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Potential Effects of Organic Waste Composts on Soil, Plant and Environment

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Abstract: *Heavy metal accumulation can be seen in soils where organic waste compost is applied, which is undesirable for plant production, environment and consumers and carries a risk in terms of sustainable soil management. According to risk-based approach there have been updated regulations and guidelines for the agricultural use of sewage sludge. It is generally accepted that treatment sludge carries a manageable risk for crop production, the environment and consumers, provided that the relevant legal regulations are complied with in the application of sludge. Currently, there is no internationally accepted standard or regulation specific to municipal solid waste compost quality criteria. Standards for heavy metal pollutants in municipal solid waste compost vary widely between countries, depending on the approaches taken in regulating compost quality. Due to the similarity of municipal solid waste compost to sewage sludge in many respects, most of the information obtained about sewage sludge can be applied to municipal solid waste compost.*

Keywords: Organic waste compost, metals, regulations

1. Introduction

Organic waste composts (mainly sewage sludge and municipal solid waste) contain significant amounts of organic matter, some lime, and macro and micro plant nutrients. For this reason, these materials are sometimes accepted and used as substrates and sometimes as soil improvement agents or fertilizers in agricultural use. The agricultural use of sewage sludge compost (SS) and municipal solid waste compost (MSWC) provides environmental benefits in terms of waste reduction and disposal, as well as economic benefits in terms of soil fertility and crop production, with the recovery of organic matter and plant nutrients in these materials. However, there are problems in the use of these materials in agriculture due to the inclusion of pathogenic organisms and heavy metals and many other chemical pollutants in the soil. Heavy metals (especially Pb, Cd, Cu and Zn) accumulations were determined in many soils where these materials were applied. Pollution of the soil with these elements deteriorates the quality of surface waters and groundwater, as well as increasing the entry of toxic metals into the food chain, reducing the quality of the soil and its sustainable use.

One of the concerns encountered in organic waste compost applications is that heavy metals and metalloids, which are mostly found in low concentrations in these materials, can adversely affect plant growth, soil organisms, water quality, and human and animal health.

In this review, a brief evaluation of the effects of compost and sewage sludge applications on soil fertility, plant growth, soil organisms and water quality, and evaluation of standards and application criteria in this regard are included.

2. Heavy Metals in Organic Waste Compost

Heavy metals are elements with atomic weights ranging from 63,546 to 200,590 [1] and specific gravity greater than 4 [2]. Many heavy metals and metalloids are present in trace amounts in soil and water in the natural state. These trace elements are naturally added to soil and water as a result of the weathering of rocks. Heavy metals can be leached into surface waters or groundwater, taken up by plants, mixed with the atmosphere as gas, or adsorbed by soil colloids such as clay and organic matter. Soils are a part of the biological equipment in terms of heavy metals and trace elements, and at the same time, it is the final storage area of large amounts of these compounds [3].

The heavy metal composition of organic waste composts can vary widely depending on the urban environment and industrial resource inputs. Metal sources in solid wastes can be mostly batteries, various electronic devices, ceramics, light bulbs, house dust, paint chips, used engine oils, plastics, some inks. Metal sources in wastewater are mostly detergents, biocides, various industrial wastewater and chimney emissions, automobile exhaust gases and various fertilizers. Composts produced from organic matter contained in solid waste inevitably contain heavy metals, which are in low concentrations in this material and although many sources have been removed. Heavy metals in the sewage sludge are concentrated in the sewage sludge with the wastewater coming from many different sources to the treatment plant [4].

Living organisms require trace amounts of some heavy metals such as cobalt, copper, iron, manganese, molybdenum, vanadium, strontium and zinc. However, excessive levels of these substances can be harmful to the organism. In small quantities, most of these trace elements (Iron, boron, zinc, copper, molybdenum) are essential for plant growth, although high concentrations of these elements can reduce plant growth. Other trace elements (eg, arsenic, chromium, nickel, cadmium, lead, and mercury) are of primary interest because of their potential harmful effects on soil organisms and humans and animals who may eat contaminated plants.

The effect of metals on plants grown in compost appied soils depends not only on the concentration of metals, but also on soil properties such as pH, organic matter content and cation exchange capacity. At the same time, different types of plants can react very differently to metals that can be found in the environment (Tirmizi et al., 1996).

3. Effects of Waste Compost on the Physical and Chemical Properties of Soil

Concentrations of potentially harmful trace elements in MSWC and SS are almost, with very few exceptions, higher than their typical concentrations in soil. In addition to nitrogen and phosphorus, MSWC and SS also contain essential nutrients for plant growth such as calcium, potassium, magnesium, sodium, iron, manganese, and zinc. In addition to the potential harmful effects of heavy metals and metalloids in MSWC and SS, they also have potential beneficial effects such as providing essential nutrients to the soil. It has been reported that when SS is applied in agronomic amounts for nitrogen and phosphorus nutrients, it will provide most of the other absolutely necessary nutrients with the possible exception of potassium [5]. Soils where cultivated crops have been grown for many years may become poor in terms of plant nutrients such as boron, zinc and copper due to plant consumption [6], and it has been reported that MSWC and SS applications can reduce such deficiencies [7]. The concentrations of trace elements in the soil generally increase with the treatment sludge applications, and the metal contents in the plants increase with the increasing sludge loading into the soil [8, 9].

Among the benefits of using organic waste compost are the positive changes in physical and chemical characteristics such as increased water holding capacity of the soil, structure development, and increased KDK levels due to increased organic matter and its humusification levels in the soil. However, most waste composts have a high salt concentration and, with prolonged use, a significant accumulation of salt can be seen in the soil. This may also cause serious physical and chemical soil problems such as ion toxicity and structural deterioration.

Certain elements in sludge (eg salts, Cd, Cu, Ni and Zn) can be phytotoxic when applied to soil above critical levels. If trace elements and trace organics in SS are taken up by the product at a level that will be harmful to consumers, it is very likely that they will act in the plant-animal-human chain and cause toxic effects to humans. It has been reported that the Cd content of most plants grown in highly sludge-treated soil is well above the level suitable for animal consumption [8]. On the other hand, as contrasting findings, the use of sewage sludge did not cause dangerous increase in heavy metal contents of the tested plant species and the levels were within acceptable range [9].

4. Effects of Waste Compost on Soil Microorganisms

There is little information in MSWC about the effects of trace elements on invertebrates and microorganisms. When sludge is applied to the field, the concentration of some trace metals (eg cadmium) increases in earthworms; however, this increase does not present a significant risk to earthworms or the wildlife that consumes it, based on the 'Risk Assessment' and implementation criteria for SS. It is even known that low metal content organic waste compost applications generally increase microbiological activity. The accumulation of metals in SS applied soils can inhibit the activity of Rhizobium and Cyanobacter species and cause decreases in microbial biomass. There are conflicting findings in the literature about whether metals in MSWC can be harmful to soil organisms, including nitrogen-fixing bacteria.[2].

5. Effects of Waste Compost on Water Quality

In addition to affecting plant and animal health, trace elements in MSWC can be washed from the soil and enter surface and groundwaters. Soil pH, organic matter content and other soil characteristics affect the extent of leaching. While data on the leaching of heavy metals from soils in MSWC are quite rare, information from long-term applications of SS has revealed that leaching rate is generally low [10]. The leaching of metals into groundwater is only likely if it occurs in sandy soils with extensive and repeated applications of MSWC for many years, or when conditions that limit the adsorption of heavy metals in the soil are created.

It has been reported that the mobility of heavy metals in soil is generally low and their transport to groundwater is not likely to be seen with agronomic sludge applications, and sludge-derived trace elements tend to be concentrated at the surface depth of the soil [7]. However, the presence, transport and fate of such potentially harmful elements in the environment is always a concern. In addition, the mobility of heavy metals added to the soil in the soil and their reactions with various soil components also affect their mixing into the ground waters. Metals from MSWC and SS applications can easily infiltrate surface and groundwater if they are not immobilized in the surface soil.

6. Regulatory Pollutant Limits on Heavy Metals in Soil and Waste Composts

Limit values have been determined for both sewage sludge and soils within the framework of the 'Treatment Regulation' in order to prevent plants from containing high amounts of heavy metals and significant heavy metal accumulation in soils depending on SS and MSWC applications. The regulations of the European Union and US Environmental Protection Agency (EPA) regarding the content and application-related pollutant limit values in soils and sewage sludge are given in Table 1 and Table 2.

TABLE I. Limit Values for Heavy Metals in Soil [11]

	mg/kg, in oven dry soil
Pb	300
Cd	3
Cr^{+3}	400
Cr^{+6}	-
Cu	At pH 5.0-5.4 = 80 At pH 5.5-5.9 = 100 At pH 6.0-7.0 = 135 At pH 7.1 + = 200
Ni	At pH 5.0-5.4 = 50 At pH 5.5-5.9 = 60 At pH 6.0-7.0 = 75 At pH 7.1+ = 110
Zn	At pH 5.0-5.4 = 200 At pH 5.5-5.9 = 250 At pH 6.0-7.0 = 300 At pH 7.1+ = 450
Hg	1
As	50
Se	3

TABLE II. Regulations on Treatment Sludge to be Used in Soil [12]

	SS metal limits	Annual Pollutant Loading Rate (based ona ten year period) (kg/ha/year)	Average monthly concentration limits of SS (mg/kg)	Cumulative Pollutant Loading Rate of SS (kg/ha)
Pb	840	15	300	300
Cd	85	1.90	39	39
Cr	-	-	1500	1500
Cu	4300	75	420	420
Ni	420	21	2800	2800
Zn	7500	140	17	17
Hg	57	0.85	41	41
As	75	2.0	100	100
Se	100	5.0	300	300

Due to the similarity of MSWC to SS composts in many respects, much of the information available on SS can be adapted to MSWC. However, regulations and policies on the composting of solid waste are still controversial. There is no internationally accepted regulation to be applied specifically to MSWC. However, there are regulations that some countries have prepared according to their own norms. It is noteworthy that some countries have adopted a very protective approach in these regulations (Table 3).

TABLE III. Heavy Metal Pollutant Limits of MSWC Used in Various European Countries [13].

	Concentration (mg/kg)				
	Cd	Cu	Cr	Pb	Hg
Austria	4	400	150	500	4
Belgium	5	100	150	600	5
Denmark	1,2	1000	100	80	1,2
Germany	1	75	100	100	1
Italy	3	200	150	200	2
Holland	0,7	25	50	65	0,2
Spain	40	1750	750	1200	25
Switzerland	3	150	150	150	2

According to the regulations of the EPA and various countries, the following practices are required for heavy metal contents in SS and MSWC [14].

1. As a result of soil analysis, SS and MSWC should not be applied to the soil in question if the heavy metal contents in the soil exceed the permissible limits.
2. Public and private institutions operating a high capacity (50 tons/day) treatment plant are required to document their SS analysis on a daily basis.
3. Metal analyzes of the produced solid waste compost should be done at maximum three-month intervals.
4. In case of exceeding the pollutant limits in waste compost, it should not be applied to the land.
5. The determined monthly average pollutant concentrations of the sewage sludge should not exceed the permissible values.
6. The cumulative pollutant load of the waste compost given to the land should not exceed the permissible limits in the 10-year period.

7. Regulation of Waste Compost Quality

Because waste composts are produced from different sources and contain various pollutants as well as the variability of their content, quality regulation is required before use. Various options are used for regulation of compost quality. A "Risk-Based" approach is the most popular approach in the regulation of land applications of SS. In this approach, a risk analysis of the potential environmental and health hazards of various chemical and pathogenic pollutants has been prepared and the numerical limits for each pollutant have been arranged to such an extent that the 'no observed adverse effect level' is adequately provided [15]. Products that meet these standards can be applied without limitation. In another frequently applied 'no net degradation' approach, the long-term preservation of soil fertility is based on the principle that certain pollutants do not increase above the background levels of the soils [16]. All these approaches are very stringent standards in practice that require composting with selected clean organic wastes.

There is very little research and analysis on MSWC that would be useful. While there are many similarities between sludge and solid wastes-derived composts, there are also some important differences. Among the most important differences are the bioavailability of metals, the ratios between different metals, and the higher potential application rate for compost. Even if the legislators have agreed on a certain approach, the transformation of current scientific findings into legal regulations requires interpretation and there is no generally accepted regulation yet [16]. The differences between the 'Risk Based' and 'no net degradation' approaches in the regulation and classification of compost quality are quite large (Table 4).

TABLE IV. Comparison of Risk-Based and No Net Degradation Standards for Metals in Compost [17]

	Risk-Esaslı (mg/kg)		Net Olmayan-Ayrışma (mg/kg)	
	Florida	New York	Switzerland	Ontario
Pb	500	250	150	150
Cd	15	10	3	3
Cr	-	1000	150	50
Cu	450	1000	150	60
Ni	50	200	100	60
Zn	-	10	3	0,15
Pb	900	2500	500	500

8. Uncertainties and Concerns in Using Waste Compost

Because the composition of SS and MSWC varies widely and their sources (urban environment and its industrial resource inputs), heavy metal and toxic compound contents are seen as limiting factors in the agricultural use of these wastes. As organic matter decomposes, the concentration of metals can increase in the compost and in the soil it is applied to. If waste compost is not applied to the soil in large quantities, it is not likely that the metal concentrations in the soil will reach the danger limits. In addition, if the soil pH does not decrease greatly or the soil is not flooded for a long time, it is predicted that the mobility of metals will remain low and will not pose a risk to the environment. However, heavy metals and toxic compounds can reach higher levels over time with repetitive applications of waste compost at agronomic rates; and thus, it is inevitable to encounter the irreversible problems of bulk loading of trace elements and toxic compounds in any soil in long-term effects. As with other agricultural soil applications, the use of sludge requires appropriate management to avoid pollutant ingress into surface and groundwater, and further, the long-term heavy metal loading effect of the sludge should be considered in subsequent applications.

In terms of safe use, it has been adopted to implement the MSWC in line with the directive in the sewage sludge regulation. For many heavy metals and metalloids, the levels in MSWC compost are lower than the newly adjusted APL (Alternative Pollutant Limits) values in the standards for sewage sludge. With the notable exception of lead, the MSWC generally meets these limits [14]. However, MSWC compost generally contains less organic matter, nitrogen and phosphorus compared to SS and shows significant differences in organic and inorganic toxic substance content. It is considered that it will be absolutely necessary to rearrange these values developed for SS for MSWC compost.

Conclusion

The production of organic wastes from various urban uses as waste compost by processing is important in terms of both waste disposal and recycling and the economic benefits of these products. Waste compost can be produced from many different sources and its content can vary greatly depending on the time and the place where it is produced. Heavy metals and various organic pollutants can be found in waste compost and can cause significant problems for soil quality and sustainable agricultural production and the environment in long-term use. While there are regulations for SS in the use of waste composts, specific accepted criteria for MSWC have not been established yet, but various countries have their own norms-specific assessments. The variability in the content of waste compost requires the standardization of these products before use.

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