Chapter 7

Soil Amendments for Agricultural Production

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Additional information is available at the end of the chapter

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Abstract

The word organic, applied to fertilizers, indicates that the nutrients are derived from the remains or by-products of a once-living organism. Farmers are continually searching for alternatives to synthetic inorganic fertilizers to alleviate the escalating production costs associated with the increasing costs of energy and fertilizers and the problems of soil and surface water deterioration associated with intensive use and release of inorganic fertilizers such as N and P fertilizers. One of the advantages of organic fertilizers is that they provide their nutrients especially the principal nutrients (NPK) to growing plants over a long period of time in a slow release process. The soil has to be moist and warm enough to allow soil microorganisms to decompose and breakdown the complex forms of organic fertilizers. Generally, the application of organic amendments to agricultural soils makes good use of natural resources and reduces the need of synthetic inorganic fertilizers. Soil structure, nutrient composition, and microbiological activity of soil are usually increased following the application of organic amendments. This is because of the presence of sugars and amino acids as simple molecules in organic amendments that contribute to microbiological activity and fertility and elevated levels of enzymes secreted by soil microbes. To investigate the soil microbiological activity after the addition of soil amendments, three enzymes that control the C, N, and P cycles should be monitored in the plant rhizosphere zone, which is defined as the zone of increased microbial and enzyme activity where soil and root make contact. An increase of organic waste originated from different humans and productive activities is a continuous concern. Waste application (i.e., municipal sewage sludge, chicken manure, horse manure, and cow manure) 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. At KSU, numerous studies have been conducted on organic soil amendments and their impact on crop yield and quality, soil erosion and nutrient availability, soil enzymes activity, and bioremediation of heavy metals in organic amendments.

Keywords: sewage sludge, chicken manure, horse manure, yard waste, soil enzymes, antibiotics, heavy metals

1. Introduction

Organic fertilizers are derived from municipal sewage sludge (SS), or chicken manure (CM), horse manure (HM), blood and bone meal, and all manures are examples of organic fertilizers. Organic fertilizers also include vegetable matter (i.e., cottonseed meal, vegetable remains, and yard waste compost). There is often low available concentrations of nutrients in organic fertilizers used in agricultural production. However, organic fertilizers have important functions that cannot be gained from synthetic inorganic fertilizers, they increase soil organic matter, improve soil physical structure, enhance soil fungal and bacterial activity, and reduce eutrophication (excess N and P in natural water resources), provide low-cost adsorbents that binds with agricultural contaminants and prevent natural water contamination by pesticides and inorganic fertilizers [1], and hence, reducing the impact of xenobiotics on surface and groundwater quality. In addition, over the last 50 years, the amount of N and P pollution entering our nation's waters has escalated dramatically. Thirty percent of US streams have high levels of N and P contamination and drinking water violations due to nitrates and phosphates that have been doubled in the last 8 years [2] due to over application of inorganic fertilizers. Accordingly, environmentally and economically viable agriculture requires the use of cultivation practices and innovative technologies that maximize agrochemical efficacy while minimizing their side-effects.

Organic farming "farming without chemicals" requires organic fertilizers. While such a definition is concise and clear, it is unfortunately untrue and misses out on several characteristics which are of fundamental importance. All materials, living or dead, contain chemical compounds; therefore, organic farming utilizes chemicals. 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 hazards of pesticide residues, nitrates, and phosphates resulting from conventional agriculture are now receiving attention. There is growing scientific evidence about the positive quality aspects of organically produced food like higher dry matter and vitamin content and improved storage quality. 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 a continued research efforts, and it is agriculture for our future.

2. Justification for using organic amendments in agricultural production

As more municipal sewage sludge (SS) treatment districts turn to composting as a means of sludge stabilization and because of the rapid growth in the poultry industry, significant chicken manure (CM), and municipal SS generation will become available in increasing quantities. Recycling wastes such as SS and CM 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. 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 [3, 4]. Antonious et al. [5–8] reported that SS and CM, that must be disposed, are excellent fertilizers.

Demand for food is ever increasing and much of future plant production systems will depend on fertilizers. In the United States, about 317 million tons of animal manure is produced annually from about 238,000 animal feeding operations [9], and nearly 90% of about 11.4 million tons of poultry litter produced annually is applied as fertilizer [10]. The current rapid growth in the poultry industry has resulted in significant manure generation [11]. Poultry litter contains all essential plant nutrients (N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, Mo, and Zn) and has been documented as an excellent fertilizer [12]. SS is rich in organic matter, and it acts much like slow release organic fertilizer that maintains productive soil and stimulates plant growth [13, 14]. The use of CM and SS as soil amendments in land farming provides a constructive means of waste disposal and a viable method for improving soil fertility and physical properties [14, 15]. Agricultural uses of SS have shown promise for a variety of field crops (e.g., maize, sorghum, and forage grasses) and production of vegetables (e.g., lettuce, cabbage, beans, potatoes, and cucumbers) [3,4]. The literature review revealed that there is lack of information regarding the impact of organic amendments on plants nutritional and antioxidant properties. Investigators have focused on the plant yield and soil physical and chemical properties following the incorporation of soil amendments with very little information on the plant nutritional and antioxidant contents. 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. Vitamin C concentration decreased in the leaves of collard and kale greens grown in no-mulch native soil compared to plants grown in CM and SS amended soil [16].

Addition of organic amendments, such as yard waste compost [17], straw [18], manure [19], tree leaf mulch [20], wood products [21], chipped wood from twigs [22], have been found to increase soil organic matter. The literature review indicated that leaves of collard plants grown in soil amended with SS contained the greatest concentrations of glucosinolates (bioactive compounds) which could play a significant role in sustainable agriculture as alternative organic tools for soil-borne disease management in conventional and organic agriculture [1, 23, 24]. High-quality kale plants (US No. 1) obtained from SS and CM amended soil were also greater compared to no-mulch native soil. In a similar study, total pepper fruit harvest was increased by 15 and 34% after the addition of CM and SS, respectively, to native soil. Whereas the number of cull fruits, the fruits that failed to meet the requirements of the USDA grades, was low in soil amended with yard waste (YW) compared to SS and CM amended soils [25].

3. Organic farming and the market for organically produced food

Consumer concern, over high levels of saturated fats, sugar and salt in food, as well as the risks from food additives and synthetic pesticide residues, has stimulated the demand for healthy food and led to significant changes in the food sector, including the active promotion of additive-free foods. These concerns have contributed to the development of the market for organically produced food that uses organic fertilizers. The development of the market for organically produced food has been largely consumer led. As a result, organic farming became one of the fastest growing segments of US agriculture since 1990s; producers, exports, and retailers are still struggling to meet consumer demand for a wide range of organic products. Organic farming, the use of organic fertilizers and organic pesticides, is increasingly being recognized as a potential solution to many of the policy problems facing agriculture in both developed and developing countries and has become an established part of the farming scene.

During the past 15 years, field studies were conducted at Kentucky State University (KSU) Research Farm (Franklin County, KY, USA) on a Lowell silty-loam soil (2.2% organic matter, pH 6.7) to study the impact of manure (SS and CM) and YW on chemical composition of treated crops, crop yield, and quality. Eighteen (18) standard plots 22 × 3.7 m each were established, and the field study area was a randomized complete block design with three replicates for each of the three tested soil management practices tested (SS, CM, and no-mulch treatments). The soil in six plots in this design was mixed with SS from the Metropolitan Sewer District, Louisville, KY (**Figure 1**) at 15 t acre^{-1} on dry weight basis.

Figure 1. Sewage sludge granules obtained from the Metropolitan Sewer District, Louisville, KY, USA.

Six plots were mixed with CM obtained from the Department of Animal and Food Sciences (**Figure 2**), University of Kentucky, Lexington, Kentucky, at 15 t acre^{-1} on dry weight basis, and

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six plots were used for comparison purposes. The plots were transplanted with collard seedlings (*Brassica oleracea* cv. Top Bunch) of 45 days old. Results revealed that soil incorporated with SS increased soil myrosinase activity compared to soil incorporated with CM and no-mulch native soil. Across all treatments, SS and CM increased soil organic matter content from 2.2% in native soil to 4.2 and 6.5%, respectively. The greater soil urease and invertase activities in soil amended with SS provided evidence of increased soil microbial population (data not shown).

Figure 2. Chicken manure obtained from the Department of Animal and Food Sciences, University of Kentucky, Lexington, Kentucky, USA.

In summer 2015, a field trial was conducted at the University of Kentucky South Farm (Lexington, KY). Arugula (*Eruca sativa*) and mustard (*Brassica juncea*) were grown in 30' × 144' beds of freshly tilled soil. Each bed, measuring 12' × 30', was divided into three replicates in a randomized complete block design (RCBD) with four soil treatments. The entire study area contained 24 plots (2 crops × 3 replicates × 4 treatments). The treatments were (1) SS amended with soil, (2) CM amended with soil, (3) horse manure (HM, **Figure 3**) amended with soil, each at 15 t acre^{-1}, and (4) no-mulch bare soil used for comparison purposes. The results in **Table 1** revealed that soil amended with SS increased plant biomass production in arugula and mustard by 26 and 21%, respectively, compared to no-mulch (NM) native bare soil [24].

Figure 3. Horse manure obtained from Kentucky horse park, College of Agriculture, University of Kentucky, Lexington, Kentucky, USA.

Soil amendment	Root weight, g	Shoot weight, g	Plant weight, g
Arugula			
SS	74.24 a	290.95 a	365.20 a
HM	54.00 b	247.21 b	301.21 b
CM	41.64 c	235.60 c	277.23 c
NM	30.08 c	240.45 c	270.54 c
Mustard			
SS	61.43 b	426.60 a	488.00 a

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Soil amendment	Root weight, g	Shoot weight, g	Plant weight, g
HM	67.21 b	393.10 b	460.30 b
CM	75.87 a	307.40 d	383.30 c
NM	44.24 c	341.90 c	386.20 c

Statistical comparisons were carried out among soil amendments for each parameter tested.
Each value is an average of three replicates.

Table 1. Mean weights of arugula and mustard plants grown under four soil management practices.

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. Attempts to improve the efficiency of biofumigation have focused on selection of biofumigant crops with high glucosinolates (GSLs) content [26]. The use of soil amendments might reduce the biomass needed to produce significant concentrations of isothiocyanate (ITCs) generating GSLs in Brassica plants for greater biofumigant potential. Soil-borne organisms are becoming more difficult to control due to pathogen resistance and restricted use of some pesticides. Brassica species produce a significant amount of GSLs in their tissue. When GSLs are hydrolyzed by the enzyme myrosinase which is also present in the Brassica plant tissues, a range of products are produced which include the volatile biocidal ITCs that is similar to the active ingredient in the nematicide, metam sodium (Vapam). New soil management practices are needed to develop and expand our knowledge and technical means of agricultural production systems related to GSLs and plant protection. The problems of soil deterioration and erosion associated with intensive farming systems and the use of synthetic pesticides have generated considerable interest in less expensive and more environmentally compatible production alternatives such as recycling wastes from several processing operations for use as fertilizers in land farming to provide high-quality organic amendments. Approximately 41,511 water body impairments across the US are attributed to synthetic pesticides and of that total 1300 water body impairments are only from the state of Kentucky [27]. Brassica plants (such as mustard and arugula) have been shown to release biotoxic compounds (GSLs) or metabolic by-products against bacteria, fungi, insects, nematodes, and weeds. When plants containing GSLs are physically disrupted, the hydrolytic enzyme myrosinase is released from ruptured cells, hydrolyzing GSLs primarily to ITCs, glucose, and nitrile products. Incorporation of allelopathic Brassica tissues, such as mustard and arugula, into soil suppresses soil-borne pests due to the biofumigant properties of the highly toxic ITCs, and moderately toxic non-glucosinolate S-containing compounds [28]. ITCs, physiologically active compounds, are the major products of hydrolysis of GSLs that are released when myrosinase (thioglucosidase), a degradative enzyme, comes into contact with GSLs in plant damaged tissues. This technology could be explored in organic agriculture as alternative to synthetic fungicides.

4. Vermicomposting

In agricultural practices, vermicomposting is the product or process of composting worms, usually red wigglers, white worms, and other earthworms such as *Eudrilus eugeniae* to create a heterogeneous mixture of decomposing vegetable or food waste and animal bedding materials to promote biotransformation of organic waste into organic fertilizer and contribute to sustainable agricultural practices. Researchers, government agencies, and farmers are seeking new ways to manage and utilize agricultural wastes to beneficial use. This way of environmental management could be used as a green technology to bio-covert plant residues or animal manure residues into nutrient rich in organic fertilizers [29]. Many factors such as available moisture, particle size, and organic content contribute to the growth of earthworms [30]. Earthworms might lose weight and die if they are fed with materials such as rice residues that are rich in lignin, even if the substrate is fortified with nitrogen-rich amendments to decrease the initial C/N ratio [31]. According to Edwards [32], the basic principle in earthworm breeding systems is to regularly add small batches of wastes in the composting chamber to allow worms to process successive layers of waste.

Data revealed that earthworm growth was lower in treatments that contained high percentages of cow dung (CD). Results also showed that *E. eugeniae* growth was reduced when the proportion of CD in feed substances was increased. This could be due to the earthworm preference of feed substances that may favor rice straw (RS) than CD, and possibly due to inadequate control of ammonia volatilization, resulting from inadequate pre-treatment of cow manure to remove urea present in the initial material. Similarly, Chan and Griffiths [33] found that earthworms feed that contained untreated pig manure killed the worms within few hours. This is because of the high sensitivity of earthworms to ammonia and presence of high concentrations of cations in livestock manure. Accordingly, availability of pre-treated cow manure could be used to enhance the reproduction and growth of *E. eugeniae* for use in composting and organic agricultural production.

5. Soil organic carbon and nutritional composition of crops grown in organic vs. conventional fertilized soil

Soil carbon includes both inorganic carbon as carbonate minerals, and organic carbon as soil organic matter. Carbon sequestration is the long-term storage of carbon in oceans, soils, vegetation (especially forests), and geologic formations. Soil carbon sequestration is a process in which CO_2 is removed from the atmosphere and stored in the soil carbon pool. About 35% of CO_2 anthropogenic emissions are related to changes in land use [34]. Methane (CH_4) and nitrous oxide (N_2O) are usually found in the atmosphere at much lower concentrations than CO_2. However, these two gases are the big contributors to the greenhouse effect, which is 298 times greater for N_2O and 25 times greater for CH_4 [35]. Carbon binds to minerals in soil that are just a few thousandths of a millimeter in size, and it accumulates there almost exclusively on rough and angular surfaces [36]. The rough mineral surfaces provide an attractive habitat for microbes that convert the carbon and play a part in binding it to minerals.

Organic wastes are usually rich in carbon and nitrogen, and their addition increases the soil content of labile carbon, accelerates the activity of soil microbes, and increases nitrification and denitrification rates. CO_2 emissions from the soil are the result of a combination of heterotrophic and autotrophic respiration, and both processes could have been stimulated by the addition of organic compost [37]. Increases in soil CO_2 fluxes in agricultural soils after the disposal of organic wastes are frequently observed [37–39]. De Urzedo et al. [40] reported that the application of organic wastes increased CO_2 emissions in the soil, as has been observed in other studies, possibly reflecting the supply of labile C to soil microorganisms, raising the microbial activity and consequently increasing the rate of soil respiration [39]. Cheng et al. [41] studied the impact of fertilizer type (organic or inorganic) on N, P, and K concentrations in runoff water from agricultural field. Although the N, P, and K loss in runoff were low, their concentrations were significantly higher from inorganic fertilizer (Scott's Turf Builder®) obtained from the Scotts Company LLC, Marysville, OH, USA, applied at the manufacturer's recommended rate of 57 kg $acre^{-1}$ than those treated with organic fertilizer (Nature's Touch® containing enzymes) obtained from Garden Way LLC, Cleveland, OH, USA, and applied at the manufacture's recommended rate of 79 kg $acre^{-1}$.

Organic systems eliminate synthetic agrochemicals and reduce external inputs to protect and improve environmental quality. The perception among organic food consumers is that organically produced crops possess higher nutritional composition. In fact, the comparisons between organically and conventionally grown crops are not experimentally valid due to the variation in crop varieties, timing in fertilization, and handling and storage after harvesting. Investigators are not in complete agreement about the nutritional composition of crops grown in organic vs. conventional fertilized soils. Some investigators found that fruits of organic crops contain more minerals and vitamins than conventional crops [42, 43]. Worthington [44] compared the nutritional quality of organic vs. conventional crops and concluded that organic crops have significantly greater levels of iron, magnesium, and phosphorus. Whereas several other authors have concluded that very few compositional differences exist, although there are reasonably consistent findings for higher nitrate contents in conventionally produced vegetables [42, 45, 46]. Another investigation found higher nitrate concentrations in organically grown compared to conventionally grown crops [47]. In organic grown carrot, lettuce, and potato, Hoefkens et al. [48] reported that they contained lower nitrate concentrations compared to the higher nitrate levels in organic spinach. The low concentration of nitrate in edible plants has many advantages for human health. This is because high concentrations of nitrate in edible plants may cause many health problems in humans, such as methemoglobinemia (a blood disorder in which an abnormal amount of methemoglobin, a form of hemoglobin is produced), and can cause some types of cancer [49]. Johansson et al. [50] assessed organically and conventionally grown tomatoes for a variety of different attributes. They found no differences in acidity, sweetness, and bitterness, but did find that organic tomatoes were less firm, less juicy, and redder. Hallmann and Rembiałkowska [51] found that bell pepper fruits of plants grown in organic agriculture have significant concentrations of vitamin c, α-carotene, cis-β-carotene, total carotenoids, and total phenolic acids, such as chlorogenic acid and flavonoids, such as quercetin D-glucoside, quercetin, and kaempferol, compared to fruits of plants grown under conventional agricultural practices.

Nitrogen (N) is a nutrient element that plants require in amounts larger than that of any other soil supplied element. Most plants can utilize both NH_4^+ and NO_3^-; however, NH_4^+ at high concentration can be toxic to plants [52]. NH_4^+ as a sole source of N can result in a variety of negative effects to most plant species. The negative effects include a reduced plant photosynthetic rate, lower dry weights, reduced root growth, and a reduced rate of water uptake [52–54]. However, plants differ in their sensitivity to NH_4^+ toxicity. Onion, a member of the Amaryllidaceae Family, is known to be fairly tolerant to high concentrations of NH_4^+ [54, 55]. On the contrary, Hippeastrum, a member of the Amaryllidaceae, suffered reduced bulb size when fertilized with NH_4^+ as the sole source of N [56]. Shoot and roots of ornamental shrub, "*Doublefile viburnums*" (*Viburnum plicatum* var. *tomentosum*) contained lower NH_4 (ammonium) concentrations when NH_4 was supplied alone compared to NH_4 supplied with NO_3 (nitrate) or a combination of NH_4 and NO_3 [57]. Al-Ghamidi et al. [58] found that date palm seedlings grown in a soilless hydroponic media had the greatest leaf area and root weight when NO_3 was used as the sole nitrogen (N) source whereas date palm seedlings had a lower root: shoot ratio when NH_4- or urea-N were used as N source [58].

Addition of organic matter could affect the adsorption, movement, and biodegradation of pesticides. The addition of organic waste, specifically to agricultural soils, is a practice that has been carried out for centuries, due to its fertilizer properties and contribution to the physico-chemical and biological properties of the soil [59, 60], which is a common agricultural practice in diverse countries [61–63]. Addition of organic waste to soil contributes to the enhancement of active humified components, such as humic acid (HA) and fulvic acid (FA) [64], which exert an important role in geochemical processes as sources of nutrients for plants and microorganisms, in acid–base buffering capacity of soils, and promoting a good soil structure, thereby improving aeration and moisture retention [65, 66]. In agronomic aspects, addition of organic waste enhances biological activity and fertility, because through this addition, nutrients and diverse groups of microorganisms, such as bacteria, fungi, and actinomycetes [67–71] play an important role in the fate of xenobiotic compounds such as heavy metals, aromatic hydrocarbons, and pesticides [72–76].

Some organic wastes are associated with inorganic and organic toxic compounds, such as heavy metals and pesticides [60, 72, 73, 77], that when incorporated into soil, constituting a pollution problem in soils and therefore causing toxic effects on microorganisms and crops [77, 78]. Excessive concentrations of heavy metals in soil can be toxic to microorganisms [79]. On the other hand, soil microorganisms need heavy metals for their growth and activity. Elevated concentrations of heavy metals in soil have shown a reduction in the activity of enzymes secreted by beneficial soil microorganisms. SS contains heavy metals, and the release of these metals into the soil solution and uptake by plants growing in soil amended with SS could be phytotoxic.

The efficiency of some pesticides and their persistence and potential as environmental contaminants depends on their retention and degradation on soil constituents [80]. The OM in soil amendments is reported as a major controller component in the sorption, transformation, and transport of many organic pollutants in soil [81]. Soil amendments could be used to intercept pesticide-contaminated runoff from agricultural fields, and this practice might provide a potential solution to pesticide contamination of surface and seepage water from farmlands. Residues of two of the herbicides commonly used in agriculture, DCPA [1,4-

Benzenedicarboxylic acid, 2, 3, 5, 6-tetrachloro-, dimethyl] ester, and metribuzin [4-amino-6-tert-butyl-4, 5-dihydro-3-methylthio-1,2,4-triazin-5-one] were monitored in runoff and infiltration water from agriculture fields. Metribuzin was detected in Ohio Rivers and Iowa wells and groundwater [82, 83]. The major mechanism by which metribuzin is lost from soil is microbial degradation. Losses due to the volatilization or photodegradation are not significant under field conditions [84, 85]. Sharom and Stephenson [86] also found that metribuzin mobility was inversely related to soil organic matter content. Similarly, soil amended with CM or SS retained DCPA residues up to 99 days compared to NM treatments [87]. Accordingly, soil OM has a major role in the transformation, transport, and adsorption/desorption of most soil organic and inorganic pollutants [81]. Because organic amendments used in agricultural production contain significant amounts of OM, it has been found that this practice (recycling waste and use of organic amendments in land farming) has a significant impact on the fate and transport of pesticides under environmental conditions. On the other hand, the addition of organic amendment to soil normally results in an increase in the microbiological activity due to the availability of simple organic molecules such as sugar and amino acids [88]. The application rate of soil amendments for agricultural soil is proposed according to nitrogen, phosphorus, and potassium requirements. However, a specific rule for animal manure application to soil does not exist, but is proposed through good agricultural practices.

6. Heavy metals in organic soil amendments and potential bioaccumulation in edible plants

In consideration of the enormous worldwide consumption of fruit and vegetables, that is, various *Capsicum* spp., the use of capsaicin as an additive in food for medicinal and other beneficial purposes requires continued monitoring of the potential harmful effects of heavy metals (also known as trace elements) accumulation in pepper fruits and other edible plants when SS or any other soil amendment is used in growing plants. The storage of great variety of molecules in animal and plant cells and the mechanism of this storage or bioaccumulation allow living organisms to accumulate nutrients and essential minerals. During this process, plants and animal cells can also absorb and accumulate harmful substances from the soil solution such as heavy metals. There is limited information on heavy metal (such as Cd, Ni, and Pb) in soil amendments and absorption by edible plants. Presently, heavy metals in the food chain are one of the pollutants of most concern around the world [89]. However, reducing the accumulation of heavy metals in edible plants can be achieved using biochar. Survey of current adsorbents indicated that the large surface area of activated carbon (ranging from 500 to 2000 $m^2 g^{-1}$) makes it a perfect candidate for heavy metals adsorption. Results indicated that biochar effectively reduced the total amount of nitrate, ammonium, and phosphate in leachates by 34, 35, and 21%, respectively, relative to native soil alone [90]. Biochar adsorption of ammonia decreases NH_3 and NO_3 losses during composting and after manure applications and offers a mechanism for developing slow release fertilizers [91]. Antonious et al. [14] revealed that total metal content of soil and/or soil amendments is not a good predictor/

indicator of the metal concentrations in plants due to the fact that only a fraction of the total metals is available for plant uptake.

Figure 4. Yard waste made from yard and lawn trimmings, and vegetable remains obtained from Con Robinson Contracting Company, Inc. Lexington, Kentucky, USA.

Municipal SS, CM, horse manure (HM), and yard waste (YW) compost (**Figures 1**, **2**, **3**, and **4**) provide amendments useful for improving soil structure and nutrient status. However, soil amendments contain heavy metals that may potentially affect soil microbes and the enzymes they produce. Accordingly, it is important to monitor NH_3^+, NO_3^-, phosphate, and trace elements (Ni, Pb, Cd) concentrations in native soil amended with SS, CM, and their transport into runoff, seepage water, and potential bioaccumulation in edible plants at harvest [92]. According to the USEPA Part 503 Biosolids rule, 10 elements (As, Cd, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn) in SS applied to soil are regulated [93]. The USEPA has defined limits for clean sludge in terms of its trace elements content (Zn 1400, Cu 1500, Ni 420, Cd 39, Pb 300, Cr 1200, Mo 75 mg kg^{-1}) and reported that sludge could be added to agricultural soil if these elements are below the standard disposal limits [94]. However, total metal concentrations in SS or even native soil do not furnish sufficient information regarding the potential availability of elements for plant uptake. Antonious et al. [14] found that the total concentration of each metal in the soil was significantly greater than concentration of metal ions available to plants. Accumulation of trace elements in plants grown in biosolids (sewage sludge) varied among plant species [92] and even among accessions of the same species [95]. Intake of trace elements-contaminated vegetables and fruits may pose risk to human health. Application of SS and CM to agricultural soils is based on crop requirements of NPK that are usually applied with a maximum application rate of 15 t year^{-1} [14]. In fact, there is no specific rate for animal manure application to soil, but the rate of application is proposed through good agricultural practices of fertilizer use. **Table 2** shows the bioaccumulation factor (BAF) of seven heavy metals from soil into pepper fruits grown under four soil management practices at Kentucky State University. BAF is defined as the concentration of metal in plant tissue divided by the concentration of the same metal in soil, expressed on dry weight basis. According to Antonious et al. [95], BAF values less than one are desirable and represent levels that do not pose human health hazards. Results revealed that BAF values in pepper fruits ranged 0–0–0.01 for Cr; 0.1–0.4 for Ni; 0.7–2.0 for Cu; 1.0–1.4 for Zn; 0.9–1.2 for Mo; 0.7–1.0 for Cd; and 0.2–0.8 for Pb.

Heavy metal	Treatment	μg g^{-1} fresh fruit	BAF
Cr	YW	0.002 ± 0.001	0.100
	SS	0.001 ± 0.001	0.098
	NM	0.000 ± 0.000	0.000
	CM	0.00 ± 0.000	0.000
Ni	YW	0.015 ± 0.010	0.353
	SS	0.013 ± 0.001	0.198
	NM	0.012 ± 0.003	0.115
	CM	0.012 ± 0.008	0.329
Cu	YW	2.980 ± 0.930	1.976
	SS	1.113 ± 0.120	1.081
	NM	0.864 ± 0.235	0.750
	CM	1.625 ± 0.964	1.523
Zn	YW	2.015 ± 0.880	1.388
	SS	1.751 ± 1.002	1.253
	NM	1.581 ± 0.600	0.995
	CM	1.595 ± 0.085	1.053
Mo	YW	0.021 ± 0.001	0.901
	SS	0.015 ± 0.002	1.198
	NM	0.009 ± 0.006	0.869
	CM	0.017 ± 0.009	1.217
Cd	YW	0.014 ± 0.001	1.132

Heavy metal	Treatment	μg g^{-1} fresh fruit	BAF
	SS	0.014 ± 0.007	1.007
	NM	0.012 ± 0.004	0.731
	CM	0.012 ± 0.006	0.876
Pb	YW	0.016 ± 0.009	0.316
	SS	0.037 ± 0.001	0.808
	NM	0.012 ± 0.005	0.222
	CM	0.035 ± 0.012	0.765

Each concentration in the table is an average of three replicates ± standard error.
YW = yard waste; SS = sewage sludge; CM = chicken manure; and NM = no-mulch bare soil.

Table 2. Concentrations and bioaccumulation factor (BAF) of seven heavy metals in pepper (*Capsicum annuum* L.) fruits of plants grown under four soil management practices.

6.1. Quantification of trace elements (Ni, Pb, Cd) in soil

To monitor the concentration of trace elements in soil following the incorporation of soil amendments, samples collected from field plots should be oven-dried at 105°C and ground manually with a ceramic mortar and pestle to pass a 1 mm sieve. Ten ml of concentrated nitric acid (HNO_3) is added to each 1-g of sieved dry powder, and the mixture is allowed to stand overnight and then heated for 4 h at 125°C on a hot plate. This mixture should be diluted with double-distilled water (50 mL) and filtered through filter paper No.1 before quantification of heavy metals. Mehlich-3 extractable Cd, Ni, and Pb can be determined in soil extracts using inductively coupled plasma (ICP) spectrometer [7, 14, 96, 97].

6.2. Quantification of trace elements (Ni, Pb, Cd) in edible plants at harvest

For the determination of trace elements in plant tissues, fruit samples of the growing plants of comparable size are collected at random, washed with deionized water, and dried in an oven at 65°C for 48 h. The dried samples should be grounded manually with ceramic mortar and pestle to pass through 1 mm sieve. Bioavailability of heavy metals can be defined as the total metals available in the soil, whereas the bioaccumulation factor (BAF) is defined as the ratio of the metal in the plant divided by total metal in the soil [98]. As described earlier, BAF values below 1 are desirable and present levels that do not pose human health hazards, while BAF values >1 would be less favorable. Assessing the bioavailability and speciation of trace elements in native soil and soil mixed with organic amendments is crucial to determining the environmental impact of contaminated soils.

7. Antibiotics and hormones

Sewage sludge (SS) obtained from waste water treatments plants contains organic matter and nutrients that, when properly treated, can be a valuable and safe resource for agriculture production systems [97, 99, 100]. Kentucky State University has been a pioneer in the use of municipal SS for land farming. Extensive work has been conducted by Antonious for more than 20 years. Composted municipal SS was proven to be a valuable fertilizer for many vegetable crops, including potatoes, peppers, broccoli, squashes, tomatoes, eggplants, onions, melons, cabbages, kales, and collards. After monitoring the bioaccumulation of heavy metals in plants grown in native soil mixed with municipal SS, data revealed that most of the heavy metals concentrations in edible plants were below their permissible limits and the plants were safe for human consumption. One of the outputs of this work was the transfer of this technology to the organic growers. Currently, municipal SS is commercially available as an organic base fertilizer known as Louisville Green (www.louisvillegreen.com). The intensive research carried out at KSU revealed the safety of SS as nutrient-rich materials resulting from the treatment of SS at the Metropolitan Water Plant Facility in Louisville, KY, (**Figure 1**).

There is an emerging concern regarding the impact of endocrine disrupting compounds (EDCs) in reclaimed water and biosolids [101]. EDCs are exogenous agents **(**agents from outside the organism or system) that have the potential to interfere with the production, release, transport, metabolism, binding, or elimination of the natural hormones responsible for the body regulation of developmental processes [102]. EDCs could be one or more of the following chemicals: pesticides, plasticizers, natural chemicals found in plants (phytoestrogens), pharmaceutical products, or hormones that are excreted in animal or human waste. Natural and synthetic estrogens are some of the most potent EDCs found in municipal wastewater. EDCs have been attributed as a cause of reproductive disturbance in humans and wildlife. Human exposure to these chemicals in the environment is a critical concern with unknown long-term impacts [103].

The group of molecules identified as endocrine disruptors is highly heterogeneous and can be classified into several categories, such as hormones (natural and synthetic estrogen or steroids), pharmaceutical and personal care products, industrial chemicals, pesticides, combustion byproducts, and surfactants [104]. There is an increasing evidence that EDCs poses a health risk in humans and animals. EDCs have been associated with adverse effects on reproduction, breast development and cancer, prostate cancer, neuroendocrinology, thyroid, metabolism and obesity, and cardiovascular endocrinology [102]. The primary source of EDCs is municipal SS. Other sources include industrial manufacturing processes and agricultural waste [105]. Wastewater treatment plants are generally not designed for the removal of trace organic compounds (i.e., detected concentration occurs at nanograms per liter) such as pharmaceuticals and potential EDCs [105]. The treatment efficiency of most pharmaceuticals and personal care products was as low as 35% [104]. Variations in wastewater treatment processes and operational conditions are generally regarded as the reason for fluctuations in removal efficiencies and effluent concentrations [101]. EDCs removal methods fall into three categories: physical removal, biodegradation, and chemical advanced oxidation. Biodegradation is the primary removal mechanisms for EDCs in activated sludge systems, which are commonly used biological treatment techniques for municipal wastewater treatment. About 90% of natural steroids are degraded in the activated sludge system [103].

Other technologies have been studied to remove the remaining EDCs. These technologies include chemical removal, activated carbon, chlorination, ozonation, ultraviolet (UV) irradiation, and membrane separation [101]. Treatment plants are seeking viable alternatives to alleviate concerns over cost, energy consumption, and brine disposal [105]. The use of ozone is a unique option because it is a highly effective oxidant for removing the majority of trace organic contaminants, particularly the steroid hormones, and because it has potential for reduced energy and chemical requirements [106]. Despite the effectiveness of ozone, there are fewer than 10 recycled water facilities (RWF) in the US that currently use ozone [105]. Some plants use UV treatment alone which has not shown to be an economically reasonable option for removing estrogens from wastewater. The application of advanced oxidation processes such as photo-oxidation which combines UV irradiation with ozone has achieved a high removal efficiency of EDCs [102]. EDCs are ubiquitous compounds with small molecular mass (<1000 Daltons), present in the range of ng L^{-1}. These compounds are biologically active, and their trace level concentrations make the detection and analysis procedures very challenging [104]. Highly sensitive measurements are necessary, including chemical monitoring, such as liquid chromatography-tandem mass spectrometry, gas chromatography-tandem mass spectrometry, high-performance liquid chromatography, and sensitive bioassay [103]. Determining the presence of EDCs in reclaimed water and municipal SS is important, because these contaminants may be introduced into the food chain through bioaccumulation. The use of SS and reclaimed water in agriculture is expected to improve rural communities and provides food crops that are consumer safe with little or no contaminants. Eleven EDCs (atrazine, bisphenol A, linuron, 4-nonylphenol, butylbenzyl phthalate, diethylhexyl phthalate, 17β-estradiol, 17α-ethynylestradiol, estrone, octylphenol, and triclosan) should be monitored prior to land application. In addition, contaminant metals (arsenic, cadmium, lead, mercury, nickel, and zinc) should be also monitored. Data of this type of research are critical for understanding the behavior and potential accumulation of EDCs and heavy metals within the particular food, when reclaimed water and biosolids [107] are used for growing edible plants.

8. Microorganisms and soil enzymes

Government agencies, research scientists, farmers, and all citizens are looking for a healthy environment. Soil microorganisms are present in low amounts; however, they have a significant role in nutrient recycling to maintain the NPK, the main plant nutrients at the required level. Microorganism's biomass is often related to crop type, soil type, and landscape [108, 109]. Soil fungi usually constitute 75–95% of the soil microbial biomass and when we include bacteria, they are responsible for about 90% of the total energy flux of organic matter mineralization in soil [110]. Among the main groups of microorganisms living with plant roots are saprotrophic fungi and mycorrhiza. Urease, invertase, phosphatase, cellulose, dehydrogenase, and amylase are among enzymes secreted by soil microorganisms (bacteria, fungi, protozoa, algae). These enzymes are responsible for degrading complex forms of organic matter and xenobiotics in soil and water ecosystems. Polysaccharides (sticky substances) are also produced by soil microorganisms. These sticky substances play a significant role in sticking and

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adhering soil particles together and help the soil to resist erosion that can reduce agricultural productivity [111].

Figure 5. Kale and collard plants grown in soil amended with sewage sludge applied at 15 t $acre^{-1}$ at Kentucky State University Harold Benson Research and Demonstration Farm (Franklin County, KY, USA).

Figures 5 and **6** revealed that kale, collard, and pepper were successfully grown in SS and CM amended soils that contained greater soil urease and invertase activities. On the contrary yard waste (**Figure 4**) used at KSU Research Farm revealed that, its application in spring broccoli did not alter soil urease or invertase activities to any appreciable extent (data not shown).

SS increased soil urease and invertase activity (**Figure 7**). Urease is an enzyme that depends on Ni for its activity [112]. Accordingly, Ni in SS might be the cause of elevated urease activity. This increase could be due to the presence of urea, the substrate of the enzyme urease. SS obtained from municipal plants contains great amounts of enzymatic substrates [113]. SS used at KSU for growing many vegetable crops including broccoli contained 1.2 μg Ni g^{-1} dry soil. However, broccoli plants showed normal growth in the field without any apparent symptoms of Ni toxicity or deficiency. Results indicated that the addition of SS to native soils has increased total crop marketable yield compared to no-mulch native soils (data not shown). Indicating that incorporation of organic materials, such as municipal SS, into soil promotes microbiological activity. Microbial activity and soil fertility are closely related because it is through the biomass that the soil mineralization of the important organic elements (C, P, and N) occurs. Accordingly, soil biological monitoring is a potential and sensitive indicator of soil ecological stress for early restoration. **Figure 7** revealed that soil invertase and urease activities were increased by 89 and 47%, respectively, in SS compared to native soil.

Figure 6. Hot pepper plants grown in soil amended with chicken manure applied at 15 t acre^{-1} at Kentucky State University Harold Benson Research and Demonstration Farm (Franklin County, KY, USA).

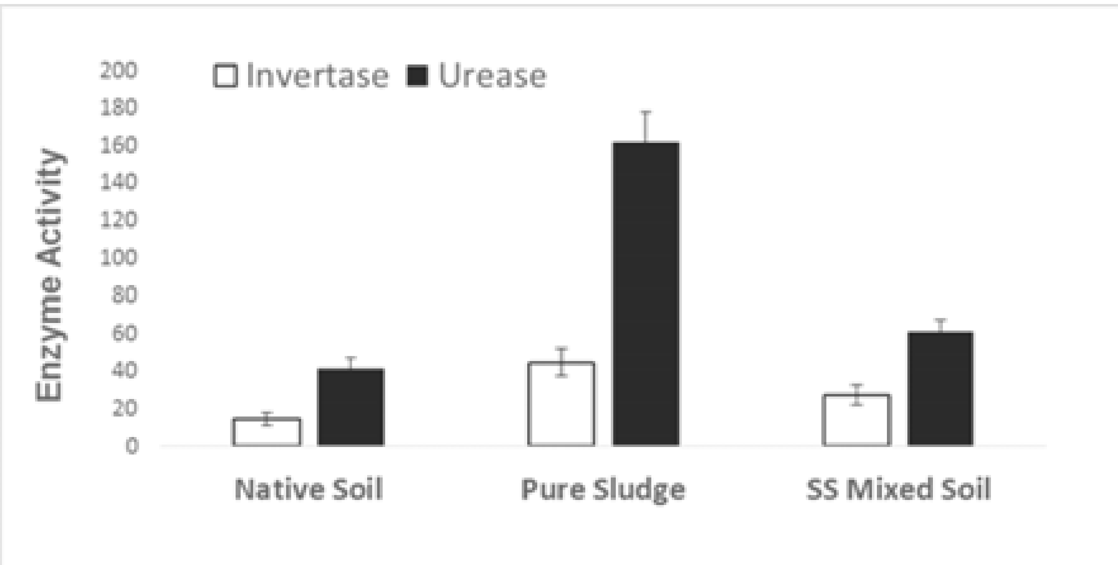

Figure 7. Invertase activity expressed as mg glucose released g^{-1} dry soil and urease activity expressed as mg NH_4–N released g^{-1} dry soil h^{-1}.

Tabatabi and Bremner [114] used a simple method for the quantification of urease activity in soil. In their method, they used a few grams of soil (about 5 g) and added 10 mL of 0.1 M phosphate buffer in a volumetric flask kept in water bath at 30°C for 1 h to allow the soil temperature to equilibrate. The liberated NH_4^+ ions were determined by the selective electrode method [115]. For standardization, a series of standard solutions of NH_4 Cl covering the concentrations of 0.1–100 μg NH_4–N mL^{-1} of water was prepared. In this method, urease activity was expressed as mg NH_4–N released g^{-1} dried soil during the 1 h incubation at 30°C [17]. For invertase quantification in soil, the method described by Balasubramanian et al. [116] was used. For standardization, a calibration curve was obtained using analytical grade glucose in the range of 10–50 μg mL^{-1} glucose standards.

Addition of SS, as a source of organic matter, to agricultural soil reduced the C/N ratio (**Table 3**). Kizilkaya and Bayrakli [117] added nitrogen as ammonium sulfate, $(NH_4)_2 SO_4$, to reduce the C/N ratio in soil from 9:1 to 6:1 and 3:1. This resulted in a rapid increase in soil enzymatic activities. Investigators [118, 119] reported that reducing the C/N ratio is indicative of a high OM decomposition rate. On the contrary, OM with high level of C/N ratios has relatively low rates of decomposition and causes low rates of N-mineralization [120] in soil.

Soil parameters	Sewage sludge incorporated with native soil	Yard waste incorporated with native soil	Native soil
% N	0.39 a	0.32 a	0.15 b
% P	0.31 a	0.24 a	0.18 a
% K	0.23 a	0.28 a	0.25 a
% C	3.7 a	3.8 a	1.6 b
% Organic matter	3.3 a	7.6 a	2.7 b
C/N ratio	9.2 c	11.9 b	17.7 a
pH	8.5 a	7.3 b	6.9 b

Statistical comparisons were done between three soil management practices (each replicated six times) for each soil parameter. Values in each row accompanied by the same letter are not significantly different ($P > 0.05$) using Duncan's multiple range test.

Table 3. Soil properties in the rhizosphere of broccoli plants grown in native soil amended with sewage sludge and soil amended with yard waste at KSU Harold Benson Research and Demonstration Farm, (Franklin County, Kentucky, USA).

9. Conclusion

Organic waste used as fertilizer must be safe for the environment and wildlife, and safe for all who apply and consume the food product. The simultaneous use of recycled waste to enhance soil physical, chemical, and microbial conditions could also enhance soil fertility and crop yield. Organic farming, farming without chemicals, requires organic fertilizers. While such a definition is concise and clear, it is unfortunately untrue and misses out on several characteristics which are of fundamental importance. All materials, living or dead, contain chemical compounds; therefore organic farming utilizes chemicals. 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, and growth regulators.” The potential health hazards of pesticide residues, nitrates, and phosphates, resulting from conventional agriculture are now receiving attention.

Thirty percent of US streams have high levels of N and P contamination and drinking water violations due to nitrates and phosphates that have been doubled in the last 8 years. Organic wastes are usually rich in carbon and nitrogen, and their addition increases the soil content of labile carbon, accelerates the activity of soil microbes, increases nitrification and denitrification rates. With the growing interest in recycling organic amendments, it is important to monitor the activity of urease, invertase, and phosphatase since these three enzymes play a significant role in the soil N, C, and P cycles, respectively. In addition, the activity of these three enzymes and other soil enzymes can be used as a direct indicator of soil health and soil microbial population and activity in the rhizosphere of growing plants (a zone of increased microbial and enzyme activity where soil and root make contact). With increasing emphasis on fertility sustainability and environmental friendliness, restoration of soil microbial ecology has become important. In agricultural practice, composting of soil with sewage sludge, chicken manure, or yard waste provides an organic amendment useful for improving soil structure and soil nutrient status and generally increases soil organic matter and stimulates soil microbial activity. In the US, about 11.4 million tons of poultry litter was produced and about 90% of this amount was used as fertilizer in agricultural production [121]. It has been found that poultry litter contains many essential plant nutrients (N, P, K, S, Ca, Mg, B, Cu, Fe, Mn, Mo, and Zn) and has been reported as excellent fertilizer [122]. It is expected that significant chicken manure generation will become available in increasing quantities because of the increasing growth in the poultry industry. In addition, as more sewage sludge treatment districts turn to composting as a viable means of sludge stabilization, sewage sludge will also become available in increasing quantities. Sewage sludge and chicken manure contain significant amounts of trace elements that may impact soil microorganisms and the enzymes they produce by blocking of either the enzyme or substrate when present in excessive concentrations. Trace elements are among the major contaminants of food supply. They are not biodegradable, have long biological half-lives, and have the potential for accumulation in edible plants grown under this practice [123] that requires environmental measurement and mitigation [124]. Trace elements may also accumulate in the different human and animal body organs leading to potential adverse effects on human health. The rate of release of trace elements from sewage sludge into soil solution and subsequent uptake by plants could also result in phytotoxicity and/or bioaccumulation. Regarding the use of horse manure as organic fertilizer, typically, a ton of horse manure contains 11 pounds of N, 2 pounds of P, and 8 pounds of K [125]. Horse manure contains about 60% solids and 40% urine [126]. During cleaning, soiled bedding removed with the horse manure may account for another 8–15 pounds of waste per day. The volume of soiled bedding removed during cleaning is almost twice the volume of manure removed but varies widely depending on management practices. As described earlier, field application of horse manure is also based on fertilizer needs of a particular crop. The approximate fertilizer value of manure from bedded horse stalls based on its dry matter content, which is about 46%, is 4 lb ton^{-1} ammonium-N, 14 lb ton^{-1} total N content, 4 lb ton^{-1} P_2O_5 (phosphate), and 14 lb ton^{-1} K_2O (potash), whereas the fertilizer value of horse manure at 20% moisture without bedding is approximately 12–5–9 lb ton^{-1} ($N–P_2O_5–K_2O$). Overall, organic amendments from animal manure are excellent fertilizers. However, there is an emerging concern regarding the impact of endocrine disrupting compounds (EDCs) in reclaimed water and sewage sludge. Most livestock grown in the US and worldwide are raised in large-scale concentrated animal-feeding operations. This high population densities require heavy use of antibiotics that can cause severe local soil, air, and water pollution.

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