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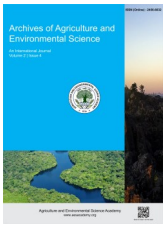

REVIEW ARTICLE

A review on co-composting of biosolids and its use in crops cultivation for agriculture sustainability

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ABSTRACT

Generation and disposal of biosolids (solid and semisolid materials left after the wastewater treatment) has becoming a challenge globally. A large number of objectionable components like heavy metals, pesticides, detergents and pathogens restricts the direct application of biosolids in the cultivation of agricultural crops as it contaminates the soil as well as the cultivated crops and causes health issues. Co-composting of biosolids can be a viable option to utilize the biosolids in a definite proportion along with different types of biodegradable materials (co-substrate) such as, kitchen waste, agricultural residues, forestry waste and waste from the animal husbandry etc. Co-composting improves the nutrients status of the composted biosolids and reduce the risk of accumulation of toxic heavy metals and pathogens in the soil and cultivated crops. The application of biosolids compost in to the soils significantly improve the physical structure, nutrients composition and microbial profile of the soils and subsequently enhance the crops productivity. It also reduces the risk of contamination of the soils and cultivated agricultural crops in comparison to the direct use of biosolids in soil amendment. In this paper we discussed the use of biosolids in agriculture, co-composting of biosolids with different co-substrates and their application in the cultivation of different agricultural crops for sustainable agriculture production.

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INTRODUCTION

Generation of waste has been increased manifolds worldwide due to a large number of developmental processes like industrialization, colonization development of infrastructure and continuous growth of human population. Biosolids are the residual products left after the treatment of wastewater after the separation of water. The biosolids and sewage sludge in generally used interchangeably and considerably rich in different nutrients left after the physical and chemical treatment of wastewater (Adelodun *et al.*, 2022, EPA, 2023). Biosolids is generally very important organic waste material that remain left after the sewage treatment. It is an important resource as it is considerably rich in different plant nutrients (C, N, P and micronutrients). Worldwide biosolids is using for the soil amendments and to fertilize the crops cultivation. The characterization of biosolids have been described by a number of scientists/researchers (Singh *et al.*, 2011, Sharma *et al.*, 2017, Kumar *et al.*, 2022). The quality of the biosolids is greatly depend on the treatment process used for the treatment of sewage wastewater (Jin *et al.*, 2018, Cristina *et al.*, 2019). Mixing of sewage with industrial effluents significantly affected the physicochemical and biological characteristics of the wastewater and also the generated biosolids after the treatment (Kumar *et al.*, 2016, 2017, Ghorbani *et al.*, 2022). The sewage generated from the offices, staff quarters in the premises of the different industries mainly influence the characterization of biosolids. Washing of cattle shed and disposal of animal dung is

a common practice in most of the cities, urban and semi urban areas to get rid of the generated waste but is importantly affect the quantitative and qualitative composition of biosolids.

The safe disposal of biosolids includes composting, land application, bioprocessing, thermal processing, incineration and landfilling that are performed worldwide (Figure 1). The land application having agricultural recycling, use in forestry, silviculture and horticulture use and for the reclamation of the lands. The bioprocessing includes the co-composting and vermicomposting with different biologically degradable materials. The thermal processing includes the incineration, co-combustion, gasification, pyrolysis thus all these processes are used for energy recovery. The landfilling and ocean dumping have several drawbacks as they cause environmental pollution (Sharma *et al.*, 2017). It is widely reported that the biosolids can be applied for the soil amendment, to enrich the macro and micro-nutrients in the soil (Hamdi *et al.*, 2019). However, presence of heavy metals and harmful pathogens restricts its use in the crops cultivation (Urra *et al.*, 2019). Joo *et al.* (2015) noted that generation of huge volume of biosolids is challenging in the handling and proper disposal and management of sewage sludge worldwide. Conventional methods like landfilling and incineration cause environmental pollution, therefore, proper care should be taken during the management of the sewage sludge as per the sludge handling and disposal and management guidelines. As per Sustainable Development Goals (SDGs), SDG 2 and SDG 12 are directly linked to the elimination of food problems globally and it is necessary to produce the safe food for all to achieve the concept of zero hunger worldwide. Therefore, sustainability in our agricultural system is very much essential to achieves the SDG 2 and SDG 12 goals.

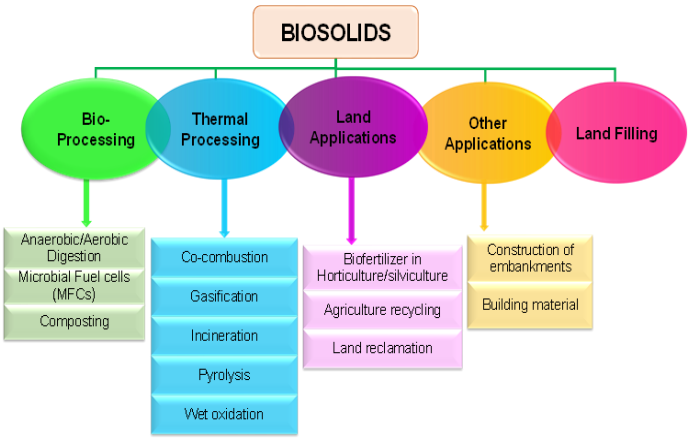

Figure 1. *Possible use management options of biosolids (Source: Sharma et al., 2017).*

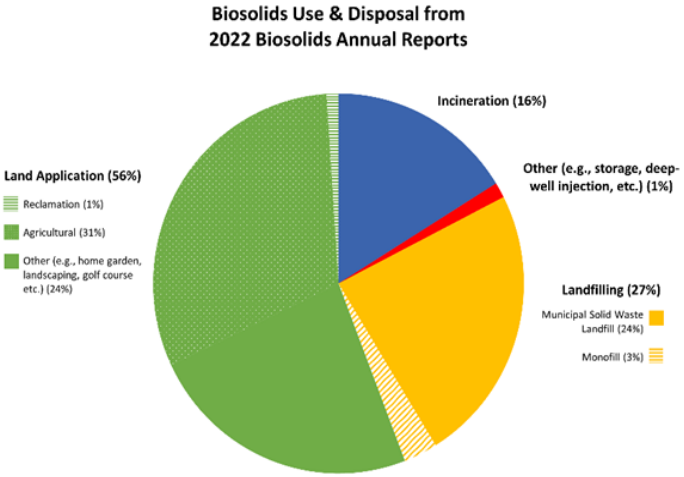

Figure 2. *Application of biosolids in different sectors (Source: EPA, 2023).*

METHODOLOGY

Authentic e-sources such as scientific journals published by Elsevier, Springer, Taylor & Francis, MDPI, PubMed etc. were considered for the collection of relevant scientific studies of biosolids and its application in agriculture, heavy metals and pathogens in biosolids, co-composting of biosolids with different biologically degradable substrates were considered for the present review. Departmental and Central library of the University have also been consulted for the thorough survey of literature on the biosolids and its application in crops cultivation.

APPLICATIONS OF BIOSOLID IN AGRICULTURE

Land application of biosolids is a most common practice due to the low price and a valuable option for the biosolids management and biosolids disposal. Biosolids are using for the soil amendments and providing the nutrients to the growing crops and reducing the application of chemical fertilizers worldwide. On the basis of characterization, the biosolids can be used for the cultivation of agricultural crops and reclamation of the mining landfills. As the biosolids contained sufficient nutrients thus, can be applied to enhance the nutrition level of the soil and for the improvement of the soil structure. As per the EPA report, about 31% of biosolids are used in the agriculture sector, 27% in landfilling, 24% in home garden, and landscaping,16% in incineration and 1% in land reclamation (Figure 2). The characterization of biosolids and their application in different countries are given in Table 1. Many researchers studied the suitability of biosolids on the basis of its characterization in the soil amendment and cultivation of agricultural crops. But the application of biosolids can cause a serious problem in the agriculture soil by building up the contents of different heavy metals and pathogens (Kumar *et al.*, 2017). As a huge content of different heavy metals like Cd, Cu, Cr, Fe, Mn, Zn have been reported by a number of researchers in the sewage sludge. Addition of Cd, Cu, Cr, Fe, Mn, Zn have been reported by Kumar & Chopra (2012 and 2013) in the soil and French bean (*Phaseolus vulgaris* L.) amended with sewage sludge (biosolids). Kumar *et al.* (2016) reported the improvement of soil nutrients profile but at the same time reported building up contents of various heavy metals in spinach (*Spinacia oleracea* L.) grown in sewage sludge amended soil. Kumar & Chopra (2016) also reported the increase in the yield of high yielding cultivar of eggplant (*Solanum melongena* L.) grown in sewage sludge amended soil.

Table 1. Characterization of biosolids and their application in different countries.

S. No.	Characteristics	Application	Country	Reference/ Source
1.	Amorphous in nature and dominant metals detected in the samples are: Fe, Zn, Mn, high humic acid, rich in organic matter with long aliphatic chains and numerous functional groups	As fertilizer	Greece	Kanteraki *et al.* (2024)
2.	Higher dissolved organic carbon, NO_3, and NH_4 contents, total carbon and dissolved organic carbon, total nitrogen and dissolved nitrogen, and nitrate content and C : N	Soil amendment	Israel	Ilani *et al.* (2016)
3.	Considerably rich in several important micro and macronutrients including nitrogen, phosphorus, potassium, manganese	Plant height, plant diameter and dry weight yield of wheat was increased	Pakistan	Dad *et al.* (2019)
4.	Mean concentrations of total N (TN) in the dry solids (DS) of different biosolids types ranged from 1.5% (air-dried lime-treated (LT) biosolids) to 7.5% (liquid mesophilic anaerobic digestion (LMAD) biosolids).	Nitrogen mineralization	Australia	Rigby *et al.* (2016)
5.	Higher content of heavy metals Cu, Zn, Mn, Cd etc.	Concentrations of heavy metals, raise the soil content and the availability of heavy metals for transfer into crop plants, both positive and negative impacts on soils and crops	United Kingdom	Smith (2009)
6.	High in nutritional value, organic carbon, nitrogen, phosphorus but also contain some toxic metals	Improve soil physical structure, nutritional composition and crops productivity	India	Sharma *et al.* (2017)
7.	Rich in nutrients as available K, available P, available Mg, Ni, Cd, Cr, Cu, Zn and Pb and microbes	Enhancement of carbon and nitrogen contents as well as enzyme activities in the soil	Poland	Skowrońska *et al.* (2020)
8.	Significantly rich in phosphorus (P), carbon (C) and nitrogen (N)	Increased P, C, N contents in the agricultural soils	Argentina	Torri *et al.* (2017)
9.	High stable C and low C: N in biosolids	Amendment of soil with biosolids having high stable organic matter and low C:N ratio can improve the C metabolism of microorganisms in agricultural soils through alleviation of microbial stress	USA	Tian *et al.* (2014)
10.	Highly odorous, and having higher contents of nutrients	Used in co-composting with eggplant waste and suitable for co-composting substrate	Spain	Toledo *et al.* (2019)
11.	Biosolids having higher carbon, nitrogen, phosphorus and potassium content	Use of biosolids as composting substrate and it increased in the N, C, P, K of the vermicompost	Hungary	Rékásia *et al.* (2019)
12.	Use of highly carbonaceous sewage sludge (biosolids) in biochar preparation	Biosolids biochar application significantly improved the soil fertility and productivity of wheat crop	Pakistan	Rehman *et al.* (2018)
13.	Uses the anaerobic digestates of sewage sludge in soil amendment rich in C, N, P, and other micronutrients	Significantly improved the soil fertility and crop yield of cucumber after application	Italy	Cristina *et al.* (2019)
14.	Sewage sludge rich in plant nutrients NO_3, PO_4 and heavy metals like Fe, Zn, Cd, Cr, Cu and Pb	Application of sewage sludge increased the productivity of French bean (*Phaseolus vulgaris* L.) but accumulated and translocated certain heavy metals in varied content	India	Kumar and Chopra (2013)
15.	Higher content of Zn, Cd, Cu in biosolids	Long term use of biosolids build up the content of metals in the soil and found risky in soil amendment	China	Li *et al.* (2020)
16.	Sewage sludge rich in different plant nutrients and heavy metals	Use of sewage sludge increased soil nutrients and improved physical structure and elevated the yield of sweet sorghum but increased heavy metals in soil and sweet sorghum	China	Zuo *et al.* (2019)
17.	Higher content of Cd, Cr, Cu, Pb and Zn in sewage sludge	Elevated accumulation and translocation of Cd, Cr, Cu, Pb and Zn in soil and tomato crop	Kuwait	Elmi *et al.* (2019)
18.	Significant content of OM, N, P, K, Ca, Mg, S, Zn, Cu, Fe, Cd, Cr, Pb in sewage sludge	Significantly accumulated all nutrients and heavy metals in the soil and found economically feasible	Brazil	Breda *et al.* (2020)

Application of sewage sludge in soil amendment generally increase the water holding capacity, electrical conductivity, organic carbon, humic acids, enzymatic activities (dehydrogenase, phosphatase, glucosidase, and urease), soil microbial activities (soil respiration and hydrolysis) and different micronutrients (Fe, Cu, Mn, Zn etc.), macronutrients (N, P, K) and heavy metals (Cd, Cr, Ni, Pb) in the soil while decrease the pH and bulk density of the soil (Sharma *et al.*, 2017). Moreover, Melo *et al.* (2018) established that the knowledge of background content of nutrients and other elements is helpful for the safe application of sewage sludge in agriculture as it minimizes the risk of contamination of the soil and the growing crops (Zieli´nska *et al.*, 2015). The electrolytic treatment of wastewater is able to kill the pathogens present in the wastewater and sewage sludge (Chopra *et al.*, 2011, Černe *et al.*, 2021). Tian *et al.* (2014) reported the role of biosolids in agricultural soil carbon sequestration and suggested that biosolids application is a best way to restore the C content of the soil. Soil amendment with biosolids increase the C sequestration of crop residue C in the agricultural soils. Likewise, Rigby *et al.* (2016) investigated the nitrogen mineralization of biosolids and its application in the crops cultivation. They reported that biosolids is a good source of nitrogen and its application in the crops cultivation can reduce the use of nitrogenous fertilizer. They also reported that the physicochemical properties of the soil influence the nitrogen mineralization in the soil.

The application of sewage sludge in soil amendment significantly increased the organic matter and microbial activities that are beneficial for the soil health and crops cultivation of willow leaf (Urbaniak *et al.*, 2017). Similarly, Wijesekara *et al.* (2017) noted that soil amended with biosolids/sewage sludge increased the total organic carbon content of the soil that is beneficial for the growth of cultivated crops. Recently, Sahin *et al.* (2020) observed that the mixture of sewage sludge and gypsum improved the saline sodic soil structure and nutritional level by adding organic matter, nitrogen and exchangeable Ca and Mg in the soil. Furthermore, Sharma *et al.* (2017) investigated the agricultural utilization of biosolids, and found that application of biosolids in soil can improve the physical and nutritional status of the soil but presence of heavy metals in biosolids limits its use in the agriculture. Higher content of metals leads to contaminate the soil as well as the cultivated crops. Also, Torri *et al.* (2017) investigated the biosolids application and its role in phosphorous (P) cycle and found that use of biosolids in soil significantly enhance the phosphorous mineralization and bioavailability of P which further enhance the C and N ratio in the soil. The use of sewage sludge/biosolids amendments significantly improved the soil quality parameters and yield of sorghum (*Sorghum bicolor* L.) reported by Zuo *et al.* (2019). Its application reduced the EC, pH, bulk density and increased the CEC, N, P in the soil. Likewise, Elmi *et al.* (2019) noted that the use of sewage sludge or biosolids in soil amendment is a common practice worldwide due to the nutrients profile of the biosolids. However, it contained several heavy metals like Cd, Cr, Cu, Pb and Zn and harmful pathogens that contaminate the soil and agricultural crops. They also reported the translocation sequence Zn > Cu > Cr > Cd for roots and Zn > Cu > Cr for fruits of tomato (*Lycopersicon esculentum* Miller) and concluded that sewage sludge application can cause harmful effects in the plants, animals and human being as these heavy metals can transfer through the food chain in the different environmental components.

Similarly, Dad *et al.* (2019) investigated the nutrients status of different types of biosolids and observed that biosolids are considerably rich in nitrogen, phosphorous, potassium and manganese. Its application the cultivation of wheat significantly increased the wheat crop parameters like plant height, dry weight and yield of wheat crop. Thus, the use of biosolids in the cultivation of wheat can reduce the fertilizer application. Likewise, Siebielec *et al.* (2018) and Skowrońska *et al.* (2020) reported the long-term use of sewage sludge and its effects on the soil characteristics and found that higher dose of sewage sludge significantly build up the content of different heavy metals in the soil that interfere in the beneficial biological activities of the microorganisms. Moreover, Breda *et al.* (2020) investigated the successive application of biosolids in soil amendment and found that long term use of biosolids build up the contents of various nutrients (Ca, P, B) and heavy metals (Fe and Zn) in the soil and established that the climatic factors influence the content of different nutrients and heavy metals in the soil. Therefore, it is necessary to understand the role of climatic factors in the mineralization process of different elements and nutrients accumulated in the soil after sewage sludge amendment.

Application of biosolids biochar significantly altered the micronutrients contents of Ca, Mg, N, P, K, S in the soil after amendments and improved the overall corn crop yield during the cultivation (Chagas *et al.*, 2021). Also, Buta *et al.* (2021) investigated the effects of sewage sludge in agriculture and concluded that there are certain emerging pollutants (antibiotics, heavy metals, resistance determinants) are present in the sewage sludge that restricts its application in soil amendments and crops cultivation. Therefore, the biosolids have the fertilizers values and can replace the application of different synthetic fertilizers in the cultivation of agricultural crops but their use should be done after the proper studies to reduce the toxicity of heavy metals and contamination of the food materials from the pathogens. Kumar *et al.* (2022) applied the sewage sludge along with plant growth-promoting rhizobia for the soil amendment and enhance the crop productivity, and reported that the treatment increased the seed germination and biochemical response and yield of ridge gourd (*Luffa acutangula* (L.) Roxb.). Moreover, foliar application of TiO_2-nanoparticles has considerable increased the yield of okra (*Abelmoschus esculentus* L. Moench) cultivated in sewage sludge–amended soils as reported by Kumar *et al.* (2022). In addition to that, Širi´c *et al.* (2023) also stated that sewage sludge application in soil is beneficial for the cultivation of Dhaincha (*Sesbania bispinosa* (Jacq.) and it significantly improves its fibre quality. Additionally, a large number of pathogens, including different groups of bacteria, viruses, fungi, helminths eggs are predominantly reported in the sewage sludge, thus its application without appropriate measures can lead a significant health risk issues in the soil, animals and humans due to the accumulation and transfer through the food chain (Jalali & Imanifard, 2021).

CO-COMPOSTING OF BIOSOLIDS AND ITS USE IN CROPS CULTIVATION

Co-composting of biosolids with different types of biologically degradable material can reduce the content of different heavy metals, pesticides and pathogens. A definite proportion of biosolids can be composted along with the cow dung, agricultural residues, kitchen waste, garden waste, forestry waste or other animal's husbandry waste to produce the bio-compost. Co-composting is a composting practice in which green waste/animal dung/organic waste is used with sewage sludge to produce the compost. This is an efficient and natural way for recycling of the organic waste for the promotion of the soil and waste management practices as the compost enhance the nutrient status of the soil and also improve its physicochemical and biological structure. Smith (2009) investigated the bioavailability of different heavy metals in municipal solid waste compost and sewage sludge and found that the application of sewage sludge enhances the heavy metals content in the soil is the background concentration of the metals in soil is also higher. Composting of the sewage sludge with green material can significantly reduce the concentration of heavy metals in the compost and in the soil after its application. This compost can also reduce the translocation of metals in the different parts of the cultivated crops. Composted biosolids are widely used to improve the nutrients composition and soil structure as the composted material is high in nutrients, soluble salts and low in contamination (Ilani *et al.*, 2016, Shah *et al.*, 2014), the composted biosolids significantly contribute to the physical and chemical properties of the soil and makes the nutrients available to plants for absorption (Rigby *et al.*, 2009, 2016). Li *et al.* (2018) and Zhou *et al.* (2019) reported the use of biochar produced from the biosolids and found that the biochar can increase the bioavailability of phosphorus in the soil through the phosphorus speciation.

Likewise, Toledo *et al.* (2019) investigated the co-composting of biosolids and waste of eggplant to reduce the odour of the biosolids and obtained a well stabilized compost free from the odour after 90 days. Thus, composting is a suitable method to reduce the negative impacts of the biosolids. It also reduces the number of pathogens significantly from the biosolids and increase the beneficial microbial activities to enhance the humic substances and mineralization of elements. Therefore, composting is widely accepted method for the biosolids treatment (Peltre *et al.*, 2015, González *et al.*, 2019). Moreover, Rékásia *et al.* (2019) compared the properties of composted biosolids and vermicomposted sewage sludge and found that more intensive mineralization was noted in the composted sewage sludge while some plant growth promoting substances was observed in the vermicomposted sewage sludge using *Eisenia fetida*. Agricultural crop residues are the good source of nutrients and can be used for the co-composting the biosolids, specially the straw of maize, wheat, rapeseed and rice straw can be used to produce a nutrient enrich bio-compost reported by Xiu-lan *et al.* (2016). Moreover, Besides, Kim *et al.* (2019) investigated the co-digestion of food waste and wastewater biosolids and found that different types of food materials can be co-digested with biosolids to generate a good quality of organic fertilizer. A number of micro-organisms like *Clostridium*, *Syntrophomonas*, *Methanosarcina*, and *Methanobacterium* can be used for the co-digestion of the materials/substrates. Therefore, biosolids can be used for co-composting to enhance the nutritional values of the compost and can be applied for enhancing the soil fertility and crops productivity.

Conclusion

This investigation concluded that biosolids have the fertilizers values and can replace the application of different synthetic fertilizers in the cultivation of agricultural crops but their use should be done after the proper studies to reduce the toxicity of heavy metals and contamination of the food materials from the pathogens. Therefore, a large number of studies suggested that, the biosolids or sewage sludge is a valuable resource but presence of different heavy metals and a large variety of pathogens, restricts its use in the agriculture, but after co-composting it with different biodegradable material the content of the metals can be reduced and it can be used in the cultivation of agricultural crops safely. The composted biosolids significantly reduces the bioavailability of heavy metals to cultivated crop plants from composted biosolids in comparison to direct use of sewage sludge (biosolids). It also increases the soil physical structure and nutritional profile and microbial activities in the soil. Therefore, co-composting of biosolids along with suitable composting substrate (cow dung, agro-residues, farm waste etc.) should be promoted for the sustainable agricultural production.

DECLARATIONS

Authors Contribution Statement

Conceptualization: V.K. and S.R., Methodology: S.R., R.G. and S., Software and Validation: S.R. and R.G., Original draft preparation: S.R. and A.R., Review and Editing: V.K. and S.R.; Supervision and advising: V.K. All the authors have read and approved the final manuscript.

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