International Journal of Environmental Health Research

ISSN: 0960-3123 (Print) 1369-1619 (Online) Journal homepage: https://www.tandfonline.com/loi/cije20

Characterization of eggplant grown in animal manure amended soil

George Fouad Antonious, Eric Turley, Bijesh Mishra, Quinn Heist, Yogendra Upadhyaya, Thomas Trivette & Lusekelo Nkuwi

To cite this article: George Fouad Antonious, Eric Turley, Bijesh Mishra, Quinn Heist, Yogendra Upadhyaya, Thomas Trivette & Lusekelo Nkuwi (2019): Characterization of eggplant grown in animal manure amended soil, International Journal of Environmental Health Research, DOI: 10.1080/09603123.2019.1602252

To link to this article: https://doi.org/10.1080/09603123.2019.1602252

Published online: 12 Apr 2019.

INTERNATIONAL JOURNAL OF ENVIRONMENTAL HEALTH RESEARCH
https://doi.org/10.1080/09603123.2019.1602252

Taylor & Francis
Taylor & Francis Group

ARTICLE

Characterization of eggplant grown in animal manure amended soil

George Fouad Antonious, Eric Turley, Bijesh Mishra, Quinn Heist, Yogendra Upadhyaya, Thomas Trivette and Lusekelo Nkuwi

Environmental Studies, Kentucky State University, Frankfort, KY, USA

ABSTRACT

A field experiment was conducted with native soil; sewage sludge (SS); horse manure (HM); chicken manure (CM); vermicompost, organic fertilizer and inorganic fertilizer mixed with the native soil. The soil in each of the seven treatments was also mixed with biochar and planted with eggplant. Eggplant fruits were analyzed for vitamin C, total phenols, and soluble sugars. The number and weight of fruits obtained from inorganic treatments were not significantly different from those obtained from organic fertilizer. Concentrations of total phenols were greatest (28 μg g^{-1} fresh fruits) in fruits of plants grown in vermicompost mixed with biochar compared to SS and HM amendments. Vitamin C was greatest (265 μg g^{-1} fresh fruits) in fruits of plants grown in soil amended with biochar compared to all other amendments. Plants grown in CM amended soil were 62% and 67% greater in size compared to plants grown in SS-biochar or vermicompost-biochar amended soil, respectively.

ARTICLE HISTORY
Received 22 March 2019
Accepted 28 March 2019

KEYWORDS
Vermicompost; chicken manure; horse manure; sewage sludge; vitamin C

Introduction

Eggplant, *Solanum melongena* L., is a *Solanaceae* crop widely grown in the subtropics and tropics areas. It is a good source of soluble sugars, protein, anthocyanin, phenolic, and glycoalkaloid compounds. The phenolic antioxidants in eggplant has hepatoprotective effect (Akanitapichat et al. 2010). Kentucky, having favorable weather for growing eggplant, has the potential to expand eggplant production and meet the growing market for fresh fruit (Agricultural Marketing Resource Center 2017). Eggplant characteristic feature is a root system of a medium range and its demand for water is greatest during the blooming and fruit-forming periods (Adamczewska-Sowińska et al. 2016). Eggplant is sensitive to frost and the growth of young plants is constrained by temperatures below 16°C (61°F). The growth of eggplant may slow down when the temperature is too high (> 30°C about 86°F), or in the absence of enough water, or in excessive humidity combined with a high temperature. High temperature and evenly distributed rainfall throughout the vegetation period are favorable conditions for eggplant yield (Adamczewska-Sowińska et al. 2016). The fruit shape range includes spherical, oblong, ovoid, oval, long and many intermediate shapes. The mean fruit weight is in the range of 200–300 g. Newer Asian types have weights of 20–40 g (Hassan et al. 2015; Caruso et al. 2017). The global production of eggplant is around 50 million tons annually, with a net value of more than $10 billion a year, which makes it the fifth most economically important *Solanaceous* crop after potato, tomato, pepper, and tobacco (FAO 2014; Taher et al. 2017). The top five eggplant producing countries are China (28.4 million tons;

CONTACT George Fouad Antonious george.antonious@kysu.edu Communities and the Environment, College of Agriculture, 231A Cooperative Extension Building.

57% of world's total), India (13.4 million tons; 27% of world's total), Egypt (1.2 million tons), Turkey (0.82 million tons), and Iran (0.75 million tons). In Asia and the Mediterranean, eggplant ranks among the top five most important vegetable crops (Taher et al. 2017).

The use of soil amendments in agricultural production systems is an affordable way to improve crop yield and quality. Antonious et al. (2008) reported that sewage sludge mixed with yard waste compost provided the highest marketable yield and greatest number of eggplant fruits compared to the no-mulch bare soil. Azarmi et al. (2008) reported that the addition of vermicompost to agricultural soil increased tomato yield and elemental content of tomato as compared to no-mulch control treatments. Laczi et al. (2016) found that the best yield of the Chinese cabbage was obtained when horse manure was used as a soil amendment. In addition, recent studies indicated that biochar (a product of burning wood by a process known as pyrolysis) used as a soil amendment could increase plant nutrients, soil cation exchange capacity (CEC), soil organic matter, soil microbial activities, and nutrients availability (Haipeng et al. 2017). Biochar is created by heating biomass at high temperature (300–1000°C which is equal to 572–1,832° F) under low oxygen conditions. Biochar application to agricultural soils has received increasing attention in recent years, due to the potential for climate change mitigation and improvement of soil properties linked with the increase of soil cation exchange capacity, nutrient and water retention, and positive influences on soil microbial communities, which influence crop yields (Ferreira et al. 2017).

Phenolic compounds are important secondary metabolites in eggplant. Eggplant has received a great interest as functional food among top 10 vegetables with antioxidant capacity because of its high content of phenolic compounds such as delphinine derivatives and chlorogenic acid isomers (Nayanathara et al. 2016; Niño-Medina et al. 2017). Eggplant is rich with nutrients and the phytochemicals that protect against cancer development, cardiovascular diseases, hypertension, and fluid retention. It has the ability to increase urine output this is why eggplant consumption is recommended for patients of kidney stones. Eggplant helps to promote biliary functions, as well as the production of pancreatic juice. Antioxidant activities and phenolic compounds found in the eggplant fruit (Huang et al. 2005; Nayanathara et al. 2016). Singh et al. (2009) identified many kinds of phenolic compounds, such as N-caffeoylputrescine, 5-caffeoylquinic acid, and 3-acetyl-5-caffeoylquinic acid in eggplant pulp. The authors indicated that the ethanol extracts of different varieties of eggplant showed considerable amount of phenols, flavonoids and anthocyanin content.

Ascorbic acid is a major antioxidant in plant cells. Its derivatives, tested on cancer cells, revealed anticancer activity (Naidu 2003). In addition, ascorbic acid as found in most fruits and vegetables protects against heart disease, high cholesterol, high blood pressure, and cancer (University of Maryland Medical Center 2008). The increasing awareness of the value of vegetables and fruits in the human diet requires monitoring of antioxidant content in plants grown under new soil management practices, such as recycling animal manure for land farming.

The objectives of this investigation were to 1) assess the effect of biochar and animal manures on eggplant yield, 2) investigate the effect of animal manures on fruit quality characteristics as specified by the U.S. eggplant standard guidelines, and 3) test the impact of biochar and animal manure on eggplant fruit composition (vitamin C, total phenols, and soluble sugars).

Materials and methods

A field experiment was conducted at the University of Kentucky Horticulture Research Farm (Fayette County, KY). Forty-two (42) field plots of 4 ft length and 10 ft width (4 × 10 ft^2 each) were used in a randomized complete block design (RCBD). Treatments were: 1) control (no-mulch untreated soil), 2) sewage sludge (SS), 3) horse manure (HM), 4) chicken manure (CM), 5) vermicompost (worm casting), 6) organic fertilizer (Nature Safe 10:2:8), and 7) inorganic fertilizer (Southern State 19:19:19). All soil amendments including SS, HM, CM, and vermicompost were applied at 5% nitrogen (N) on dry weight basis as shown in Table 1 to eliminate variations in N

Table 1. Concentrations of NPK in animal manures, organic and inorganic fertilizers used as soil amendments for growing eggplant at the University of Kentucky Research Farm (Fayette County, Kentucky, USA).

Soil amendment	Nitrogen (% N)	Phosphorus (% P)	Potassium (% K)
Sewage sludge	5.00	3.00	0.00
Chicken manure	1.10	0.80	0.50
Horse manure	0.70	0.30	0.60
Vermicompost	1.50	0.75	1.50
Organic fertilizer	10.00	2.00	8.00
Inorganic fertilizer	20.00	20.00	20.00
	Amounts of Soil Amendments added to in lb Acre $^{-1}$		
Soil amendment	Nitrogen (N)	Phosphorus (P)	Potassium (K)
Sewage sludge	2000.00	1200.00	0.00
Chicken manure	5882.00	4277.80	2673.60
Horse manure	14,285.00	6122.00	12,244.29
Vermicompost	8333.00	4166.50	8333.00
Organic fertilizer	1000.00	200.00	800.00
Inorganic fertilizer	500.00	500.00	500.00

content among soil treatments (Antonious 2018). SS was purchased from the Metropolitan Sewer District, Louisville, KY and used at 5% N on dry weight basis, CM was obtained from the Department of Animal and Food Sciences, University of Kentucky, Lexington, Kentucky and used at 5% N on dry weight basis. HM was obtained from the Kentucky horse park, College of Agriculture, University of Kentucky, Lexington, Kentucky and used at 5% N. Vermicompost (worm castings) was obtained from Worm Power (Montpelier, Vermont, USA), whereas organic and inorganic commercial fertilizers were purchased from the Southern States Cooperative Co. (Lexington, Kentucky) and used at 5% N. It is important to mention here that growers using animal manure should adhere to the recommendation that there should be 120 days between manure storage after production and mixing with soil to avoid possible burning and phytotoxicity effect on growing plants. Animal manure that heats up naturally for at least 15 days does the following: kills harmful pathogens, such as *Escherichia coli*, kills undigested seed weeds, dilutes and evaporates ammonia that burns plants, stabilizes N into slow-release compounds, and reduces animal manure odors.

Each the soil in each of the seven treatments was also mixed with 10% (w/w) biochar obtained from Wakefield Agricultural Carbon (Columbia, MO) to make a total of 14 treatments. Soil amendments were added to native topsoil, mixed, and rototilled to a depth of 15 cm of topsoil. Sixty days old seedlings of eggplant, *Solanum melongena v*ar. 'Epic' were planted in a freshly tilled soil at 18-in. in-row spacing on 17 May 2017 and drip irrigated as needed. Weeding and other intercultural operations were done regularly. The insecticides esfenvalerate (Asana XL) was applied three times during the growing season in a seven-day interval at a rate of 5.5 fluid oz/acre to control Japanese and Colorado potato beetles. The eggplant fruits were harvested five times during the growing season on June 26, July 21, August 9, August 29, and 26 September 2017 and graded according to the USDA guidelines into Fancy, U.S. No. 1, U.S. No. 2, and Culls (USDA, 2013). U.S. Fancy fruits are well colored, firm, well shaped, and free from decay, disease or wormholes. U.S. No. 1 fruits are fairly well colored, fairly well shaped, and free of decay, disease or wormholes. U.S. No. 2 fruits are free from cuts, decay or serious damage caused by discoloration, or mechanical or other means. Culls are fruits that are not marketable due to the presence of holes caused by disease and/or damage.

Pepper yield and fruit quality characteristics

At each of five harvests (June, 26; July, 21; August 9; August 29; and 26 September 2017) eggplant weight, number of fruits, fruit grading characteristics (Fancy, U.S. No. 1, U.S. No.2, and culls),

fruit vitamin C, total phenols, and soluble sugar contents were recorded and statistically analyzed using analysis of variance (ANOVA, SAS Institute 2016).

Quantification of antioxidants in eggplant fruits

Vitamin C, soluble sugars and phenolic contents were determined in eggplant fruits collected from the field experiment at each of the five harvests. At each harvest, 10 ripe fruits collected from each treatment were cut into small pieces. Vitamin C (ascorbic acid) was extracted by blending 20 g of chopped fruits with 100 mL of 0.4% (w/v) oxalic acid solution and quantified using the potassium ferricyanide method (Hashmi 1973). To determine the degree of fruit sweetness, soluble sugars in eggplant fruits were extracted with 80% ethanol and quantified using the methods used by Antonious et al. (2011). Representative fruit samples (20 g) were blended with 150 mL of ethanol to extract phenols. The homogenates were filtered through Whatman No. 1 filter paper and 1-mL aliquots of filtrates was used for determination of total phenols using a standard calibration curve of chlorogenic acid (McGrath et al. 1982).

Impact of animal manure and biochar on eggplant plant size

Considering that eggplant plant shaped like a cone, we measured the plant volume as:

V = 1/3 * 3.14 * r2 * h, where v is the plant volume, r is the plant radius, and h is the plant height. Eggplant size, fruit composition, fruit and plant morphological characteristics were statistically analyzed using analysis of variance (ANOVA, SAS Institute 2016).

Result and discussion

Results revealed no significant differences ($P > 0.05$) among biochar and no-biochar treatments in crop yield, number of fruits, or fruit quality characteristics (data not shown), indicating no impact of biochar on all the morphological parameters tested. Total weight of fruits obtained from CM amended soil was significantly ($P < 0.05$) greater compared to vermicompost-amended soil (Figure 1, upper graph). Regardless of biochar treatments, the number of total fruits obtained from inorganic treatments were significantly greater compared to CM, HM, and SS amended soils (Figure 1, lower graph). This response may be due to increase in nutrient availability, soil porosity, and water-holding capacity in soil amended with CM. CM can be an effective source of essential plant nutrients such as N and P, and as a source of soil organic carbon. However, many investigators reported signs of phytotoxicity in some plants grown in CM amended soils indicating the need for further trials to reduce CM toxic impact that might be through composting with other animal manure such as vermicompost to improve nutrient content and reduce its potential phytotoxicity to growing plants (Ravindran et al. 2017). Recycling animal manure for use as a low-cost organic fertilizer has resulted in a positive effect on the growth and yield of a wide variety of crops and promoted the restoration of ecologic and economic functions of soil. The organic matter (OM) content of composted animal manure is high and its addition to agricultural soils often improves soil physical, chemical, and biological properties (Antonious 2016).

Data in Figure 2, upper graph revealed that vermicompost produced greater weight of culls compared to other animal manures (CM, HM, and SS amendments). Soil amended with vermicompost produced a significant number of culls (unmarketable fruits, Figure 2, lower graph). On the contrary, some investigators (Yadav et al. 2013) reported that vermicompost has important properties that can be explored as a new technology for converting organic wastes into a product rich in plant nutrients. Plants treated with inorganic fertilizer produced the greatest number of fancy fruits (Figure 3, upper graph), but also produced a low number of U.S. No. 1 fruits (Figure 3, middle graph). Inorganic fertilizer also produced great number of U.S. No. 2 fruit compared to HM or SS treatments (Figure 3, lower graph).

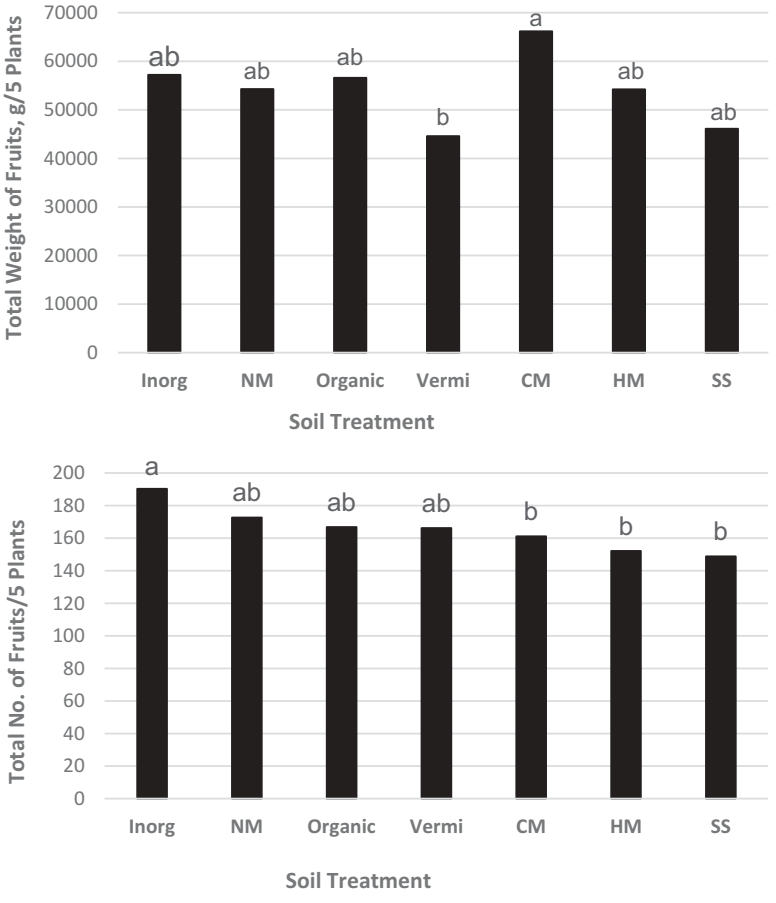

Figure 1. Total weight of eggplant fruits (upper graph) and number of fruits (lower graph) collected from five harvests of plants grown under seven soil management practices: inorganic fertilizer, no-mulch (NM), organic fertilizer, vermicompost, chicken manure (CM), horse manure (HM), and sewage sludge (SS). Statistical comparisons were carried out among treatments. Bars accompanied by different letter(s) in each graph indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

Average fruit length and width for each of the three USDA categories are shown in Table 2. There was no significant difference ($P > 0.05$) between organic fertilizer (Nature Safe) and inorganic fertilizer (Southern State) used in this investigation in Fancy and US1 fruit length and width among soil amendments other than US2 fruits produced from plant grown in inorganic fertilizer were greater in length and width compared to plants grown in organic fertilizer. Results in Figure 4 show that eggplants grown in CM amended soil were significantly ($P < 0.05$) greater in size (38,827 in.^{3}) compared to plants grown in soil amended with SS-biochar or vermicompost-biochar (23,932 and 23,247 in.^{3}, respectively) indicating 62% and 67% increase in plant grown in CM amended soil compared to SS-biochar or vermicompost-biochar plants. Eggplant, *Solanum melongena* L. yield of plants cultivated in the field depends significantly on the weather conditions. High temperature and evenly distributed rainfall throughout the vegetation period are favorable conditions for eggplant production (Adamczewska-Sowińska et al. 2016). In commercial production, eggplant is harvested and consumed when the fruit is immature, prior to seed development (Radicetti et al. 2016). Mature eggplant fruits are unmarketable due to their unpleasant fruit color, texture, sharp and bitter taste due to the presence of large amount of mature seeds.

Some agricultural production systems that produce high marketable yields result in less than optimal organoleptic and nutraceutical fruit qualities (Kader 2008; Radicetti et al. 2016).

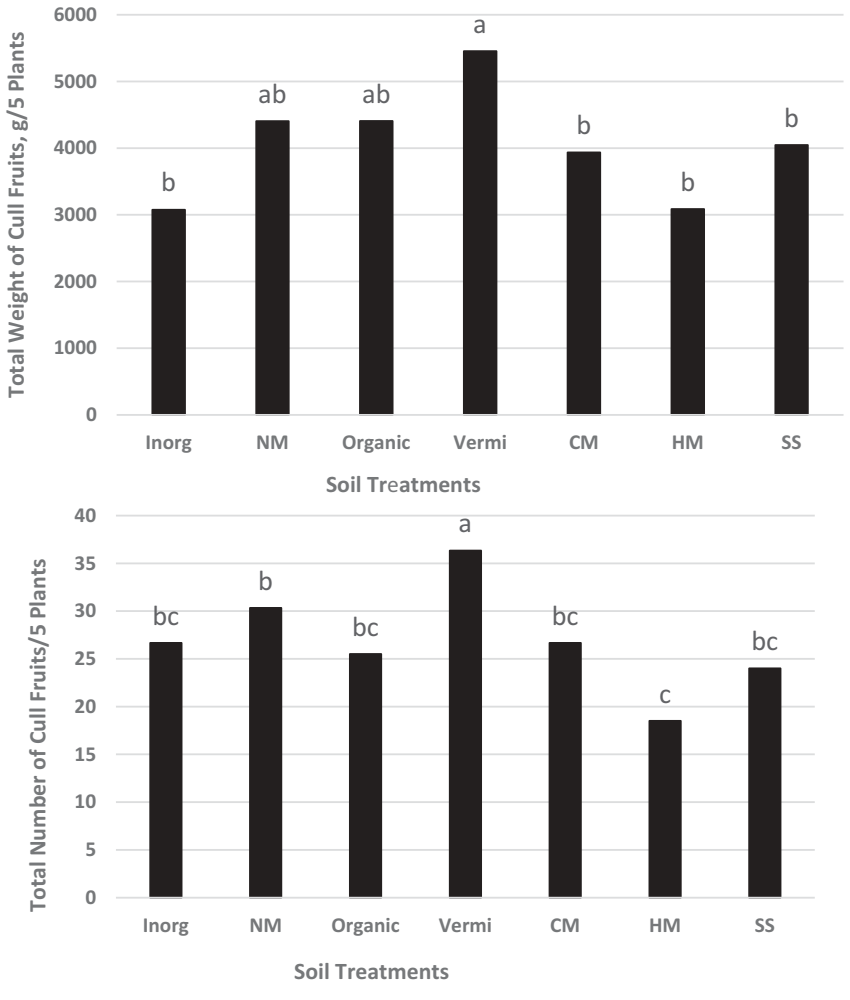

Figure 2. Total weight of eggplant cull (unmarketable fruits, upper graph) and number of cull fruits (lower graph) collected from five harvests of plants grown under seven soil management practices: inorganic fertilizer, no-mulch (NM), organic fertilizer, vermicompost, chicken manure (CM), horse manure (HM), and sewage sludge (SS). Statistical comparisons were carried out among treatments. Bars accompanied by different letter(s) in each graph indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

Accordingly, field and laboratory research to identify the agricultural practices that use recycled animal manure and optimizing the organoleptic qualities of marketable fruits is the focus of this investigation. Soil amendments used in this investigation provided the nutrients most used in fertilizers such as N and K (Lopes et al. 2010; De Souza et al. 2017). N is a main nutrient related to the increase in plant growth and crop yield (Aminifard et al. 2010; De Souza et al. 2017). N is responsible for structural functions and participates in various organic compounds that are vital for the plant, such as proteins, proline and amino acids (Parida and Das 2005; De Souza et al. 2017). Amiri et al. (2012) observed that the eggplant responds up to the dose of 120 kg of N ha^{-1}, while Trani (2014) recommended up to 200 kg of N ha^{-1} for cultivation in protected environments. De Souza et al. (2017) found that the maximum number of fruits $plant^{-1}$ and crop yield were obtained when N concentration ranged between 14.0 and 17.0 g of N $plant^{-1}$ (145 to 177 kg of N ha^{-1}), while N doses higher than 15.03 and 14.04 g $plant^{-1}$ reduced yields and number of fruits $plant^{-1}$, respectively. In our investigation, we applied each soil amendment at 5% N indicating that N rate of application is not a limiting factor in eggplant growth, but more

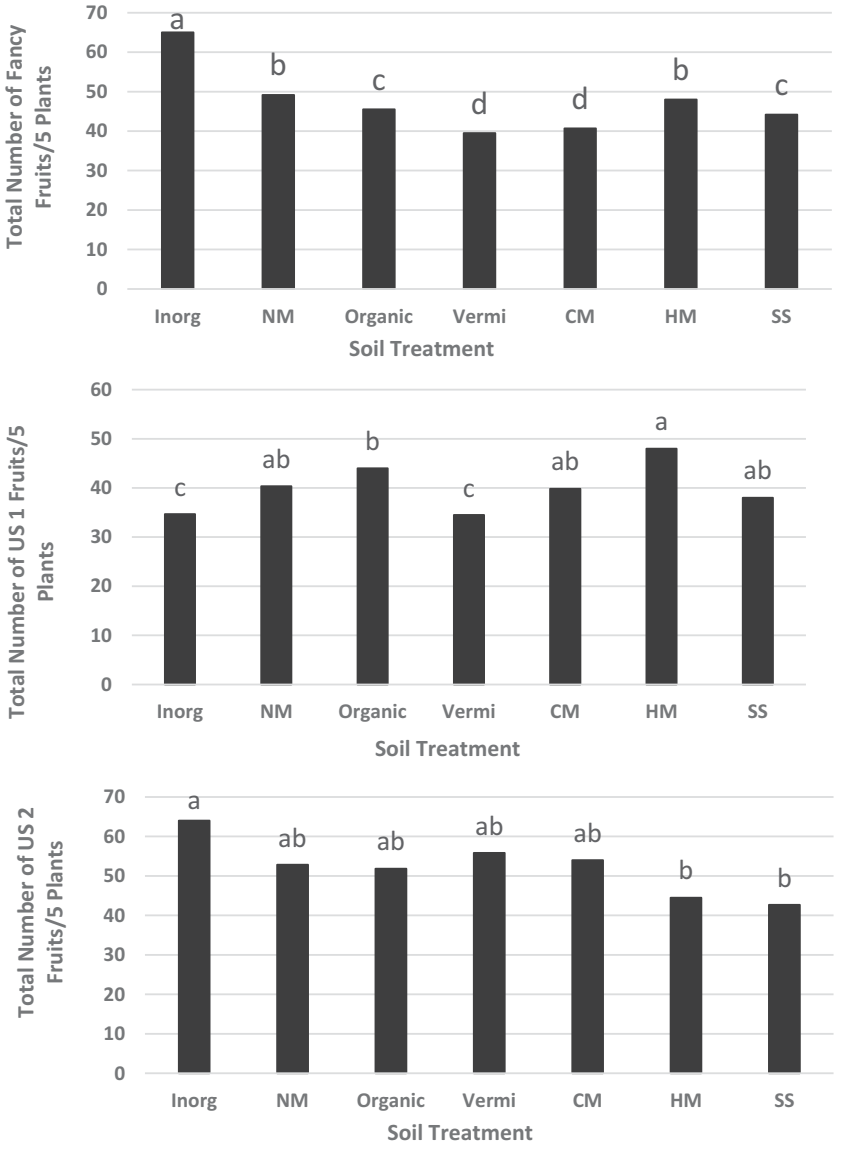

Figure 3. Number of Fancy eggplant fruits (upper graph), U.S. No. 1 fruits (middle graph), and Number of U.S. No. 2 fruits (lower graph) of plants grown under seven soil management practices: inorganic fertilizer, no-mulch (NM), organic fertilizer, vermicompost, chicken manure (CM), horse manure (HM), and sewage sludge (SS). Statistical comparisons were carried out among treatments. Bars accompanied by different letter(s) in each graph indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

important is the availability of N to growing plants in a soluble form, such as ammonium ions (NH^{+}_{4}) and nitrates (NO^{-}_{3}).

In addition, potassium (K) is the nutrient most required by fruits and performs various functions in the plant, such as activation of enzymes involved in respiration and direct effect on CO_2 assimilation rate, through the control of stomatal opening and closure (Faquin and Andrade 2004; De Souza et al. 2017). Trani (2014) recommend the dose of 220 kg of K ha^{-1}. Eggplant has a very low caloric value and is considered among the healthiest vegetables for its high content of vitamins, minerals and bioactive compounds for human health (Raigón et al. 2008; Plazas et al. 2014; Docimo et al. 2016; Taher et al. 2017). In this respect, eggplant is ranked among the top 10

Table 2. Eggplant fruit length and width in centimeters for each USDA marketable fruit category.

	Fancy Fruit		US1 Fruit		US2 Fruit	
Soil amendment	Length	Width	Length	Width	Length	Width
Sewage sludge	9.7 a	8.5 a	12.7 a	6.6 a	10.1 ab	5.2 b
Chicken manure	5.1 c	8.4 a	15.3 a	6.6 a	8.8 ab	4.9 b
Horse manure	12.5 a	8.8 a	14.0 a	7.1 a	13.1 a	7.3 a
Vermicompost	10.1 a	8.5 a	15.4 a	8.0 a	11.6 ab	8.7 a
Organic fertilizer	9.8 a	8.3 a	13.9 a	7.4 a	5.2 b	3.3 b
Inorganic fertilizer	11.2 a	8.4 a	15.3 a	8.1 a	12.7 a	6.5 a
No-mulch	7.4 b	8.4 a	14.4 a	6.9 a	7.2 ab	4.1 b

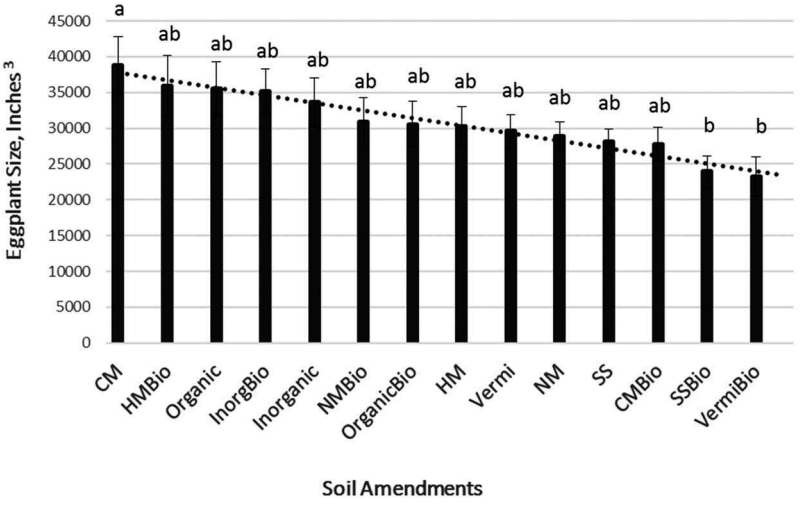

Figure 4. Impact of soil amended with organic, inorganic, or animal manures mixed with biochar or no-biochar on eggplant size. CM = chicken manure, HMBio = horse manure mixed with biochar, Organic = organic fertilizer, InorgBio = inorganic fertilizer mixed with biochar, Inorganic = inorganic fertilizer, NMBio = no-mulch soil mixed with biochar, OrganicBio = organic fertilizer mixed with biochar, HM = horse manure, Vermi = vermicompost, NM = no-mulch bare soil, SS = sewage sludge, CMBio = chicken manure mixed with biochar, SSBio-sewage sludge mixed with biochar, and VermiBio = vermicompost mixed with biochar. Statistical comparisons were carried out among soil treatments. Bars accompanied by different letter(s) indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test.

vegetables in terms of oxygen radical absorbance capacity (Taher et al. 2017). The bioactive properties of eggplant are mostly associated with high content in phenolic compounds (Plazas et al. 2013; Taher et al. 2017), which are mostly phenolic acids, particularly chlorogenic acid in the fruit flesh (Stommel et al. 2015; Taher et al. 2017) and anthocyanins in the fruit skin (Mennella et al. 2012; Taher et al. 2017). Both phenolic acids and anthocyanins have multiple properties beneficial for human health (Plazas et al. 2013; Braga et al. 2016; Taher et al. 2017).

Vitamin C was greatest (265 μg g^{-1} fresh fruits) in fruits of plants grown in no-mulch soil amended with biochar compared to all other amendments (Figure 5(a)). Total phenol concentrations varied among the various soil treatments and were greatest (28 μg g^{-1} fresh fruits) in fruits of plants grown in vermicompost mixed with biochar compared to SS and HM amendments (Figure 5(b)). whereas no significant differences were found among soil treatments in eggplant fruit soluble sugars content (Figure 5(c)).

Each value in the table is an average of ten fruits collected from each treatment. Values in each column accompanied by the same letter(s) are not significantly different ($P > 0.05$) using Duncan's multiple range test.

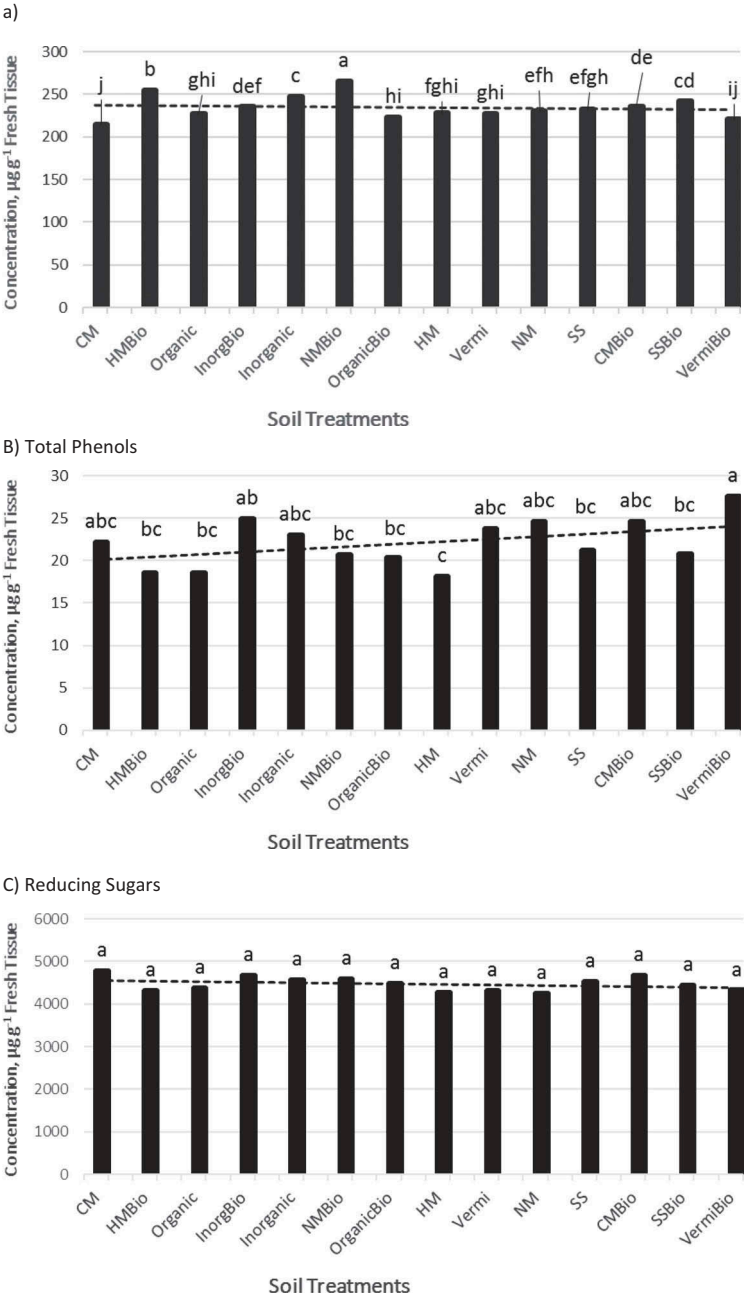

Figure 5. Impact of soil amended with organic, inorganic, or animal manures mixed with biochar or no-biochar on concentrations of vitamin c (upper graph), total phenols (middle graph), and reducing sugars (lower graph) in eggplant fruits. CM = chicken manure, HMBio = horse manure mixed with biochar, Organic = organic fertilizer, InorgBio = inorganic fertilizer mixed with biochar, Inorganic = inorganic fertilizer, NMBio = no-mulch soil mixed with biochar, OrganicBio = organic fertilizer mixed with biochar, HM = horse manure, Vermi = vermicompost, NM = no-mulch bare soil, SS = sewage sludge, CMBio = chicken manure mixed with biochar, SSBio=sewage sludge mixed with biochar, and VermiBio = vermicompost mixed with biochar. Bars accompanied by different letter(s) in each graph indicate significant differences ($P \leq 0.05$) using Duncan's multiple range-test.

Conclusions

Eggplant, *Solanum melongena* var. Epic seedlings were planted under field conditions in a raised freshly tilled field plots at 18 in. in row spacing. The main objective was to assess the impact of soil amendments on eggplant yield and fruit quality (fruit length, width, and antioxidants composition). Eggplant fruits were harvested five times during the growing season, graded according to the USDA guidelines into Fancy, U.S. No.1, U.S. No. 2, and culls (unmarketable fruits), and analyzed for vitamin C, total phenols, and soluble sugars. Overall five harvests, the number of fruits (190 fruits/5 plants) and weight of fruits (57 kg/5 plants) obtained from inorganic treatments were similar to those obtained from organic fertilizer. Total number of culls and weight of culls obtained from vermicompost treatment were greater compared to CM, HM, SS, or inorganic treatments. Total phenols concentrations were greatest (28 μg g^{-1} fresh fruits) in fruits of plants grown in vermicompost mixed with biochar compared to SS and HM amendments. Vitamin C was greatest (265 μg g^{-1} fresh fruits) in fruits of plants grown in no-mulch soil amended with biochar compared to all other amendments. No significant differences were found among soil treatments in fruit soluble sugars content.

Acknowledgments

The authors thank Steven Diver and his farm crew for maintaining the field plots. The study was funded by a grant # KYX-10-18-P65 (accession # 1017900) from the United States Department of Agriculture, National Institute of Food and Agriculture (USDA/NIFA) to Kentucky State University.

Funding

This work was supported by the United States Department of Agriculture/National Institute of Food and Agriculture [Accession # 1017900 KYX-10-18-P65].

References

Adamczewska-Sowińska K, Krygier M, Turczuk J. 2016. The yield of eggplant depending on climate conditions and mulching. Folia Hortic. 28(1):19–24.

Agricultural Marketing Resource Center. 2017. Eggplant. Iowa State University. [accessed 2019 Apr 4]. https://www.agmrc.org/commodities-products/vegetables/eggplants

Akanitapichat P, Phraibung K, Nuchklang K, Prompitakkul S. 2010. Antioxidant and hepatoprotective activities of five eggplant varieties. Food Chem Toxicol. 48(10):3017–3021.

Aminifard MH, Aroiee H, Fatemi H, Ameri A, Karimpour S. 2010. Responses of eggplant (*Solanum melongena* L.) to different rates of nitrogen under field conditions. J Cent Eur Agric. 11:453–458.

Amiri E, Gohari AA, Esmailian Y. 2012. Effect of irrigation and nitrogen on yield, yield componentes and water use efficiency of eggplant. Afr J Biotechnol. 11:3070–3079.

Antonious GF. 2016. Organic fertilizers: from basic concepts to applied outcomes. Chapter 7 In: Larramendy ML, Soloneski S, editors. Soil Amendments for Agricultural Production. Rijeka (Croatia): Intech; p. 157–187.

Antonious GF. 2018. Biochar and animal manure impact on soil, crop yield and quality. Chapter 4, pages 45-67 In: Aladjadjiyan A, editor. Agricultural waste and Residues. Rijeka, Croatia: National Biomass Association, Bulgaria & Published by Intech- Open Science Books, Janeza Trdine 9.

Antonious GF, Dennis SO, Unrine JM, Snyder JC. 2011. Ascorbic acid, β-carotene, sugars, phenols, and heavy metals in sweet potato grown in soil fertilized with municipal sewage sludge. J Environ Sci Health. B46 (2):112–121.

Antonious GF, Turley ET, Sikora F, Snyder JC. 2008. Heavy metal mobility in runoff water and absorption by eggplant fruits from sludge treated soil. J. Environ. Sci. Health B. 43(6):526–532.

Azarmi R, Ziveh PS, Satari MR. 2008. Effect of vermicompost on growth, yield and nutrition status of tomato (*Lycopersicum esculentum*). Pak J Biol Sci. 11(14):1797–1802.

Braga PC, Lo Scalzo R, dal Sasso M, Lattuada N, Greco V, Fibiani M. 2016. Characterization and antioxidant activity of semi-purified extracts and pure delphinine-glycosides from eggplant peel (Solanum melongena L.) and allied species. J Funct Foods. 20:411–421.

Caruso G, Pokluda R, Sękara A, Kalisz A, Jezdinský A, Kopta R, Grabowska A. 2017. Agricultural practices, biology and quality of eggplant cultivated in Central Europe. A review. Hort Sci. 44(4):201–212.
De Souza AHC, Rezende R, Lorenzoni MZ, Seron CC, Hachmann TL, Lozano CS. 2017. Response of eggplant crop fertigated with doses of nitrogen and potassium. Revista Brasileira de Engenharia Agrícola e Ambiental. 21(1). doi:10.1590/1807-1929/agriambi.v21n1p21-26.
Docimo T, Francese G, Ruggiero A, Batelli G, De Palma M, Bassolino L. 2016. Phenylpropanoids accumulation in eggplant fruit: characterization of biosynthetic genes and regulation by a MYB transcription factor. Front Plant Sci. 6:1233. doi:10.3389/fpls.2015.01233
FAO 2014. FAOSTAT Production Databases. [accessed 2017 Jan 30]. http://www.faostat.fao.org
Faquin V, Andrade AT. 2004. Nutrição mineral e diagnose do estado nutricional das hortaliças. Lavras: FAEPE-UFLA; p. 88.
Ferreira C, Verheijen F, Puga K, Keizer J, Ferreira A. 2017. Biochar in vineyards: impact on soil quality and crop yield four years after the application. 19th EGU General Assembly.
Haipeng W, Cui L, Guangming Z, Jie L, Jin C, Jijun X, Juan D, Xiaodong L, Junfeng L, Ming C, et al. 2017. The interactions of composting and biochar and their implications for soil amendment and pollution remediation: A review. Cri. Rev. Biotechnol. 37(6):754–764.
Hashmi MH. 1973. Vitamin C (L. Ascorbic acid), chapter 13, pages 286–323 In: Hashmi, M.H., editors. Assay of vitamins in pharmaceutical preparations. London (UK): John Wiley and Sons.
Hassan I, Jatoi SA, Arif M, Siddiqui SU. 2015. Genetic variability in eggplant for agro-morphological traits. Sci Technol Dev. 34:35–40.
Huang D, Ou B, Prior RL. 2005. The chemistry behind antioxidant capacity assays. J Agric Food Chem. 53:1841–1856.
Kader AA. 2008. Flavor quality of fruits and vegetables. J Sci Food Agric. 88:1863–1868.
Laczi E, Apahidean A, Luca E, Dumitraş A, Boancă P. 2016. Headed Chinese cabbage growth and yield influenced by different manure types in organic farming system. Hort Sci. 43:42–49.
Lopes LN, Souza CF, Santoro BL. 2010. Utilização da TDR para monitoramento da solução de nitrato de potássio em Latossolo Vermelho-Amarelo. Engenharia Agrícola. 30:932–947.
McGrath RM, Kaluza WZ, Daiber KH, Yan der Riel WR, Glennie CW. 1982. Polyphenols of sorghum grain, their changes during malting and their inhibitory nature. J Agric Food Chem. 30:450–456.
Mennella G, Lo Scalzo R, Fibiani M, D'Alessandro A, Francese G, Toppino L, Acciarri N, de Almeida AE, Rotino GL. 2012. Chemical and bioactive quality traits during fruit ripening in eggplant (*S. melongena* L.) and allied species. J Agric Food Chem. 60:11821–11831.
Naidu KA. 2003. Vitamin C in human health and disease is still a mystery? An overview. Nutr J. 2:2–7.
Nayanathara AR, Anu M, Aalolam KP, Reshma JK. 2016. Evaluation of total phenol, flavonoid and anthocyanin content in different varieties of eggplant. Emer Life Sci Res. 2(2):63–65.
Niño-Medina G, Urías-Orona V, Muy-Rangel MD, Heredia JB. 2017. Structure and content of phenolics in eggplant (*Solanum melongena*) - a review. S Afr J Botany. 111:161–169.
Parida AK, Das AB. 2005. Salt tolerance and salinity effects on plants: A review. Ecotoxicol Environ Saf. 60:324–349.
Plazas M, Andújar I, Vilanova S, Hurtado M, Gramazio P, Herraiz FJ. 2013. Breeding for chlorogenic acid content in eggplant: interest and prospects. Not Bot Horti Agrobot. 41:26–35. doi:10.15835/nbha4119036
Plazas M, Prohens J, Cuñat AN, Vilanova S, Gramazio P, Herraiz FJ. 2014. Reducing capacity, chlorogenic acid content and biological activity in a collection of scarlet (*Solanum aethiopicum*) and gboma (*S. macrocarpon*) eggplants. Int J Mol Sci. 15:17221–17241.
Radicetti E, Massantini R, Campiglia E, Mancinelli R, Ferri S, Moscetti R. 2016. Yield and quality of eggplant (Solanum melongena L.) as affected by cover crop species and residue management. Sci Hortic (Amsterdam). 204:161–171.
Raigón MD, Prohens J, Muñoz-Falcón JE, Nuez F. 2008. Comparison of eggplant landraces and commercial varieties for fruit content of phenolics, minerals, dry matter and protein. J Food Comp Anal. 21:370–376. doi:10.1016/j.jfca.2008.03.006
Ravindran B, Mupambwa HA, Silwana S, Mnkeni PNS. 2017. Assessment of nutrient quality, heavy metals and phytotoxic properties of chicken manure on selected commercial vegetable crops. Heliyon. 3(12):e00493.
SAS Institute Inc. SAS/STAT guide, version 6.4. Cary (NC): SAS Inc, Campus Drive; 2016.
Singh AP, Luthria D, Wilson T, Vorsa N, Singh V, Banuelos GS, Pasakdee S. 2009. Polyphenols content and antioxidant capacity of eggplant pulp. Food Chem. 114:955–961.
Stommel JR, Whitaker BD, Haynes KG, Prohens J. 2015. Genotype × environment interactions in eggplant for fruit phenolic acid content. Euphytica. 205:823–836.
Taher D, Solberg S, Prohens J, Chou Y, Rakha M, Wu T. 2017. World vegetable center eggplant collection: origin, composition, seed dissemination and utilization in breeding. Front Plant Sci. 8:1484.

Trani PE. 2014. Calagem e adubação para hortaliças sob cultivo protegido. 1 ed. Campinas: Instituto Agronômico; p. 25.
United States Department of Agriculture (USDA), Fruit and Vegetable Program. United States standards grades of eggplant. Washington (DC): USDA; 2013 February 4.
University of Maryland Medical Center. 2008. Vitamin C (Ascorbic acid). Baltimore (MD). www.umm.edu/altmed/articles/vitamin-c-000339.htm.
Yadav A, Gupta R, Garg VK. 2013. Organic manure production from cow dung and biogas plant slurry by vermicomposting under field conditions. Int J Recycling Organic Waste Agri. 2(21):3–7.