Chapter 10
Microbial Biomass Improvement Following Municipal Solid Waste Compost Application in Agricultural Soil

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Abstract Soil microbial biomass (SMB) was considered as a sensitive and as indicator of soil management especially for agricultural soil. Municipal solid waste (MSW) composting process is a promising way to reduce waste production and to obtain a stable end product such as compost available for agricultural use. However, the main requirement for the safe use or application of compost to agricultural lands is its degree of stability, which implies stable organic matter content. This practice is becoming one of the most promising ways for the reclamation and correction of organic matters loses in degraded soils. Many studies showed that MSW compost soil application could (i) improve soil physico-chemical properties, (ii) increase soil microbial biomass and activity (iii), play a biopesticide role to control soil borne diseases. Many authors investigated the different doses of MSW compost and examined their effects on soil microbial biomass available on the vertical and horizontal distribution. However MSW compost application could contaminated agricultural soil by heavy metals, toxic compounds and pathogens. Concerning the heavy metals pollution of agricultural soils is related essentially to crop quality and human health. In this review we tried to show the different investigations concerning the progress of microbial biomass following the MSW compost application in agricultural soil.

Keywords Soil microbial biomass · MSW composing process · Organic matter

10.1 Introduction

Municipal solid wastes microorganisms (fungi and bacteria) are responsible for degradation and biological transformation of organic matter. These microorganisms degradation is responsible for temperature increase in wastes (Mustin 1987). Consequently composting is known of heat treatment (sanitization of compost)

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stabilization process of wastes with two principal steps: aerobic digestion and maturation (Hassen et al. 2001; Ben Ayed et al. 2007). This process controlled and optimized different parameters especially temperature, water content, oxygenation to produce a stable and pathogens free-compost. Pathogens were destroyed within the thermophilic phase (Epstein 1997). Heavy metals did not eliminate with heat treatment of the process (Richard 1992). Consequently various countries from European Union and the USA have providing permissible limit of heavy metals content in MSW compost for land application. However Land application of MSW compost is an excellent way of recycling both the nutrients and the organic matter contained in waste and became the promising ways to correct the degraded soil (Sanchez-Mondero et al. 2004; Bouzaiane 2007a). In agricultural systems, biotic (e.g., micro-organisms) and abiotic factors (e.g., soil acidity and water content) affect the fertility of the soil, its nutrient content and its organic matter. Soil amendment with mature MSW compost, affects both biotic and abiotic factors. In fact, the application of compost introduces new organic matter, nutrients and microbial organisms (Beffa et al. 1995) that considerably improve the texture of soils (Mays et al. 1973), and increase the soil water content. Biotic factors such as the microbial biomass activities are stimulated (Pedra et al. 2007; Roca-Perez et al. 2009). Measurement of soil microbial biomass and their extracellular enzymes after MSW compost application provide valuable information for soil quality and for a sustainable management of agricultural soils.

10.2 Soil Microbial Biomass Role and Assessment

Soil microbial biomass mainly bacteria and fungi and their extracellular enzymes activities (Tabatabai 1994) are responsible for the biological transformation that make nutrients available to plants and for sustaining soil functions. Since soil microbial communities play a critical and a key role in nutrient cycling and may be used as a sensitive and as an indicator of environmental changes or disturbance of soil management (Bouzaiane et al. 2007a). In addition soil microbial biomass (SMB) is one of the major indices applied today to study soil fertility and soil health (Sparling 1997) and conducts biochemical transformations in soil (Breland and Eltun 1999). Several studies showed that the SMB varies with soil management including the farming system (Hu et al. 1997) fertilisation (Salinas-Garcia et al. 1997), municipal solid waste application (Jedidi et al. 2004; Bouzaiane et al. 2007a) and heavy metals (Garcia-Gil et al. 2000; Fagnano et al. 2011).

Measurement of the soil microbial biomass provide valuable information for soil quality and for a sustainable management of agricultural soils. The potential influence of the SMB in a soil sample may be assessed by its amount (Anderson and Domsch 1989). Assessment of SMB can be achieved by direct methods which asses the cultivable microbes, such as the plating counts (Paul and Johnson 1977), or by several indirect methods which asses the non cultivable microbes, such as the chloroform fumigation-extraction method (CFE), the chloroform fumigation-incubation method (CFI) (Vance et al. 1987; Tate et al. 1988), and the substrate-induced respiration (SIR).

The different methods (Vance et al. 1987; Brookes 1995) have been widely used to estimate microbial biomass under different field and laboratory conditions. The microbial biomass have been estimated, in both cultivated and uncultivated soils (Vong et al. 1990), in forest soils (Gallardo and Schlesinger 1990), edaphically conditions characterized by the alternation of desiccation–rehumidification cycles (Van Gestel et al. 1991), as well as the effects of seasonally dried soils (Wu and Brookes 2005). Molecular methods such as DNA quantification method has been used for SMB estimation in different soils (Marstorp et al. 2000; Bailey et al. 2002; Leckie et al. 2004). The DNA quantification method (DNA) has been compared to the CFE method in different soils (Marstorp et al. 2000; Bailey et al. 2002; Leckie et al. 2004) and has been proposed as an alternative method of CFE to measure SMB (Marstorp et al. 2000; Anderson and Martens 2013). Bouzaiane et al. (2007b) showed that the quantification of DNA yields could be used as an alternative and a reliable method to estimate microbial biomass in wheat cultivated soil after municipal solid waste compost application.

10.3 Municipal Solid Waste Composting Process

The municipal solid waste composting process has been defined as a controlled aerobic microbial process widely used to transform organic matter contained in wastes by their microbes into a stable product consisting of a humus-like substance (Michel and Reddy 1995).

10.3.1 Composting Process

Composting is one of the most complex biotechnologies since many factors influence the optimization and the reproducibility of the process such as mechanical (wastes composition and mix), chemical (temperature of environmental conditions eg. season, pH, moisture water content, O_2 concentration, porosity, C/N ratio), and biological parameters (microorganisms composition and content).

These different factors influence the quality and the degree of stability of the end product (Mondini et al. 2002; Jedidi et al. 2004). In general the composting process occurs into three major and classic stages based on temperature parameter (Fig. 10.1) (Hassen et al. 2001; Ben Ayed et al. 2007).

Mesophilic Phase: During this phase, the temperature and the water content increased as a consequence of increase of psychrophilic and mesophilic microorganisms which improved the biodegradation of organic compounds like lipids glucose and amino acid (Mustin 1987). This phase is short in time between 20 and 30 days (Hassen et al. 2001; Ben Ayed et al. 2007), the temperature increased to reach 45 °C to improve the maximum of biodegradation.

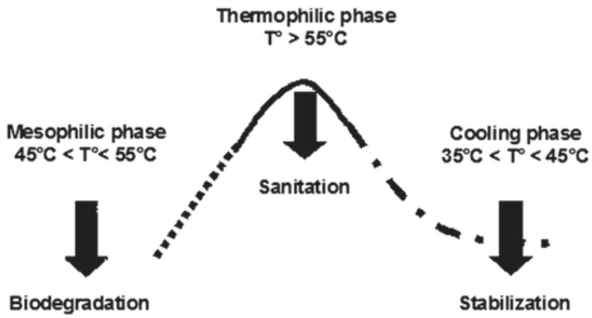

Fig. 10.1 Major classic phases of municipal solid waste composting process based on temperature parameter

Thermopilic Phase: this phase is important in time which could be occurred between 30 and 100 days of composting process (Hassen et al. 2001; Ben Ayed et al. 2007). This phase improve the development of thermophilic microorganisms according to the authors. The temperature must be maintained below 65 °C inside the windrow of wastes by ventilation and watering. Marrug et al. (1993) mentioned that temperature above 60 °C affect the decomposition rate of the waste organic matter as a result of microbes activities decrease. This phase is known as a phase of compost sanitation which heat sensitive pathogens like viruses, bacteria, protozoa or helminthes (Strauch 1991) could be eliminated.

Cooling or Stabilization Phase: in this phase the temperature began to decrease after 12th week according to Hassen et al. 2001 and after 111 days according to Ben Ayed et al. (2007). By the end of the process, the average temperature inside the windrow showed a reduction of values to reach approximately 30 °C. This decrease was the result of depletion of organic compounds in compost and C/N ratio tend to stabilize. The end product or compost is available for agricultural use. This practice is becoming one of the most promising ways for the remediation of degraded soils (Bouzaiane et al. 2007a). However, the main requirement for the safe use or application of compost to agricultural lands is its degree of stability, which implies stable organic matter content (Castaldi et al. 2004, 2008; Mondini et al. 2004).

Bouzaiane et al. (2011) evaluated that the microbial biomass C and N and DNA content during the municipal solid waste composting process can be used to understand the compost stability state. According to the authors biological properties could be combined to chemical properties, to indicate the compost stability.

10.3.2 MSW Compost Application Improves Agricultural Soil Properties

Application of MSW compost in agricultural soils can directly improves soil physico-chemical properties such as soil organic matter contents, soil aggregates, buffering capacity (Reeves 1997) and soil biological properties such as soil microbial biomass and activity (Pedra et al. 2007; Roca-Perez et al. 2009).

10.3.2.1 MSW Compost Application Improves Soil Physico-Chemical Properties

Compost from MSW represents an important resource of organic matter to maintain and restore soil fertility. Since it is important source of the plants nutrient and is of great value nowadays, particularly in those countries where the organic matter content of the soil is low (Castaldi et al. 2004). Bouzaiane et al. (2007a) showed that the application of MSW compost improves the organic matter of degraded soils in semiarid zone of Mediterranean countries like Tunisia. Roca-Perez et al. (2009) reported that the application of MSWC into the soil increased soil quality in two soils from Spain and increased soil organic matter, N, P and stable aggregates from both amended soils.

The soil addition with mature or stable MSW compost represents a valuable and effective tool to increase the long term of soil aggregates. Recently Spaccini and Piccolo (2013) showed that field application on three different agricultural soils of mature compost improve the distribution of water stable aggregates with the significant improvement of soil aggregate stability.

In the other hand MSW compost could reduce the adverse effects of salinity showed by Lakdhar et al. (2008) in *Hordeum maritimum* under greenhouse conditions. Plants were cultivated in pots filled with soil added with 0 and 40 t ha^{-1} of MSW compost, and irrigated twice a week with tap water at two salinities (0 and 4 g l^{-1} NaCl). According to the authors the MSW compost may be safely applied to salt-affected soils without adverse effects on plant physiology.

10.3.2.2 MSW Compost Application Improves Soil Microbial Biomass and Activity

Addition of good quality of compost may increase global microbial biomass and enhance soil enzyme activity (Albiach et al. 2000; Debosz et al. 2002; Garcia-Gill et al. 2000). The improve of this soil biological properties was study with many authors to evaluate the MSW compost effect. Perruci (1990) showed that microbial biomass, carbon, nitrogen, sulphur and phosphorus were significantly increased over a period of 12 months in a soil treated with compost of municipal solid waste.

According to Garcia-Gill et al. (2000), a long-term field experiment utilizing barley received MSW compost at 20 t ha^{-1} (C20) or at 80 t ha^{-1} (C80) were studied. The effects of these applications on soil enzyme activities and microbial biomass at crop harvest were measured after nine years in upper horizon of 0–20 cm. In comparison with the control (no amendment soil) MSW compost addition increased biomass C by 10 and 46 % at application rates of 20 and 80 t ha^{-1}, respectively. The authors evaluated enzyme activities and they showed that the dehydrogenase and catalase enzymes, were higher in the MSW compost treatments by 730 (C20) and 200 % (C80), respectively, indicating an increase in the microbial metabolism in the soil as a result of the mineralization of biodegradable C fractions contained in the amendments. The addition of MSW caused different responses in hydrolase enzymes. Phosphatase activity decreased with MSW (±62% at both rates) to less than that in the control treatments. Urease activity decreased by 21% (C20) and 28% (C80), possibly being affected by the heavy metals contained in the MSW. However, β-glucosidase and protease increased with MSW compost.

The use of composts in agricultural soils is a widespread practice and the positive effects on soil and plants are known from numerous studies. Ros et al. (2006) investigate a long term of crop-rotation (maize, summer-wheat and winter barley) in field experiment in Austria. The application of compost produced from urban organic wastes at rate of 175 kg N ha^{-1} yr^{-1} for 12 years. The microbial biomass C (B_C), was analyzed at different depths (0–10, 10–20 and 20–30 cm). The results showed that the continued addition of compost to soil enhances B_C compared to control soil and which this effect declined with depth.

The application of organic wastes as amendments to improve soil properties has become a very common practice, especially under Mediterranean semiarid conditions. Bouzaiane et al. (2007b) evaluated the microbial biomass C and N (B_C and B_N) by the chloroform fumigation-extraction (CFE) method and microbial biomass DNA concentration in a loam-clayey wheat cultivated soil. They obtained the highest values of microorganisms counts with MSW compost at 40 t ha^{-1}. The microbial biomasses C and N and DNA concentration increased in wheat cultivated soil amended with MSW compost at 40 t ha^{-1} in comparison with 80 t ha^{-1} and in the superficial profile (0–20 cm) than in the deep one (20–40 cm). Recently Mardomingo et al. (2013) have investigated the changes in soil microbial activity under field conditions over a one-year period after the application of a single high dose (160 Mg ha^{-1} dry mass) of municipal solid waste compost (MSWC). Measurements were made for microbial biomass carbon (MBC), basal respiration (BR) and enzymatic activities evaluated by assays of catalase (CA), dehydrogenase (DA), urease (UA), protease (PA), phosphatase (PhA) and β-glucosidase (βGA). This organic amendment produced different effects on soil microbial activity. The application of MSWC significantly increased ($p \leq 0.05$) the B_C, with the highest content observed in summer season (1369.1 ± 13.2 mg C kg^{-1}). According to the authors soil microbial activity (BR, CA, DA and hydrolase activity) remained stable throughout the one-year period in MSW compost.

Other authors were interested on the biopesticide view of organic materials that could be used to control many soil-borne plant pathogens (Boulter et al. 2000; Hoitink et al. 1993). Since the microbial biodiversity may be increased (Peacock et al. 2001) and soil borne pathogens may be reduced by stimulation of antagonistic organisms (Tilston et al. 2002) allowing less use of potentially fumigants or pesticides (Pascual et al. 2000; Ros et al. 2005). Moreover MSW compost could contained many antagonistic microorganisms such as *Bacillus sublilis*, *Trichoderma* and *Pseudomonas* (Serra-Wittling et al. 1996; Hoitink et al. 1993) that controlled wheat plants phytopathogenic like *Fusarium oxysporum*.

10.3.2.3 Effect of MSWC Heavy Metals on Agricultural Soil

Heavy metals do not degrade throughout the composting process, and frequently become more concentrated due to microbial degradation and loss of carbon and water from the compost (Richard 1992). A significant decrease of soil microbial biomass was noted after three years of MSW compost application (Bouzaiane et al. 2007b). The decrease of microbial biomass was due to heavy metals content elevation in compost at 80 t ha^{-1} treated soil. Thus according to the authors the highest rate of MSW compost induced the lowest ratio of biomass C to soil organic carbon and the lowest ratio of biomass N to soil organic nitrogen.

Carbonell et al. 2011 conducted to assess the inputs of metals to agricultural land from soil amendments. Maize seeds were exposed to a municipal solid waste (MSW) compost (50 Mg ha^{-1}) and NPK fertilizer (33 g $plant^{-1}$) amendments considering N plant requirement until the harvesting stage with the following objectives: (1) determine the accumulation of total and available metals in soil and (2) know the uptake and ability of translocation of metals from roots to different plant parts, and their effect on biomass production. According to the authors the results showed that MSW compost increased Cu, Pb and Zn in soil, while NPK fertilizer increased Cd and Ni, but decreased Hg concentration in soil. The root system acted as a barrier for Cr, Ni, Pb and Hg, so metal uptake and translocation were lower in aerial plant parts. Biomass production was significantly enhanced in both MSW and NPK fertilizer-amended soils (17 %), but also provoked slight increases of metals and their bioavailability in soil. The highest metal concentrations were observed in roots, but there were no significant differences between plants growing in amended soil and the control soil. Important differences were found for aerial plant parts as regards metal accumulation, whereas metal levels in grains were negligible in all the treatments.

10.4 Conclusion

The MSW compost application to an agricultural soil can improve and maintain soil quality by decreasing the need of chemical fertilizers and pesticides, improving soil tillage, increasing soil microbial biomass and enzyme activities, increasing the organic matter of degraded soils and increasing the plants productivities. However the MSW compost could be contaminated by heavy metals, toxics compounds and pathogens that limits the use of the compost. The utilization of MSW compost in low rate should be used for sustainable agricultural soil to mitigate the cumulative effects of environmental pollution and gain public acceptance.

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References

Albiach R, Canet R, Pomares F, Ingelmo F (2000) Microbial biomass content and enzymatic activities after the application of organic amendments to a horticultural soil. Bioresour Technol 75:43–48

Anderson TH, Domsch KH (1989) Ratios of microbial biomass carbon to total organic carbon in arable soils. Soil Biol Biochem 21:471–479

Anderson TH, Martens R (2013) DNA determinations during growth of soil microbial biomasses. Soil Biol Biochem 57:487–495

Bailey VL, Peacock AD, Smith JL, Bolten HJ (2002) Relationships between soil microbial biomass determined by chloroform fumigation-extraction, substrate-induced respiration, and phospholipid fatty acid analysis. Soil Biol Biochem 34:1385–1389

Beffa T, Blanc M, Marilley L, Lott Fischer J, Lyon PF, Aragno M (1995) Taxonomic and metabolic microbial diversity during composting. In: de Bertoldi M, Sequi P, Lemmes B, Papi T (eds) The science of composting, vol 1. Blackies Academic and Professional, Glasgow, Scotland, pp 149–161

Ben Ayed L, Hassen A, Jedidi N, SaidiI N, Bouzaiane O, Murano F (2007) Microbial C and N dynamics during composting process of urban solid waste. Waste Manage Res 25:24–29

Boulter JI, Boland GJ, Trevors JT (2000) Compost: a study of the development process and end-product potential for suppression of turfgrass disease. World J Microbiol Biotech 16:115–134

Bouzaiane O, Cherif H, Saidi N, Jedidi N, Hassen A (2007a) Effects of municipal solid waste compost application on the microbial biomass of cultivated and non-cultivated soil in a semi-arid zone. Waste Manage Res 25:327–333

Bouzaiane O, Cherif H, Saidi N, Hassen A, Jedidi N (2007b) Municipal solid waste compost dose effects on soil microbial biomass determined by chloroform fumigation-extraction and DNA methods. Ann Microb 57(4):681–686. (ISSN 1590-4261)

Bouzaiane O, Saidi N, Ben Ayed L, Jedidi N, Hassen A (2011) Relationship between microbial C, microbial N and microbial DNA extracts during municipal solid waste composting process. Progress in biomass and bioenergy production. pp 239–252. (ISBN 978-953-307-491-7 (chapter 12))

Breland TA, Eltun R (1999) Soil microbial biomass and mineralization of carbon and nitrogen in ecological, integrated and conventional forage and arable cropping systems. Biol Fert Soils 30:193–201

Brookes PC (1995) The use of microbial parameters in monitoring soil pollution by heavy metals. Biol Fert Soils 19:269–279

Carbonell G, de Imperial RM, Torrijos M, Delgado M, Rodriguez JA (2011) Effects of municipal solid waste compost and mineral fertilizer amendments on soil properties and heavy metals distribution in maize plants (*Zea mays* L). Chemosphere 85:1614–1623

Castaldi P, Garau G, Melis P (2004) Influence of compost from sea weeds on heavy metal dynamics in the soil–plant system. Fresenius Environ Bull 13:1322–1328. (ISSN 1018–4619)

Castaldi P, Garau G, Melis P (2008) Maturity assessment of compost from municipal solid waste through the study of enzyme activities and water-soluble fractions. Waste Manage 28:534–540

Debosz K, Petersen SO, Kure L K, Ambus P (2002) Evaluating effects of sewage sludge and household compost on soil physical, chemical and microbiological properties. Appl Soil Ecol 19:237–248

Epstein E (1997) The science of composting. Technomic Publishing, Lancaster

Fagnano M, Adamo P, Zampella M, Fiorentino N (2011) Environmental and agronomic impact of fertilization with composted organic fraction from municipal solid waste: a case study in the region of Naples, Italy. Agric Ecosyst Environ 141:100–107

Gallardo A, Schlesinger WH (1990) Estimation of microbial biomass nitrogen by the fumigation-incubation and fumigation-extraction in warm temperate forest soil. Soil Biol Biochem 22:927–932

Garcia-Gil JC, Plaza C, Soler-Rovira P, Polo A (2000) Long term effects of municipal solid waste compost application on soil enzyme activities and microbial biomass. Soil Biol Biochem 32:1907–1913

Hassen A, Belguith K, Jedidi N, Cherif A, Cherif M, Boudabbous A (2001) Microbial characterization during composting of municipal solid waste. Bioresour Technol 80:185–192

Hoitink HAJ, Hadar MJY (1993) Mechanisms of suppression of soil borne plant pathogens in compost amended substrates. In: Hoitink HAJ, Keener HM (eds) Science and engineering of composting: design, environmental, microbiological and utilization aspects. The Ohio State University, Ohio, pp 601–621

Hu S, Grunwald NJ, Van Bruggen AHC, Gamble GR, Drinkwater LE, Shennan C, Demment MH (1997) Short term effects of cover crop incorporation on soil carbon pools and nitrogen availability. Soil Sci Soc Am J 61:901–911

Jedidi N, Hassen A, Van Cleemput O, M'hiri A (2004) Microbial biomass in soil amended with different types of organic wastes. Waste Manage Res 22:93–99

Lakdhar A, Hafsi C, Rabhi M, Debez A, Montemurro F, Abdelly C, Jedidi N, Ouerghi Z (2008) Application of municipal solid waste compost reduces the negative effects of saline water in Hordeum maritimum L Bioresour Technol 99:7160–7167

Leckie SE, Prescott CE, Grayston SJ, Neufeld JD, Mohn WW (2004) Comparison of chloroform fumigation-extraction, phospholipid fatty acid, and DNA methods to determine microbial biomass in forest humus. Soil Biol Biochem 36:529–532

Mardomingo IJ, Rovira P S, Casermeiro MA, de la Cruz MT, Polo A (2013) Seasonal changes in microbial activity in a semiarid soil after application of a high dose of different organic amendments. Geoderma 206:40–48

Marrug C, Grebus M, Hassen RC, Keener HM, Hoitink HA J (1993) A kinetic model of yard waste composting process. Compost Sci Util 1:38–51

Marstorp H, Guan X, Gong P (2000) Relationship between dsDNA, chloroform labile C and ergosterol in soils of different organic matter contents and pH. Soil Biol Biochem 32:879–882

Mays DA, Ternan GL, Duggan JC (1973) Municipal compost effects on crops yields and soil properties. J Environ Qual 2:89–92

Michel FC, Reddy CA & Forney LJ (1995) Microbial-degradation and humification of the lawn care pesticide 2, 4-dichlorophenoxyacetic acid during the composting of yard trimmings. Appl Environ Microbiol 61:2566–2571

Mondini C, Contin M, Leita L, De Nobili M (2002) Response of microbial biomass to air-drying and rewetting in soils and compost. Geoderma 105:111–124

Mondini C, Fornasier F, Sinicco T (2004) Enzymatic activity as a parameter for the characterization of the composting processes. Soil Biol Biochem 36:1587–1594

Mustin M (1987) Le Compost: gestion de la matière organique. Editions François Dubusc Paris, 953 p

Pascual JA, Hermander T, Garcia C, Deleij FAAM, Lynch JM (2000) Long-term suppression of *Pythium ultinum* in arid soil using fresh and composted municipal wastes. Biol Fertil Soils 30:478–484

Paul EA, Johnson RL (1977) Microscopic counting and adenosine 5′-triphosphate measurement in determining microbial growth in soils. Appl Environ Microbiol 34:263–269

Peacock AD, Mullen MD, Ringelberg DB, Tyler DD, Herdrick DB, Gale PM, White DC (2001) Soil microbial community response to dairy manure or ammonium nitrate applications. Soil Biol Biochem 33:1011–1019

Pedra F, Polo A, Ribeiro A, Domingues H (2007) Effects of municipal solid waste compost and sewage sludge on mineralization of soil organic matter. Soil Biol Biochem 39:1375–1382

Perez PA, Edel HV, Alabouvette C et Steinberg C (2006) Response of soil microbial communities to compost amendments. Soil Biol Biochem 38:460–470

Perruci P (1990) Effect on the addition of municipal solid waste compost on microbial biomass and enzyme activities. Biol Fert Soils 10:221–226

Reeves DW (1997) The list of soil organic matter in maintaining soil quality in continuous cropping systems. Soil Till Res 43:131–167

Richard TL (1992) Municipal solid waste composting: physical and biological processing. Biomass Bioenerg 3:163–180
Roca-Perez L, Martinez C, Marcilia P, Boluda R (2009) Composting rice straw with sewage sludge and compost effects on the soil-plant system. Chemosphere 75:781–787
Ros M, Hernandez MT, Garcia C, Pascual JA (2005) Biopesticide effects of green composts against Fusarium wilt on melon plants. J Appl Microbiol 98:845–854
Ros M, Hernandez MT, Garcia C (2003) Soil microbial activity after restoration of a semiarid soil by organic amendments. Soil Biol Biochem 35:463–469
Ros M, Pascual JA, Garcia C, Hernandez MT, Insam H (2006) Hydrolase activities, microbial biomass and bacterial community in a soil after long-term amendment with different composts. Soil Biol Biochem 38:3443–3452
Salinas-Garcia JR, Hons FM, Matocha JE (1997) Long term effect of tillage and fertilization on soil organic matter dynamics. Soil Sci Soc Am J 61:152–159
Sanchez-Mondero MA, Mondini C, de Nobili M, Leita L, Roig A (2004) Land application of biosolids: soil response to different stabilization degree of the treatment organic matter. Waste Manage 24:325–332
Serra-Wittling C, Houot S, Alabouvette C (1996) Increased soil suppressiveness to Fusarium wilt of flax after addition of municipal solid waste compost. Soil Biol Biochem 28:1207–1214
Spaccini R, Piccolo A (2013) Effects of field managements for soil organic matter stabilization on water-stable aggregate distribution and aggregate stability in three agricultural soils. J Geochem Explor 129:45–51
Sparling GP (1997) Soil microbial biomass, activity and nutrient cycling as indicators of soil health. In: Pankhurst C, Doube B.M, Gupta VVSR (eds) Biological indicators of soil health. CAB International, Wallingford, pp 97–119
Strauch D (1991) Survival of pathogenic micro-organism and parasites in excreta, manure and sewage sludge. Rev Sci Tech Off Int Epiz 10:813–846
Tabatabai MA (1994) Soil enzymes. In: weaver RW, Angle S, Bottomley P (eds) Methods of soil Analysis, part 2: microbiological and biochimical methods, SSSA Book series: S Soil Science. Society of America, Madison, pp 775–883
Tate KR, Ross DJ, Feltham CW (1988) A direct extraction method to estimate soil microbial C: effects of experimental variables and some different calibration procedures. Soil Biol Biochem 20:329–335
Tilston EL, Pill D, Groenhof AC (2002) Composted recycled organic water suppresses soil borne diseases of field crops. New Phytol 154:731–740
Van Gestel M, Ladd JN, Amato M (1991) Carbon and nitrogen mineralization from two soils of contrasting texture and microagregate stability: influence of sequential fumigation, drying and storage. Soil Biol Biochem 23:313–322
Vance ED, Brookes PC, Jenkinson DS (1987) Microbial biomass measurements in forest soils: determination of KC values and tests of hypotheses to explain the failure of the chloroform fumigation-incubation method in acid soils. Soil Biol Biochem 19:689–696
Vong PC, Kabibou I, Jacquin F (1990) Etude des corrélations entre biomasse microbienne et differentes fractions d'azote organique présentées dans deux sols Lorrains. Soil Biol Biochem 22:385–399
Wu J, Brookes PC (2005) The proportional mineralisation of microbial biomass and organic matter caused by air-drying and rewetting of a grassland soil. Soil Biol Biochem 37:507–515