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Chitin, Biochar, and Animal Manures Impact on Eggplant and Green Pepper Yield and Quality

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Abstract

The global obligation for food requires soil and plant management practices that provide valuable effects on the physical, chemical, and organic properties of soils. The use of animal manure, in agricultural production systems as alternative to synthetic elemental fertilizers has potential application to improve crop yield and fruit quality. A randomized complete block design (RCBD) was established to investigate the impact of nine soil treatments on yield and quality of bell pepper, *Capsicum annuum* and eggplant, *Solanum melongena*. The nine soil treatments included: chitin CH, biochar Bio, sewage sludge SS, chicken manure CM, SS mixed with biochar (SSBio), SS mixed with CH (SSCH), CM mixed with biochar (CMBio), CM mixed with CH (CMCH), and unamended (UN) native soil used as control treatment. At maturity, fruits from each treatment, were counted, weighed, and classified according to the USDA grades to U.S. Fancy, U.S. No.1, U.S. No.2, and culls. Overall number and weight of green pepper fruits collected from plants grown in SSCH were significantly greater (26.2 and 3.14 kg 5 plants^{-1}) compared to fruits of plants grown in unamended control treatment (17.1 and 1.98 kg 5 Plants^{-1}, respectively). Whereas CH alone was superior in increasing the number and weight of eggplant fruits compared to the control treatment. Average weight and number of eggplant fruits of plants grown in soil amended with chitin (4.46 kg and 11.5, respectively) were significantly ($P \le 0.05$) greater than weight and number of fruits obtained from plants grown in other soil treatments. Results also revealed a positive correlation coefficient (r) and high probability of significance (*P*) between number of fruits and weight of fruits among the nine soil treatments. Utilization of animal manures in agricultural systems is an inexpensive means for limited-resource farmers looking for improvements in crop yield and quality at affordable costs.

Keywords

Soil Amendments, Chicken Manure, Sewage Sludge, USDA Fruit Grades

1. Introduction

Chitin $(C_8H_{13}O_5N)_n$ is a long-chain unbranched polysaccharide made of $\beta - 1$, 4-linked anhydro-2-acetamido-2-deoxy-D-glucose. It is one of the most abundant biopolymers worldwide obtained from a renewable organic resource that has been effective in the removal of heavy metals by adsorption [1]. Addition of chitin to agricultural soil provides a valuable C and N source for soil microorganisms [2]. Chitin in the exoskeleton of crustacean's species (shrimp, crab, lobster, crawfish shells, and other marine zooplankton), could be used in agriculture as organic fertilizer. The annual chitin production in the biosphere is around 1000 billion tons per year [3]. The increased availability of chitin-containing waste materials from the seafood industry, has led to the testing and development of chitin-containing products for a wide variety of applications in the agriculture systems. Chitin and its derivatives (chitosan) have beneficial effects as fertilizers, soil conditioning agents, and plant-disease control agent [4]. In fact, chitin is one of the promising natural alternatives to current plant protection products with low environmental impact. In respect to the mechanism of action, the fertilizer effect of chitin or chitosan is due to biodegradation of the polymer in the soil by bacterial chitinases, and enzymes that degrade chitin to ammonia-derived compounds that have fertilizer effect on their own due to presence of amino-groups which promote the growth of selected soil microorganisms [5].

Biochar is the carbon-rich product from the thermochemical conversion of biomass, such as wood, manure, and plant leaves. The process of converting biomass to biochar cannot only result in renewable energy (synthetic gas and bio-oil), but also decreases the content of CO_2 in the atmosphere [6]. The extremely hygroscopic and porous nature of biochar is very effective at retaining both water and water-soluble nutrients that make biochar a habitat for many beneficial soil microorganisms. Biochar production for agricultural use is a promising strategy to sequester carbon, increase soil productivity through improved nutrient availability to growing plants and soil physical, chemical, and biological properties and environmental quality [7]. When applied to soil, biochar is function as a long-term carbon storage that improves properties of the soil [8]. Biochar reduces soil acidity as an ion-exchanger and therefore, reduces leaching of nutrients from agricultural soils, adsorbs pollutants from soil, and benefits the soil biota [9] [10] due to its ability to host and shelter soil microorganisms. An ample body of literature supports the idea that soil amended with biochar has a high potential to increase crop productivity due to the improvement in soil structure, high nutrient use efficiency, soil aeration, porosity, and water-holding capacity, compared to other soil amendments [11]. Biochar typically has a high surface area and contain many functional groups and high cation exchange capacity.

Excessive chemical fertilization in agricultural production systems could negatively affect crop production and sustainability by deteriorating soil (due to salinity, heavy metal accumulation) and water quality (due to eutrophication). It could also pollute the atmosphere with the release of N and S gases causing greenhouse effect and global warming [12]. On the other hand, recycling animal manure for use as a low-cost organic fertilizer 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 content of composted soil amendments is high and its addition to agricultural soils often improves soil physical and chemical properties and enhances soil biological activities [13]. Composts provide a stabilized form of organic matter that improves the physical properties of soils by increasing nutrient and water holding capacity, total pore space, aggregate stability, erosion resistance, temperature insulation, and decreasing apparent soil density. Animal manures (sewage sludge SS, chicken manure CM, etc.) represent a valuable source of N. The use of SS as a soil conditioner to enhance soil physical, chemical, and microbial conditions might also enhance soil bioremediation [14]. CM also enhances soil biological activity and fertility, nutrient status and growth of several groups of microorganisms, such as bacteria, fungi, and actinomycetes [15]. The economic cost of using animal manure depends on several factors such as its purchase, application and transfer costs. The type of animal manure may also influence the cost. For example, Araji *et al.* [6] reported that chicken manure application cost only 18% of the commercial fertilizer cost, whereas cow manure cost 125% of commercial fertilizer cost. Animal manures cost is low compared to the purchase of inorganic commercial fertilizer. However, its transport and application costs are generally higher than commercial fertilizer. Hence, if animal manure source is on-farm, or nearby the site of application, substituting commercial fertilizer with animal manure may not increase production cost.

Chemical analysis of soil amended with CM and SS revealed a significant increase in organic matter, N, P, and K content, the primary nutrients required to achieve target crop yields [13]. The rapid growth in the poultry industry has resulted in significant manure generation [16]. Poultry litter contains all essential plant nutrients (N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, Mo, and Zn) required for an excellent fertilizer [17]. SS is rich in organic matter, and it acts much like slow-release organic fertilizer that maintains productive soil and stimulates plant growth [18]. The use of CM and SS as soil amendments in land farming provides a useful means of waste recycling. Microorganisms in animal manures break down complex forms of nutrients and facilitate the slow release of N, P, and K from soil organic matter for plant uptake. N fertilizers are used to promote leaf growth [19], while P fertilizers promote growth of the roots, flowers, seeds, and fruits [20]. K fertilizers promote strength of the plant stem, movement of water in the plant xylem, and improve flowering and fruiting [21]. An important quality of N fertilizer is the carbon to nitrogen C: N ratio, the ratio of mass of carbon to mass of nitrogen in fertilizer. C: N ratio (w/w), among other factors, determines how fast the fertilizer decomposes and hence becomes available for the plant [22]. Efficient fertilizers maintain a C: N ratio in the range of 25 - 30. Too high C:N ratio > 25:1 with excess of carbon usually means that fertilizer will decompose slowly. If the C: N ratio is, contrarily, too low with excess of N, it may lead to immobilization of plant nutrients in the soil [23]. Chitin and chitosan have C: N ratio of 6 for fully deacetylated chitosan, to 7 for fully acetylated chitin [4].

The objectives of this study were to: 1) Investigate the impact of soil mixed with chitin CH, biochar Bio (**Figure 1**), sewage sludge SS, chicken manure CM, SS mixed with biochar (SS + Bio), SS mixed with CH (SS + CH), CM mixed with biochar (CM + Bio), CM mixed with CH (CM+CH) on the number and weight of bell pepper and eggplant fruits. 2) Assess the impact of adding soil amendments to native soil on bell pepper and eggplant fruit quality.

2. Materials and Methods

2.1. Field Study

A field study was set up in a randomized complete block design (RCBD) with 27 plots (3 replicates × 9 treatments) for pepper and similar 27 plots established for eggplants. Each plot measured 4 ft. × 5 ft. (121.9 cm × 152.4 cm). Soil treatments included chitin CH, biochar Bio, sewage sludge SS, chicken manure CM, SS mixed with biochar (SS + Bio), SS mixed with CH (SS + CH), CM mixed with biochar

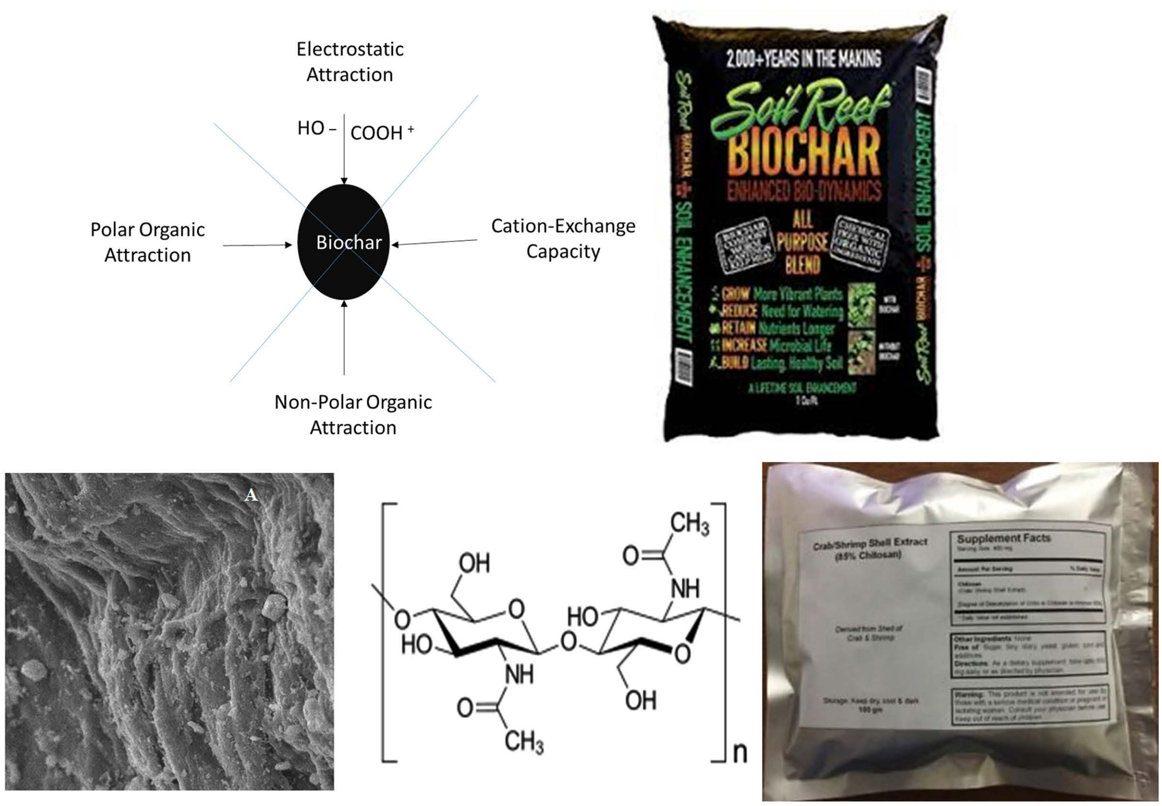


Figure 1. Representation of biochar adsorption active sites for binding organic and inorganic pollutants (upper picture) and micrograph and chemical structure of chitin molecule, showing two of the N-acetylglucosamine units that repeat to form long chains in β-(1 → 4)-linkage (lower picture).

(CM + Bio), CM mixed with CH (CM + CH), and unamended (UN) native soil used as control treatment. Chitin was purchased from OptiVig Company (Titan Biologic, Topanga, CA), and biochar was purchased from Wakefield Agricultural Carbon (Columbia, MO). SS purchased from the Metropolitan Sewer District, Louisville, KY, and CM (1.1 N) obtained from the Department of Animal and Food Sciences, University of Kentucky (Lexington, Kentucky). HM obtained from the Kentucky Horse Park (Lexington, KY, USA). A typical horse weighing 1000 pounds will produce approximately 50 pounds of manure and 10 pounds of urine per day and horses that housed in stalls may generate an additional 20 pounds of bedding material. Kentucky's horse population (approximately 200,000) has the potential of producing about 14 million pounds of waste per day. Each soil amendment used in this investigation was mixed with native soil at the rates described in **Table 1**.

At planting time, each amendment was rototilled with the native topsoil to a depth of 15 cm of topsoil. Seventy-five days old seedlings of bell pepper, *Capsicum annuum* variety Intruder, and eggplant, *Solanum melongena* variety Nadia were planted in a freshly tilled soil at 18 inch (45 cm) in-row spacing and drip irrigated as needed. Weeding and other agricultural operations were carried out regularly as needed. The growing plants were sprayed with the insecticide esfenvalerate (Asana XL) three times during the growing season at seven days intervals at a rate of 5.5 fluid oz acre^{-1} to control flea beetles, Colorado potato beetles, and spider mites [24].

2.2. Green Pepper, Eggplant Yield, and Fruit Quality Characteristics

At each of the six bell pepper harvests (August 19, September 19, 17, 30, October 14, and November 1, 2021), and at eggplant harvests (August 19, September 9, 17, 30, October 14, and November 1, 2021), fruit weights and number of fruits, as well as USDA fruit quality characteristics (Fancy, U.S. No. 1, U.S. No.2, and culls) were recorded. According to the USDA standard fruit grades, U.S. Fancy fruits are well-colored, firm, well-shaped, and free from decay, disease or wormholes.

Table 1. Rate of application used for growing bell pepper and eggplant at Fayette County), Lexington, Kentucky, USA).

Soil Amendment	Rate, g Plot^{-1}	Rate, Kg Acre^{-1}	Rate Kg Hectare^{-1}
Sewage Sludge (SS)	417.31	908.90	2245.94
Chicken Manure (CM)	1891.48	4119.64	10179.85
Biochar (BIO)	226.80	0.227	0.561
Chitin (CH)	226.80	0.227	0.561
SS + CH	417.3 1+ 226.8	908.90 + 0.227	2245.94 + 0.561
SS + BIO	417.31 + 226.80	908.90 + 0.227	2245.94 + 0.561
CM + CH	1891.48 + 226.80	4119.64 + 0.227	10179.85 + 0.561
CM + BIO	1891.48 + 2 26.80	4119.64 + 0.227	10179.85 + 0.561

Soil amendments applied to each treatment and mixed with native soil prior to planting.

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 other damage [25] [26].

2.3. Statistical Analysis

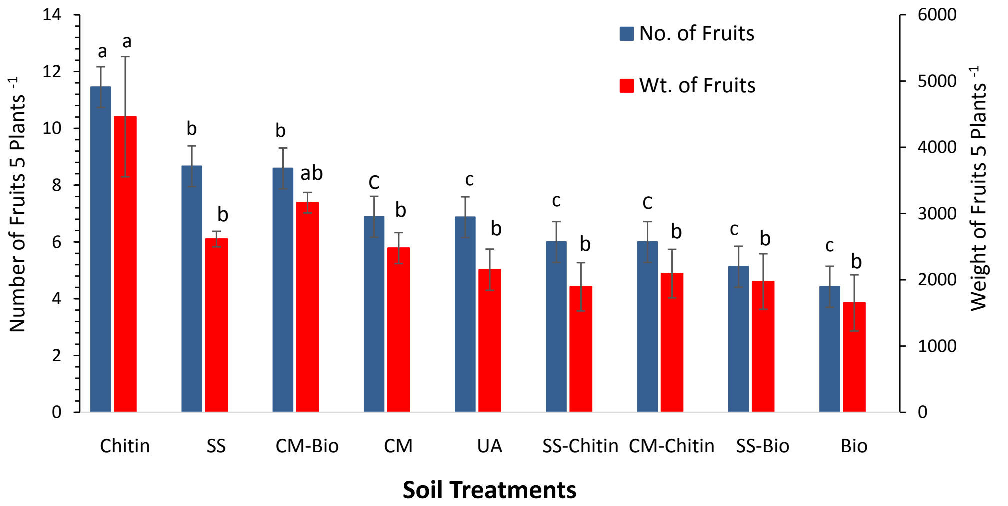
Data containing soil treatments, number of fruits, weight of fruits, and fruit quality characteristics were statistically analyzed using analysis of variance (ANOVA) and the means were compared using Duncan's multiple range test using SAS [27].

3. Results and Discussion

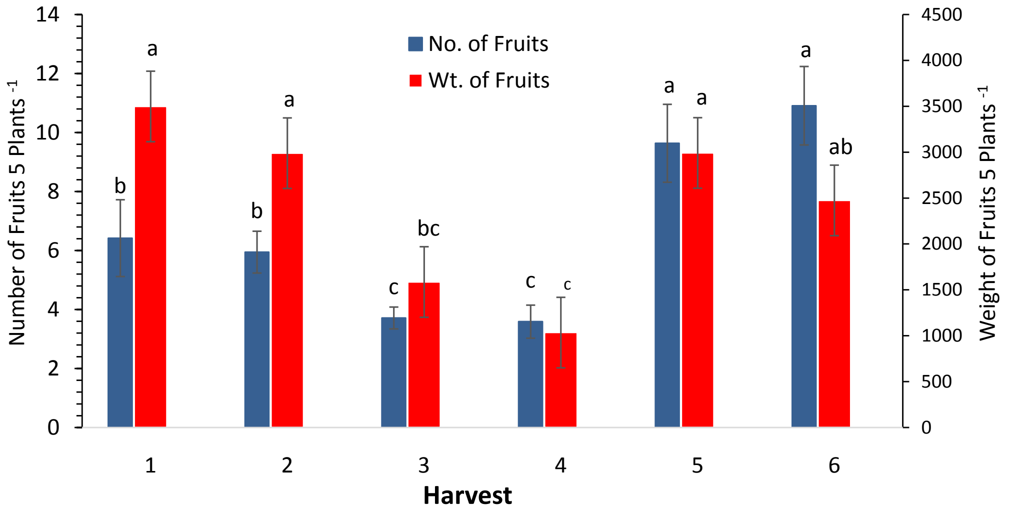
Figure 2 shows the morphological appearance of the high quality "Fancy" fruits of bell pepper, *Capsicum annuum* and eggplant and eggplant, *Solanum melongena* categorized in this investigation. While about 20 Capsicum species are recognized, *Capsicum annuum* is the predominant species cultivated, covering both hot- and sweet-peppers and several hybrids, gaining increasing popularity among consumers and farmers throughout the world. Fancy eggplant and bell pepper fruits are well-colored, firm, well-shaped, and free from decay, disease, or wormholes.

Average weight and number of eggplant fruits of plants grown in soil amended with chitin (4.46 kg and 11.5, respectively) were significantly ($P \le 0.05$) greater than weight and number of fruits obtained from plants grown in other soil treatments, including the control treatment (UA unamended soil) (**Figure 3(A)**). Chitin is a valuable C and N source for soil microorganisms and is a major component of particulate organic matter in agricultural soils [2]. Microbial chitin degradation occurs under both oxic and anoxic environmental conditions that occur simultaneously in soil. Chitin is mineralized within 20 days under oxic

Figure 2. Fruit morphology of bell pepper, *Capsicum annuum* variety Intruder (left photo) and eggplant, *Solanum melongena* variety Nadia (right photo) grown at the University of Kentucky Research Farm (Fayette County, Kentucky, USA).



(A)



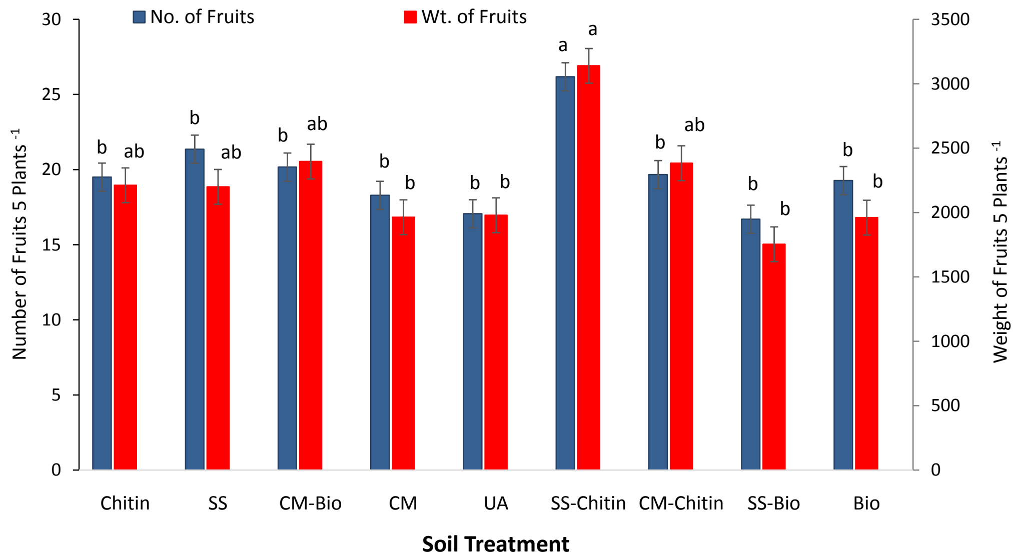
(B)

Figure 3. Number of eggplant fruits and weight of fruits ± std. error of plants grown under nine soil treatments. Chitin, sewage sludge SS, chicken manure mixed with biochar (CM-Bio), chicken manure (CM), unamended (UA) native soil, sewage sludge mixed with chitin (SS-Chitin), sewage sludge mixed with biochar (CM-Bio), and biochar (Bio) (A) and number of eggplant fruits and weight of fruits ± std. error at each harvest (B). Statistical analysis was carried-out using analysis of variance (ANOVA). Values ± std. errors having different letter(s) indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test for mean comparisons (SAS Institute, 2016) [27].

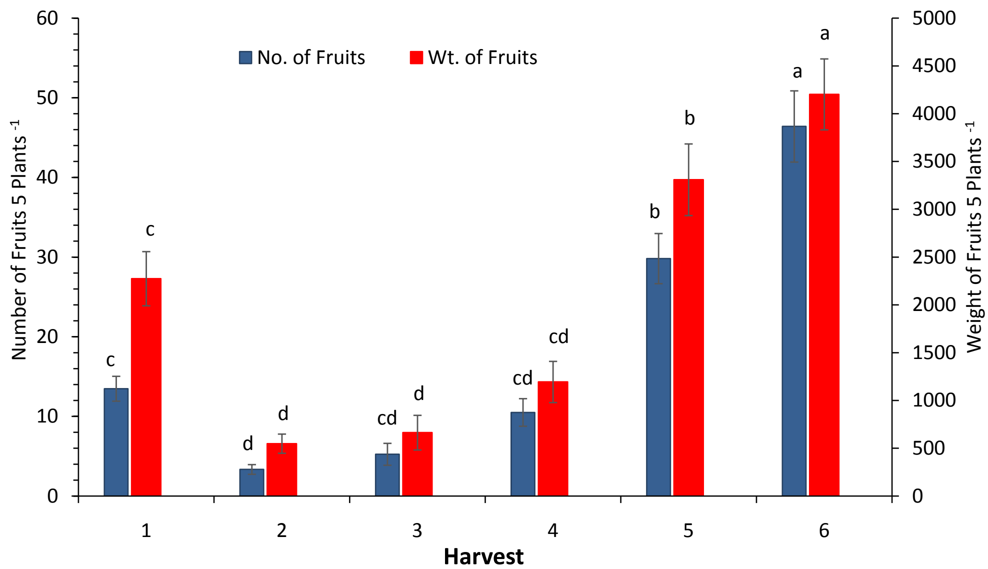
conditions. Figure 3(A) also revealed that adding biochar to CM (CM-Bio) increased number and weight of fruits (8.6 and 3.17 kg, respectively) compared to the CM treatment (6.9 and 2.48 kg, respectively), indicating that biochar was not effective in promoting eggplant fruit number and weight. Whereas biochar addition to SS (SS-Bio) decreased eggplant fruit weight and number compared to SS treatment not amended with biochar. Investigators [28] reported the duality of biochar impact on soil enzymes activity that might influence plants yield. Soil enzymes are very delicate to the environmental stress caused by pH changes and high levels of trace metals in biochar and animal manures. Biochar was not consistent in promoting all enzymes activities [28]. These results confirm the findings of other investigators, who reported that biochar has positive [29] and negative effect [30] on soil enzymes activity that might be due to the different characteristics of each of the amendments, such as variations in absorbing and retaining water molecules that impact microbial secretions. Liu *et al.* [31] reported that the increased concentrations of Cd and Pb have negative impacts on soil microbes, and the effect of Cd on soil urease and hydrolyzing enzymes activity is more than that on invertase, while Pb has more effect on invertase activity than Cd. Cd significantly inhibited alkaline phosphatase activity, whereas Zn inhibited urease activity [32]. It is important to mention that the organic matter loss during biochar preparation through the pyrolysis process contributes to an increase in the concentration of heavy metals in biochar [28]. Results also showed that the addition of chitin to SS (SS-Chitin) or chitin to CM (CM-Chitin) significantly reduced the fruit weight compared to chitin treatments not mixed with SS or CM.

Figure 3(B) revealed that among the eggplant six harvests, fruits collected in harvests 1 and 2 were significantly greater ($P \leq 0.05$) compared to harvests 3 and 4. Whereas, fruit number and weight of harvests 5 and 6 showed greater yield compared to harvests 3 and 4. Peprah [33] presented the relationship between crop yield and weather conditions (temperature, solar radiation, and rainfall events). The author found that when temperature varied naturally or artificially, there was a linear positive correlation between crop yield and solar radiation, as well as linear negative correlation with temperature. Others [34] reported that water stress is one of the major abiotic stresses that directly affects crop growth and influences crop yields. Average number and weight of pepper fruits collected from plants grown in soil amended with SS mixed with chitin (SS + chitin) (26.2 and 3.14 kg, respectively) were significantly greater compared to fruits of plants grown in UA control plots (17.1 and 1.98 kg, respectively (**Figure 4(A)**). Plants grown in soil amended with chitin, SS, CM-Bio, and CM-Chitin had the greater weight of fruits compared to CM, SSBio, Bio, and UA control treatments. Regarding harvest time, **Figure 4(B)** revealed that harvest 6 produced the greatest fruit number and fruit weight (46.4 and 4.20 kg) followed by harvest 5 (29.8 and 3.31 kg) and harvest 1 (13.5 and 2.27 kg, respectively). Results also revealed that pepper fruits collected from harvests 2, 3, and 4 fell significantly compared to all other harvests. This low fruit number and weight may be due to the drought and unfavorable weather conditions during these three harvests.

Regarding fruit quality, the United States Department of Agriculture/Agriculture Research Service (USDA/ARS) grouped eggplant and pepper fruits into grades according to their size, appearance, and quality. This grading system breaks eggplants and pepper fruits into U.S. Fancy, U.S. No. 1, and U.S. No. 2, while fruits that do not fit into these categories (culls) are discarded since they do not



(A)



(B)

Figure 4. Number of pepper fruits and weight of fruits ± std. error of plants grown under nine soil treatments. Chitin, sewage sludge SS, chicken manure mixed with biochar (CM-Bio), chicken manure (CM), unamended (UA) native soil, sewage sludge mixed with chitin (SS-Chitin), sewage sludge mixed with biochar (CM-Bio), and biochar (Bio) (A) and number of pepper fruits and weight of fruits ± std. error at each harvest (B). Statistical analysis was carried-out using analysis of variance (ANOVA). Values ± std. errors having different letter(s) indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test for mean comparisons (SAS Institute, 2016) [27].

fit for any type of this sale. For all grades, fruit size is determined based on minimum qualifications for each specific type of grade. Fruits of eggplant [26] and green pepper [25] must also be at least 90% of the species color. Fancy fruits are mature and not malformed of similar varietal characteristics, firm, well-shaped, and free from damage, caused by insects, disease, weather phenomena, or mechanical injury. US No. 1 fruits consist of mature fruits of similar varietal characteristics, which are firm, fairly well shaped, and free from damage, whether is caused by insects, disease, weather phenomena, or mechanical injury. US No. 2 grades consists of mature fruits of similar varietal characteristics, which are firm, uniform, and not seriously damaged by insects, disease, weather, or mechanical injury [35].

Figure 5 shows the variability among the soil treatments on bell pepper fruit quality characteristics. SS treatment has the lowest weight of fruit culls compared to other treatments. In addition, soil amended with chitin, CM, CM + chitin, SS, and SS + chitin elevated pepper fruit of grade "Fancy" compared fruits obtained from soil amended with biochar. Whereas fruits of US #1 grade collected from soil amended with chitin, CM + Bio, and the unamended soil (the control treatment) were greater compared to all other treatments. Regarding US #2 grades, biochar added to SS (SS + Bio) treatments did not significantly increase number of U.S. No.2 compared to biochar treatment not amended with SS, whereas biochar added to CM amended soil (CM + Bio) and chitin treatments significantly increased bell pepper fruit quality of US #1 compared to biochar treatment not amended with CM.

In fact, the use of soil amendments in commercial agricultural production is an affordable way to elevate crop yield and fruit quality at low cost to limited resource growers. Antonious *et al.* [36] reported that sewage sludge mixed with yard waste provided the highest marketable yield and greatest number of eggplant fruits compared to the no-amended control soil. 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 [12].

Animal manures is rich in N and other minerals that provide the nutrients most used in inorganic fertilizers, such as N and K [37] [38]. N is a main nutrient required to increase plant growth and crop yield [38] [39]. N is responsible for structural functions and participates in various organic compounds that are vital for the plant, such as proteins and amino acids [40]. Amiri *et al.* [41] observed that the eggplant responds up to the dose of 120 kg of N ha^{-1}, while Trani [42] recommended up to 200 kg of N ha^{-1} for cultivation in protected environments. De Souza *et al.* [38] also found that the maximum number of fruits $plant^{-1}$ 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.

Figure 6 revealed that mixing SS with chitin (SS + Chitin) significantly ($P \leq 0.05$) increased the weight of eggplant fruit "Fancy" compared to other soil treatments including the control treatment. Whereas soil amended with chitin alone was effective in producing the greatest US #1 compared to biochar treatment.

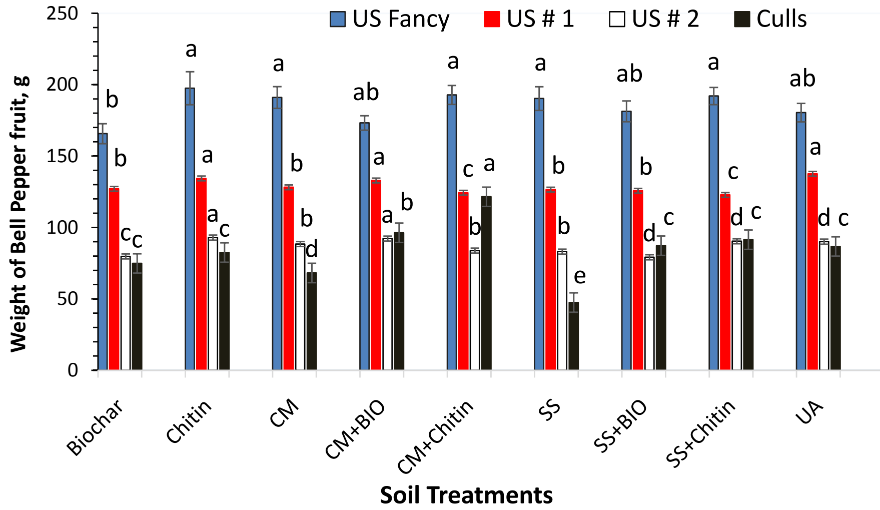


Figure 5. Bell pepper fruit grading based on USDA marketable fruit quality characteristics. Weight of fruit ± std. error of plants grown under nine soil treatments: biochar, chitin, chicken manure CM, CM mixed with biochar (CM + Bio), CM mixed with chitin (CM + Chitin), sewage sludge SS, SS mixed with biochar (SS + Bio), SS mixed with chitin (SS + Chitin), and unamended (UA) control soil. Statistical analysis was carried-out using analysis of variance (ANOVA). Values ± std. errors having different letter(s) indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test for mean comparisons (SAS Institute, 2016) [27].

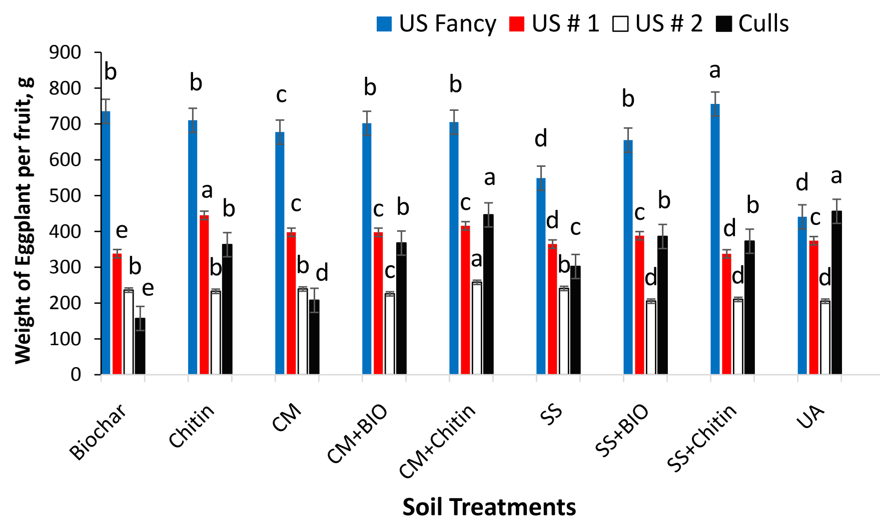


Figure 6. Eggplant fruit grading based on USDA marketable fruit quality characteristics. Weight of fruits ± std. error of plants grown under nine soil treatments: biochar, chitin, chicken manure CM, CM mixed with biochar (CM + Bio), CM mixed with chitin (CM + Chitin), sewage sludge SS, SS mixed with biochar (SS + Bio), SS mixed with chitin (SS + Chitin), and unamended (UA) control soil. Statistical analysis was carried-out using analysis of variance (ANOVA). Values ± std. errors having different letter indicate significant differences ($P \leq 0.05$) using Duncan's multiple range test for mean comparisons (SAS Institute, 2016) [27].

Results also revealed that plants grown in soil amended with CM + Chitin produced the greatest US #2 eggplant fruit. Figure 6 showed that CM + Chitin and

Table 2. Overall Pearson's correlation coefficients (r) * and probability of significance (*P*) between number of fruits and weight of fruits of eggplant (A) and green pepper (B) grown in nine soil treatments.

	A-Eggplant								
Eggplant	Chitin	SS	CM-Bio	UA	CM	SS-Chitin	CM-Chitin	SS-Bio	Bio
Fruit weight	r = −0.887	0.909	0.791	0.822	0.737	0.84	0.948	0.793	0.802
No. of fruits	($P = 0.0003$)	($P = 0.0007$)	($P = 0.002$)	($P \leq 0.0001$)	($P = 0.0005$)	($P = 0.001$)	($P \leq 0.0001$)	($P = 0.0004$)	($P = 0.001$)
	Pearson–Green B-Green Pepper								
Green pepper	Chitin	SS	CM-Bio	UA	CM	SS-Chitin	CM-Chitin	SS-Bio	Bio
Fruit weight	r = 0.976	0.959	0.972	0.977	0.972	0.938	0.929	0.959	0.927
No. of fruits	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)	($P \leq 0.0001$)

SS sewage sludge, CM-Bio chicken manure mixed with biochar, UA unamended soil, CM chicken manure, SS-Chitin sewage sludge mixed with chitin, SS-Bio chicken manure mixed with biochar, and Bio Biochar. *indicates highly positive correlation.

UA treatments produced the highest weight of culls (unmarketable fruits). Eggplant yield of cultivated soil depends significantly on the weather conditions. High temperature and distributed rainfall throughout the vegetation period are favorable conditions for eggplant production [43]. In eggplant commercial production systems, eggplant fruits are harvested and consumed when the fruit immature, prior to seed development [44]. Mature eggplant fruits are unmarketable due to their unpleasant fruit color, texture, sharp and bitter taste induced by the presence of large number of mature seeds. Accordingly, field research to identify the optimum rate of animal manure fertilizer application in agricultural production systems in relation to yield and quality of marketable fruit is needed. Table 2 revealed the high significant positive correlations between number of fruits and weight of fruits of eggplants and green pepper grown in nine soil treatments. These results showed that increasing the fruit weight positively correlated with number of fruits.

4. Conclusions

Eggplant, *Solanum melongena* var. Epic and bell pepper, *Capsicum annuum* variety intruder seedlings planted under field conditions in a raised freshly tilled field plot under nine soil management practices at 18 in. in row spacing. The soil management practices included: chitin CH, biochar Bio, sewage sludge SS, chicken manure CM, SS mixed with biochar (SSBio), SS mixed with CH (SSCH), CM mixed with biochar (CMBio), CM mixed with CH (CMCH), and unamended (UN) native soil used as control treatment. The main objectives were to assess the impact of soil amendments on eggplant and bell pepper yield and fruit quality characteristics established by the USDA fruit marketing. Eggplant and pepper fruits harvested five times during the growing season and graded according to the USDA guidelines into Fancy, U.S. No.1, U.S. No. 2, and culls (unmarketable fruits). Average weight and number of eggplant fruits of plants grown in soil amended with chitin were significantly ($P \leq 0.05$) greater than weight and number of fruits obtained from plants grown in other soil treatments.

The United States Department of Agriculture (USDA) has framed a handy definition of organic farming: "Organic farming is a production system, which avoids or largely excludes the use of synthetically compounded fertilizers, pesticides, growth regulators, and livestock feed additives." The potential health hazard from synthetic pesticide residues and nitrates in food resulting from conventional agriculture is now receiving attention. Unlike conventional agriculture, organic farming has not been blessed with extensive research and development, nor have organic farmers had the back-up of advisory services. Organic farming needs continued research efforts since it is our future agriculture.

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Authors' Contributions

George F. Antonious designed the field study, implemented the laboratory analysis, and wrote the manuscript. Anjan Nepal worked on the field experiments and compiled and graded the six harvests. Anuj Chiluwal participated in reviewing and editing the manuscript.

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Conflicts of Interest

The authors declare that there is no conflict of interest.

References

[1] Anastopoulos, I., Bhatnagar, A., Bikiaris, D.N. and Kyzas, G.Z. (2017) Chitin Adsorbents for Toxic Metals: A Review. *International Journal of Molecular Sciences*, **18**, Article 114. https://doi.org/10.3390/ijms18010114

[2] Wieczorek, A.S., Schmidt, O., Chatzinotas, A., von Bergen, M., Gorissen, A. and Kolb, S. (2019) Ecological Functions of Agricultural Soil Bacteria and Microeukaryotes in Chitin Degradation: A Case Study. *Frontiers in Microbiology*, **10**, Article 1293. https://doi.org/10.3389/fmicb.2019.01293

[3] Revathi, M., Saravanan, R. and Shanmugam, A. (2012) Production and Characterization of Chitinase from *Vibrio* Species, a Head Waste of Shrimp, *Metapenaeus dobsonii* (Miers, 1878) and Chitin of *Sepiella inermis* Orbigny, 1848. *Advances in Bioscience and Biotechnology*, **3**, 392-397. https://doi.org/10.4236/abb.2012.34056

[4] Shamshina, J.L., Oldham, T. and Rogers, R.D. (2019) Applications of Chitin in

Agriculture. In: Grégorio, C. and Eric, L., Eds., *Sustainable Agriculture Reviews* 36, *Chitin and Chitosan*: *Applications in Food*, *Agriculture*, Pharmacy, *Medicine and Wastewater Treatment*, Springer, Cham, 125-146. https://doi.org/10.1007/978-3-030-16581-9_4

[5] Dahiya, N., Tewari, R. and Hoondal, G.S. (2006) Biotechnological Aspects of Chitinolytic Enzymes: A Review. *Applied Microbiology and Biotechnology*, **71**, 773-782. https://doi.org/10.1007/s00253-005-0183-7

[6] Araji, A.A., Abdo, Z.O. and Joyce, P. (2001) Efficient Use of Animal Manure on Cropland—Economic Analysis. *Bioresource Technology*, **79**, 179-191. https://doi.org/10.1016/S0960-8524(01)00042-6

[7] Qian, K., Kumar, A., Zhang, H., Bellmer, D. and Huhnke, R. (2015) Recent Advances in Utilization of Biochar. *Renewable and Sustainable Energy Reviews*, **42**, 1055-1064. https://doi.org/10.1016/j.rser.2014.10.074

[8] Kavitha, B., Reddy, P.V.L., Kim, B., Lee, S.S., Pandey, S.K. and Kim, K.H. (2018) Benefits and Limitations of Biochar Amendment in Agricultural Soils: A Review. *Journal of Environmental Management*, **227**, 146-154. https://doi.org/10.1016/j.jenvman.2018.08.082

[9] Ding, Y., Liu, Y., Liu, S., Huang, X., Li, Z., Tan, X., Zeng, G. and Zhou, L. (2017) Potential Benefits of Biochar in Agricultural Soils: A Review. *Pedosphere*, **27**, 645-661. https://doi.org/10.1016/S1002-0160(17)60375-8

[10] Shaaban, M., Van Zwieten, L., Bashir, S., Younas, A., Núñez-Delgado, A., Chhajro, M.A., Kubar, K.A., Ali, U., Rana, M.S., Mehmood, M.A. and Hu, R. (2018) A Concise Review of Biochar Application to Agricultural Soils to Improve Soil Conditions and Fight Pollution. *Journal of Environmental Management*, **228**, 429-440. https://doi.org/10.1016/j.jenvman.2018.09.006

[11] Alkharabsheh, H.M., Seleiman, M.F., Battaglia, M.L., Shami, A., Jalal, R.S., Alhammad, B.A., Almutairi, K.F. and Al-Saif, A.M. (2021) Biochar and Its Broad Impacts in Soil Quality and Fertility, Nutrient Leaching and Crop Productivity: A Review. *Agronomy*, **11**, Article 993. https://doi.org/10.3390/agronomy11050993

[12] Savci, S. (2012) An Agricultural Pollutant: Chemical Fertilizer. *International Journal of Environmental Science and Development*, **3**, 73-80. https://doi.org/10.7763/IJESD.2012.V3.191

[13] Antonious, G.F. (2016) Chapter 7. Soil Amendments for Agricultural Production. In: Larramendy, M.L. and Soloneski, S., Eds., *Organic Fertilizers—From Basic Concepts to Applied Outcomes*, Intech, Rijeka, Croatia, 158-187. https://doi.org/10.5772/63047

[14] Antonious, G.F. and Snyder, J.C. (2007) Accumulation of Heavy Metals in Plants and Potential Phytoremediation of Lead by Potato, *Solanum tuberosum* L. *Journal of Environmental Science and Health*, *Part A*, **42**, 811-816. https://doi.org/10.1080/10934520701304757

[15] Wanner, U., Fuhr, F. and Burauel, P. (2005) Influence of the Amendment of Corn Straw on the Degradation Behaviour of the Fungicide Dithianon in Soil. *Environmental Pollution*, **133**, 63-70. https://doi.org/10.1016/j.envpol.2004.04.013

[16] Payne, J. and Zhang, H. (2012) Poultry Litter Nutrient Management: A Guide for Producers and Applicators. Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources, Oklahoma State University, Stillwater, OK, Publication # E-1027. http://pods.dasnr.okstate.edu/docushare/dsweb/Get/Document-7962/E-1027.pdf

[17] Subramanian, B. and Gupta, G. (2006) Adsorption of Trace Elements from Poultry Litter by Montmorillonite Clay. *Journal of Hazardous Materials*, **128**, 80-83. https://doi.org/10.1016/j.jhazmat.2005.05.036

[18] Antonious, G.F., Silitonga, M.R., Tsegaye, T., Unrine, J.M., Coolong, T. and Snyder, J.C. (2013) Elevated Concentrations of Trace Elements in Soil do not Necessarily Reflect Metals Available to Plants. *Journal of Environmental Science and Health*, *Part B*, **48**, 219-225. https://doi.org/10.1080/03601234.2013.730340

[19] Liu, C.W., Sung, Y., Chen, B.C. and Lai, H.Y. (2014) Effects of Nitrogen Fertilizers on the Growth and Nitrate Content of Lettuce (*Lactuca sativa* L.). *International Journal of Environmental Research and Public Health*, **11**, 4427-4440. https://doi.org/10.3390/ijerph110404427

[20] Razaq, M., Zhang, P., Shen, H.-L. and Salahuddin (2017) Influence of Nitrogen and Phosphorous on the Growth and Root Morphology of *Acer mono*. *PLOS ONE*, **12**, e0171321. https://doi.org/10.1371/journal.pone.0171321

[21] Barber, S.A., Walker, J.M. and Vasey, E.H. (1963) Mechanisms for Movement of Plant Nutrients from Soil and Fertilizer to Plant Root. *Journal of Agricultural Food Chemistry*, **11**, 204-207. https://doi.org/10.1021/jf60127a017

[22] USDA NRCS (2011) USDA Natural Resources Conservation Service. Carbon to Nitrogen Ratios in Cropping Systems.

[23] Jat, R.A., Wani, S.P. and Sahrawat, K.L. (2012) Chapter Four-Conservation Agriculture in the Semi-Arid Tropics: Prospects and Problems. In: Sparks, D.L., Ed., *Advances in Agronomy*, Elsevier, New York, 191-273. https://doi.org/10.1016/B978-0-12-394278-4.00004-0

[24] Pfeufer, E., Bessin, R., Wright, S. and Strang, J. (2017) 2018-19 Vegetable Production Guide for Commercial Growers. Cooperative Extension Service, University of Kentucky College of Agriculture, Food and Environment, Lexington, KY, 44-48.

[25] United States Department of Agriculture (USDA 2005) United States Standards for Grades of Sweet Peppers. Consumer and Marketing Service, Washington DC. https://www.ams.usda.gov/sites/default/files/media/Sweet_Pepper_Standard%5B1%5D.pdf

[26] United States Department of Agriculture (USDA 2013) United States Standards for Grades of Eggplant. Consumer and Marketing Service, United States Department of Agriculture, Washington DC. https://www.ams.usda.gov/sites/default/files/media/Eggplant_Standard%5B1%5D.pdf

[27] SAS Institute Inc. (2016) SAS/STAT Guide, Version 9.4. Campus Drive, SAS Institute Inc., Cary, NC, 27513.

[28] Antonious, G.F., Turley, E.T., Shrestha D.S. and Dawood, M.H. (2021) Variability of Biochar Performance among Soil Amendments and Enzymes Activity. *International Journal of Applied Agricultural Sciences* (*IJAAS*), **7**, 66-76. https://doi.org/10.11648/j.ijaas.20210701.16

[29] Mierzwa-Hersztek, M., Gondek, K., Klimkowicz-Pawlas, A. and Baran, A. (2017) Effect of Wheat and Miscanthus Straw Biochars on Soil Enzymatic Activity, Ecotoxicity, and Plant Yield. *International Agrophysics*, **31**, 367-375. https://doi.org/10.1515/intag-2016-0063

[30] Ameloot, N., Neve, S.D., Jegajeevagan, K., Yildiz, G., Buchan, D., Funkuin, Y.N., Prins, W., Bouckaert, L. and Sleutel, S. (2013) Short-Term CO_2 and N_2O Emissions and Microbial Properties of Biochar Amended Sandy Loam Soils. *Soil Biology and Biochemistry*, **57**, 401-410. https://doi.org/10.1016/j.soilbio.2012.10.025

[31] Liu, S., Yang, Z., Wang, X., Gao, R. and Liu, X. (2007) Effects of Cd and Pb Pollution on Soil Enzymatic Activities and Soil Microbiota. *Frontiers of Agriculture in China*, **1**, 85-89. https://doi.org/10.1007/s11703-007-0016-9

[32] Antonious, G.F. (2015) Elevating Concentrations of Capsaicin and Dihydrocapsaicin in Hot Peppers Using Recycled Waste. *Journal of Environmental Science and Health*, *Part B*, **50**, 523-532. https://doi.org/10.1080/03601234.2015.1018765

[33] Peprah, K. (2014) Rainfall and Temperature Correlation with Crop Yield: The Case of Asunafo Forest, Ghana. *International Journal of Science and Research* (*IJSR*), **3**, 784-789.

[34] Zhou, W., Guan, K., Peng, B., Shi, J., Jiang, S., Chongya, J., *et al.* (2020) Connections between the Hydrological Cycle and Crop Yield in the Rainfed U.S. Corn Belt. *Journal of Hydrology*, **590**, Article ID: 125398. https://doi.org/10.1016/j.jhydrol.2020.125398

[35] Agricultural Marketing Resource Center (2017) Eggplant. Iowa State University, Ames, IA. https://www.agmrc.org/commodities-products/vegetables/eggplants

[36] Antonious, G.F., Turley, E.T., Sikora, F. and Snyder, J.C. (2008) Heavy Metal Mobility in Runoff Water and Absorption by Eggplant Fruits from Sludge Treated Soil. *Journal of Environmental Science and Health*, *Part B*, **43**, 526-532. https://doi.org/10.1080/03601230802174748

[37] Lopes, L.N., Souza, C.F. and Santoro, B.L. (2010) Utilização da TDR para monitoramento da solução de nitrato de potássioem Latossolo Vermelho-Amarelo. *Engenharia Agrícola*, **30**, 932-947. https://doi.org/10.1590/S0100-69162010000500015

[38] De Souza, A.H.C., Rezende, R., Lorenzoni, M.Z., Seron, C.C., Hachmann, T.L. and Lozano, C.S. (2017) Response of Eggplant Crop Fertigated with Doses of Nitrogen and Potassium. *Revista Brasileira de Engenharia Agrícola e Ambiental*, **21**, 21-26. https://doi.org/10.1590/1807-1929/agriambi.v21n1p21-26

[39] Aminifard, M.H., Aroiee, H., Fatemi, H., Ameri, A. and Karimpour, S. (2010) Responses of Eggplant (*Solanum melongena* L.) to Different Rates of Nitrogen under Field Conditions. *Journal of Central European Agriculture*, **11**, 453-458. https://doi.org/10.5513/JCEA01/11.4.863

[40] Parida, A.K. and Das, A.B. (2005) Salt Tolerance and Salinity Effects on Plants: A Review. *Ecotoxicology and Environmental Safety*, **60**, 324-349. https://doi.org/10.1016/j.ecoenv.2004.06.010

[41] Amiri, E., Gohari, A.A. and Esmailian, Y. (2012) Effect of Irrigation and Nitrogen on Yield, Yield Components and Water Use Efficiency of Eggplant. *African Journal of Biotechnology*, **11**, 3070-3079. https://doi.org/10.5897/AJB11.2450

[42] Trani, P.E. (2014) Calagem e adubação para hortaliças sob cultivo protegido. 1st Edition, Instituto Agronômico, Campinas (SP), 25.

[43] Adamczewska-Sowińska, K., Krygier, M. and Turczuk, J. (2016) The Yield of Eggplant Depending on Climate Conditions and Mulching. *Folia Horticulturae*, **28**, 19-24. https://doi.org/10.1515/fhort-2016-0003

[44] Radicetti, E., Massantini, R., Campiglia, E., Mancinelli, R., Ferri, S. and Moscetti, R. (2016) Yield and Quality of Eggplant (*Solanum melongena* L.) as Affected by Cover Crop Species and Residue Management. *Scientia Horticulturae*, **204**, 161-171. https://doi.org/10.1016/j.scienta.2016.04.005