Review Article

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Municipal Solid Waste Compost and its Effects on Soil Health

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Abstract

Modern industrial growth and urbanization with population explosion leads to disposal of huge amount of municipal solid waste (MSW) in the environment. The conventional ways of waste management based on physico-chemical treatment further aggravate the situation of soil contamination. To combat the situation of soil pollution, composting of municipal solid waste is a viable and eco-friendly approach in minimizing the environmental risk of contamination. Further, it also enhances the physical, nutritional and biological properties of soil in sustainable manner. However, huge volumes of MSW compost may poses a potential risk of trace elements or heavy metal loading in the soil. Heavy metal content in MSW compost is one of the potential soil pollutants which may easily transfer from soil to food plants through root absorption, and accumulate in plant tissues causing various phyto-toxic effects. In this context, strategies based on biological approaches such as bioremediation or phyto-remediation serves as important management option to combat to heavy metal stress in the soil. However, the positive impact of this MSW compost is far greater than of adverse effect. This review addresses the impact of municipal solid waste compost on various soil properties and managing the soil heavy metal contamination to promote soil health.

Keywords: Municipal Solid Waste; Compost; Heavy Metal; Soil Health.

Introduction

As municipal areas grow its size along with the rapid industrialization, urbanization and increased population density, it has led to the greater generation of municipal solid waste (MSW) in India. Municipal solid waste or urban solid waste is a waste type that includes predominantly household waste (domestic waste) with sometimes the addition of commercial wastes, construction and demolition debris, sanitation residue, and waste from streets collected by a municipality within a given area (Zhu et al., 2008). They may be in either solid or semisolid form. The MSW consists mainly of a large organic fraction (40–60%), ash and fine earth (30–40%), paper (3–6%), plastic, glass and metals (each less than 1%) and C/ N ratio ranges between 20-30 (Sharholy et al., 2008). A considerable quantity of MSW can be recycled and reused but it contains high amount of undesirable heavy metals which may cause contamination of soil. The waste disposal methods has become inadequate and its needs eco-friendly approach to save the environment.

Composting MSW is an important management strategy which is gaining interest as suitable option for chemical fertilizers with environmental profit, since this process eliminates or reduces the toxicity of pollutants which is present in MSW (Araujo and Monteiro, 2005) and leads to a final product which can be applied in improving and maintaining soil quality (Larney and Hao, 2007). Composting of municipal solid waste has been considered an attractive waste management tool for effective reduction of waste volume and can eventually turn waste into a valuable resource for beneficial utilization. It is also the most cost effective option for disposal over traditional means such as landfilling or incineration.

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With the rising interest in organic agriculture, the production of organic-grade MSW compost for agriculture is also gaining popularity because of its positive effect on biological, physical, and chemical soil properties (Iglesias-Jimenez and Alvarez, 1993). Application of MSW compost in agricultural soils can directly alter soil physico-chemical properties and act as nutrient supplements for crops and as soil conditioner. The soil microbial biomass is considered as the living part of soil organic matter, is very closely related to the soil organic matter content in many arable agricultural soils. The application of MSW compost in agricultural lands can be justified by the need of finding an appropriate destination for waste recycling. However, agricultural use of MSW may present a potential threat to the environment due to the presence of pathogens and several toxic pollutants such as heavy metals or organic pollutants and salts (Srivastava et al., 2016).

Application of MSW compost in agricultural soils can directly improves soil physico-chemical properties such as: soil structure, water retention capacity, buffering capacity and soil nutrient status (Barral et al., 2009). Besides these, in relation to soil biological properties, numerous researchers have reported different effects of MSW compost on soil microbial biomass and biochemical activity (Garcıa-Gil et al., 2000; Bhattacharyya et al., 2003; Crecchio et al., 2004; Domínguez et al., 2019). Thus agricultural use MSW compost not only helps to improve the overall soil quality but also sustaining the soil productivity for a long-run (McGeehan, 2012; Scotti et al., 2016; Hossain et al., 2017).

Effect of MSW compost on soil physical properties

Production of municipal solid waste including other organic waste is increasing while soils are progressively losing organic matter due to intensive cultivation and climatic conditions. In this scenario, recycling of organic waste as soil amendments acts as useful alternative to incineration (Mrabet et al., 2012; Chatterjee et al., 2017). A primary benefit of MSW compost is that it contains high organic matter and low bulk density (Soumare et al., 2003). Municipal solid waste compost had a higher water holding capacity because of its organic matter content which in turn improved the water holding capacity of the soil (Ingelmo et al. 2012). Furthermore, application rates of 30 and 60 Mg ha-1 of MSW compost increased the aggregate stability of soil through the formation of cationic bridges thereby, improving the soil structure (Hernando et al., 1989). Addition of mature MSW compost increased aggregate stability in silt loam soil (Annabi et al., 2007). In a field trials experiment, applying MSW compost as an organic soil amendments lead to increase in agricultural production, improving soil physical properties and increasing both water retention and the supply of essential nutrients (Rosen et al., 1993; Raviv, 1998; Lal, 2006).

The soil moisture retention benefits of compost applied to soils are well documented. The organic matter in these compost additions has the ability to absorb relatively large amounts of water (Edmeades, 2003). The soil moisture levels increased in MSW compost treated areas in both broad-acre and horticultural soils indicating the material is performing as would be expected of high quality compost.

Effect of MSW compost on chemical soil properties

Effect on pH and Electrical Conductivity

Municipal solid waste compost generally contains high salt concentrations, which can inhibit plant growth and negatively affect soil aggregation (Hargreaves et al., 2008). Application of different amendment of municipal solid waste (viz. kitchen waste) compost found significant effect on pH which may be due to the mineralization of carbon and subsequent production of hydroxyl (OH-) ions by ligand exchange as well as the introduction of basic cations, such as K+, Ca+2, and Mg+2. Plants are negatively affected by excess salts in soils and Na can be detrimental to soil structure (Machado and Serralheiro, 2017). Electrical conductivity (EC) of the soil solution is related to the dissolved solutes content of soil and is often used as a measurement of soil salt content (Brady and Weil, 1996). MSW compost was found to be an ideal component of mixed-peat substrates for tomato seedlings, provided that it accounts for less than half the mixture (30% MSWC and 65% peat) (Herrera et al., 2008). These proportions reduce the negative effects of high pH and EC on seedling growth, and provide a seedling comparable to that obtained using standard peat-based mixtures.

Effect on Organic Carbon

Application of different amendment of municipal solid waste compost has significant effect and increase the organic carbon content in soil over the years (Zinati, et al., 2001). A survey of MSW compost reported that on average, 20% of the total C in MSW compost was organic C, 8% carbonate C, and 71% residual C which may have included organic C components (He et al., 1995). Further more, the majority of the humic substances found in MSW compost were identified as humic acid, with a humic acid to fulvic acid ratio of 3.55 (He et al., 1995). Humic acid is generally considered to be more stable than fulvic acid and has been associated with increasing the buffering capacity of soil (Garcia-Gil et al., 2004). When MSW compost was applied to soil at application rates of 20 and 80 Mg ha-1, the major structural units of humic acid in MSW compost were incorporated into the humic acids in the soil. The change in soil structure persisted and was structurally changed with long-term application. Repeated application of MSW compost consistently increased soil organic matter content and soil C/N ratio to levels greater than those of unamended soil (Montemurro et al., 2006; Walter et al., 2006).

Soil organic carbon plays a major role in maintaining soil quality. In addition to supplying plant nutrients, the type and amount of soil organic matter influences several soil properties (Araujo et al., 2008). Amendments of cropped plots with MSW compost increased the contents of organic C from 13.3 to 15.0 g kg-1 soil (Crecchio et al., 2004). Utilization of MSW compost in agricultural land increase the soil organic matter, improves soil properties, and reduces soil erosion, increases plant productivity and soil microbial biomass. Thus, in the regions where organic matter content of the soil is low, agricultural use of organic compost is recommended for increasing soil organic matter content and consequently to improve and maintain soil quality (Liu et al., 2006).

Effect on Nitrogen, phosphorus and Potassium

Application of different amendment of municipal solid waste compost was found to have significant effect on nitrogen content. It may be due to mineralization of organic N in compost and is dependent on many factors including C/N ratio of raw material, composting conditions, compost maturity, time of application, and compost quality (i.e., C/N ratio and C- and N-fractions) (Amlinger et al., 2003). Cropped plots amended with MSW compost increased their organic C content; the influence of MSW compost on the total N content was more evident when double the amount of compost was added to soil and was comparable to the effect of the NH_4NO_3 treatment (Crecchio et al., 2001).

Amendment of municipal solid waste compost found significant effect to phosphorus. Due to the competition between organic ligand and phosphate for sites on metallic oxides as well as the formation of phosphohumic complexes increase P mobility (Oburger et al., 2011). Compost from Katowice (CK) and Zywiec (CZ) caused a large increase of plant-available P, K in sandy soil cultivated in a 3-year monoculture with Triticale (X Triticosecale) (Weber et al., 2007). Soil K concentrations were also increased in all the season and significantly affect the soil potassium when different rates of MSW compost are used. The same patterns are agreement with (Giusquiani et al., 1988) where increased K content was reported for soils treated with MSW compost. A pot experiment was conducted to compare the effects of compost and mineral fertilization on the growth and chemical composition of ryegrass (Lolium perenne L.) and increases in soil K was observed in treatments with compost in addition to other micro and major nutrients (Soumare et al., 2003).

Effect on other essential elements

In small amounts, many of the trace elements (e.g., boron, zinc, copper, and nickel) are essential for plant growth. Application of municipal solid waste compost on soil significantly increased the concentration of available Mn, Cu, Zn and Fe (Roghanian et al., 2012). However, in higher amounts they may decrease plant growth. Other trace elements (e.g., arsenic, cadmium, lead, and mercury) are of concern primarily because of their potential to harm soil organisms and animals and humans who may eat contaminated plants or soil (Woodbury, 2005). The impact of metals on plants grown in compost amended soils depends not only on the concentration of metals, but also on other soil properties such as pH, organic content and cation exchange capacity. Different types of plants also react differently to metals which may be present in the compost amended soil.

Effect of MSW compost on soil biological properties

Composting is a microbiological process, little is known about microorganisms involved and their activities during specific phases of the composting process. Defining the diversity and structure of microbial communities of compost through their constituent populations has been of considerable interest to compost researchers. In order to address basic ecological questions such as how similar are microbial communities in mature compost that were made from different feedstocks and using different composting methods (Tiquia and Michel, 2002). Composting is a spontaneous biological decomposition process of organic materials in a predominantly aerobic environment. During the process bacteria, fungi and other microorganisms, including micro arthropods, break down organic materials to stable, usable organic substances called compost (Bernal et al., 2008). It is also known as a biological reduction of organic wastes to humus or humus like substances (Gautam et al., 2010). Municipal solid waste (MSW) is largely made-up of kitchen and yard waste, and its composting has been adopted by many municipalities (Otten, 2001). Composting of MSW is seen as a method of diverting organic waste materials from landfills while creating a product, at relatively low-cost, that is suitable for agricultural purposes.

Soil ecological studies are increasingly being used to evaluate soil quality. It is thought that soil microbiological properties are most sensitive to changes in the soil environment (Pankhurst et al., 1997; Crecchio et al., 2001). Biomass N, C, and S showed increase in the soil immediately after compost addition and for up to one month, while biomass P showed an increasing trend for 5 months (Perucci, 1990). Application of MSW compost increased soil microbial biomass C and soil respiration (an index of general metabolic activity of soil microorganisms) when compared to a control (Bhattacharyya et al., 2003). Soil basal respiration rate, a parameter used to monitor microbial activity, was also seen to increase where MSW compost was applied when compared to a control.

Another measure of soil microbial health is the activity of soil enzymes involved in the transformation of the essential nutrients (Crecchio et al., 2004). After application of MSW compost, the enzyme activities of phosphodiesterase, alkaline phosphomonoesterase, arylsulphatase, deaminase, urease, and protease were increased (Perucci, 1990; Bhattacharyya et al., 2003). The activity of phosphatase remained constant in the soil after reaching its maximum value, and so it may be concluded that MSW compost may stimulate the transformation of organic P to its inorganic and available form. Application of MSW compost has significant increase soil enzyme activities such as dehydrogenase (9.6%), b-glucosidase (13.5%), urease (15.4%), nitrate reductase (21.4%) and phosphatase (9.7%) activities (Crecchio et al., 2004). Enzyme activities of arylsulphatase, dehydrogenase, and L-asparaginase have also been seen to increase with the addition of MSW compost, with application rates up to 90 Mg ha-1, while the activities of phosphodiesterase and phosphomonoesterase increased linearly with increasing application rates (Giusquiani et al., 1994). Dehydrogenase activity was affected in the long-term when MSW compost was applied at low rates (Pascual et al., 1999). Increases of urease and acid phosphatase activities were observed in soils treated with 2.5–40 Mg ha-1 and were proportional to MSW compost application rate (Bhattacharyya et al., 2003). In a long term field experiment, MSW addition increased biomass C by 10 and 46%, dehydrogenase and catalase, by 730 and 200%, respectively over the control at crop harvest were measured after nine years (Garcıa-Gil et al., 2000).

The enzyme activities of β-glucosidase and nitrate reductase have also been reported to increase with the addition of MSW compost when compared to a control (Crecchio et al., 2001). Some enzyme activities were reported to decrease where MSW compost was applied. For example, protease activities were found to decrease where only 24 Mg ha-1 MSW compost was applied, probably reflecting the low protein content of the product (Crecchio et al., 2004). Furthermore, it was found that the addition of MSW compost at 20 and 80 Mg ha-1 in hibited the activity of urease and protease (Garcia-Gil et al., 2000). The decrease, in both cases, was attributed to the potential toxic effects exerted by trace elements in this particular compost. A significant reduction in protease activity (from 3.6 to 2.8 μg/ g soil) was measured when a double dose of compost (24 t ha-1) was added to the cropped plots which may due to the fact that protease was probably more sensitive to the amounts of heavy metals introduced into the soil plots by compost amendments than were the other enzymes assayed (Crecchio et al., 2004). Variability of metal levels in MSW compost somewhat hinders the ability to directly compare studies because of the sensitivity of soil microorganism to heavy metal.

The effect of trace elements in MSW composts on soil organisms such as invertebrates (e.g., earthworms) and microorganisms (e.g., nitrogen-fixing bacteria) is largely unexplored. When sewage sludge is applied to land, the concentration of some trace metals (e.g., cadmium) in earthworms is increased, but this increase does not pose a significant risk to the worms or to wildlife that consumes them based on the risk assessment performed for sewage sludge. There is contradictory evidence as to whether metals in MSW composts may harm soil microorganisms, including nitrogen-fixing bacteria.

Heavy metals occurrence in MSW compost

Heavy metal loading in MSW and its bioavailability

Municipal solid waste compost is increasingly used in agriculture not only used as a soil conditioner but also as a fertilizer. Proponents of this practice consider it an important recycling tool since MSW would otherwise be land filled and critics are concerned with its often elevated metal concentrations. The main sources of heavy metals in the dumping sites are garden pesticides, pharmaceuticals, photographic chemicals, certain detergents, personal care products, fluorescent tubes, waste oil, batteries, wood treated with dangerous substances, electronic waste, electrical equipments, and paint etc. generated at the household (Slack et al., 2009). Composts made from the organic material in solid waste will inevitably contain these elements that have detrimental effect on the environment.

Large amounts of compost are frequently used in agriculture to meet crop N requirements and for the addition of organic matter. The main concern is loading the soil with heavy metals that can result in increased metal content of crops. Furthermore, in some cases, metals and excess nutrients can move through the soil profile into groundwater. Many researchers agree that bioavailability should be addressed in the guideline limits, in addition to metal loading. For agriculture, complete examination of metal bioavailability in soils exhibiting a range of the factors affecting plant uptake is necessary. These factors include pH, cation exchange capacity (CEC), organic matter content, soil structure, and soil texture (Pinamonti et al., 1999). The main effects of MSW compost application may have on increased soil pH and organic matter content (Deportes et al., 1995; Mkhabela and Warman, 2005). A fraction of the added organic matter is resistant to decomposition but some of the humic substances eventually decompose releasing metals bound in this fraction. Rather, it is thought that the inorganic elements in the compost such as the phosphates, silicates, Fe, Al, and Mn oxide most likely provide long-term retention of metals demonstrating the need for long-term experiments (McBride, 1995).

The effect of MSW compost application leads to continuous accumulation of heavy metal into the soil (Richard, 1992). Large amounts of MSW composts are applied to agricultural soils, in which half of the organic matter may decompose within one or two decades. Metal concentrations in soil are unlikely to exceed the concentration present in the original compost, unless very large amounts of compost high in organic matter are applied. Over time, metals generally become less available to plants and other organisms unless soil pH decreases greatly or the soil is flooded for a long period of time.

Potential adverse effects of heavy metals and metalloids in MSW compost is well established, there are also potential beneficial effects for agriculture and horticulture. Soils that have been cropped for many years may be deficient in nutrients such as boron, zinc and copper, and MSW compost could mitigate such deficiencies of micronutrients. MSW compost may also limit harm to plants by tying up trace pollutants and toxic organic compounds.

Management of heavy metals in MSW

The presence of heavy metals in the MSW compost can be management using the strategies such as bioremediation. The microbes cannot degrade heavy metals directly but they can change the valence states of metals rendering them immobile or less toxic. Microorganisms destroy the organic pollutants present in the compost as a source of nutrient or energy source for their own growth and reproduction utilizing carbon for cell building materials (Abatenh et al., 2017). The most important parameters that influence the process of bioremediation are nature of pollutants, pH, moisture content, nutritional state, microbial diversity of the site, temperature and redox potential. Bioremediation in combination with phytoremediation and rhizoremediation contribute significantly in the removal of unwanted compounds from the biosphere

Besides bacteria, fungi also play an important role for remediation of contaminated soil with heavy metals. In biotransformation and biosorption, microorganisms are used to transform or adsorb metals. Intact microbial cells, live or dead, and their products can be highly efficient bioaccumulator of heavy metals. The fungal biomass contains a relatively higher percentage of cell wall materials that are excellent metal binder. Suitable biotechnological method and proper configuration may enhance bio-sorption of heavy metals from the municipal solid waste by using potential fungi.

Implication on overall soil health and sustainability

The application of MSW compost increased soil organic matter, N, P and stable aggregates and also showed a positive response of plant growth to application. The sources of heavy metals found in all MSW compost such as Cd, Cu, Pb and Zn and there are obvious concerns about such toxic elements entering the food chain through food crops leads to biomagnifications of food chain (Gillet, 1992). Heavy metals are not biodegraded by process of composting, and can become concentrated due to the loss of carbon and water from the compost due to microbial metabolism or respiration. However, Araujo and Monteiro (2006) reported a decreasing in heavy metals (HMs) content in textile sludge as a result of composting. The application of MSW compost in soil can promote changes in soil microbial biomass and activity, mainly due heavy metals content. The soil microbial biomass is an important indicator in the heavy metal contaminated soil by application of MSW compost.

Organic materials amendment in soil, such as MSW compost, promotes soil microbiological activity, but the presence of potential toxic heavy metals is of much concern (Bundela et al., 2010). An appreciable amount of heavy metals in MSW Compost does not seem to have any detrimental influence on microbiasscrobial biomass present in the organic residues and the addition of substrate C, which stimulates the indigenous soil microbes. Effect of heavy metals on soil microbes depends on soil as well as MSW characteristics and its amendment rates.

Sewage sludge as well as MSW compost contains valuable plant nutrients and organic matter that can improve soil fertility and overall soil health. The phyto-nutritive capacity of compost has often been demonstrated to be analogous to that of manure; the same level of productivity, both quantitatively and qualitatively, can be maintained by replacing manure with compost (Beyca et al 1993; Roe et al, 1993). However, sewage sludge and MSW compost often contains potentially toxic elements that can cause soil pollution, phytotoxicity and undesirable residues in plant and animal products (Alloway and Jackson, 1991). As a matter of fact, pollution problems may arise if toxic metals are mobilized into the soil solution and are either taken up by plants or transported in drainage or ground waters. In the long term, the use of sewage sludge and MSW compost can also cause a significant accumulation of Zn, Cu, Pb, Ni and Cd in the soil and plants (Mulchi et al, 1991).

Heavy metal pollution of agricultural soils and crops through the application of MSW compost as organic fertilizers is of great concern. Since mobility, environmental diffusion and bioavailability largely depend on soil physico-chemical characteristics and, likewise, on trace metal chemical forms that dictates the toxicity of metals in the soil environment system. From an environmental point of view, the evaluation and forecast of food contamination is related to the bioavailable fraction of heavy metals in soil.

Conclusion

Composting municipal solid waste (MSW) is becoming increasingly recognized as a viable and economical method for waste management. Composting has advantages over land-filling and incineration because of lower operational costs, less environmental pollution, and beneficial use of the end product. Municipal solid waste compost significantly influences the soil physico-chemical properties and promotes microbiological activity, but the presence of potential toxic heavy metals is of much concern. There are, however, some uncertainties about potential health hazards resulting from excessive MSW compost application to agricultural lands. It was observed that the positive effects resulting from compost application far outweigh than the negative effects, but more research is needed on a wide range of MSW composts with more precise determination of the fate of MSW compost-applied trace elements in the environment.

Conflict of Interest: None

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