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Original Research

Physical and Chemical Characterization of Municipal Solid Waste Compost in Different Particle Size Fractions

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Abstract

Particle size fractions, varying from 1.6 to 0.1 mm, were separated from samples of municipal solid waste (MSW) compost. Several physical and chemical parameters of the samples with different particle sizes were measured. The results indicated particle size fractionation changed the physical properties and chemical component distribution of compost. Bulk density of the compost increased as particle size decreased. However, with the decrease of particle size there is a trend to decrease some soil parameters as pH, porosity, saturated water holding capacity, organic content, and Ca, Fe, Mg, and Mn contents. Higher organic content was found in fractions of diameter exceeding 0.4 mm, and total N content was higher ($P<0.05$) in fractions of diameter exceeding 0.8 mm than <0.8 mm fractions. Phosphorus was mainly distributed in coarse fractions larger than 0.8 mm, but K was concentrated in fine fractions of <0.8 mm. Calcium, Fe, Mg, and Mn contents in fractions >0.8 mm were higher ($P<0.05$) than those in fractions < 0.4 mm and control. Heavy metal concentrations in individual particles have strong particle size dependence. Lead was largely contained in fractions <0.8 mm, 244% higher than in >0.8 mm fractions. High Cu content was observed in the size range of 0.2-0.4 mm and 0.8-0.4 mm, with the maximum of 1,317 $mg \cdot kg^{-1}$ in the range of 0.8-0.4 mm. Zinc concentration was found to be the lowest in the range of 1.6-0.8 mm as compared to other fractions and control. No significant differences in Cd content were found between each treatment and control. Chromium and Ni were associated with the <0.8 mm particles more than any other fractions, and their concentrations were 177% and 140% higher than other particle sizes obtained, respectively. Based on the physical and chemical properties of different compost fractions used in this experiment, it is observed that coarse compost particles larger than 0.8 mm have considerable potential in agricultural applications as soil amendments.

Keywords: MSW compost, particle size fraction, physico-chemical properties, nutrient element, heavy metal

Introduction

There is a rapid increase in the amount of municipal solid waste (MSW) due to the rise in population and economic development. In China, more than one hundred million tons of MSW are generated every year and two-thirds of Chinese cities are encircled by MSW [1]. In the world, the MSW disposal has three primary ways such as landfilling, incineration, and composting. MSW composting has proved to be a safe and effective way to reduce MSW in

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large quantities and produce a stable humus-like material beneficially reused as a soil amendment [2-5]. As an alternate soil amendment, MSW compost is gaining high popularity. This should make up for the effective disposal of solid waste through the recycling of a potential resource for soil amelioration [6]. Many studies have shown that compost may improve soil quality by increasing nutrient and water holding capacity, organic matter and cation exchange capacity, and providing different kinds of microelements to further improve crop yield and quality [7-11]. However, MSW compost may also have some negative effects on the agricultural environment due to their content of potentially hazardous heavy metals [2, 12-14]. Achiba et al. [15] reported that a 5-year application of municipal solid waste compost increased the content of organic matter, total nitrogen content and electrical conductivity while increasing the total concentration of heavy metals in the soil. Jordão et al. [16] found that the application of composted urban solid wastes to soil increased the available concentrations of Cu, Pb, and Ni in the soil according to the increase of the doses of the compost used. Businelli et al. [17] found that the municipal waste compost amendment resulted in a significant enhancement of the metal loadings in the amended topsoils, particularly for Cu, Zn, and Pb.

At present, many studies on MSW compost have been focused on bulk compost applications. There has been little report on separation of different compost fractions and their application in the literature. Studies showed that the contents of organic matter and mineral elements in soil varied greatly with different particle sizes [18, 19]. Christensen and Olesen [20] found that the content of N varied in different particle sizes after compost applied in three kinds of soil. Because the fine particle size had great specific surface area and strong adsorption ability, the nutrient elements and heavy metals were primarily enriched in the minute particle sizes of soil [21-23].

A high concentration of heavy metals in MSW compost limits its application in agriculture. Moreover, different ranges of particle sizes have different characteristics. Therefore, the present research is carried out to screen the bulk compost in order to remove unwanted particles with high heavy metal concentrations and low nutrient content, and use MSW compost effectively and environmentally safely. The objectives of the present study are to investigate physical properties of different compost size fractions, to investigate the distribution behavior of nutrient elements and heavy metals among compost fractions, and to achieve some basic understanding about nutrient and heavy metal distribution in different MSW compost fractions.

Materials and Methods

About 10 kg MSW compost samples composed of five subsamples (2 kg each) were collected from Tianiin Xiaodian MSW Disposal Plant. The MSW feedstock consisted of organic waste, inorganic waste, and recoverable waste, including 40% food waste, 4.2% plastics, 6.5% paper, 1.0% glass, 0.8% metals, 0.6% fabric, and 46.9% brickbat and dust. The compost was produced at a full-scale composting reactor that processed 400 tons of MSW per day through aerobic transformation of MSW. Throughout the process, the reactor was aerated and cooled with forced air. Moisture content was maintained at a level of 50 and 60% and temperature at 55-65ºC. After 45 days' composting, the cured compost was size separated to remove >25 mm particles and piled in a 4 m high windrow for final curing. After 20 days, the compost was size separated to remove >12 mm particles.

After collection, the compost subsamples were mixed thoroughly and aggregated into one sample for further experiments. The bulk sample was air-dried and sieved by hand with a nest of flat sieves that consisted of 5 aperture sizes: 1.6 mm, 0.8 mm, 0.4 mm, 0.2 mm, and 0.1mm to separate fractions in the size ranges of >1.6 mm, 1.6-0.8 mm, 0.8-0.4 mm, 0.4-0.2 mm, 0.2-0.1 mm, and <0.1 mm. The bulk sample was reserved as control. Treatments were replicated three times. The basic physical and chemical properties of bulk compost were organic matter 22.0%, bulk density 0.75 g/cm^{-3}, pH value 7.62, porosity 68.0%, saturated water holding capacity 66.6%, total N 0.57%, total P 0.34%, total K 1.21%, Ca 30.6 g·kg^{-1}, Fe 20.0 g·kg^{-1}, Mg 5.78 g·kg^{-1}, Cu 546 mg·kg^{-1}, Zn 535 mg·kg^{-1}, Pb 164 mg·kg^{-1}, Cd 2.06 mg·kg^{-1}, Mn 325 mg·kg^{-1}, Cr 89.9 mg·kg^{-1}, and Ni 76.3 mg·kg^{-1}.

Bulk density (B_d) was measured by obtaining the dry weight of a known volume of the sample. Bulk density was calculated by the following formula [24]:

$$B_d = M_s/V_t \qquad (1)$$

...where M_s is mass of oven dry compost (g), and V_t is total volume of compost (cm^3). Particle density (P_d in g·cm^{-3}) was measured using the water pycnometer method [25]. Total porosity (T_p) was obtained from bulk density with particle density values as follow:

$$T_p = 100\ (1\text{-}B_d/P_d) \qquad (2)$$

The saturated water holding capacity is defined as water content when all pores are filled with water, which was determined by the following method. A special container with a hole in its bottom was filled with a compost sample. A piece of filter paper was put into the container to block the hole. Then the container was put into water (with height 1-2 mm lower than the container) to make the compost adsorb until saturation (about 24 h). The compost sample was taken out, weighed (W_1) and oven-dried. Dry weight (W_2) was weighed. Saturated water holding capacity (θ_s) was calculated by the difference of two weights.

$$\theta_s\ (\%) = (W_1 - W_2) / W_2 \times 100 \qquad (3)$$

Compost pH was measured in distilled water (free of CO_2) using 10 g of compost sample and 25 ml distilled water (ratio 1:2.5). The suspension was agitated for 3-5 min and placed for half an hour before measuring the pH value with a glass membrane electrode. Organic matter content

Table 1. Some physical characteristics and pH values of different compost particle size fractions. Means and standard deviations (n=3) are presented.

Compost particle size	pH	Bulk density	Porosity	Saturated water-holding capacity
(mm)		($g \cdot cm^{-3}$)	(%)	
Control	7.62±0.01[d]*	0.75±0.01[d]	68.0±0.7[a]	66.6±0.9[b]
>1.6	7.85±0.01[a]	0.75±0.01[d]	68.8±0.6[a]	71.4±0.8[a]
1.6-0.8	7.79±0.00[b]	0.76±0.02[d]	59.3±0.5[b]	54.5±0.7[c]
0.8-0.4	7.71±0.01[c]	0.79±0.01[c]	51.9±0.7[c]	47.1±0.8[d]
0.4-0.2	7.68±0.00[c]	0.81±0.01[c]	42.2±0.7[d]	39.9±0.8[e]
0.2-0.1	7.63±0.05[d]	0.86±0.00[b]	30.1±1.1[e]	23.1±0.8[f]
<0.1	7.62±0.03[d]	0.91±0.02[a]	27.7±0.6[f]	17.1±0.3[f]

*Data in the same column followed by the same letter are not significantly different ($P<0.05$).

was determined by the method of $K_2Cr_2O_7$-H_2SO_4 oxidation. Then, 0.1 g compost sample was mixed with H_2SO_4-$K_2Cr_2O_7$ solution and heated at 170-180ºC. The solution was kept boiling for 5 min. After cooling, the residual $K_2Cr_2O_7$ was titrated by $FeSO_4$ standard solution with O-phenanthroline hydrate as an indicator. Organic matter content was calculated based on the amount of $K_2Cr_2O_7$ consumed. Total N content of the compost sample was analyzed using Kjeldahl digestion [26]. For the determination of total P, total K, Ca, Mg, Fe, Mn and heavy metals, each sample (0.5 g) was digested with H_2SO_4-HCl/HNO_3 (aqua regia)-$HClO_4$. Digests were cooled, filtered, and diluted to 25 ml with deionized water. The contents of total P (TP), total K (TK), Ca, Fe, Mg, Mn, and heavy metals (Cu, Zn, Pb, Cd, Cr, and Ni) were determined by inductively coupled plasma atomic emission spectrometry (ICP-AES).

Data were examined by one-way ANOVA followed by Duncan's Multiple Range Test using the SPSS 12.0 statistical package.

Results and Discussion

The Physical Properties and pH Values of Different Size Fractions of the Compost

Results of compost pH (Table 1) showed that the decrease in particle size reduced compost pH value and fractions larger than 0.2 mm were all significantly higher than control in pH value ($P<0.05$). The pH variation might be due to the difference of cation adsorption capacity caused by various specific surface areas of different particle sizes. Smith [27] suggested that optimal pH value for growth of the majority of plants was between 6.5 and 7.0. Also, soil pH is one of the major factors controlling the availability of heavy metals. In most situations, metal availability declines with increasing soil pH value [13]. Compost application could increase acidic soil pH, therefore reducing crop uptake, especially the coarse fractions.

The bulk density increased when the particle size decreased, significantly higher bulk density was found in fractions of <0.8 mm than control (Table 1). Higher ($P<0.05$) bulk density suggests that these compost fractions have less pore space and are more compact. The variation of total porosity and the saturated water-holding capacity of different compost particle size fractions were similar to those of bulk density in the reverse order ($P<0.05$) due to the inverse relationship between bulk density and porosity or water-holding capacity (Table 1). The results demonstrated that the larger compost particle range (>0.8 mm) as soil amendment could improve ($P<0.05$) the bulk density, total porosity, and saturated water-holding capacity of the soil. Some researchers indicate the positive effects of organic wastes on soil physical properties, like bulk density and porosity [28, 29]. High bulk density, low porosity and water-holding capacity might cause poor aeration and higher resistance to root penetration, limiting water and minerals uptake by plants and inhibiting plant growth [30].

The Content of Organic Matter and Total N

With one exception (see 0.2-0.1mm range in Fig. 1a), there was a trend of decreasing organic content with the decrease of particle size. Although particle size fractionation significantly decreased organic contents as compared to the control ($P<0.05$), organic matter was largely contained in the coarse fractions (>0.4 mm), accounting for 66% of total organic matter (Fig. 1a). The percentage was calculated as the proportion of 3 fraction concentrations (>1.6 mm, 1.6-0.8 mm, and 0.8-0.4 mm) over the sum of all 6 fraction concentrations.

Similarly, sieving decreased TN contents in different compost fractions remarkably (Fig. 1b). The distribution pattern of TN showed higher concentrations in the coarse fractions (>0.4 mm). However, no large changes in TN content were observed in fine fractions (<0.4 mm). The enrichment of organic matter in particle size range (>0.4 mm) is in fact in good agreement with the result of TN measurement. Mbagwu and Piccolo [31] reported the close relationship in the dynamics of soil organic matter and total N.

Soil organic matter consists of a variety of simple and complex carbon compounds and thus provides food for a variety of organisms. It provides much of the cation exchange and water-holding capacities of surface soils. Certain components of soil organic matter are largely responsible for the formation and stabilization of soil aggregates [32]. Soil organic matter also contains large quantities of plant nutrients that act as a slow-release nutrient storehouse, especially for nitrogen. Furthermore, organic matter supplies energy and body-building constituents for most of the microorganisms. However, the reduction of soil organic matter content is of worldwide concern. An increase in soil organic matter can be obtained by external organic amendments. Among these, compost belongs to the most stable sources of organic matter [9]. The results of organic content and TN were consistent with other research on this subject [33] and confirmed that higher concentrations of organic matter and TN were found in macro-size compost fractions. Other studies on soil fractionation also reported that organic matter and N are associated with macroaggregates [31, 34]. Coarse compost size fractions could be used in increasing soil organic matter and TN content of soil more effectively than fine fractions.

The Content of Total P and Total K

Current research showed that with the exception of <0.1 mm fractions, a greater concentration of total P was retained with the coarse fractions (>1.6 mm and 1.6-0.8 mm), with the maximum content of 1.89 g·kg^{-1} occurring in fraction of diameter exceeding 1.6 mm (Fig. 2). However, total K concentration showed the inverse distribution pattern with total P. K was found predominantly in the particle size range of 0.8-0.4 mm, 0.4-0.2 mm, and 0.2-0.1 mm, with the highest concentration of 7.78 g·kg^{-1}, 20% higher than that of control. As macronutrients, phosphorus and potassium are essential for plant growth. Phosphorus is also frequently deficient in soils where there is very little P in the parent material or where most of the P has been lost through weathering during the soil formation processes. Potassium plays a wide variety of roles in plant biochemistry and ecophysiology. Free K^+ also balances the charges of major organic and inorganic anions within the cytoplasm, playing a major role in pH buffering. Potassium is also involved in enzyme activation, protein synthesis and photosynthesis. Potassium is especially important in helping plants adapt to environmental stresses [35]. P and K deficiency could be improved by adding fertilizers to soils. The distributions of P and K in different compost fractions is consistent with the findings of Ding et al. [33], who proposed the following

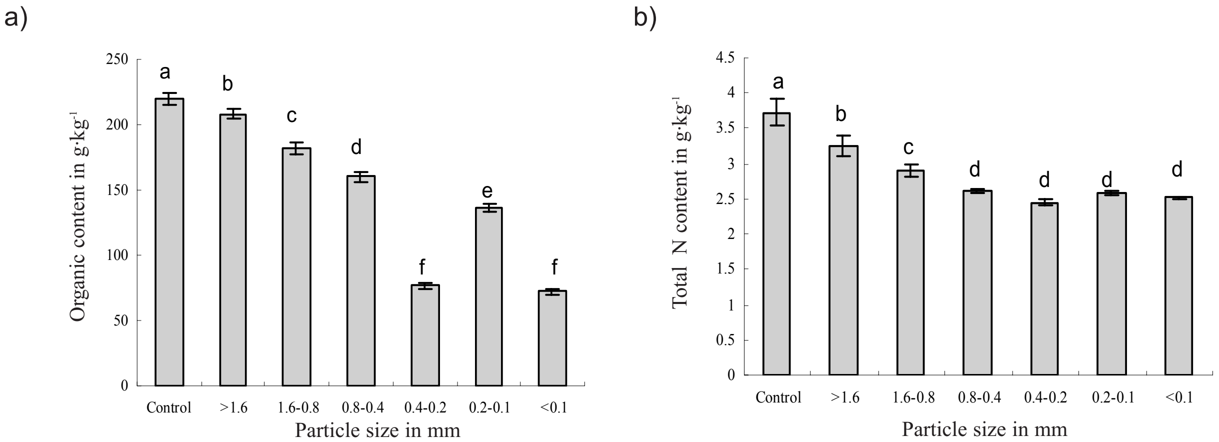

Fig. 1. Organic matter (a) and TN (b) in different compost particle size fractions. Error bars represent standard deviation. Means followed by the same letter are not significantly different (*P*<0.05).

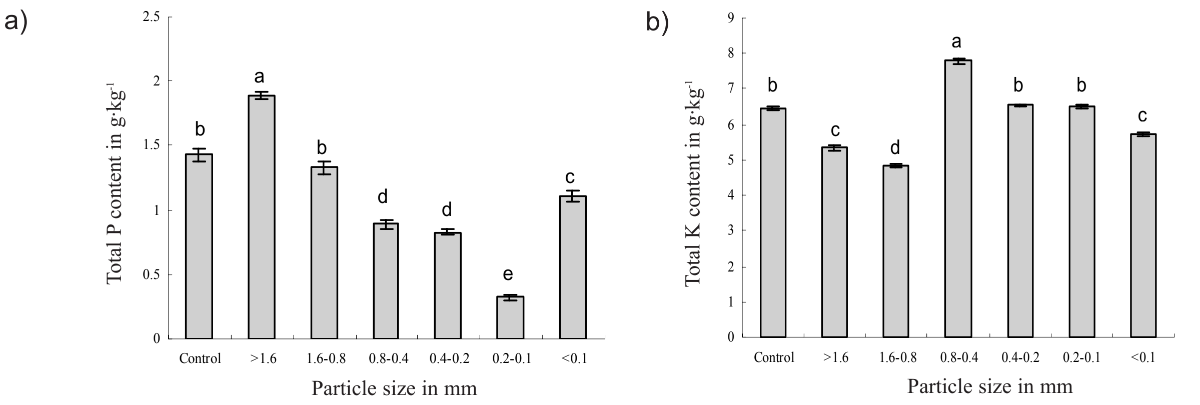

Fig. 2. Total P (a) and Total K (b) in different compost particle size fractions. Error bars represent standard deviation. Means followed by the same letter are not significantly different (*P*<0.05).

Table 2. The contents of nutrient elements in different compost particle size fractions. Means and standard deviations (n=3) are presented.

Compost particle size	Ca	Fe	Mg	Mn
(mm)	($g \cdot kg^{-1}$)			
Control	30.6±1.4[cd]*	19.9±2.0[b]	5.78±0.34[c]	325±5[d]
>1.6	55.5±0.9[a]	27.3±0.9[a]	8.69±0.32[a]	503±11[a]
1.6-0.8	41.4±2.6[b]	30.0±0.9[a]	8.59±0.14[a]	449±22[b]
0.8-0.4	28.2±4.0[de]	18.8±1.0[b]	5.33±0.36[c]	298±5[e]
0.4-0.2	30.7±2.5[cd]	17.8±0.7[b]	6.77±0.27[b]	377±6[cd]
0.2-0.1	33.8±2.1[c]	25.1±1.6[a]	7.33±0.50[b]	391±17[c]
<0.1	25.0±4.4[e]	19.7±1.0[b]	6.09±0.27[c]	359±8[d]

* Data in the same column followed by the same letter are not significantly different ($P<0.05$).

Table 3. Concentrations of heavy metals in different compost particle size fractions. Means and standard deviations (n=3) are presented.

Compost particle size	Pb	Cu	Zn	Cd	Cr	Ni
(mm)	($mg \cdot kg^{-1}$)					
Control	164±22[cd]*	546±33[c]	535±27[d]	2.26±0.13[a]	89.9±2.7[cd]	76.3±7.9[c]
>1.6	118±11[e]	391±25[d]	911±70[a]	2.22±0.1[a]	73.9±1.6[e]	74.9±2.5[c]
1.6-0.8	122±24[de]	411±21[d]	480±14[d]	2.24±0.11[a]	74.0±6.2[e]	73.6±4.7[c]
0.8-0.4	224±30[a]	1317±159[a]	729±44[b]	2.33±0.06[a]	119.1±12.3[a]	108.1±7.3[a]
0.4-0.2	209±26[ab]	723±49[b]	636±32[c]	2.35±0.06[a]	82.4±5.7[de]	96.4±3.5[b]
0.2-0.1	219±19[a]	396±37[d]	615±34[c]	2.26±0.13[a]	108.4±2.7[b]	88.4±2.7[b]
<0.1	174±31[bc]	500±29[cd]	545±28[d]	2.15±0.41[a]	99.6±1.3[bc]	63.0±2.0[d]

* Data in the same column followed by the same letter are not significantly different ($P<0.05$).

mechanisms to account for the distribution of P and K within compost fractions: P mainly exists in the organic matter component, which is higher in coarse compost size fractions. High K concentration in fine compost fractions is attributed to K presence in the mineral elements as inorganic form. As compost particles decrease, inorganic components increase, thus mineral content increases.

The Content of Ca, Mg, Fe, and Mn

Results of Ca, Mg, Fe, and Mn contents in different compost fractions were shown in Table 2. High concentrations of the four elements in coarse fractions of >1.6 mm and 1.6-0.8 mm were observed. The highest concentration of Ca was 55.5 $g \cdot kg^{-1}$ in the fraction of diameter exceeding 1.6 mm, 81% higher ($P<0.05$) than control. Fe reached the maximum in size range of 1.6-0.8 mm, higher ($P<0.05$) than other fractions and control. Compost fractions of diameter exceeding 1.6 mm showed the highest concentrations of Mg and Mn with the values of 8.69 and 502.54 $g \cdot kg^{-1}$ (50% and 55% higher than control), respectively.

Ca and Mg are two macronutrients in the soil. Ca is important in the structure and permeability of cell membranes. Ca enhances the uptake of NO_3^- and therefore is interrelated with N metabolism. Ca is essential in cell elongation and division and Ca deficiency limits the formation and development of terminal buds of shoots and apical tips of roots, thus causing plant growth to cease. Mg is known as a constituent of the chlorophyll. Mg also serves as a structural component in ribosomes and is also associated with transfer reactions involving phosphate-reactive groups. Mg is important throughout plant metabolism. As micronutrients, Fe and Mn are required by plants in very small quantities. However, they play important roles in plant growth [35]. Our results suggest that sieving alters Ca, Mg, Fe, and Mn distribution in different compost fractions. Coarse fractions account for more amounts of these elements than fine fractions. The reason might be attributed to higher organic matter in coarse compost fractions. Zhang [18] found that Ca, Mg, Fe, and Mn in sandy soil were significantly enriched in particulate organic matter. Ding et al. [33] also reported that concentrations of Ca, Mg, Fe, and Mn decreased as compost particle size decreased. Coarse compost fractions might be good soil amendments for soil Ca, Mg, Fe, and Mn deficiency.

Concentrations of Heavy Metals

Table 3 shows Pb, Cu, Zn Cd, Cr, and Ni distribution in different particle fractions of compost. Results suggest that heavy metal concentrations in individual particles have strong particle size dependence. Lead concentrations of coarse particles (>0.8 mm) decreased as compared to the control. Pb was predominately enriched in the size range between 0.8 and 0.1 mm, with significantly higher concentrations than that of control. Dermatas and Chrysochoou [36] also reported the accumulation of Pb in the finer soil fractions. Copper in coarse fractions (> 0.8 mm) was found to have lower (P<0.05) concentrations than control. The particle fractions of <0.8 mm account for about 79% of total Cu; in contrast, the coarse fraction only contributed 21%. Especially, there is a marked increase of Cu concentrations in the size range of 0.8-0.4 mm. Though the highest concentration of Zn occurred in particle size fractions of >1.6 mm with the value of 911 $mg \cdot kg^{-1}$, the coarse fractions of >0.8 mm account for only 36% of total Zn. Among heavy metals, Zn is more mobile and a large proportion of Zn contained in MSW compost is organically bound [37]. High Zn content found in 0.8-0.4 mm might be attributed to more substances contained in this particle size to which Zn is bound. However, no significant differences in Cd concentration among all treatments were observed. Chromium and Ni were found to be associated with particle size fractions of 0.8-0.4 mm. Approximately 73% and 71% of total Cr and Ni were present in fine particles of <0.8 mm, respectively. Coarse particles (>0.8 mm) contained lower amounts of Cr and Ni than those of control. Our results were in agreement with the findings of other researchers. From a review of literature on the chemical characteristics of composted, mechanically-segregated MSW, Bardos [38] reported that heavy metals were mainly associated with finer particle size classes. Sharma et al. [39] noted that the highest metal concentrations were present in very fine clusters. According to Petruzzelli et al. [40], the highest concentrations of heavy metals (Cu, Zn, Ni, Cr, Pb, Cd) were found in the finest fraction.

Conclusions

In the present study, different compost particle size analyses were carried out to estimate the physico-chemical properties of MSW compost. The bulk density increased while pH value, porosity, and saturated water holding capacity decreased with decreasing particle sizes of MSW compost. Compost fractions larger than 0.4 mm contained relatively high concentrations of organic matter and total N. Total P was concentrated in coarse particles larger than 0.8 mm, but K in fine particles smaller than 0.8 mm reversely. Calcium, Fe, Mg, and Mn were mainly concentrated in coarse particles larger than 0.8 mm, and their concentrations were significantly higher than control. However, heavy metals were found predominantly in particles smaller than 0.8 mm. Coarse particles larger than 0.8 mm had lower concentrations of Pb, Cu, Cd, Cr, and Ni than control. Thus, results above indicate that the physical and chemical properties of individual particles of MSW compost are strongly dependent on particle size. The coarse compost particles larger than 0.8 mm have a considerable potential in agriculture application as soil amendment. The practical implications of this work are to separate out the fine compost particle fractions (<0.8 mm), which have lower contents of nutrients and more heavy metals, and to utilize MSW compost effectively and environmentally safely. However, further studies should be carried out in the field to confirm their positive effects.

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