

ISSN 1569-1705, Volume 9, Number 1



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Municipal solid waste compost amendment in agricultural soil: changes in soil microbial biomass

Ademir Sérgio Ferreira de Araújo ·
Wanderley José de Melo · Rajeev Pratap Singh

Published online: 10 November 2009
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Abstract Agricultural application of Municipal Solid Waste (MSW), as nutrient source for plants and as soil conditioner, is the most cost-effective option of MSW management because of its advantages over traditional means such as landfilling or incineration. However, agricultural application of MSW can lead to a potential environmental threat due to the presence of pathogens and toxic pollutants. Composting is an attractive alternative of MSW recycling. Application of MSW compost (MSWC) in agricultural soils can directly alter soil physico-chemical properties as well as promote plant growth. The soil microbial biomass, considered as the living part of soil organic matter, is very closely related to the soil organic matter content in many arable agricultural soils. Numerous studies, with different MSWC amendment doses on different soil types and under different water regimes revealed no detrimental effect on soil microbial biomass. In this review, we show the

state of art about the effects of MSWC amendment on soil microbial biomass.

Keywords Soil quality · Microorganisms · Composting · Organic C · Plant nutrients

1 Introduction

The rapid urbanisation and industrialisation in develop and developing countries have led to generation of large volumes of Municipal Solid Waste (MSW). The waste generated is consequently released into the nearby environment. Consequently, the management of the MSW needs to be revamped to accommodate the changes in the quantity and quality to ensure the longevity of the environment. Due to several legislative, environmental, economic and social constraints, the identification of most sustainable disposal route for MSW management remains an important issue in almost all industrialized countries (Adani et al. 2000). Agricultural application of MSW, as nutrient source for plants and as soil conditioner, is the most cost-effective MSW disposal option because of its advantages over traditional means such as landfilling or incineration. According to Canellas et al. (2001), the use of MSW in agricultural lands can be justified by the need of finding an appropriate destination for waste recycling. However, agricultural application of MSW may present a potential threat to

A. S. F. de Araújo (✉)
Agricultural Science Center, Soil Quality Lab, Federal
University of Piauí, Teresina, PI, Brazil
e-mail: asfaraui@yahoo.com.br

W. J. de Melo
Faculty of Animal and Agricultural Sciences, FCAV, São
Paulo State University (UNESP), Jaboticabal, SP, Brazil

R. P. Singh
School of Industrial Technology, Universiti Sains
Malaysia, Pulau Penang, Malaysia

the environment due to the presence of pathogens and several pollutants (i.e., heavy metals or organic pollutants). An attractive alternative to recycling such wastes is composting.

Composting is a stabilization process through aerobic decomposition of waste, which has been widely used for different types of wastes (Cai et al. 2007). During composting, through microbial action organic nutrients present in the wastes are converted into plants available forms (Ndegwa and Thompson 2001). The process can effectively reduce the mixture volume by 40–50% and by means of the metabolic heat generated in the thermophilic phase destroy the pathogens (Epstein 1997). Composting cannot be considered a new technology, but among the MSW management strategies it is gaining interest as suitable option for chemical fertilizers with environmental profit, since this process eliminates or reduces the toxicity of MSW (Araujo et al. 2001; Kaushik and Garg 2003; Araújo and Monteiro 2005) and leads to a final product which can be used in improving and maintaining soil quality (Larney and Hao 2007).

Application of MSW compost in agricultural soils can directly improves soil physico-chemical properties such as: soil structure, water retention capacity, buffering capacity and nutrient status (Reeves 1997). In relation to soil biological properties, numerous researchers have reported different effects of MSW compost on soil microbial biomass and activity (Moreno et al. 1999; Selivanovskaya et al. 2001; Saviozzi et al. 2002; Araújo and Monteiro 2006; Pedra et al. 2007; Barral et al. 2009; Roca-Perez et al. 2009).

2 Composting of MSW

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.

The extension or efficiency of the composting process is dependent on various factors (Bernal et al. 2008) such as on the formulation of the composting mix, nutrient balance, pH, particle size, porosity and

moisture, and also on the process management, such as O₂ concentration, temperature and water content. Nutrient balance is basically defined by C quality and C/N ratio. Thus, the presence of readily degradable carbon (C), like carbohydrate in waste, accelerates the process of decomposition. Thereafter, decomposition slows on account of the greater resistance to decomposition of remaining C compounds (lignin and cellulose). Generally, the higher the lignin and polyphenolic content of organic materials, the slower their decomposition (Palm and Sanchez 1991).

The process of composting occurs into two stages (Pereira Neto and Stentiford 1992). The initial stage is known as the thermophilic stage in which an increase in temperature occurs (about 65°C). In this stage, there is the decomposition of readily degradable compounds like sugars, fats and proteins. During this stage, the organic compounds are degraded to CO₂ and NH₃, with the consumption of O₂. The pH typically decreases since organic acids are produced (Chen and Inbar 1993). Additionally, pathogenic microbes and helminthes eggs are eliminated as a result of heat generated during this process. Thus, the organic compost is safer for use by farmers.

The second and final stage is known as stabilization stage, where there is decrease in temperature which remains about 25–30°C. In this step the process of humification of organic compost occurs. At the end of this stage, the organic compost is cured and there are increases in humic matter content and cation exchange capacity (CEC) of the compost. Thus, compost can be defined as the stabilized and sanitized end product of composting, which has undergone an initial rapid stage of decomposition. The compost has certain humic characteristics and is beneficial to plant growth thus making the composting of MSW a key issue for sustainable agriculture and resource management (Bernal et al. 2008; Araújo et al. 2008; Araújo and Monteiro 2006; Zucconi and Bertoldi 1987).

3 Use of MSW compost in agricultural soils

Compost represent an important resource to maintain and restore soil fertility and are of great values nowadays, particularly in those countries where the organic matter content of the soil is low (Castaldi et al. 2004). Soil organic matter plays a major role in maintaining soil quality (Pedra et al. 2007). In addition

to supplying plant nutrients, the type and amount of soil organic matter influences several soil properties (Araújo et al. 2008). Increasing the soil organic matter improves soil properties, enhances soil quality, 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.

Apart of increasing soil organic matter content, application of organic compost can affect soil quality by: (a) Decreasing the need of chemical fertilizers and pesticides (Zibilske 1987); (b) Allowing for more rapid growth in plants (Bulluck and Ristaino 2002); (c) Sequestering C in soil that has received compost application; (d) Improving tillage and workability of soil; (e) Increasing soil microbial biomass and activity (Bulluck and Ristaino 2002; Araújo and Monteiro 2006).

Recently, Roca-Perez et al. (2009) incorporated MSW compost into soil and reported that the use of compost increased soil quality in two soils from Spain. The application of MSW compost increased soil organic matter, N, P and stable aggregates from both amended soils. The results also showed a positive response of plant growth to application of MSW compost in both soils.

However, heavy metals (HMs) such as Cd, Cu, Pb and Zn are found in all MSW compost, and there are obvious concerns about such toxic elements entering the food chain through food crops to which composts have been applied as fertilizer (Gillet 1992).

According to Richard (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 respiration. However, Araújo and Monteiro (2006) showed a decreasing in heavy metals (HMs) content in textile sludge as a result of composting. In order to regulate the land application of heavy metals in MSW compost, various countries from European Union and the USA have regulated the heavy metal content in MSW compost by providing permissible limit.

Thus, the application of MSW compost in soil can promote changes in soil microbial biomass and activity, mainly due heavy metals content. There is an important need to evaluate the effect of MSW compost on soil microbial biomass.

4 Soil microbial biomass

The biological activity in soils is largely concentrated in the topsoil, which may vary from a few to 30 cm. In topsoil, the biological component inhabit a tiny fraction (<0.5%) of the total soil volume and make up less than 10% of the total organic matter. These biological components consist mainly of soil organisms, specially, microorganisms (Araújo and Monteiro 2007).

The microorganisms carry out important functions in the soil, such as nutrient cycling and the degradation of pollutant (pesticides, urban and industrial wastes) (Dick 1997; Haney et al. 2003; Watanabe and Hamamura 2003; Araújo et al. 2003; Araújo and Monteiro 2006; Gonçalves et al. 2009). Microorganisms are largely responsible for the elements cycles within the soil and are involved in decomposing of the organic matter at the ecosystem level (Bastida et al. 2008). According to Powlson et al. (1987), the main function of microorganisms is to mediate soil processes, being a sensitive indicator of changes in soil organic matter.

The soil microbial biomass comprises of all soil organisms, other than plant tissue, with a volume of less than about $5 \times 10^3 \mu\text{m}^3$ and can thus be considered as the living part of soil organic matter (Brookes 2001). The proportion present as living microbial cells in soil (microbial biomass C in mg per kg of soil) typically comprises 1–5% (w/w) of total organic C, and microbial N forms 1–6% (w/w) of total organic N (Jenkinson and Ladd 1981; Wardle 1992).

Soil microbial biomass represents the fraction of the soil responsible for the energy and nutrient cycling and regulation of organic matter transformation. In this way the organic residues are converted to biomass or mineralized to CO_2 , H_2O and mineral nutrients representing an important pool of nutrients (N, P and S), which are continually assimilated during the growth of microorganisms. Thus, microbial biomass is considered important source and drain of nutrients in the soil, promoting mineralization of organic matter in inorganic nutrients (NH_4^+ , NO_3^- , H_2PO_4^- , SO_4^{2-} and CO_2) and consequent availability for plant growth, or immobilizing the nutrients in microbial tissues for their maintenance and growth. Consequently, soils that maintain a high content of microbial biomass are capable of accumulating and cycling nutrients in the soil system (Gregorich et al. 1994).

5 Effect of MSW compost amendment on soil microbial biomass

Compost is rich in organic matter and is an important source plants nutrient (Gallardo-Lara and Nogales 1987). Nutrients present in compost are also used by the soil microbial biomass. Incorporation of organic materials, such as MSW compost, in soil promotes soil microbiological activity. Consequently, compost promotes directly or indirectly changes in soil biological properties. Several studies have been conducted to evaluate the effect of MSW compost on soil microbial biomass. The most of research focused the effect of composted sewage sludge on soil microbial biomass and activity (Fließbach et al. 1994; Kandeler et al. 2000; Singh and Agrawal 2008). Soil microbial biomass is very closely related to the soil organic matter content in many arable agricultural soils (Houot and Chaussod 1995) and biomass C is generally about 2–3% of soil organic C (Anderson and Domsch 1989). In view of the fact that, it is through the microbial biomass mineralization of important organic elements take place, microbial activity is very closely related with soil fertility (Frankenberger and Dick 1983). Semiarid areas soils have a very low microbial activity, low levels of microbial biomass and low organic matter content (Garci'a-Gil et al. 2000b; Garci'a et al. 1994). The microbial biomass C can be used more effectively than the total organic C content as an indicator of variations in soil fertility (Garci'a-Gil et al. 2000a), since it responds more rapidly and with a greater degree of sensitivity to soil changes. However, according to Garci'a et al. (1994), dehydrogenase activity can also be used as an indicator of microbial activity in semiarid soils. It is mainly due to the increased oxidation after cultivation, tillage operations etc. that results in physical disruption on the soil surface and results in erosion of top organic matter rich soil (Smith et al. 1993). Therefore, being the living part of soil, the microbial biomass can be a useful index for comparison of natural (Ross et al. 1982) and degraded (Sparling et al. 1981) ecosystems.

Composted municipal solid wastes may also contain heavy metals (Giusquiani et al. 1995) that can cause environmental hazards (Brookes 1995; Stratton et al. 1995) and affect soil microbial and biochemical quality (Brookes and McGrath 1984; Tyler 1981). It is very hard to quantify changes in soil characteristics

following MSW amendment. Combinations of soil biochemical, microbiological and physical properties have been investigated using conventional determinants, such as C, N, P contents, pH, texture, metabolic quotient, biomass and enzyme activities (Nannipieri 1994; Trasar-Cepeda et al. 1998; Leirós et al. 1999). Various soil processes have been considered to be the most suitable rapid indicators of changes in soil quality (Visser and Parkinson 1992). The soil chemical characteristics also make a significant contribution to its quality and therefore can be measured to define soil quality (Hassink 1997). It is the soil microbiological and biochemical components, which are more sensitive to the changes in soil quality. Soil microbial biomass and its activities are rapid markers of detecting changes in soil quality and gives early indication of soil pollution due to exogenous input in soil (Nannipieri 1994). Microbial biomass C and enzyme activities studies of soil provide information on the biochemical processes occurring in the soil and also provide evidence that soil biological parameters may serve as potential early and sensitive indicators of soil ecological stress and restoration (Doran and Parkin 1994; Dick and Tabatai 1992).

Laboratory incubation studies, with different municipal solid waste compost (MSWC) amendment doses on different soil types (Bhattacharyya et al. 2001) and under different water regimes (Bhattacharyya et al. 2003), revealed no detrimental effect on soil microbial biomass-C (MBC), urease as well as phosphatase activities of soil. Garci'a-Gil et al. (2000a) carried out a long term field experiment to study the changes in microbial activity that took place in an agricultural soil as a result of MSW compost amendment at two different rates over 9 years and to compare a manure treatment, a mineral fertilization and a non-amended control. The treatments used in the experiments were control without fertilization (Control), compost applied at two rates i.e. 20 t ha⁻¹ (C20) and 80 t ha⁻¹ (C80), cow manure (MA) 20 t ha⁻¹ and mineral fertilization (MIN) consisting of 400 kg ha⁻¹ of NPK 15–15–15 and 150 kg ha⁻¹ of NH₄NO₃. Three consecutive years of compost treatment at the mentioned rates were carried, followed by three years of no application and two successive years repeating the initial treatments.

Garci'a-Gil et al. (2000a) reported that MSW addition increased microbial biomass C by 10 and 46%, respectively at application rates of 20 and

80 t ha⁻¹, as compared to the control (no amendment) while MA treatment increased microbial biomass C by 29%. The ratio of soil microbial C to soil organic C was found to be lowest at the high rate of MSW application. Dehydrogenase and catalase are intracellular enzymes which are involved in microbial oxidoreductase metabolism. The activity of such enzymes basically depends on the metabolic state of soil biota. Dehydrogenase and catalase enzymes were reported to be higher in the MSW treatments by 730 (C20) and 200% (C80), respectively, and by 993 and 140% in MA treatments than in the unamended control soil (García-Gil et al. 2000a), indicating an increase in the microbial metabolism in the soil, as a result of biodegradable C fraction mineralization contained in the amendments. Inhibition in dehydrogenase activity has also been reported by several workers due to the toxic effect of heavy metals added with an organic amendment (Marzadori et al. 1996) and Cu (Chander and Brookes 1991). The presence of heavy metals in MSW, as confirmed by the increasing Zn, Cu and Pb concentrations in soil with compost amendment, contributed to the decrease in phosphatase and urease activities while other enzymes (dehydrogenase, catalase, protease) were not affected (García-Gil et al. 2000a).

The increase in soil microbial biomass with the organic amendments is mainly due to the microbial biomass contained in the organic residues and the addition of substrate-C, which stimulates the indigenous soil microbes (García-Gil et al. 2000a). Heavy metals present in MSWC decrease the proportion of microbial biomass C in total soil organic matter (Brookes and McGrath 1984) and the ratio of soil microbial C to soil organic C has been suggested as a useful measure of soil pollution caused by heavy metals (Brookes 1995) and reduction in soil microbial C to soil organic C ratio due to metal pollution has been reported many workers (Chander and Brookes 1991; Fliessbach and Reber 1992). In semiarid conditions, soil biomass is subjected to seasonal variations and has an influence on soil microbial C to soil organic C ratio. García-Gil et al. (2000a) reported that highest rate of MSW compost application had the lowest ratio of biomass C to soil C, indicating a low biomass C content in soil as compared to the organic C. Pascual et al. (1999) have reported that an 8 year amendment of an arid soil with the organic fraction of a MSW at 6.5 and 26 t ha⁻¹ positively affected the activity of

enzymes involved in the C, N, P cycles as well as on biomass C, suggesting that addition of MSW might be an appropriate technique to restore soil quality.

Bhattacharyya et al. (2003) carried an experiment to study the residual effect of MSW compost (MSWC) and cow dung manure (CDM) either singly or integrated with urea on microbial biomass and enzyme activities of mustard after submerged rice paddies were grown. Study was carried out for two consecutive winter seasons of 1997 to 1998 on mustard grown at the Agriculture Experimental Farm, Calcutta University, Baruipur, West Bengal, India. The treatments consisted of control, no input and MSWC, at 60 Kg N ha⁻¹ and well rotted cow dung manure (CDM), at 60 Kg N ha⁻¹ and MSWC (30 Kg N ha⁻¹) + Urea (U, 30 Kg N ha⁻¹) and CDM (30 Kg N ha⁻¹) + Urea (30 Kg N ha⁻¹) and fertilizer (at recommended dose at 60:30:30 NPK ha⁻¹ through urea, single super phosphate and muriate of potash, respectively). Bhattacharyya et al. (2003) reported that soil microbial biomass-C (MBC), urease (UR) and acid phosphatase (AP) activities were higher in cow dung manure amended soil than that amended with MSW compost, due to the qualitative differences between the two materials. Organic matter, like CDM or MSWC, addition significantly increased the soil microbial biomass-C (MBC) in contrast to amended with fertilizer and control. Soil system receiving more organic matter tends to harbour higher levels of soil MBC with greater microbial activity (Bhattacharyya et al. 2001). Bhattacharyya et al. (2003) also reported that appreciable amounts of heavy metals present in MSWC produced no evidence of any detrimental influence on MBC, UR and AP activities of soil.

Bhattacharyya et al. (2001) carried an experiment to study the effect of the MSW compost addition to a lateritic soil on the dynamics of soil quality indicators, such as microbial biomass carbon (C), glucose-induced soil respiration, urease (UR) and phosphatase activities under laboratory conditions. Calcutta municipal solid waste compost (MSWC) were amended at different doses (0, 2.5, 5, 10 and 20 t ha⁻¹) in laterite soil (Typic Haplustalf) and were studied over 120 days of incubation at 30°C under 60% soil water holding capacity.

The microbial biomass C, soil respiration activity, and enzyme activities were found to increase with the increasing doses of MSWC. Soil microbial biomass-C (MBC) and soil respiration activity reached its

peak values at 30 days of incubation and thereafter gradually decreased up to 120 days of incubation. Urease and acid phosphatase activities showed its peak values at 60 and 90 days of incubation, respectively (Bhattacharyya et al. 2001). Bhattacharyya et al. (2001) also reported that although the compost harboured appreciable amounts of heavy metals. Municipal solid waste compost doses as high as 20 t ha^{-1} did not generate any detrimental effect on soil quality indicators (Bhattacharyya et al. 2001).

In an arid soil from Spain, the addition of MSW compost at different doses (6.5 t ha^{-1} and 26.0 kg m^{-2}) showed higher values of microbial biomass C, soil basal respiration and dehydrogenase activity than that of control soil, which reached values near to those of the natural soils in the area (Pascual et al. 1999). The MSWC amendment had a positive effect on the activity of enzymes related with C, N, P cycles, mainly when the amendment was at the highest dose. The results indicated that the addition of MSWC could be an appropriate practice with which soil quality can be restored (Pascual et al. 1999). Albiach et al. (2001) investigated the effects of recommended rates of five organic amendments ($24 \text{ t ha}^{-1} \text{ yr}^{-1}$ of MSWC, sewage sludge, and ovine manure, $2.4 \text{ t ha}^{-1} \text{ yr}^{-1}$ of commercial vermicompost, and $100 \text{ l ha}^{-1} \text{ yr}^{-1}$ of a commercial humic acids solution) application on organic matter, total humified substances, humic acids, carbohydrates and microbial gums contents in soil, and the structural stability of aggregates. Four and five years after the beginning of the experiment, significant increments in most of the parameters studied were found, whereas the two commercial amendments (Vermicompost and humic acid) did not produce any significant change. These amendments (Vermicompost and humic acid) also did not produce any significant effect on soil biological activity (Albiach et al. 2000). MSW compost yielded the highest increases, even if the amount of organic matter applied as ovine manure was very similar. Organic matter and carbohydrates appeared to be the parameters most closely related to soil aggregate stability (Albiach et al. 2001). Bastida et al. (2007) carried out a study to evaluate the long-term (17 years) effect of five doses of MSW addition (0, 65, 130, 195, and 260 Mg ha^{-1}) on the microbiological, biochemical, and physical properties of semiarid soil. Bastida et al. (2007) reported increased values of parameters that serve as indicators of general microbiological activity, such as,

basal respiration, adenosine triphosphate (ATP) or dehydrogenase activity; microbial population size (microbial biomass C), and extracellular hydrolase activity related to macronutrient cycles, such as, urease, β -glucosidase, and N- α -benzoyl-L-argininamide protease in the amended soils. The highest MSW doses (260 Mg ha^{-1}) showed the highest values in the hydrolase activities (Bastida et al. 2007).

In short-term, high quantity of MSW compost promoted an increase in microbial biomass of forest soil at Russia (Selivanovskaya and Latypova 2006). In all studies, the increase in soil microbial biomass content after application of MSW compost is result of the availability of organic C in the amendment. Thus, the application of MSW compost affected the soil content of C and N, and ultimately soil microbial biomass and activity.

On the other hand, according with heavy metals quantity and bioavailability in MSW compost and MSWC amendment in soil may affect soil microbial biomass. Bouzaiane et al. (2007) evaluated the use of MSWC amendment (at 40 and 80 Mg ha^{-1}) on soil microbial biomass, in a semi-arid zone of Tunisia. The microbial biomass content showed the highest values with use of compost 40 t ha^{-1} . According to the authors, the lower soil microbial biomass content was due to high content of heavy metals in compost at 80 t ha^{-1} treated soil. In a short-term experiment, Pedra et al. (2007) evaluated the effect of low and high rates (30 and 60 Mg ha^{-1}) of MSWC on soil microbial biomass. In low rate there was an increase in soil microbial biomass, while that in high rates soil microbial biomass decreased.

6 Conclusion

Agricultural utilization of MSWC is the most cost-effective MSW management option over traditional means such as landfilling or incineration as it enables recycling of potential plants nutrients. Soil microbial biomass use the nutrients present in compost. Organic materials amendment in soil, such as municipal solid waste compost (MSWC), promotes microbiological activity, but the presence of potential toxic heavy metals is of much concern. Different effects of MSW compost application on soil microbial biomass and activity have been reported by numerous researchers. According to some studies, appreciable amount of

heavy metals in MSWC does not seem to have any detrimental influence on microbial biomass and enzyme activities in soil. But there are some reports which show that heavy metals present in MSWC decrease the proportion of microbial biomass C in total soil organic matter.

The increase in soil microbial biomass with the MSWC amendments is mainly due to the microbial biomass present in the organic residues and the addition of substrate-C, which stimulates the indigenous soil microbes. Effect of HMs on soil microbes depends on soil as well as MSW characteristics and its amendment rates. Therefore physicochemical analysis of MSWC is necessary before its land application. More research is needed with different soil types and MSW amendment rates to evaluate the effect of MSWC application on soil microbial biomass and reach the final conclusion.

Acknowledgments The author is grateful to “Conselho Nacional de Desenvolvimento Científico e Tecnológico” (CNPq-Brazil) and “Fundação de Amparo a Pesquisa do Estado do Piauí” (FAPEPI) for financial support, and the research of the “Soil Microbial Ecology in Mid-North Region” group (UFPI-CNPq). Ademir S.F. Araújo and Wanderley J. Melo are supported by personal fellowships from CNPq-Brazil. Mr Rajeev Pratap Singh is thankful to Universiti Sains Malaysia, Malaysia for offering Post Doctoral Fellowship and giving opportunity in esteemed organization.

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