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# Biochar and Animal Manure Impact on Soil, Crop Yield and Quality

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## Abstract

Four low-cost organic soil amendments (chicken manure, CM; horse manure, HM; yard water, YW; and sewage sludge, SS) that are generated daily in large amounts, and native bare soil were planted with tomato (*Solanum lycopersicum* var. Mountain spring) seedlings of 52 days old in raised black plastic-mulch. Each of the 5 treatments was also mixed with biochar to make a total of 10 treatments in a randomized complete block design (RCBD). Results revealed that total fresh weight of tomato fruits collected after three harvests from CM and CM mixed with biochar significantly ( $P < 0.05$ ) increased, whereas yield obtained from HM was the lowest indicating a positive effect of CM on the growth and yield of tomato. HM increased soil urease activity, while CM and SS increased soil invertase activity. Total marketable tomato yield of biochar amended soils was increased by 63 and 20% in HM and YW treatments, respectively compared to other soil treatments. Ascorbic acid (vitamin C) was greatest in fruits of plants grown in CM amended soil. Results of this investigation may help limited-resource farmers in selecting an affordable soil management practice to enhance crop yield, crop nutritional composition, and soil microbial activity.

**Keywords:** low cost fertilizer, soil amendments, sewage sludge, chicken manure, horse manure, total phenols, vitamin C, soluble sugars

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## 1. Introduction

Recycling animal manure for use as a low-cost organic fertilizer has resulted 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 [1]. Soil organic amendments alleviate OM that improves the properties of soils

through increasing nutrient availability and water holding capacity, total pore space, aggregate stability, erosion resistance, temperature insulation, and decreasing soil density. Antonious [1] reported that sewage sludge (SS) and chicken manure (CM), that must be disposed, are excellent fertilizers.

Tomatoes (*Solanum lycopersicum*, formerly *Lycopersicon esculentum* Mill) belong to the Solanaceae family. Tomato has achieved a remarkable status among other vegetables because of its rich nutritional composition and widespread consumption. It is one of the major vegetable crops grown in almost every country of the world. Fresh tomato fruits contain several nutritional compounds including vitamin C (ascorbic acid) and minerals [2] and have been shown to reduce the risks of cardiovascular diseases and certain types of cancer, such as prostate, lung, and stomach cancers [3]. Accordingly, enhancing the nutritional value of fresh tomatoes and tomato products require frequent investigations to evaluate the influences of agricultural practices, such as the use of fertilizers, organic soil amendments, and the environmental conditions on tomato yield and fruit quality. It was demonstrated that increasing N fertilization under field conditions reduced the fruit vitamin C concentration [4]. This is due to the fact that the high N concentration in the fertilizers favors plant leaf area development, thereby lessening light penetration in the canopy and fruit vitamin C development. Similarly, the negative effects of N application on vitamin C contents occur in other vegetables such as potatoes [5]. The typical taste of tomato is mainly attributed to soluble sugars, organic acids and volatile compounds. Sugars are important macronutrients of the human diet and plants. During tomato ripening total soluble solids (TSS), such as sugars (fructose and glucose) are found to be predominant in domesticated tomato fruits. Tomato possesses a wide range of bioactive compounds as a pool of antioxidants that have positive effects on health, associated with their anti-carcinogenic and antiatherogenic potential [6]. These bioactive compounds include carotenoids (vitamin A), ascorbic acid (vitamin C), phenolic compounds, and tocopherols (Vitamin E), which are at higher concentrations in the skin followed by seed and pulp fractions [7]. In addition, concentrations of bioactive compounds in tomato fruit are significantly influenced by tomato genotype [8, 9], environmental factors and agricultural techniques [10]. Regarding tomato phenolic compounds content, chlorogenic acid and rutin have been found to be the most important flavonoids in tomato. Butta and Spaulding [11] found high concentrations of total phenols in tomato fruits at the early stages of fruit development, then phenols concentration declined rapidly during fruit ripening, although other authors have shown that the content of total phenols remained stable during ripening [12].

The literature review verified the potential of biochar, a product of wood pyrolysis, applications for improving N input in agricultural systems, while indicating the needs for long-term field studies to better understand the effect of biochar on biological N<sub>2</sub> fixation. When biomass, such as wood, manure, or leaves, is heated in a closed container with little or no available air, this process is known as pyrolysis. Research results indicated that the conversion of biomass into biochar can not only result in renewable energy (synthetic gas and bio oil), but also decrease the content of CO<sub>2</sub> in the atmosphere [13]. When biochar was used in column leaching experiments to assess its ability to hold nutrients, results indicated that biochar effectively reduced the total amount of nitrate (NO<sub>3</sub>), ammonium (NH<sub>4</sub>), and phosphate in leachates by 34, 35, and 21%, respectively, relative to native soil alone [14]. The adsorption of N by biochar particles decreases NH<sub>4</sub> and NO<sub>3</sub> loss during composting and after manure applications, providing a mechanism for releasing nitrogen fertilizers in a slow release process [15]. Biochar is a porous and

hygroscopic material in nature. These properties make biochar very effective at retaining water-soluble nutrients and make it an environment for many beneficial soil microorganisms. Studies have shown that foliar N concentrations of crops decreased when biochar was added to soil [16]. Rondon et al. [17] showed the potential of biochar applications for managing N input in agricultural systems, while indicating the requirements for more field studies to provide more explanations and understanding of biochar effects on soil biological N<sub>2</sub> fixation.

Regarding the need for healthy food, the demand for low cholesterol meat products and high protein sources, as well as agricultural production and economic incentive have led to a tremendous expansion in the worldwide poultry industry [18]. Due to the rapid growth in the poultry industry, Chicken manure (CM) generation is currently accessible in increasing quantities, resulting in unplanned disposal to soil with potential negative environmental consequences [19]. Manures, especially poultry litter and feedlot manure, may raise or maintain pH in acidic and near neutral soils via a liming effect because they contain some CaCO<sub>3</sub>, which originates in the animal diet [20]. Animal manures are not just a waste material requiring disposal, but a crucial raw material needed to enhance plant production. If animal manure applied properly, it can replace significant amounts of mineral fertilizers and save energy. Over a billion tons of animal manure is produced annually in the US [21]. Organic animal manure is a rich source of plant nutrients and soil amendment when used at the adequate rate of application. Organic waste is a source of plant macro- and micronutrients, organic matter (OM), recovers soil quality, and increases soil pH in acid soils. However, nutrients, such as P and N build up in the soil if application rates are higher than the nutrient requirements of the intended crops. An increase of organic waste originated from different humans and productive activities is a continuous concern. Waste application to soil is proposed as a solution to disposal problem. This practice is popular in the agricultural fields because of the value of this waste as organic fertilizer.

## 2. Sewage sludge, horse manure, chicken manure, and vermicompost: an overview

### 2.1. Municipal sewage sludge

Municipal sewage sludge (SS), also known as biosolids (**Figure 1**) is derived from wastewater treatment plants in which wastewater, primarily derived from domestic sources or discharges from commercial and industrial enterprises. Most of these enterprises carry out pretreatments prior to discharging wastes into the conventional community sewer system. As a result of pretreatment, total fertilizer nutrient concentration rarely exceeds 10% in most manure sources and frequently is a fraction of that. Commercial fertilizers usually contain about 30% nutrients by weight. Low nutrient concentration increases the time and cost of transportation and land application [22]. Nutrients in most commercial fertilizers are designed to be rapidly available to crops when applied to the soil. Whereas, the organic nitrogen fraction of manure reduces the availability and predictability of the manure as a nitrogen source because the availability of organic nutrients is dependent on soil microbial activity. In addition, the chemistry of manure makes inorganic nitrogen in manure prone to volatilization losses when it is surface applied. Successful use of organic manure fertilizer requires adjusting application rates to account for reduced nutrient availability.



**Figure 1.** Metropolitan wastewater treatment plants in Louisville, Kentucky turned municipal sewage sludge into package of organic fertilizer “Louisville green” available in stores.

Organic manure products sold as commercial crop fertilizers have nutrients concentrations typically vary spatially and over time within the manure storage facilities making it hard to meet fertilizer needs. Accordingly, calculating the recommended rate of organic fertilizer application is a challenge when farmers follow the label instructions. Should farmers apply a rate that on average supplies the target nutrients rate or use a rate of application that insures the entire field gets at least the needed fertilizer rate? The first strategy insures portions of the field will have nutrient deficits, an economic liability to the farmer; the second strategy maximizes yield but also insures that part of the field will have nutrient excess and a water quality liability [22]. Biosolids have become less contaminated with trace metals and organic compounds [23]. In wastewater treatments plants solids are removed during primary and secondary treatment. SS product is usually incinerated, landfilled or further treated. Further treatment may consist of digestion, composting or alkaline stabilization. After treatment, this material is called biosolids. Biosolids contain inorganic materials, plant nutrients, trace elements, and organic compounds.

## 2.2. Chicken manure

Tremendous expansion in the poultry industry occurs worldwide [18]. Due to the fast expansion in the poultry industry, production of poultry manure (**Figure 2**) has increased significantly. Chicken manure (CM), which is the most abundant poultry manure, is a mixture of feces, waste feed, feathers and bedding material, and contains essential plant nutrients making it an organic source of nutrients. For example, N, P, and potash (K) are approximately 8.5% of the weight of poultry litter. Though beneficial as an organic amendment, the huge quantities being produced in poultry farms have resulted in unplanned disposal of this manure to the soil in some cases, where it poses environmental challenges like eutrophication, air pollution, emission of greenhouse gasses and production of phytotoxic substances [19, 24, 25]. On the other hand, animal manure like poultry manure have been found to contain potentially harmful trace elements like arsenic, copper and zinc, which originate from the chemicals used to treat diseases in commercial chicken production [25]. Broiler chicken litter is a source of trace elements that can potentially accumulate in the soil after repeated applications and this is why it is important to test for poultry manure composition before direct application to farm lands. In addition, arsenic (As) which is a severe carcinogenic compound [26] is a feed additive in conventional raised broilers





**Figure 2.** Chicken manure waste turned into package of organic fertilizer available in stores.

used to control protozoan parasites and to enhance poultry weight gain. Despite this, CM can be effective sources of essential plant nutrients such as N and P, and as a source of soil organic carbon. The phytotoxicity in some plants grown in CM amended soils indicated the need for further trials to reduce its toxic impact through composting and/or vermicomposting to improve nutrient content and reduce the phytotoxicity to growing plants [19].

## 2.3. Yard waste compost, vermicompost, and horse manure

### 2.3.1. Yard waste compost

Recycling agricultural waste for use in crop production has become a vital component of organic agriculture. In the US, about 95% of food scraps and 42% of yard waste (**Figure 3A**) are currently used in landfill [27]. There are some concerns about the varying composition of yard waste by region and by season. The Department of Environmental Protection in Pennsylvania [28] estimated that, during the summer, grass clippings constitute up to 50% of municipal waste. In the fall, leaves make up 60–80% of the material in this category. Many communities ban dumping and outdoor burning of plant materials such as leaves and tree branches. Accordingly, composting and mulching have become a management way to recycle yard waste as economical soil amendment to improve garden soils and growing plants.

### 2.3.2. Vermicomposting or worm castings

The interaction of earthworms with microorganisms and other fauna within a decomposer, especially designed for this incubation process, produces a product known as vermicomposting (**Figure 3B**). Vermicomposting accelerates the stabilization of organic matter (OM) and its physical and biochemical properties. Physical participation in degrading organic substrates results in fragmentation, thereby increasing the surface area of action, turnover and soil aeration. The degradation of OM is carried out by enzymatic secretions by microorganisms. This process is enriched by transport of inorganic and organic materials. The benefit of vermicomposting is the recycling of organic wastes, like animal wastes [29, 30], crop residues [31], and industrial wastes [32–35] for use as N fertilizer. Anoop et al. [35] concluded that cow

dung and biogas plant slurry can be used as a raw material in vermicomposting. The NPK elements and C/N ratio of vermicompost revealed its agronomic value as organic soil conditioner. Accordingly, many investigators 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 [35].

### 2.3.3. Horse manure

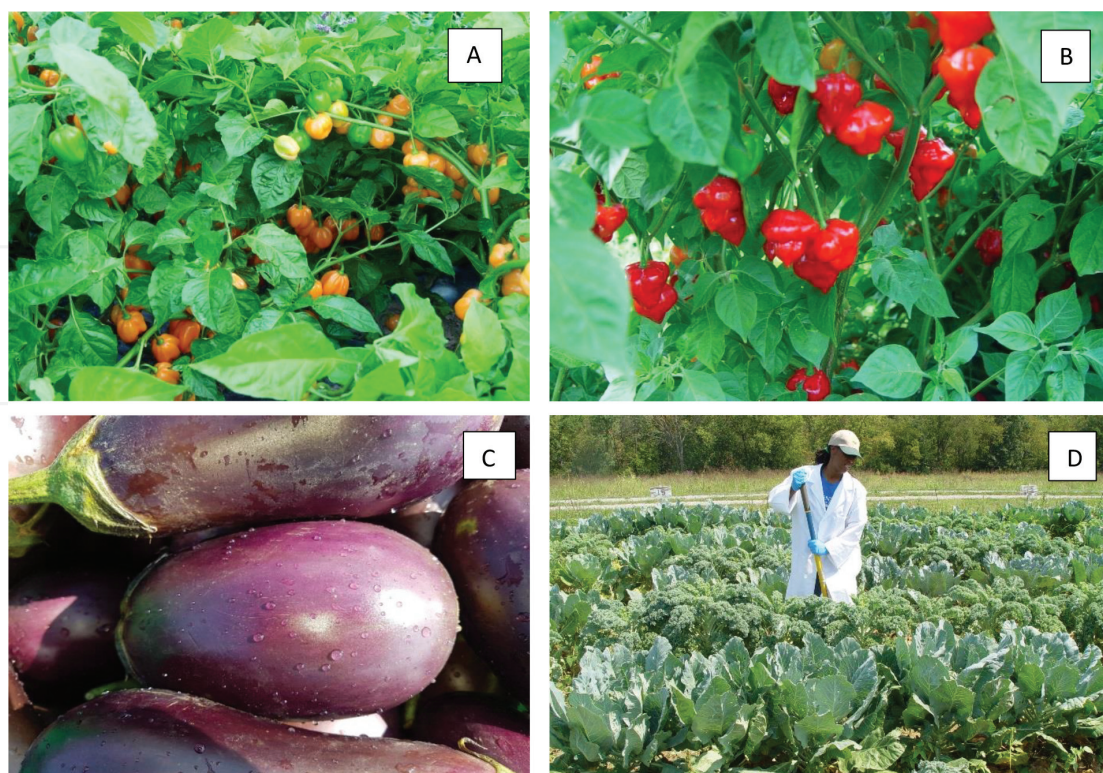
Approximately 75% of horse farms utilize or store horse manure (HM) on-site as grasslands and this is the primary means of disposal [36]. Equine waste produces odors and could contaminate water natural sources via runoff during storage or after land application [37, 38]. Due to the importance of storing waste for potential use in agricultural production systems, an increasing cost is tolerated by the farmer to handle this material for potential use [39]. The disposal of HM (**Figure 3C**) in some Germany regions became increasingly difficult for the owners during the last years due to the lack of arable land and its low fertilizer quality. Additionally, equitation becomes more and more popular in urban areas. This leads to an increase in horse barns and an excess of HM in these regions, which causes a sharp rise in manure removal costs. The composition of HM is dependent on the bedding material and the frequency of stall cleaning. HM is a good source of nitrogen because of its suitable C/N ration that can be also explored for the digestion of nitrogen rich organic waste such as liquid pig manure and poultry manure [40].

**Figure 4** shows some of the crops grown with organic fertilizers. Peppers grown in sewage sludge amended soil (**Figure 4A**), peppers grown in chicken manure amended soil (**Figure 4B**), eggplants grown in horse manure amended soil (**Figure 4C**), kale and collards grown in yard waste amended soil (**Figure 4D**). The increase in crop yield due to incorporation of organic amendments in agricultural production systems reduces the need of synthetic inorganic fertilizers.



**Figure 3.** Yard waste compost (A), vermicompost (B), and horse manure (C) organic fertilizers.



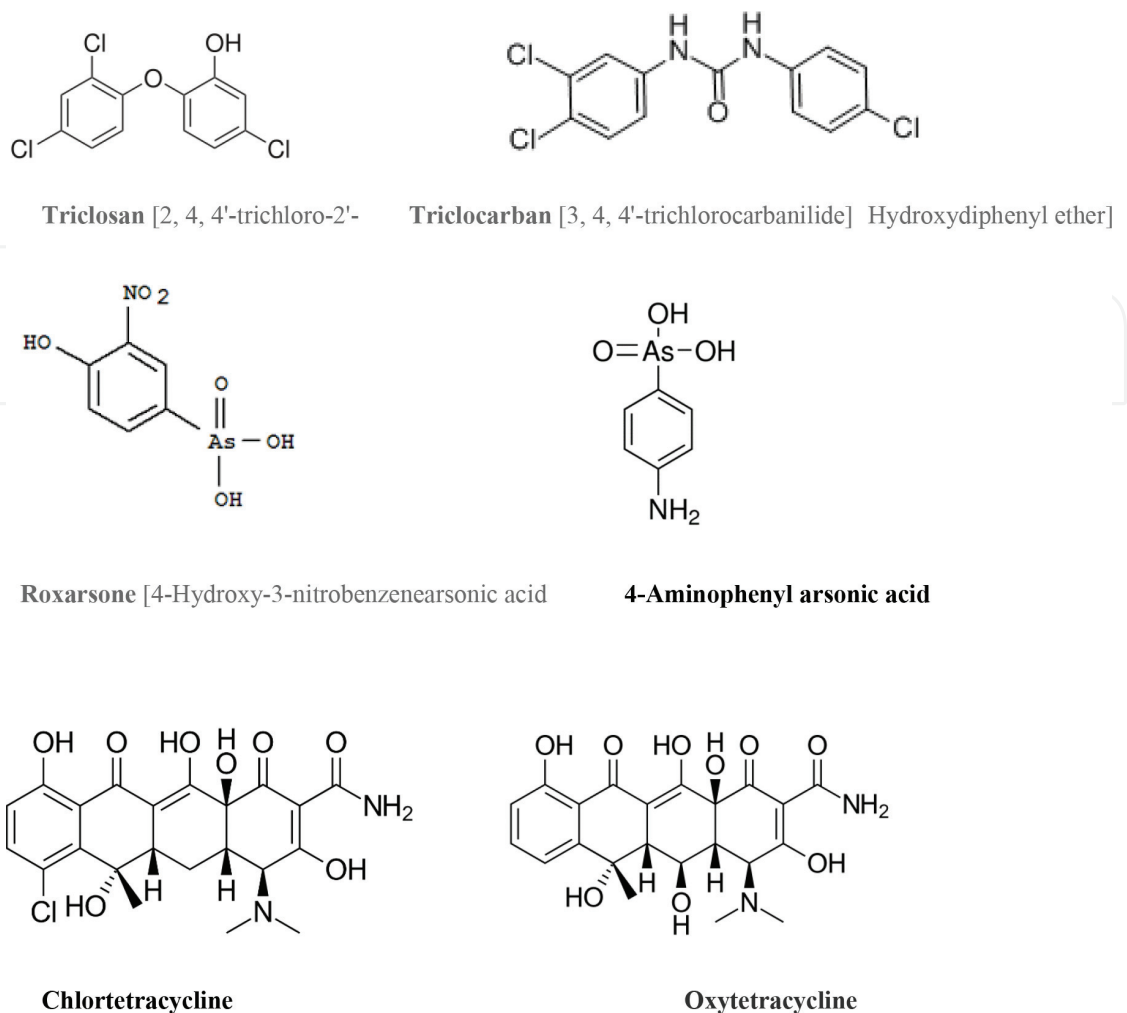


**Figure 4.** Crops grown with animal manure: (peppers (A) grown with sewage sludge; peppers grown with chicken manure (B); eggplants grown with horse manure (C); kale and collards grown in yard waste compost (D) under field condition at Kentucky State University HR Benson Research and Demonstration Farm (Franklin County, Kentucky, USA).

## 2.4. Antibiotics in animal manure

The American Association of Concerned Scientists reported that 11.2–12.8 million kg of antibacterial compounds were used for on-farm animals for medicinal purposes [41] in 1 year alone. Because pharmaceuticals (**Figure 5**) do not metabolize completely in the animal body, they excrete with urine and feces either in their native form or in the form of metabolites [42]. Increased fertilization of farmland with organic fertilizers such as municipal SS, CM, HM and cow manures contribute to the introduction of antibiotics into soil used for growing plants, surface water (through runoff), groundwater (through leaching), and into edible plants or other living organisms through bioaccumulation. These pharmaceuticals can generate a number of negative consequences. Pharmaceuticals in agricultural production systems are one of the emerging contaminants [43]. Among all groups of veterinary pharmaceuticals, antibiotics exert significant influence on soil microorganisms that recycle waste. Once introduced to the soil, they might affect the structure and function of bacterial communities and the development and spread of antibiotic resistance. Numerous studies have documented changes of soil microbial community structure due to exposure to antibiotics in the environment [44]. According to Masse et al. [45], the most persistent groups of pharmaceuticals are tetracyclines ( $TC_S$ ,  $T_{1/2} > 100$  days). The presence and persistence of chlortetracycline, tetracycline, oxytetracycline, and other members of the TCs in animal manures used as organic soil amendment might remain in soils for many years [45, 46], due to their strong sorption to the soil particles. There is a lack of information on the behavior of pharmaceuticals and veterinary medicine in soils and fertilizers used in agricultural production and their potential risk to human health [47].





**Figure 5.** Pharmaceuticals used in animal feeding operations to protect against bacterial and disease infection.

## 2.5. Trace metals in animal manure

Animal manure is a source of valuable plant nutrients, but also a source of air and soil pollution and a threat to aquifers and surface waters unless managed carefully to minimize nutrient loss [48]. In addition, animal manures such as municipal SS is a source of trace metals [49] that might accumulate in edible plants when SS is used as an organic fertilizer and might also contaminate our natural water resources with trace metals. To avoid direct leakage to water abstraction plants or groundwater, manure must not be applied 50 feet (15 m) from potable water wells and 200 feet (60 m) uphill of conduits to groundwater. Furthermore, special care must be taken when applying manure to fields with high leaching potential or within 1000 feet (305 m) of municipal wells [50].

Studies carried out by Gondek et al. [51] revealed that composting of organic materials has a significant effect on changes in mobile forms of heavy metals. The authors found that biochar and municipal SS added to maize straw immobilized Cd and Pb soluble forms due to addition of biochar, whereas maize straw and SS alone did not impact cd and Pb mobility.

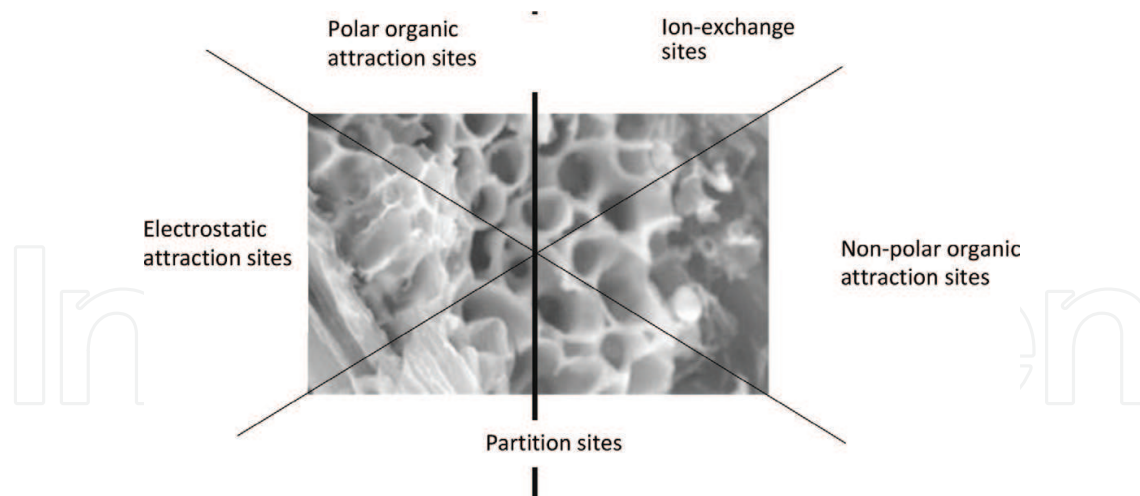
## 2.6. Application of biochar in agricultural production

Currently little information exists in the literature if biochar addition to soil as organic amendment can reduce the plant uptake of trace-elements and reduce toxic metals bioavailability to edible plants. Such practice, if found effective, can assist in management of contaminated agricultural and urban soils from current and past use of municipal SS and might be also useful in mining reclamation. Acidification can affect both the soil biota and biogeochemical processes, thus decreasing agricultural production [52, 53]. Biochar has been reported to modify soil quality characteristics, thereby increasing crop yields [54]. Because it is usually alkaline in nature, biochar can increase the pH of acidic soils [55, 56]. Furthermore, biochar application has also been promoted as a means of contributing to the mitigation of climate change by reducing soil N<sub>2</sub>O emissions [53, 57, 58]. Biochar addition changed soil chemical properties, including increasing soil pH, total nitrogen (TN), total carbon (TC), C/N ratio, and cation-exchange capacity (CEC), and shifted the bacterial community composition. As biochar has been considered unlikely to be used by soil microbes [59], and it cannot directly impact soil microbial community. Therefore, biochar may affect soil microbial community via improving soil chemical properties [53].

When used in acidified soil amelioration, biochar can increase crop yield through improving soil chemical conditions and changing the availability of nutrients. It can also impact soil microbial community by increasing diversity of soil microbes and changing relative abundances of their taxa) via changing soil chemical properties, thus influencing soil nutrient (e.g., C, N) cycling and controlling greenhouse gas emissions. By contrast, biochar can also enhance soil N losses to the atmosphere by stimulating both nitrification and denitrification, thus decreasing the efficiency of N-fertilizer utilization. Therefore, the effect of biochar on the efficiency of N fertilizer should be considered when it is widely recommended as soil amendment [53].

## 2.7. Animal manure and agricultural waste application: An overview

Gómez-Muñoz et al. [60] reported that, when diverse types of urban waste (human urine, sewage sludge, composted household waste) and agricultural wastes (cattle slurry, farmyard manure and deep litter) applied annually for 11 years (at normal and accelerated rates), soil water retention and total carbon improved. Cattle manure, sewage sludge and composted household waste increased soil total N by 13–131% compared to the mineral fertilizer (NPK). The interaction of biochar and compost used in agricultural practices affect each other's properties. Biochar could change the physicochemical properties, microorganisms, degradation, mummification and gas emission of composting, such as the increase of nutrients, cation exchange capacity (CEC), organic matter and microbial activities. Composting and addition of animal manure to biochar could change the characteristic properties of biochar such as its surface polar and non-polar attractions sites, ion-exchange sites, and electrostatic attraction functional groups (**Figure 6**), such as the improvement of nutrients availability, CEC, functional groups on biochar surface and soil organic matter (OM). These changes would potentially improve the efficiency of the biochar and remediation of pollution [61].



**Figure 6.** Schematic diagram of biochar showing its electrostatic attraction sites, ion-exchange sites, polar and non-polar attraction sites collectively known as surface functional groups.

### 3. Experimental studies conducted at the University of Kentucky South Farm (Fayette County, Kentucky)

#### 3.1. Impact of animal manure on tomato yield

Tomato (*Solanum lycopersicum* var. Mountain Spring) seedlings of 52 days old were planted in raised, plastic-mulched, freshly tilled soil at 18 inch in-row spacing. The entire study area contained 30 plots (3 replicates  $\times$  10 treatments). Each treatment was replicated three times in a randomized complete block design (RCBD) with the following treatments: (1) control (NM no-mulch untreated soil); (2) sewage sludge (SS); (3) horse manure (HM); (4) chicken manure (CM); and (5) yard waste compost (YWC). Each of the five treatments was also mixed with 1% (w/w) biochar obtained from Wakefield Agricultural Carbon (Columbia, MO) to make a total of 10 treatments. The soil in six plots was mixed with SS obtained from the Metropolitan Sewer District, Louisville, KY at 5% N on dry weight basis [62, 63]. Six plots were mixed with CM obtained from the Department of Animal and Food Sciences, University of Kentucky, Lexington, Kentucky at 5% N on dry weight basis. The soil in six plots was mixed with HM obtained from the Kentucky horse park, College of Agriculture, University of Kentucky, Lexington, Kentucky at 5% N. The soil in six plots was mixed with YWC at 5% N and the native soils in six plots was used as a no-mulch (NM) control treatment (roto-tilled bare soil) for comparison purposes. Biochar was mixed in three plots in each of the soil amendments, while other three plots in each soil amendment were left without biochar for comparison purposes. Soil amendments were added to native topsoil, mixed, and rototilled to a depth of 15 cm of top soil. The plots were hand transplanted with tomato and irrigated by a uniform drip irrigation system. Fruits were harvested three times during the growing season on August 3, August 19, and September 8, 2016. At each harvest, fruits were collected, weighed and counted. Data were statistically analyzed using ANOVA and the means were compared using Duncan's multiple range test [64].



### 3.1.1. Research findings

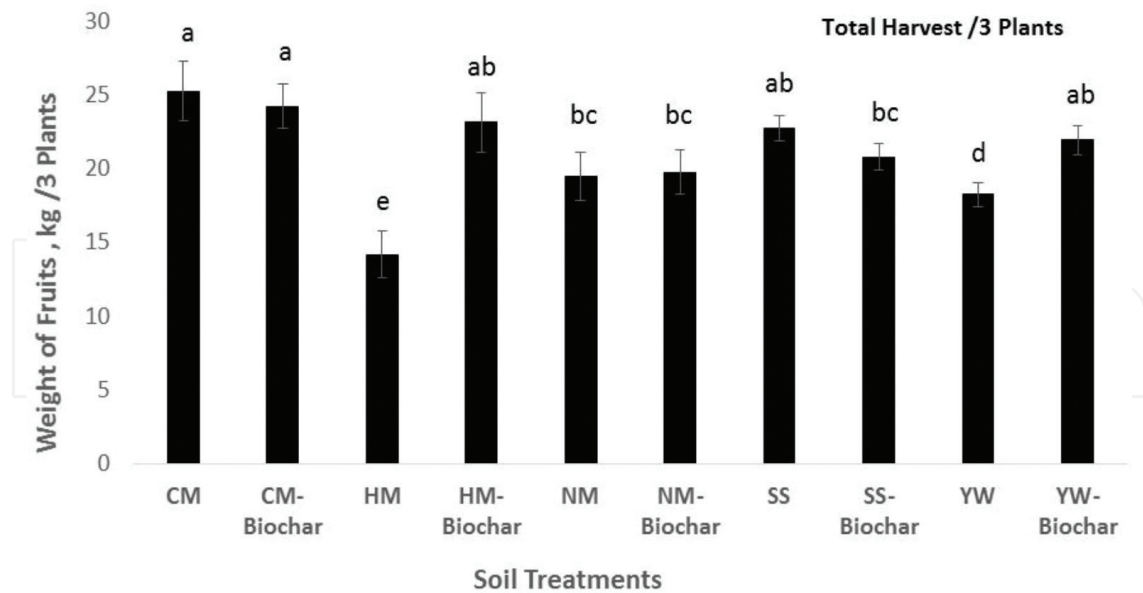
Plants grown in soil fertilized with CM had 8.2, 15.8, and 1.3 kg fruits/3 plants in harvest 1, harvest 2, and harvest 3, respectively (**Table 1**). Whereas, biochar added to CM, HM, and NM native soil did not alter tomato yield in harvest 1 ( $P > 0.05$ ). Accordingly, the synergistic effects of biochar mixed with soil amendments used in this study was not observed after biochar addition in harvest 1. This could be due to the low amount of biochar (1% w/w) used in each treatment. Results of harvest 1 also revealed that the addition of biochar to SS and YW treatments significantly increased fruit yield from 5.2 kg and 3.9 to 6.3 and 5.7 kg/3 plants, respectively, indicating a positive effect of biochar on the growth and yield of tomato grown in SS and YW treatments. In harvest 2, plots fertilized with HM mixed with biochar revealed a significant increase ( $P < 0.05$ ) in tomato yield. Whereas, biochar added to other soil treatments did not promote tomato yield (**Table 1**). In harvest 3, the synergistic effect of biochar was observed in HM and NM native soil (**Table 1**). However, total weight of tomato fruits collected after three harvests presented in **Figure 7** revealed that HM and YW amended with biochar significantly ( $P < 0.05$ ) increased tomato yield compared to other treatments indicating a positive effect on the growth and yield of tomato.

Overall tomato three harvests, the synergistic effects of biochar was only observed in HM and YW amended soils (**Figure 7**). Total marketable tomato yield of biochar amended soils was increased by 63 and 20% in HM and YW treatments, respectively compared to other soil treatments. Regardless of soil treatments, it could be concluded that harvest 2 had the greatest yield and greatest number of fruits compared to the other two harvests (**Figure 8**).

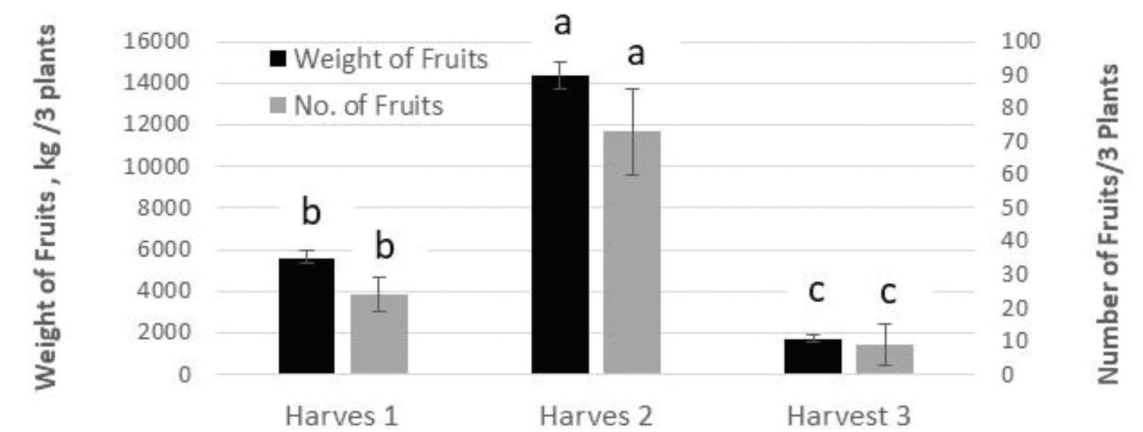
Soil	Weight of fruits, g Plants <sup>-3</sup>		
Treatment	Harvest –1	Harvest –2	Harvest –3
CM	8145.3 ± 413	15806.2 ± 1227	1326.1 ± 354
CM-Biochar	8261.5 ± 218	14761.4 ± 937	1218.6 ± 158
HM	4932.7 ± 356	8423.8 ± 1154	839.7 ± 360
HM-Biochar	4901.9 ± 556	15623.2 ± 1644	2618.7 ± 466
NM	744.7 ± 555	14555.7 ± 597	534.7 ± 353
NM-Biochar	4077.4 ± 94.3	12782.2 ± 939	2913.6 ± 278
SS	5139.1 ± 187	16094.9 ± 566	1505.9 ± 347
SS-Biochar	6287.7 ± 432	13858.8 ± 274	625.2 ± 166
YW	3925.7 ± 96	13636.5 ± 1285	690.4 ± 503
YW-Biochar	5711.9 ± 380	14788.6 ± 1244	1466.6 ± 503

Statistical comparisons were carried out among soil management practices using SAS procedure. Each value is an average of three replicates ± std. error.

**Table 1.** Average weights of tomato fruits collected at three harvests from plants grown under 10 soil management practices at the University of Kentucky South Farm (Fayette County, Kentucky, USA).



**Figure 7.** Total weights of tomato fruits collected from three harvests of tomato plants grown under 10 soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ( $P > 0.05$ ) different. Each value is an average of three replicates  $\pm$  std. error.



**Figure 8.** Overall tomato fruit harvests of three plants grown at the university of Kentucky south farm, regardless of soil treatments. Statistical comparisons were carried out among three harvests using SAS procedure. Values accompanied by the same letter(s) are not significantly ( $P > 0.05$ ) different. Each value is an average of 10 treatments  $\pm$  std. error.

The use of organic wastes is also being encouraged for by different environmental organizations world-wide to preserve the sustainability of agricultural systems [65]. These two authors conducted a greenhouse experiment to assess the effect of CM on soil chemical properties and yield of spinach. They concluded that CM is a potential source of plant nutrients. Their study provided insights to critical threshold values in response to the optimum yield in spinach and uptake of N and P on leaves particularly at high CM application rate. The results indicated an increase in spinach yield as measured in dry matter content. In addition, the use of 15 different amendment combinations that contain equal amounts of carbon (C), were applied through CM compost, charcoal, and forest litter during four cropping cycles with rice and sorghum. The authors reported that CM amendments resulted in the highest ( $P < 0.05$ ) cumulative crop yield

(12.4 Mg ha<sup>-1</sup>) over four seasons. Most importantly, surface soil pH, P, Ca, and Mg were significantly enhanced by CM addition. Antonious et al. [63] also reported that CM enhanced yield and quality of field-grown kale and collard greens. CM is preferred among other animal wastes because of its high concentration of macro-nutrients [66]. Poultry litter is poultry manure mixed with the bedding (wood shavings, rice hulls, etc.) that is scooped up when the houses are cleaned. Chicken litter nutrient composition depends on the technique used for clean-out the house, methods of litter storage, and many other factors, such as storage house air conditions. An average nutrient percentage content of 3-3-2 means that an average ton of poultry litter contains 60 pounds of nitrogen, 60 pounds of phosphate (P<sub>2</sub>O<sub>5</sub>) and 40 pounds of potash (K<sub>2</sub>O) per ton of litter. Poultry litter may contain nearly small amounts of essential elements needed for plant growth and composition. Such as sulfur, but the amounts are usually small. Due to the increased prices of inorganic fertilizers, farmers interest in using poultry litter as organic fertilizer has also risen sharply.

Due to the consumer demand of chicken meat, chicken manure from chicken condensed feeding operations has become available in increasing quantities for utilization in agricultural production systems as organic fertilizer. While the use of organic wastes has been in practice for centuries world-wide and in the recent times, there still exists a need to assess the potential impacts of CM on soil chemical properties and crop yield and in particular evaluating the critical application levels. Moreover, the need and utilization of CM has overtaken the use of other animal manure (e.g., pig manure, horse manure, and cow manure) because of its high content of N, P, and K [67]. Escalating prices of inorganic fertilizers due to the increase in the fuel prices has also prompted the use of CM and other animal manure. Accordingly, knowledge about the environmental problems and adoption of appropriate solutions and practices to enhance and protect soil quality require timely delivery of research and educational technology.

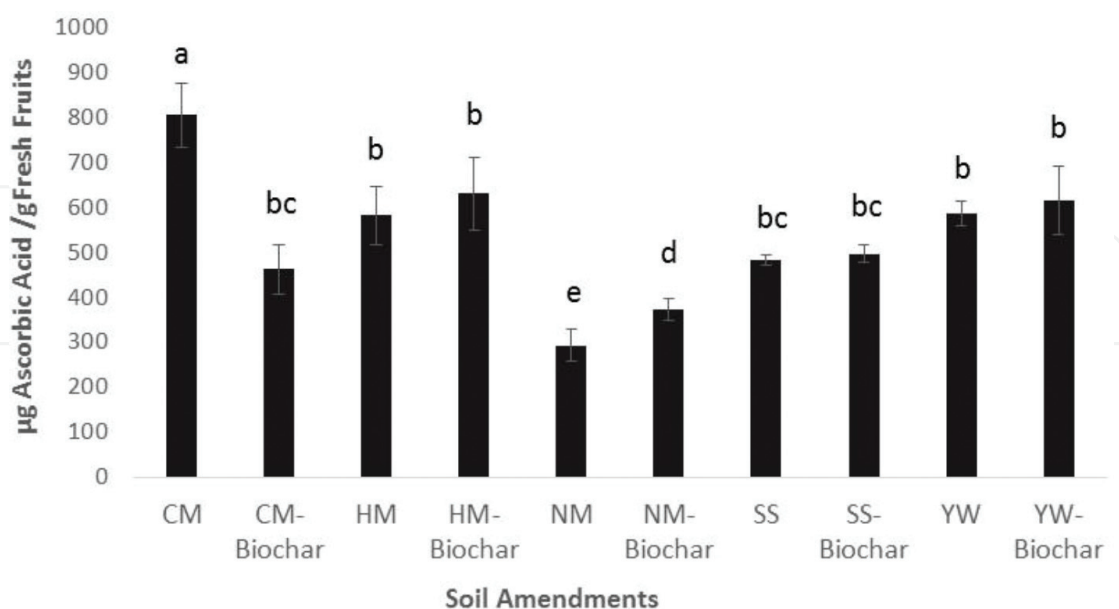
### 3.2. Impact of animal manure on tomato fruit nutritional composition

Fruits and vegetables contain various vitamins and nutrients important for human health. Discovery of phytochemicals with antioxidant properties and their health promoting benefit have paved the way to a food revolution and promising for an age of food with nutritional composition and good health [68]. Tomato (*Solanum lycopersicum*), among antioxidant-rich commodities, has achieved a spectacular status because of its rich composition and widespread consumption. It is one of the major vegetable crops, grown in almost every country of the world. Studies indicated that regular intake of cooked tomato as a part of the vegetable regime appears to be the major nutritional factor accounting for lower risk of prostate cancer, digestive tract cancer and coronary heart diseases in the Mediterranean region. In tomato fruits and most vegetables, ascorbic acid (vitamin C) and phenols that have antioxidant properties protect animals and humans from various diseases. Lycopene, constituting 80–90% of the total carotenoid content present in tomatoes and tomato products, has been believed to contribute to the reduced risks of some types of cancers. Vitamin C (ascorbic acid) in tomato fruits provides about 40% of the required dietary allowance for human health. As a result, enhancing the levels of these healthy chemicals in tomato fruits may form an efficient way to improve

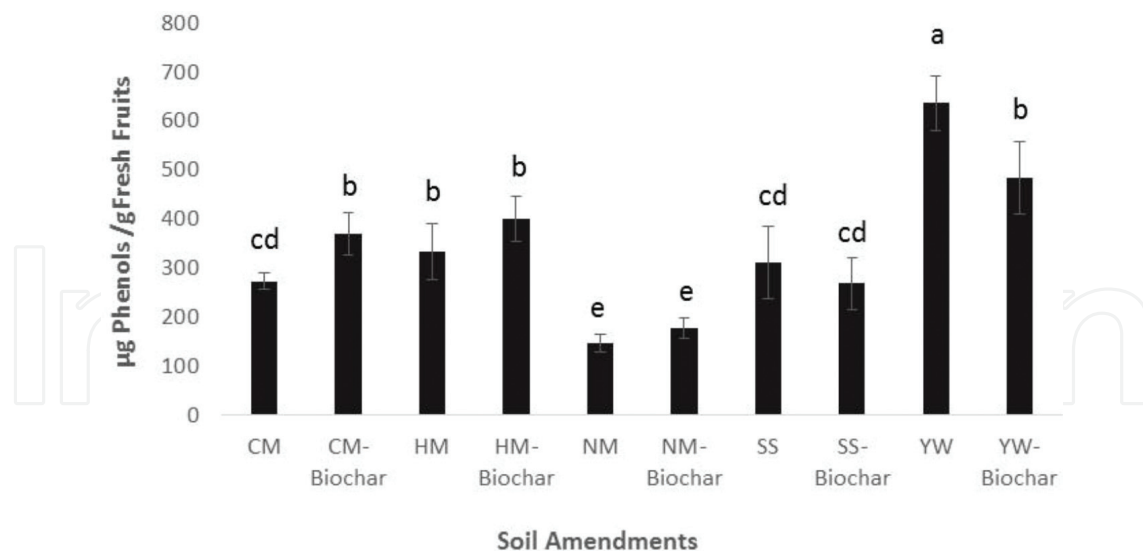


human health conditions. In response to this opportunity, numerous investigations have been conducted to identify the factors influencing the contents of lycopene and vitamin C in tomatoes. The results demonstrated consistent differences in lycopene and vitamin C content between tomato cultivars, which can be magnified by agricultural management. A relationship has been established associating electrical conductivity (EC) and light intensity with lycopene and vitamin C content in tomato fruits. Generally, moderate EC growing conditions enhance tomato health quality; solar radiation is favorable to lycopene and vitamin C accumulation, whereas strongly intense light exposure inhibits lycopene synthesis. Temperatures beyond the optimum temperature range may inhibit lycopene biosynthesis. However, the effects of temperature on vitamin C content are not always conclusive. The effects of nutrients (N, P, K, and Ca) and water availability have also been reviewed, but results are sometimes contradictory. Up-to-date studies dealing with soil amendments and vitamin C, phenols, and sugars contents in tomato fruits are reviewed in this chapter. Previous studies indicated that increasing both P and N application (up to  $140 \text{ kg P ha}^{-1}$  and  $150 \text{ kg N ha}^{-1}$ , respectively) significantly increased the vitamin C content of tomato fruits [10]. Concentrations of vitamin C varied significantly among plant species and among plants grown under different animal manures. Ascorbic acid in tomato fruits (**Figure 9**) was greatest in plants grown in CM amended soils compared to NM un-amended soil.

Tomatoes also contain moderate amounts of water-soluble phenolic, flavonoids (quercetin, kaempferol and naringenin) and the hydrocinnamic acids (caffeic, chlorogenic, ferulic and *p*-coumaric acids), mainly concentrated in skin [69, 70]. Polyphenols are secondary metabolites of plants that contain in their structure the aromatic ring with one or more phenolic groups. Such molecules have great antioxidant potential. The phenolics of tomatoes are found to occur in the skin. Total phenols in tomato fruits of plants grown in amended soils were significantly



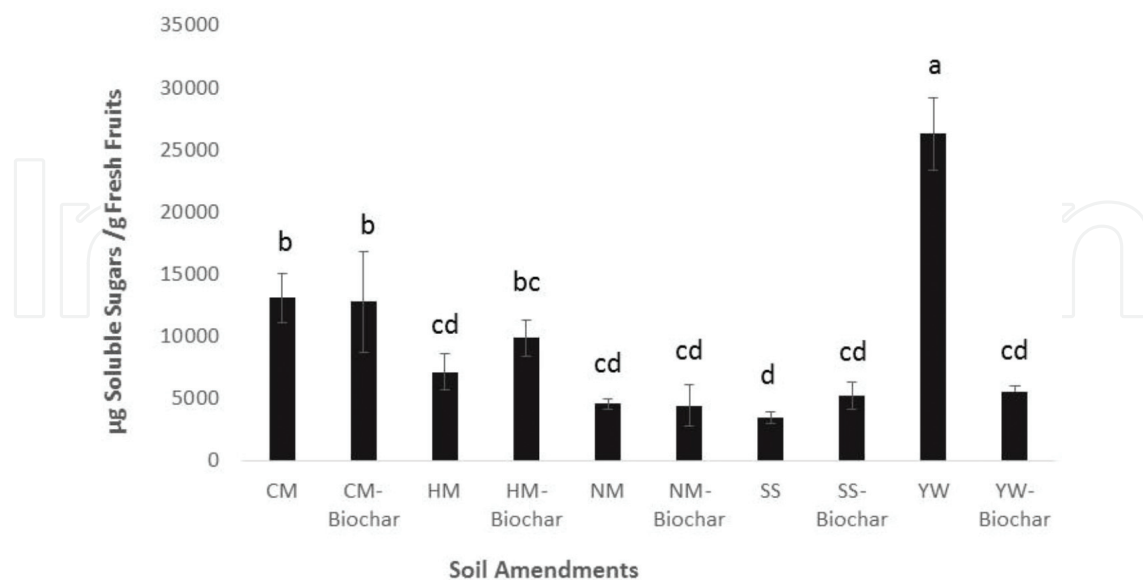
**Figure 9.** Concentrations of ascorbic acid (vitamin C) in tomato fruits of plants grown under different soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ( $P > 0.05$ ) different. Each value is an average of three replicates  $\pm$  std. error.



**Figure 10.** Concentrations of total phenols in tomato fruits of plants grown under different soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ( $P > 0.05$ ) different. Each value is an average of three replicates  $\pm$  std. error.

( $P < 0.05$ ) greater compared to NM un-amended soil (**Figure 10**). Concentration levels of soluble sugars in tomato fruits (**Figure 11**) revealed also that YW compost provided the highest concentrations of total phenols among the other amendments tested.

However, one can ask whether the higher content of vitamin C, phenols, and soluble sugars in plants grown in animal manure treatments is due to higher synthesis of these water soluble compounds by plants grown in organic manure, or due to increased absorption from soil by the plants roots, or these compounds were found in the plants due to their presence in native

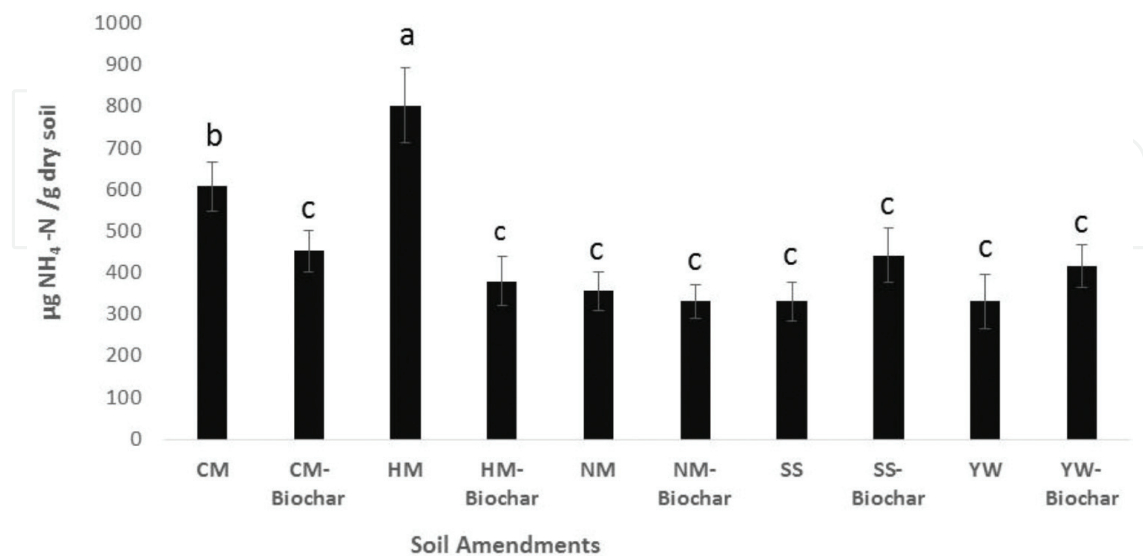


**Figure 11.** Concentrations of soluble sugars in tomato fruits of plants grown under different soil management practices. Statistical comparisons were carried out among soil treatments using SAS procedure. Values accompanied by the same letter(s) are not significantly ( $P > 0.05$ ) different. Each value is an average of three replicates  $\pm$  std. error.

soil (soil origin)? Or this increase might be due to increased soil organic matter and microbial activity. Based on the results in **Figures 9 and 10**, plants grown in NM bare soil (control plants) contained the lowest concentrations of the two phytochemicals (vitamin C and phenols) compared to the plants grown in animal manure amended soils. Therefore, the native soil used in this study is not the source of these three compounds. SS, CM, and HM contain many enzyme substrates such as urea, sucrose, and phosphates compounds that activate soil enzymes, such as urease, invertase, and phosphatase, respectively. Accordingly, the pronounced differences in vitamin C and phenols concentrations found among tomato fruits of plants grown under the different soil amendments tested could be attributed to increased microbial activity and the enzymes they produce. Many reasons have been suggested for this variability, but none of them have been extensively investigated. In either way, the use of animal manure such as municipal waste compost is an economic way to recover nutrients, reduce dependence on inorganic fertilizers, reduce dunghill areas of disposal, and eliminate unpleasant smell [71].

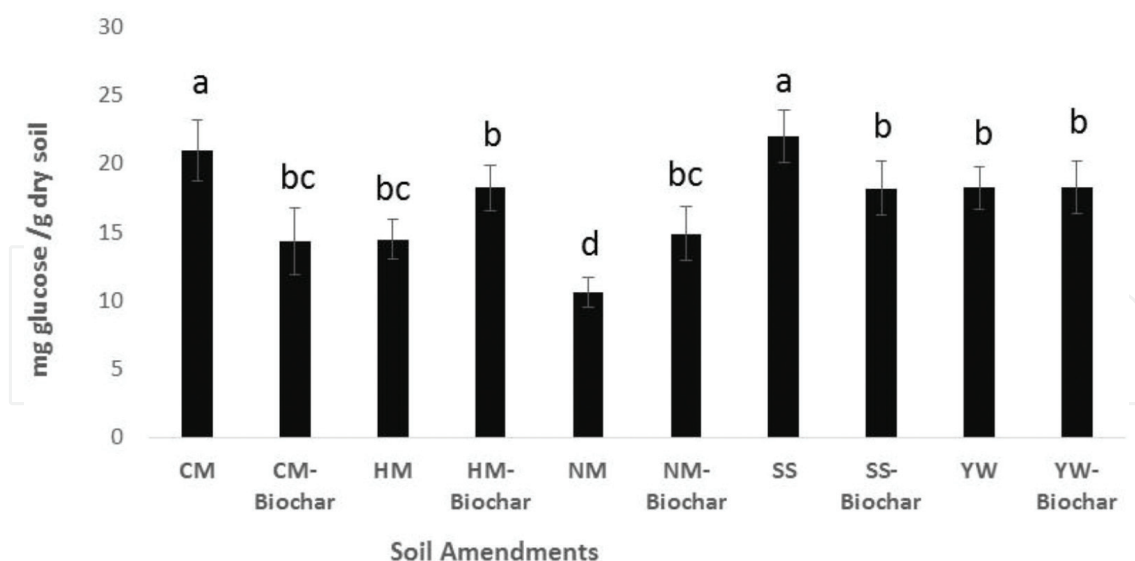
3.3. Impact of agricultural waste on soil enzymes (urease and invertase) activity

Animal manures used as organic soil amendments protect soil microorganisms, soil biological processes, improve soil quality, and increase agricultural productivity [72]. There are three enzymes in soil play a significant role in the N, C, and P cycles. These three enzymes are, urease (urea amidohydrolase, EC 3.5.1.5) is the enzyme that catalyzes the hydrolysis of urea to carbon dioxide (CO<sub>2</sub>) and ammonium (NH<sub>4</sub><sup>+</sup>) ions. Urease breaks-down and converts N from its organic form into inorganic N by hydrolysis of urea or organic forms of N into ammonia. Invertase (β-D-fructofuranosidase) is ubiquitous enzyme in soils. The activity of these two soil enzymes (urease and invertase) in soil is responsible for the release of C and N needed for the growth and proliferation of soil microorganisms and the enzymes they produce. Phosphatases, a group of enzymes that catalyze the hydrolysis of esters and anhydrides of phosphoric acid



**Figure 12.** Urease activity expressed as µg NH<sub>4</sub>-N released g<sup>-1</sup> dry soil. Statistical comparisons were carried out among soil management practices using SAS procedure. Values accompanied by the same letter are not significantly (*P* > 0.05) different. Each value is an average of three replicates ± std. error.





**Figure 13.** Invertase activity expressed as mg glucose released  $\text{g}^{-1}$  dry soil. Statistical comparisons were carried out among soil management practices using SAS procedure. Values accompanied by the same letter(s) are not significantly ( $P > 0.05$ ) different. Each value is an average of three replicates  $\pm$  std. error.

( $\text{H}_3\text{PO}_4$ ), catalyze the hydrolysis of organic phosphate esters to orthophosphate, and thus constitute an important link between biologically unavailable and bioavailable P pools in the soil. Phosphatases are ubiquitous in soil and are produced by microorganisms in response to low levels of inorganic phosphates. Bacteria, fungi, protozoa, and algae secrete soil enzymes such as dehydrogenases, invertase, urease, cellulase, amylases, and phosphatases capable of degrading xenobiotics in soil and water systems improving soil health and plant production.

This investigation revealed that CM and HM increased the activities of soil urease (**Figure 12**), due to the break-down of urea by urease and the release of ammonium ions ( $\text{NH}_4^+-\text{N}$ ). Whereas, CM and SS increased soil invertase activity (**Figure 13**).

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