a	108.78a	572.6a	339.6a	10.13ab	5.08b	6.36a	3.58a	2.53a	1.39a
V×A ($p<0.05$)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Mean value with same letters along the column are not significantly different by DMRT ($p<0.05$). NS- not significantly

Note: CTR- Control; **CHSW**– Composted home sorted waste; **CMSW**– Composted municipal solid waste. **PHSW**– Pyrolyzed home sorted waste; **PMSW**-Pyrolyzed municipal solid waste, Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg)

Chemical Properties of Field Experiment at Both Planting Season After Harvest

The soil properties at the end of the trial in the field experiment at both planting seasons (Table 6) indicated that pH of the soils ranged from neutral to moderately alkaline. At early season, there were no significant differences in the K, Ca and Na of the soil across all the treatments. The pH of the soil ranged from neutral to mildly alkaline. However, the phosphorus concentration was highest ($p< 0.05$) in the plot treated with PHSW (29.53 mg $kg^{–1}$) compared to the other treatments. According to ([21]; [17]), pyrolyzed organic materials can act as an alternative source of P fertilizer in the soil, with its effect depending on the nature of feedstock, pyrolysis temperature, and dosage. Biochar applied to soil enhance P sorption of the soil and help to extend the supply of mineralized P [24]. Among the treatments applied, the highest OC (10.80 g kg^{-1}) and TN (2.28 g kg^{-1}) were observed with PMSW and PHSW respectively, while the least OC and TN were observed in control. The highest increase in OC and TN could be due to decomposition which might have occurred when pyrolyzed waste material is added to soil. Plots treated with pyrolyzed waste materials [PHSW (0.84 cmol $kg^{–1}$) and PMSW (0.88 cmol $kg^{–1}$)] had the highest Mg compared with composted waste materials [CHSW (0.40 cmol $kg^{–1}$)] and CMSW (0.40 cmol $kg^{–1}$)]; control (0.37 cmol $kg^{–1}$) had the least Mg. The observed increase in exchangeable cation (Mg) in pyrolyzed amendment soil at early season might be attributed to the ash content of the pyrolyzed material. [48]; [42] reported ash content of biochar helps for the immediate release of occluded mineral nutrients like Ca Mg and K for crop use. At late season, the pH of the soil ranged from neutral to mildly alkaline. Pyrolyzed waste materials increased the soil pH more than composted waste materials which was not significantly higher than the control. Application of pyrolyzed materials (biochar) increased soil pH, and also decreased Al^{3+} concentration in acid soils [49]. There was no significant difference between the amendments whether pyrolyzed or composted in OC, Mg and Na. However, all the amendments significantly increased OC, Mg and Na above control. Highest TN was observed with incorporation of CHSW (2.84 g kg^{-1}), and this was in line with the finding of [7] who stated that application of compost resulted in a significant increase in nitrogen in the soil.

Table 6: Chemical properties of soil after harvest

Treatments	Early Season								Late Season							
	pH	OC	T N	P	K	Ca	Mg	Na	pH	OC	TN	P	K	Ca	Mg	Na
		(g kg^{-1})		($mgkg^{-1}$)	(cmol kg^{-1})					(g kg^{-1})		(m gkg^{-1})	(cmol kg^{-1})			
CTR	6.80b	7.84d	1.08d	24.33d	0.40a	0.39a	0.37c	0.58a	6.72b	5.44b	1.08c	19.39b	0.27b	0.28a	0.31b	0.24b
CMSW	7.51a	8.42c	1.99c	27.45b	0.40a	0.40a	0.40b	0.59a	6.84b	5.99a	1.98b	21.21a	0.40a	0.30a	0.35a	0.34a
CHSW	7.49a	8.85c	2.11b	26.59c	0.40a	0.40a	0.40b	0.59a	6.82b	6.20a	2.84a	21.13a	0.40a	0.33a	0.33a	0.39a
PHSW	7.52a	9.33b	2.28a	29.53a	0.40a	0.41a	0.84a	0.59a	7.22a	6.22a	1.95b	20.60ab	0.38ab	0.32a	0.34a	0.36a
PMSW	7.50a	10.80a	1.95c	27.48b	0.41a	0.40a	0.88a	0.62a	7.42a	6.28a	1.92b	21.47a	0.43a	0.31a	0.35a	0.34a

Mean value with same letters along the column are not significantly different by DMRT ($p<0.05$).

Note: CTR- Control; **CHSW**– Composted home sorted waste; **CMSW**– Composted municipal solid waste. **PHSW**– Pyrolyzed home sorted waste; **PMSW**-Pyrolyzed municipal solid waste, Nitrogen (N), Phosphorus

(P), Potassium (K),Calcium (Ca),Magnesium (Mg)

Plot amended with PMSW (1.92 g kg^{-1}), PHSW (1.95 g kg^{-1}) and CMSW (1.98 g kg^{-1}) were not statistically different from one another, with least in control. However, all the amendments increased P and K with the exception of PHSW which was not statistically different from the control.

CONCLUSION

The benefit and importance of incorporating organic waste materials like compost and biochar for crop production, particularly tomato, has been demonstrated by this research which showed that incorporation of organic waste materials into the soil enhances tomato yield and nutrient uptake. Generally, tomato plants treated with pyrolyzed home sorted waste (PHSW) at 10 t ha^{-1} stimulated highest yield of tomato varieties compared to other treatments and rates applied in the screenhouse, at main cropping (early season) and residual (late season) on the field. Roma VF performed better in the screenhouse while Ibadan local responded well on the field. Different performances of these varieties may be attributed to genetic variability, adaptability, morphological features as well as physiological factors during the crop growth period. Composted home sorted waste (CHSW) at 5 t ha^{-1} resulted in highest nutrient uptake than other treatments and rates of application in the screenhouse. Meanwhile, pyrolyzed municipal solid waste (PMSW) and pyrolyzed home-sorted waste (PHSW) were better than composted municipal solid waste (CMSW) and composted home sorted waste (CHSW) in enhancing nutrient uptake by tomato on the field at early and late seasons. Soil chemical properties (OC, TN, P, Mg and Na) were significantly improved by pyrolyzed wastes compared to composted waste at early season. However, composted home sorted wastes and pyrolyzed municipal solid wastes had greater residual effects.

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