American Journal of Plant Sciences, 2022, 13, 960-971
https://www.scirp.org/journal/ajps
ISSN Online: 2158-2750
ISSN Print: 2158-2742

Soil Amendments Improved Tomato Growth, Yield and Soil Properties

Gabriel Ddamulira[1], Alex Malaala[2], Alfred Otim[1], Nakityo Florence[1], Mcebisi Maphosa[3]

[1]National Crops Resource Research Institute, Kampala, Uganda
[2]Makerere University Kampala, Kampala, Uganda
[3]Lupane State University, Lupane, Zimbabwe
Email: ddamuliragab@yahoo.co.uk

How to cite this paper: Ddamulira, G., Malaala, A., Otim, A., Florence, N. and Maphosa, M. (2022) Soil Amendments Improved Tomato Growth, Yield and Soil Properties. *American Journal of Plant Sciences*, **13**, 960-971.
https://doi.org/10.4236/ajps.2022.137063

Received: March 16, 2022
Accepted: July 15, 2022
Published: July 18, 2022

Abstract

Different soil amendments have varying effects on crop growth, yield and soil properties. The study evaluated the effect of poultry manure, inorganic fertilizer (NPK), and biochar-based fertilizer (organo-yield) on tomato growth, yield and post-cropping soil properties. The experiment was laid out in a Randomized Complete Block Design (RCBD) with three replications. Data on tomato growth and yield were collected and soils were tested before and after the cropping seasons. Analysis of variance was performed on the data and the effect of soil amendments on tomato growth and yield was determined. The effect of soil amendments on post-production soil properties was tested by comparing soil properties before and after the cropping seasons with published critical values. Results showed that all amendments increased the growth and yield of tomato significantly ($P < 0.05$) compared to the control (without soil amendments). Plant height was higher in plots applied with soil amendments as compared to the control, while stem girth was highest in poultry-manured plots. Poultry manure and organo-yield applied plants exhibited high tomato fruit number and yield compared to control plots. In terms of soil properties, poultry manure and organo-yield improved the soil's physical and chemical properties. Organo-yield decreased the soil bulk density and increased the pH from 4.8 to 5.5, while, application of NPK only increased calcium content in the soil. The findings confirmed that soil amendments applied increased tomato growth, and yield and also improved soil bulky density and pH.

Keywords

Organo-Yield, Poultry Manure, NPK, Soil

1. Introduction

Tomato (*Lycopersicon esculentum* Mill.) is among the most popular vegetable globally grown [1]. The popularity of tomato among consumers is not only because of its good taste, but also because it contains high levels of vitamin C, lycopene, and beta-carotene, which are antioxidants that promote good health [2] [3]. Indeed, the high demand for tomato makes it a high-value crop that generates income and provides employment to smallholder farmers [4]. Tomato's popularity as a vegetable is also reflected in its high production volumes globally. The global tomato production in 2016 was 4.9 million hectares, yielding 177 million tonnes annually [5]. Africa produces 19.7 million tonnes of tomato on 1.3 million hectares. In Uganda, 38,234 metric tonnes of tomato are produced on 6485 hectares [5] which are spread across the country. The major tomato production districts in Uganda include; Kasese, Kabaale, Mbarara, Mbale, Kapchorwa, Mubende, Masaka, Mpigi and Wakiso [6].

The national average tomato yield in Uganda stands at 5.9 $t \cdot ha^{-1}$, but this varies among production areas with some having as low as 0.6 $t \cdot ha^{-1}$ [5] [6]. Indeed, the national tomato yield in Uganda of 5.9 $t \cdot ha^{-1}$ is still far below compared of other African countries like Egypt whose average yield is 39 $t \cdot ha^{-1}$ [5]. The low tomato yield in Uganda is attributed to a number of constraints which include poor varieties, drought, pests and diseases [7], as well as low soil fertility [8]. The low soil fertility reduces tomato yield by 40%, which greatly affects tomato productivity in Uganda. The decline in soil fertility in most tomato production areas in Uganda is attributed to low nutrient inputs relative to nutrient exports that go along with harvested tomato fruits and residues [8]. This is exacerbated by the continuous cultivation of land without crop rotation. Such practices deplete soil nutrients hence affecting tomato yields and productivity.

In order to improve tomato yield, farmers use soil inputs such as manure, crop residues, mulch and inorganic fertilizers, especially NPK. Some farmers strictly practice organic farming using poultry and cow manure, while others practice an integrated soil fertility management approach which combines organic and inorganic fertilizers [9]. Presently, innovative and environmentally friendly soil amendments such as biochar-based fertilizers are also being used by a few farmers. Biochar provides nutrients, especially nitrogen [10], and improves response to water uptake when combined with inorganic fertilizers [11]. Biochar-based fertilizer (organo-yield) not only provides nutrients but also improves soil conditions for further production in the subsequent seasons due to its residual effects. It has been found to be effective on maize in Kenya but its efficacy on tomato as a soil amendment remains unknown. Although tomato farmers currently use biochar-based amendments, poultry manure and NPK to improve tomato yield, the best option among the three that can provide maximum yield is not yet defined. Besides, improving tomato yields, the three commonly used fertilizer options have effects on soil properties whose impacts are also less known. Hence the need to ascertain the benefits of using soil amendments in tomato production. The study assessed the effect of soil amendments on tomato growth, yield and soil properties.

2. Materials and Methods

2.1. Study Area

The study was conducted for two seasons (August to December 2017 and March to July 2018) at the National Crops Resources Research Institute (NaCRRI), Namulonge, Wakiso district in Uganda. The station is located between 0˚32" and 32˚37" North and East at an elevation of 1150 m above sea level. It experiences a bimodal rainfall pattern with an average rainfall of 1270 mm. The minimum and maximum temperatures of 15.9˚C and 28.4˚C with Ferrallisol soils covered with tall grassland vegetation.

2.2. Soil Nutrient Status of the Study Site

Prior to the start of the experiment, soils from the study site where tested in the laboratory to ascertain their nutrient compositions. Four soil samples were randomly taken (0.0 - 15 cm) from the experimental site. The samples were properly mixed to make one composite sample which was taken to the laboratory for routine analysis. Routine analysis was done by the soil and plant analytical laboratory of Makerere University following procedures described by Carter [12]. Organic matter (O.M) was determined by Walkley-Black dichromate digestion method [13] and total soil nitrogen was determined by the Salicylate-hypochlorite method [14]. Available P was determined by Bray-1 method and colour was developed in soil extracts using the ascorbic and acid blue colour method [15]. Exchangeable K, Ca and Mg were extracted using ammonium acetate. K was determined on flame photometer and Ca and Mg by EDTA titration. The soil pH in 0.01 M $CaCl_2$ was determined using a pH meter. The soil nutrient composition is shown in Table 1.

2.3. Tomato Seedling Establishment

Tomato seeds of line MT56 were obtained from Horticulture and Oil palm program at NaCRRI. The MT56 line was selected as a test crop for the study due to

Table 1. Nutrient composition of soil amendments used in the experiment.

Soil property	Poultry manure Percent (g/100g)	Biochar-based Percent (g/100g)
pH	6.8	6.6
Nitrogen	2.2	4.1
Phosphorus	0.88	2.0
Potassium	1.99	5.2
Calcium	1.42	0.42
Magnesium	0.58	0.24
C:N	6.7	4.8
Organic matter	14.3	12.5

its good attributes of disease resistance and high yield [16]. A raised nursery bed of 1 × 2 m was prepared where tomato seeds were planted in a mixture of forest soil and sand mixed in a ratio of 3:1. Tomato seeds were sown at 1 - 2 cm deep and spaced 5 × 10 cm between plants and rows. The seeds were lightly covered with fine-sand and mulched with banana leaves. The nursery bed was watered twice (morning and evening) a day to ensure sufficient moisture for seed germination. The mulch was removed on germination to allow proper seedling establishment. Cypermethrin at a rate of 1.5 ml/L was used to control insect pests. Similarly, Mancozeb (80 WP) was applied at a rate of 2.5 g/L to control common fungal diseases like dumping off. The seedlings were thinned and harden to adapt to field conditions before being transplanted into the main field.

2.4. Field Experiment Establishment and Crop Maintenance

Land meant for the trial was cleared using herbicide Agrosate (Glyphosate as the active ingredient) which was applied at a rate of 10 ml/L followed by primary and secondary tillage. Harrowing was done to make a fine seed bed. The land was then marked into 3 × 3 m plots. NPK 17:7:17 fertilizers were obtained from agro-input dealers in Kampala and decomposed poultry manure was collected locally from poultry units on farms. The organo-yield biochar was acquired from organo-yield Uganda limited. To ascertain the levels of nutrients in the soil amendments, samples were taken from poultry manure and organo-yield for analysis. Previous laboratory procedures used to analyze soil was used for nutrient analysis. Nutrient analysis for NPK was not done because its nutrient content was already known from the manufacturer's formulation.

Healthy, vigorous and uniform in size tomato seedlings were selected and transplanted from the nursery to the main field, 21 days after sowing. Transplanting was done in the evening to avoid transplanting shock. A seedling was planted per hole in a 3 × 3 m plot at a spacing of 60 × 60 cm to attain a planting density of 25 plants per plot. The seedlings were immediately watered after transplanting and all plots were mulched to conserve moisture within the soil. The experiment was laid in a Complete Randomized Block Design (CRBD) with four treatments, replicated three times. The treatments were; poultry manure, NPK 17:17:17, organo-yield fertilizer and a control. The treatments which constituted the soil amendments (poultry manure, NPK and organo-yield) were applied within the planting hole at a rate of 1.25 kg per plot.

Hand weeding was done twice, at the plant establishment stage and at flowering stage, pruning of some leaves and emerging twigs were among the managerial activities which were done during the cropping season. Mancozeb (80% WP) was sprayed at rate of 2.5g/L at an interval of two weeks to control late blight (*Phytophthora infestans*) and other fungal related diseases. Furthermore, scouting for pests attacks was done every after a fortnight and spraying of cypermethrin at a rate of 1.2 ml/L was done when scouting results shown pest infestation above the threshold.

2.5. Data Collection and Analysis

During growth, 20 plants from each plot were randomly selected and tagged from which all the required data was collected. Data on plant height (cm), number of branches and leaves per plant as well as stem girth was collected from tagged plants at 20, 40 and 60 days after transplanting. Plant height was measured in centimeters using a tape measure with the zero cm end placed at the soil level and measurements taken at the tip of the plant. Number of branches per plant was the minor branches from the main stem, which were singly counted and leaves per plant were obtained by singly counting each leaf on the plant. Stem girth was measured using a small thread. The thread was placed around the stem, 2 cm above the soil level, to obtain the circumference and then transferred to a ruler to read off the measurements. Similarly, during the reproductive and maturity stages data on flower clusters and fruits was collected. The number of flower clusters per plant was obtained by counting the number of flower clusters on each plant and number of fruits for each plant per harvest was obtained by singly counting the number of fruits harvested. Fruit weight for each plant was obtained by weighing the fruits harvested per plant using a digital weighing scale. Three fruit harvests were done at one-week interval and the accumulative harvests were summed up to get the total yield. The total yield from the 20 plants was extrapolated to plot basis and finally to per hectare basis. All the data collected were subjected to analysis of variance (ANOVA) using Genstat software version 11 [17] and results were expressed as mean values. Significances of treatment means were derived using the least significant difference. On the other hand, the soil property data collected before and after cropping were compared for all treatments with critical values to determine effect of the treatments on the soil properties.

3. Results

3.1. Plant Height and Stem Girth

The trend of tomato height under different soil amendments was observed at 20 days interval and for all amendments including the control plant exhibited an increment in height from transplanting up to the 60^{th} day. However, at 20^{th}, 40^{th} and 60^{th} day plant height in plots applied with organo-yield, poultry manure and NPK was significantly ($P < 0.05$) different from the control (**Table 2**). Similarly, stem girth also increased from the day of transplanting up to the 60^{th} day. But at 20^{th} day stem girth in plots applied with poultry manure was significantly different from the rest of other plots applied with amendments (**Table 2**). On the hand at 40^{th} day stem girth of plants applied with soil amendments was significantly ($P < 0.05$) different from plants in the control plot. At 60 days, plants applied with poultry manure had significantly ($P < 0.05$) higher stem girth than the rest of the treatments (**Table 2**).

3.2. Number of Branches and Leaves

From the transplanting date, the number of tomato branches and leaves was

Table 2. Plant height and stem girth of tomato applied with different soil amendments.

Treatment	Plant height (cm)			Stem girth (cm)		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
Organo-yield	22.4a	47.9a	53.0a	2.1a	3.4a	3.5a
Poultry manure	22.9a	48.4a	52.9a	2.3b	3.8a	4.7b
NPK	19.2a	44.7a	55.1a	1.7a	3.4a	3.7a
Control	15.5b	31.4b	38.5b	1.6a	2.1b	2.5a
L.S. $D_{(0.05)}$	4.24	8.61	10.3	0.5	0.7	1.8

Plant height and stem girth means followed by different letters in a column are significantly different and means followed by a similar letter are not significantly different.

monitored and an increase in both was observed (Table 3). This was expected as the leaves and branches are expected to increase during the vegetative stage. However, at 20 and 40 DAT the number of leaves in plants applied with poultry manure and NPK were significantly ($P < 0.05$) higher than that of organo-yield and the control. But at 60 DAT all plants applied with different soil amendments had significantly high number of branches than the control (Table 3). On the other hand, the number of leaves also varied after transplanting, at 20 DAT plants applied with organo-yield and poultry manure had significantly high number of leaves than control and NPK. Whereas at 40 and 60 DAT all plants in soil amendment applied plots had significantly more leaves than the control

3.3. Effects of Soil Amendments on Tomato Fruits and Yield

The number of fruits per tomato plant and yield where significantly ($P < 0.05$) influenced by season and soil amendments applied (Table 4). The number of tomato fruits per plant observed in season 2018B was two folds higher than in season 2017A. During 2017A season plots applied with poultry manure and NPK produced the highest number of tomato fruits while plots applied with organo-yield and the control produced the least number of fruits per plant (Table 4). On the other hand, in 2018A, the highest and the lowest number of tomato fruits were recorded in plots applied with organo-yield and the control respectively. However, for either season, the number of fruits observed in plots applied with poultry manure and NPK did not vary significantly. Furtherstill, a significant interaction between soil amendments and seasons were observed which indicated that the soil amendments and seasons interacted to influence number of tomato fruits produced per plant.

The results further showed that tomato yield was significantly ($P < 0.05$) influenced by season and soil amendments applied. Tomato yield realized in 2018A was twice higher than in 2017B (Table 4). In 2017B, plots applied with poultry manure and NPK produced equally high yield which was significantly different from yield obtained from the organo-yield and control applied plots. On the contrary, in 2018A, plots applied with organo-yield produced the highest

Table 3. Number of branches and leaves of tomato applied with different soil amendments.

Treatment	Number of branches			Number of leaves		
	20 DAT	40 DAT	60 DAT	20 DAT	40 DAT	60 DAT
Organo-yield	3.4a	6.2a	9.4a	9.2a	20.4a	22.9a
Poultry manure	4.4b	8.7b	10.1a	10.0a	22.4a	29.9a
NPK	4.0b	9.8b	11.2a	7.4b	24.6a	27.9a
Control	1.3a	2.7a	2.9b	6.4b	9.3b	9.9b
L.S. $D_{(0.05)}$	2.1	4.1	5.6	2.45	8.6	18.2

Number of branches and leaves followed by different letters in a column are significantly different and means followed by a similar letter are not significantly different.

Table 4. The number of fruits per plant and yield of tomato applied with different soil amendments.

Treatments	Number of fruits/plant		Yield kg·ha^{-1}	
	Season 2017B	Season 2018A	Season 2017B	Season 2018A
Organo-yield	5.77a	24.77a	636a	2981a
Poultry	10.03b	19.93b	1189b	2320b
NPK	11.33b	19.90b	1270b	2181b
Control	4.20a	8.63c	418a	837c
Mean yield	7.83	18.30	898	2080

Number of fruits and yield means followed by different letters in a column are significantly different and means followed by a similar letter are not significantly different.

yield followed by poultry manure, NPK and the lowest yield was obtained from the control plots (Table 4).

3.4. Effects of the Soil Inputs on Post Cropping Soil Properties

Before conducting the experiment, the nutrient status of soil was determined and observations were made at the end of experiment to ascertain any changes in soil properties that might have arose due to soil amendment application. The application of organo-yield and poultry manure led to greater and marginal improvement in soil pH, respectively. Similarly, application of organo-yield improved organic content above the critical level while in plots where NPK was applied no change in organic carbon was observed (Table 5). The results also indicated that application of organo-yield and poultry manure greatly and marginally reduced the bulk density at the end of the cropping season while in plots where NPK was applied the bulk density did not change (Table 5). Before application of the soil amendments nitrogen levels in the soil were below the critical levels, but application of organ-yield greatly raised the N levels above the critical level at the end of the cropping season. Also, application of organo-yield greatly improved levels of phosphorus and potassium in the soil whereas poultry

Table 5. The soil composition before and after application of soil amendments.

Soil property	Soil nutrient level before amendment application	Soil nutrient levels after different amendment application			Critical values
		Organo yield	Poultry manure	NPK	
pH	4.8	5.5***	4.97**	4.7*	5.5 - 6.5
Organic carbon%	2.8	3.1***	2.9**	2.6*	>3.0
Bulky density ($g \cdot cm^{-1}$)	1.39	1.11***	1.23**	1.39*	<1.40
Nitrogen (%)	0.17	1.21***	0.26**	0.17*	>0.25
Phosphorus (mg/kg)	2.4	3.74***	2.45**	2.12*	>1.5
Potassium ($cmol \cdot kg^{-1}$)	0.19	2.63***	0.21**	0.19*	≥2.0
Calcium ($cmol \cdot kg^{-1}$)	2.26	2.68**	2.77**	2.99***	≥4.0
Magnesium ($cmol \cdot kg^{-1}$)	2.72	2.9**	3.22***	2.70*	≥0.5

*** Great improvement; **Marginal improvement; *No improvement.

manure and NPK did not improve P and K levels above the critical levels at the end of the cropping season. Furthermore, application of NPK greatly improved calcium content though at the end of cropping season it was still below the critical level. Although at the beginning of the cropping season, there was sufficient magnesium in the soil but application of organo-yield and poultry manure marginally and greatly improved its content, respectively. However, in plots applied with NPK no improvement in magnesium content was observed. Application of poultry and organo-yield improved soil properties significantly ($P < 0.05$) as compared to NPK use.

4. Discussion

Throughout the 60 DAT plant height was influenced by soil amendments made through fertilizer application. The fertilizers applied promoted plant height through supplying nutrients required for tomato growth compared to tomato plants in control plots which lacked the nutrients. The results indicated that the nutrients contained in the fertilizer where utilized by tomato plant to promote growth height, resulting in significant increase in plant height. This was in agreement with earlier findings by [18] who reported that soil amendments applied in different forms of fertilizer increased tomato height in the first sixty days after transplanting. Similarly, stem girth was influenced by poultry manure application at 20 and 60 DAT. Unlike other amendments, the positive effect of poultry manure on stem girth at 20 DAT was attributed to faster decomposition and mineralization of poultry manure which possibly released the nutrients required by tomato plant in comparison with other soil amendments that were tested.

The number of tomato branches and leaves were positively influenced by soil amendments. The soil amendments used in this experiment such as NPK and poultry manure contain nutrients that are known to enhance vegetative growth [19]. According to [20] nutrients in poultry manure led to high vegetative growth in tomato compared to plants which never received the manure. The findings from this study did not differ from what earlier researchers have reported. But, the negative influence of organo-yield to branching of tomato at 20 and 40 DAT could be explained by [21] findings who reported that limitation of nitrogen supply by organic fertilizers such as biochar during early growth might delay its response to plant growth. However, the negative effect of NPK on number of leaves at 20 DAT could not be explained by the results from this study.

The variation in number of fruits per plant and tomato yield observed was probably attributed to differences in nutrient release of the soil amendments applied. In 2017B, soil nutrients from slow releasing amendments might have not readily available for uptake by tomato plant. The growth cycle of only three months did not provide ample time for decomposition and mineralization of soil amendments to release the required nutrients for plant uptake, hence compromising the yield registered during 2017B. This is further confirmed by the low yield of organo-yield during 2017B and high yield for faster nutrient releasing amendments like poultry manure and NPK. This clearly indicated that the rate of nutrient release and uptake was responsible for the variation in fruits and yield observed in the two seasons.

Furthermore, in terms of season the number of fruits and tomato yield obtained from plots applied with organo-yield was lower compared to other amendments applied. Although earlier studies by [22] indicated the critical role biochar plays in improving soil physical properties but its high C:N slows the mineralization and decomposition process of organo-yield which in turn slows nutrient release. This is reflected in the yield results of 2017B of organo-yield when compared to other amendments used but due to cumulative effect, in 2018A it contributed the highest yield compared to other amendments applied. This further indicates that organo-yield has residual effect of which proceeding crops may benefit from in case it's used for tomato production for more than one season.

The soil amendments applied poultry manure and organo-yield contributed the highest number of fruits and yield in 2017B and 2018A respectively while the control contributed the least number of fruits and yield. This was as a result of available macro and micro nutrients (**Table 1**) contained in poultry manure which contribute to fruit formation. On the other hand, organo-yield biochar has particles with large internal surface area and pores which retain soil moisture and nutrients making them available for uptake by the plant hence, organo-yield had the capacity to contribute to increased fruit number. Since the number of fruits per plant is one of the tomato yield components its increment due to nutrients availed by applying organo-yield led to the high tomato yield recorded when compared to the control which lacked the required nutrients. This was in agreement with results reported by [23] which indicated that a positive effect of poultry manure on tomato yield compared to the control.

Poultry manure and NPK had the same effect on the number of fruits per plant and yield. This was attributed to the fact that with exception of micro nutrients, poultry manure provided readily available and similar nutrients like that of NPK for uptake by tomato plants. This is because of the fast decomposition and release of nutrients in poultry manure and the readily available NPK nutrients as compared to the organo-yield whose nutrient release is slow. Similar observations were reported by [19] [24] in their studies about response of tomatoes to organic and inorganic fertilizers in which poultry manure and NPK had similar effect with NPK on tomato yield. This observation also agrees with [25], [26] [27] who observed the same effect of NPK and poultry manure in their studies. They noted significant fruit yield increase arising from application of the two soil amendments which clearly demonstrated the benefit of using fertilizers in tomato production.

Soil amendments of organic origin play a critical role in amending soil properties. Organo-yield improved soil properties after the cropping season through reduction in soil bulk density, increased pH and organic matter and availed soil nutrients (N, P, K, Ca and Mg) for uptake by tomato plants. The increase in organic matter as a result of the application of poultry manure and organo-yield possibly contributed to the improvement of soil physical properties through stabilizing soil structure thereby reducing soil bulk density, increasing porosity, and infiltration rate and water retention. These favorable soil physical conditions adduced the high tomato yield observed in plots applied with poultry manure and organo-yield. Similarly, findings have been earlier reported by [23] [28] [29]. Furthermore, reduced soil bulk density by organo-yield probably enhanced root growth and better water and nutrient uptake contributing to high tomato yield. Similar findings were previously reported by [22] when undertaking studies related to biochar.

5. Conclusion

The soil amendments applied positively influenced tomato growth, yield and post-cropping soil properties. Application of poultry manure and organo-yield improved the physical and chemical soil properties which led to increased tomato yield. Based on the results from the study, poultry manure and organo-yield can be recommended to farmers to improve tomato yields in Uganda.

Acknowledgements

This research was supported by the National Agriculture Research Organization (NARO) with funding from the Government of Uganda (GOU), under the NARO Competitive Grant Scheme. The authors are also grateful to National Crops Resources Research Institute (NaCRRI) for hosting the trials.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Araujo, J.C., Telhado, S.F.P., Sakai, R.H., Lebo, C.A.S. and Melo, P.C.T. (2016) Univariate and Multivariate Procedures for Agronomic Evaluation of Organically Grown Tomato Cultivars. *Horticultura Brasileira*, **34**, 374-380. https://doi.org/10.1590/S0102-05362016003011

[2] Sainju, U.M., Dris, R. and Singh, B. (2003) Mineral Nutrition of Tomato. *Journal of Food Agriculture & Environment*, **1**, 176-183.

[3] Kelly, T.W. and Boyhan, G. (2010) Commercial Tomato Production Handbook. University of Georgia Cooperative Extension Research Bulletin 1312.

[4] Ssejjemba, K.F. (2008) Value Chain Analysis of Fresh Tomatoes in Uganda and Kenya. Assignment 3, Mastricht School of Management, 17 p.

[5] FAOSTAT (Food and Agriculture Organization of the United Nations) (2017) Food Supply - Lifestock and Fish Primary Equivalent. Statistics Division. https://www.eea.europa.eu/data-and-maps/indicators/13.2-development-in-consumption-of-2/rationalereference.2012-10-10.0631395283

[6] Sonko, R., Njue, E., Ssebuliba, J.M. and Jager, A.D. (2005) Pro-Poor Horticulture in East Africa and South East Asia: The Horticultural Sector in Uganda. Agricultural Economics Research Institute, Wageningen University and Research Centre, Hague.

[7] Karungi, J., Tusiime, G., Rubaihayo, P., Ssonko, R., Asiimwe, D., Kyamanywa, S., Miller, S. and Erbaugh, J.M. (2013) Integrated Pest Management of *Ralstonia solanacearum* on Tomato in Uganda. https://www.semanticscholar.org/paper/Integrated-pest-management-of-Ralstonia-on-tomato-Karungi-Muwanga/c3d4e187544f90100bdba39bf078f50feaa5a8ed

[8] Geoffrey, T. and Mbabazi, S. (2014) Evaluating Horticultural Practices for Sustainable Tomato Production in Kamuli, Uganda. Graduate Theses and Dissertations, Paper 14033.

[9] International Food Policy Research Institute (IFPRI) (2015) 2014 Annual Report. International Food Policy Research Institute (IFPRI), Washington DC. http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129163 https://doi.org/10.2499/9780896295629

[10] Wisnubroto, E.I., Utomo, W.H. and Soelistyari, H.T. (2017) Biochar as a Carrier for Nitrogen Plant Nutrition: The Release of Nitrogen from Biochar Enriched with Ammonium Sulfate and Nitrate Acid. *International Journal of Applied Engineering Research*, **12**, 1035-1942.

[11] Chan, K.Y., Van Zwieten, L., Meszaros, I., Downie, A. and Joseph, S. (2008) Agronomic Values of Green Waste Biochar as a Soil Amendment. *Soil Research*, **45**, 629-634. https://doi.org/10.1071/SR07109

[12] Carter, M.R. (1993) Soil Sampling and Methods of Analysis. Lewis Publishers, Boca Raton, FL.

[13] Olsen, S.R. and Sommers, L.E. (1982) Determination of Available Phosphorus. In: Page, A.L., Miller, R.H. and Keeney, D.R., Eds., *Method of Soil Analysis*, American Society of Agronomy, Madison, WI, 403-427. https://doi.org/10.2134/agronmonogr9.2.2ed.c24

[14] Okalebo, J.R., Gathua, K.W. and Woomer. P.L. (2002) Laboratory Methods of Soil

and Plant Analysis: A Working Manual. 2nd Edition, TSBF-CIAT and SACRED Africa, Nairobi.

[15] Murphy, J. and Riley, J.P. (1962) A Modified Single Solution Method for Determination of Phosphate in Natural Waters. *Analytica Chimica Acta*, **27**, 31-36. https://doi.org/10.1016/S0003-2670(00)88444-5

[16] Asiimwe, D., Tusiime, G., Karungi, J., Kyamanywa, S., Miller, S. and Rubaihayo, P.R. (2013) Comparison of the Reaction of MT56 with Other Popular Tomato Genotypesto Bacterial Wilt (*Ralstonia solanacearum*) in Six Locations in Uganda. *African Crop Science Conference Proceedings*, **11**, 203-209.

[17] Payne, R.W., Murray, D.A., Harding, S.A., Baird, D.B. and Soutar, D.M. (2011) GenStat for Windows. 14th Edition, VSN International, Hemel Hempstead.

[18] Ortas, I. (2013) Influences of Nitrogen and Potassium Fertilizer Rates on Pepper and Tomato Yield and Nutrient Uptake under Field Conditions. *Academic Journals*, **8**, 1048-1055.

[19] Saidu, A., Bello, L.Y., Tsado, E.K. and Ibrahim, F.K. (2011) Effect of Cow Dung on the Performance of Tomato. *International Journal of Applied Biological Research*, **17**, 169-176.

[20] Tonfack, L.B., Bernadac, A., Youmbi, E., Mbouapouognigni, V.P., Ngueguim, M. and Akoa, A. (2009) Impact of Organic and Inorganic Fertilizers on Tomato Vigor, Yield and Fruit Composition under Tropical Andosol Soil Conditions. *Fruits*, **64**, 167-177. https://doi.org/10.1051/fruits/2009012

[21] Heeb, A., Lundegardh, B., Savage, G.P. and Ericsson, T. (2006) Impact of Organic and Inorganic Fertilizers on Yield, Taste, and Nutritional Quality of Tomatoes. *Journal of Plant Nutrition and Soil Science*, **169**, 535-541. https://doi.org/10.1002/jpln.200520553

[22] Hass, A., Gonzalez, J.M., Lima, I.M., Godwin, H.W., Halvorson, J.J. and Boyer, D.G. (2012) Chicken Manure Biochar as Liming and Nutrient Source for Acid Appalachian Soil. *Journal of Environmental Quality*, **41**, 1096-1106. https://doi.org/10.2134/jeq2011.0124

[23] Lehmann, J., Rillig, M.C., Thies, J., Masiello, C.A., Hockaday, W.C. and Crowley, D. (2011) Biochar Effects on Soil Biota—A Review. *Soil Biology and Biochemistry*, **43**, 1812-1836. https://doi.org/10.1016/j.soilbio.2011.04.022

[24] Tiamiyu, R.A., Ahmed, H.G. and Muhammad, A.S. (2012) Effect of Sources of Organic Manure on Growth and Yields of Okra (*Abelmoschus esculentus* L.) in Sokoto, Nigeria. *Nigerian Journal of Basic and Applied Sciences*, **20**, 213-216.

[25] Law-Ogbomo, K.E. and Egharevba, R.K.A. (2008) Effects of Planting Density and NPK Fertilizer on Growth and Fruit Yield of Tomato (*Lycospersicon esculentus* Mill). *Research Journal of Agriculture and Biological Sciences*, **4**, 265-272.

[26] Thalib, H. and Heryati, B. (2009) Response of Carrot to N.P.K. Fertilizer. *Journal of Horticultural Science*, **3**, 339-345.

[27] Chinda, J. (2006) Effect of NPK and Minor Element Application on Tomato Growing in KPS Soil. *Research Journal of Agriculture & Biological Sciences*, **2**, 186-192.

[28] Downie, A., Crosky, A. and Munroe, P. (2009) Physical Properties of Biochar. In: Lehmann, J. and Joseph, S., Eds., *Biochar for Environmental Management: Science and Technology*, Earthscan, London, 13-32.

[29] Atkinson, C.J., Fitzgerald, J.D. and Hipps, N.A. (2010) Potential Mechanisms for Achieving Agricultural Benefits from Biochar Application to Temperate Soils: A Review. *Plant and Soil*, **337**, 1-18. https://doi.org/10.1007/s11104-010-0464-5