



COMPOSTING OF MUNICIPAL SOLID WASTE: A SUSTAINABLE WASTE MANAGEMENT
TECHNIQUE IN INDIAN CITIES – A REVIEW

A.K. Pathak¹, M.M. Singh² and V. Kumar¹,

¹Institute of Environment and Development Studies, Bundelkhand University, Jhansi (U.P.), India

²Department of Geology, Bundelkhand University, Jhansi (U.P.), India.

ARTICLE INFO

Article History:

Received 24th September, 2011
Received in revised form
28th October, 2011
Accepted 08th November, 2011
Published online 31th December, 2011

Key words:

Municipal solid waste (MSW),
Composting,
Fertilizer,
Kitchen waste.

***Corresponding author:**

pathakawadhesh@gmail.com

ABSTRACT

Attending sustainability in waste management require an option that employs environmental friendliness. The generation of municipal solid waste is increasing year by year and there are many options for handing and disposing of these wastes. Composting is the natural biological process in which degradable part of waste is transformed to a stable material with excellent characteristics for application on soils. Thus it requires a pretreatment such as removal of big fractions and other contaminants that could affect the composting process and final quality of compost. Such type of technique must be effective efficient and less costly Agricultural application of composted Municipal Solid Waste, as nutrient source for plants and as soil conditioner, is the most cost effective option of MSW management. Municipal solid waste (MSW) compost is increasingly used in agriculture as a soil conditioner but also as a fertilizer. Proponents of this practice consider it an important recycling tool since MSW would otherwise be land filled and critics are concerned with its often elevated metal concentrations. In this review, we show the state of art about the composting of Municipal solid waste (viz. Kitchen waste) and its application in agriculture.

Copy Right, IJCR, 2011, Academic Journals. All rights reserved.

INTRODUCTION

Waste management has become a critical area of practice and research due to the increasing concerns of environmental pollution and resources shortage (Brewer, 2001). Most of solid waste management professionals recognize that there is no single, simple solution to solid waste problems. Instead, an integrated approach, combining the elements of multiple techniques, is used in an increasing number of cases (Uif, 1998; Fromme, 1999).

Waste Management Techniques

Waste management is the collection, transportation, processing, treatment, recycling or disposal of waste materials to reduce their adverse effects on human health or amenities. The type of waste management techniques that should be applied for proper management of waste depend on the composition of waste. Although composting is the appropriate for all organic wastes: wastes such as plastic metals and glasses are better handled through recycling. Waste management technique take place in many ways viz., landfill, incineration, pyrolysis and gasification, composting and anaerobic digestion (Adewale *et al.*, 2011).

Land filling

Land filling is an economical method of waste materials in developing countries involving pitching refuses into a

depression, abandoned, mining void, excavated land, or borrowed pits (Daskalopoulos *et al.*, 1998, Adewale *et al.*, 2011).

Open Dump System/ordinary landfill

This disposal of waste material is in pits, excavated land, canal, sloping land scape, or flat surface without covering the waste. From time to time open dumps burn leading to air pollution. Other environmental implication of landfill are the sites eyesore, windblow of litters along the landscape, presence of faecal matters, intrusion of vermin such as mice and rats, odor, smoke with resultant effects on human health (Adewale *et al.*, 2011).

Sanitary Land fill

The engineering means of disposing solid waste uses thin layers, compacted in to the smallest practical volume and cover with inert ash at the end of each working day. Environmental effects of sanitary landfill are production of Landfill Gases (LFGs), lichates and leaving heavy metals. LFGs are produced when methogens are decomposed primarily in to methane and Carbon di oxide and other gases such as CO, N₂, alcohols, Hydrocarbons and organosulphur compounds (EL-Fadel *et al.*, 1997, Adewale *et al.*, 2011).

Incineration

Incineration refers to high temperature combustion of waste in a high efficiency furnace to produce steam and ash (EPA, 1995). The benefits of incineration are a major reduction in waste volume and production of energy in form of electricity and heat production (Seo *et al.*, 2004). However, the problems of waste incineration cannot be overemphasized in the light of the following: construction and start up cost of facility, which could be too expensive for developing countries (Rand *et al.*, 2000, Adewale *et al.*, 2011).

Composting

Composting is the regulated decomposition of organic matter to produce a final product called compost; it is used in waste management as a method to recover organic waste (Haight 2006). The composting process entails managing and accelerating the biological and oxygen demanding process as a mixture of organic materials pass through a series of stages that are characterized by increases in temperature and bacterial types leading to a stable organic material called compost (Haight and Taylor 2000). Composting of organic waste is recognized as an effective method to manage this waste type as it aims to recover organic waste in the waste stream and produces a useful end-product (Hoorweg 1999). Composting may be defined as part of a sustainable resource management strategy (Richard, 1992; Golueke and Diaz, 1996; Faucette, 2004). It is essential to encourage recycling, the only sustainable waste management practice which avoids the existence itself of wastes by transforming possible waste materials into a series of products (Campbell, 1990). With sustainable transformation of wastes into organic fertilizers, composting would complement sustainable agriculture (Cathcart *et al.*, 1986). The sustainable agriculture and the use of compost can be considered as essential activities for a sustainable society (Sinha and Heart, 2002). Hence, sustainability considerations are major driving forces for composting technologies. Improvements in composting process control will help increase the efficiency and economic viability of the related technologies, and thus contributing to agricultural and societal sustainability (Molla, 2005).

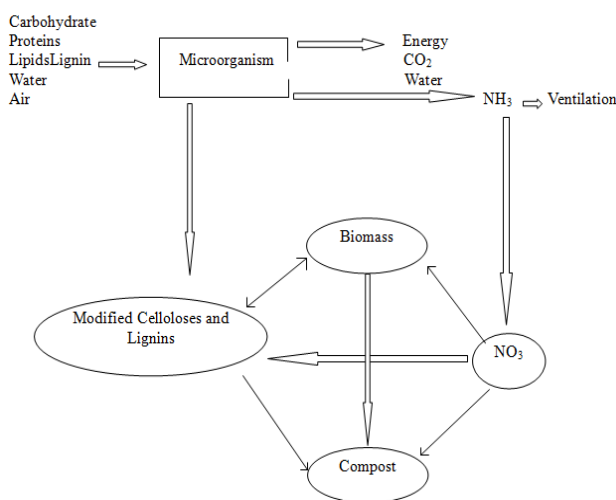


Fig. 1. Schematic Diagram of Composting Process (Source: Teira, 2003)

Composting can meet multiple objectives, including reduction of odor, recycling of nutrients to soils, and management of livestock wastes through an integrated approach (Haug, 1980, 1986; Miller, 1991; Hansen *et al.*, 1993; Alpert *et al.*, 2002; Park *et al.*, 2004). Thus, composting offers a potential for producing a usable product from the organic fraction of solid waste and is thus a form of recycling. Composting can also produce combustible fuel for energy recovery (Brodie, 1996). By itself, composting is not a solution to all waste problems; however it can serve as a valuable component in a waste management plan (Lasoff, 2000). It advances the goals of decomposing putrescible material, decreasing volume, weight and water content, producing a stabilized process residue, and inactivating pathogenic organisms (Godden, 1983; Hoitink and Keener, 1992; Finstein and Hogan, 1992; Szmidski and Fox, 2001).

Factor affecting composting Process

Many factors can affect composting processes, including temperature, moisture, gas flow and many other physical, chemical and biological variables (Beck, 1984; Ljung and Glad 1994; Ekinici, 2001).

C/N ratio

C/N ratio is a traditional parameter, which has been used to evaluate the compost maturity and stability as it defines the agronomic quality. The composting process results in the fall of C/N ratio because the microorganism activities: the conservation of nitrogen and transformation of carbon to CO₂ and humic substances. During active aerobic growth, living organisms use about 25 to 35 units of carbon for every unit of nitrogen (Gotaas, 1956). Poincelot (1975) verified that the C/N ratio within the range between 25 and 35 is the most desirable for rapid and efficient composting. If excess carbon is available (a higher C/N ratio), rapid cell growth will cause a depletion of available nitrogen and a temporary slowdown in cellular growth. The ideal C/N ratio or well-matured compost is about 10, but it is usually difficult to achieve by composting (Mathur, 1991).

pH value

The pH value of compost is looked as an indicator of process of decomposition and stabilization. The change of pH value during composting is quite predictable (Miller, 1993; Benito, 2003; Page, 1982): it drops slightly early in processing, and then rises rapidly to approximately 8.5 because of ammonification. The pH value settles to between 7.5~8.0 as the compost stabilizes. Sanchez-Monedero (2001) found that pH value varies within 7.0 ~8.0 in 4 composting mixtures (wide range feedstock) in 20 weeks. But pH value is not an absolute reliable indicator of maturity and stability. Campbell (1992) found that the pH value of compost stopped at 6.7 after 6 weeks.

Nitrogen element related

Nitrification or ammonification process has been studied extensively as a maturity and stability index for composting (Finstein and Mille, 1985; Bernal *et al.*, 1998). NH₄⁺-N/NO₃⁻-N ratio is a clear indicator of nitrification (Haug, 1993).

According to Haug (1993), high ammonia concentration is usually found in the early stages of composting as organic nitrogen is decomposed; the ammonia concentration is eventually reduced through volatilization or oxidation to the nitrate form; thus the presence of nitrate and absence of ammonia are indicative of a stabilized condition.

Electricity Conductivity (EC)

A low electric conductivity could be an indicator of complex nutrients and therefore desirable. The decrease of EC in the composting process is the direct consequence of the increased concentration of nutrients, such as nitrate and nitrite. EC is a measure of soluble salt content. Undesired salt levels can be harmful to germinating seeds and plants when compost is applied as growing medium. The desired ranges may not apply when compost is used as an amendment because of the diluting effect of mixing the compost with soil ().

Oxygen/Aeration

Gas exchange supplies oxygen and removes carbon dioxide, heat, and water vapor. The significance of supplying oxygen is that aerobic respiration generates heat at a rate sufficient for self-heating (Cooney *et al.*, 1968; Atchley and Clark, 1979; Rynk, 1991; Sesay, 1998). A number of researchers considered oxygen or carbon dioxide levels as feedback variables (Jeris and Regan, 1973a, b; Nakasaki and Shoda, 1987; DeBertoldi *et al.*, 1988; Haug, 1993, 1996; Vinci, 1996; Bodelier and Laanbroek, 1997; Richard *et al.*, 1999; Zhang, 2000; Ekinci, 2001). With a known flow rate, measurement of carbon dioxide or oxygen should be sufficient to define the rate of degradation (Jeris and Regan, 1973a).

Moisture/Water Content/Temperature

Sufficient moisture in the solid waste is required for maximum efficiency of microbial stabilization (Dirksen and Dasberg, 1993; Iriarte and Ciria, 2001). Water is both required for and produced by microbial activities. A major part of the composting process is the loss of water, as a result of evaporation as the process progresses (Stentiford, 1996). Moisture also affects porosity and gas diffusivity and is removed via vaporization (evaporative cooling), as driven by microbial heat generation (Dean *et al.*, 1987; Oppenheimer, 1997). The moisture content of the compost affects the structural properties of the materials, the thermal properties of the materials as well as the rate of biodegradation (Stentiford, 1996; Nakasaki *et al.*, 2004, 2005).

The temperature of compost is a function of the accumulation of heat generated metabolically and, simultaneously, the temperature is a determinant of metabolic activities (MacGregor *et al.*, 1981). It is a critical variable in the composting process and a number of studies have addressed heat and mass transport in composting processes (Finger *et al.*, 1976; Characklis and Gujer, 1979; Luong and Volesky, 1983; Incropera and DeWitt, 1985; Macky and Derrick, 1986; Kishimoto *et al.*, 1987; Bach *et al.*, 1987; Nakasaki and Akiyama, 1988; Richard and Walker, 1989; Keener *et al.*, 1992; VanderGheynst *et al.*, 1997; Hall, 1998; Ekinci, 2001; Nakasaki *et al.*, 2004, 2005).

The Microbiology of Composting

Composting is a complex biological process that involves the combined activities of many individual microorganisms. Two classes of microorganism are considered regarding to the temperatures at which they can grow: mesophiles and thermophiles. Mesophiles are organisms that grow optimally at temperatures from 20.0 to 35.0°C. Organisms that are best adapted to temperatures between 50.0 and 60.0°C are known as thermophiles. They can tolerate and survive at minimum temperatures of 30.0 to 40.0°C and maximum temperatures of 80.0 to 90.0°C (Swatek 1967; Lyles 1969; Henis 1987; Lester and Birkett 1999). Bacteria, fungi, and actinomycetes are the three principle microbial species associated with the decomposition of organic matter, which can be categorized as readily, moderately, and highly resistant degradable matter (Stentiford 1993; Eklind *et al.* 1997). Different microbial communities predominate at various stages: mesophilic, thermophilic, cooling, and stabilization, of the composting process; each microbial community is adapted to a particular type of organic material and environment (Gray *et al.* 1971a; Ryckeboer *et al.* 2003).

Compost Phases

Composting characteristically is an ecological succession of microbial populations almost Invariably present in wastes. The succession begins with the establishment of composting conditions. "Resident" (indigenous) microbes capable of utilizing nutrients in the raw waste immediately begin to proliferate. Owing to the activity of this group, conditions in the composting mass become favorable for other indigenous populations to proliferate. composting proceeds in three stages, namely (1) an initial lag period ("lag phase"), and (2) a period of exponential growth and accompanying intensification of activity ("active phase") that (3) eventually tapers into one of final decline, which continues until ambient levels are reached ("curing phase" or "maturation phase") (Luis F. Diaz *et al.*, 2004).

Lag Phase

The lag phase begins as soon as composting conditions are established. It is a period of adaptation of the microbes characteristically present in the waste. Microbes begin to proliferate, by using sugars, starches, simple celluloses, and amino acids present in the raw waste. Breakdown of waste to release nutrients begins. Because of the accelerating activity, temperature begins to rise in the mass. (Luis F. Diaz *et al.*, 2004).

Active Phase

The transition from lag phase to active phase is marked by an exponential increase in microbial numbers and a corresponding intensification of microbial activity. This activity is manifested by a precipitous and uninterrupted rise in the temperature of the composting mass. The rise continues until the concentration of easily decomposable waste remains great enough to support the microbial expansion and intense activity. Unless countermeasures are taken, the temperature may peak at 70°C or higher. The activity remains at peak level until the supply of readily available nutrients and easily

Table 1. Summary of agricultural studies of MSW compost. (Source: Hargreaves J.C. et al., 2007)

MSW source	Soil type/pH/E.C. (dS/m)	Crop	Rate (Mg ha-1)	Comments	Reference
Source-separated from Netanya sewage treatment plant, Israel	Sand/7.5/8.5	Wheat	0.03, 0.06, 0.12	Increase yield, downward movement of P observed, pot experiment	Bar-Tal et al. (2004)
Calcutta city wastes, India	Clay/5.5/2.7-2.8	Rice	5.9-6; 40	Increased yield, pH (field experiment); high rates did not affect microbiology of soil (pot experiment)	Bhattacharyya et al. (2003a,b)
Castel di Sangro, Italy	Clay/8.3	N/A	12-24	Increased enzyme activities but no effect of community structure 6 years after application	Crecchio et al. (2001, 2004)
Not stated	Sand/6.4	Maize	0, 63, 126, 189 (fw)	First year N immobilization	Eriksen et al. (1999)
Valdemingomez MSW treatment plant, Madrid, Spain	Sandy loam/6.4/7.0 (2001)	Barley	20 and 80	Increased microbial metabolism in soil; long-term increased buffering capacity of soil	Garcia-Gil et al. (2000, 2004)
Gesenu MSW treatment plant, Perugia, Italy	Sandy loam/7.7; clay silt loam/7.8	N/A	~ 50	Increased soil Zn concentrations in both soils, pot experiment	Giusquiani et al. (1988)
Gesenu MSW treatment plant, Perugia, Italy	Clay loam/8.3	Corn	30, 90, and 270	Increased enzyme activities despite adding three times the heavy metals limit specified by Italian law	Giusquiani et al. (1994)
Valdemingomez urban solid waste treatment plant, Madrid, Spain	Sandy clay loam/6.1/10	N/A	15, 30, and 60	Increased water holding capacity, pH, soil Zn and Cu concentrations, pot experiment	Hernando et al. (1989)
Santa Cruz de Tenerife, Canary Islands, Spain	Clay loam/5.8/16	Ryegrass	10, 20, 30, 40, and 50	High rates can provide sufficient N for ryegrass, E.C. increased with rate, soil P retention decreased, pot experiment	Iglesias-Jimenez and Alvarez (1993) and Iglesias-Jimenez et al. (1993)
Not stated	Clay loam/7.7/0.8	Spinach	0, 20, 40, 60, and 80	Increased yield, increased P, Mn, Pb, Na, and Cl uptake, pot Experiment	Maftoun et al. (2004)
Truman, MN (OTVD French technology) and Buffalo, MN (Buhler Swiss technology)	Sandy loam/5.8	Corn	90 and 270	Composts highly variable year to year	Mamo et al. (1999)
Source-separated Lunenburg regional recycling and composting facility, NS, Canada	Sandy loam/potatoes: 5.8, sweet corn: 6.5	Potatoes and sweet corn	Potatoes: 21.7, 43.4, and 65.1; sweet corn: 7.5, 15, and 22.5 (half these amounts were applied the second year)	pH increased, compost supplied similar amount of P as mineral fertilizer	Mkhabela and Warman (2005)
Cupello engineering, Italy	Clay/7.4	Alfalfa and cocksfoot	Alfalfa: 150, cocksfoot: 60	Organic carbon increased	Montemurro et al. (2006)
Sevilla city wastes (fraction <30mm), Spain	Sandy clay loam/7.8	Clover	100 (2 applications)	Increased N, Zn, Cu, Ni, and Cr uptake, pot experiment	Murillo and Cabrera (1997)
Lunenburg regional recycling and composting facility, NS, Canada	Sandy loam/4.55; gravelly loams/4.53, 4.80	Blueberries	35, 70, and 140 (2 applications)	Increased soil Mn at high rate, increased leaf Ni at high rate	Murphy and Warman (2001)
Agrisoil compost	Very gravelly loam/7.2-7.6	Tomatoes; squash	24 and 48	Increased soil concentrations of Cd, Cu, Pb, Ni, and Zn, fruit uptake was not observed	Ozores-Hampton and Hanlon (1997)

decomposed materials begins to dwindle. (Luis F. Diaz *et al.*, 2004).

Maturation or Curing Phase

Eventually, the supply of easily decomposable material is depleted, and the maturation stage begins. In the maturation phase, the proportion of material that is resistant steadily

rises and microbial proliferation correspondingly declines. Temperature begins an inexorable decline, which persists until ambient temperature is reached. The time involved in maturation is a function of substrate and environmental and operational conditions (i.e., as brief as a few weeks to as long as a year or two) (Luis F. Diaz *et al.*, 2004).

Utilization of MSWC in agricultural land

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 Araujo *et al.*, (2008). Utilization of MSWC in agricultural land Increase 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 (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 Araujo and Monteiro (2006). Recently, RocaPerez *et al.*, (2009). Soil ecology is increasingly being used to evaluate soil quality. It is thought that soil microbiological properties are most sensitive to changes in the soil environment (Pankhurst *et al.*, 1997; Crecchio *et al.*, 2001). Biomass N, C, and S showed increases in the soil immediately after compost addition and for up to 1 month, while biomass P showed an increasing trend for 5 months (Perucci, 1990). Application of 2.5, 10, 20, and 40 Mg ha⁻¹ MSW compost increased soil microbial biomass C and soil respiration(Bundela *et al.*, 2010)

Effect of MSW compost amendments on soil microbial biomass

Compost is rich in organic matter and is an important source plants nutrient GallardoLara 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. Soil microbial biomass is very closely related to the soil organic matter content in many arable agricultural soils Houot and Chaussod (1995). 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). 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 (Bundela *et al.*, 2010).

Conclusion

In the present review composting of municipal solid waste could be seen as an option of waste management in indian cities. It is environmental friendly, wealth creating and sustainable. This technique has been used for bioremediation of polluted sites. Effect of Hms on soil microbes depend upon soil as well as municipal solid waste characteristic and its

application rates. Thus physico-chemical analysis of municipal solid waste compost is necessary before its application in to agricultural land.

REFERENCES

- Adewale M.T.aiwo (2011). Composting as a sustainable waste management technique in developing countries, *Journal of Env. Sci & Tech.*, 4 (2):93-102.
- Alpert, J. E., M. Hernandez, and Y. Soto (2002). Process and structural upgrades - improving a state-of-the-art composting facility. *Bio Cycle*, 43(5): 40-42.
- Araujo, A.S.F. and Monteiro, R.T.R., 2006, : "Microbial biomass and activity in a Brazilian soil plus untreated and composted textile sludge", *Chemosphere*, 64, pp 1043-1046.
- Araujo, A.S.F., Santos, V.B., Monteiro, R.T.R., 2008, : "Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piau' state", *Brazil. Eur J Soil Biol.*, 44, pp 25-30.
- Atchley, S. H. and J. B. Clark (1979). Variability of temperature, pH, and moisture in an aerobic composting process. *Applied and Environmental Microbiology*, 38(6): 1040-1044.
- Bach, P. D., K. Nakasaki, M. Shoda, and H. Kubota (1987). Thermal balance in composting operations. *Journal of Fermentation Technology*, 65(3): 199-209.
- Bar-Tal, A., Yermiyahu, U., Beraud, J., Keinan, M., Rosenberg, R., Zohar, D., Rosen, V., Fine, P., 2004. Nitrogen, phosphorus, and potassium uptake by wheat and their distribution following successive, annual compost applications. *J. Environ. Qual.*, 33, 1855-1865.
- Beck, M. B. (1984). Understanding environmental systems. In: Predictability and Nonlinear Modeling in Natural Sciences and Economics, eds. J. Grassman and G van Straten, Kluwer Academic Publishers, Kluwer, the Netherlands, pp. 294-311.
- Benito, M; To Masaguer; To Moliner; N Arrigo; M Palm. 2003. Microbiological Chemical and parameters for the characterization of the stability and maturity of pruning waste compost. *Biol. Fertil. Soils*, 37:184 - 189.
- Bernal, MP; Navarrese high frequency; MA Sanchez-Monedero; To Roig; J Cegarra. 1998. Influence of sewage sludge compost stability and maturity on coal and nitrogen mineralization in soil. *Soil Biol. Biochem.*, 30: 305-313.
- Bhattacharyya, P., Chakrabarti, K., Chakraborty, A., 2003a. Effect of MSW compost on microbiological and biochemical soil quality indicators. *Compost Sci. Util.*, 11 (3), 220-227.
- Bhattacharyya, P., Chakraborty, A., Bhattacharya, B., Chakrabarti, K., 2003b. Evaluation of MSW compost as a component of integrated nutrient management in wetland rice. *Compost Sci. Util.*, 11 (4), 343-350.
- Bodelier, P. L., and H. J. Laanbroek (1997). Oxygen uptake kinetics of pseudomonas chlororaphis grown in glucose- or glutamate-limited continuous cultures. *Archives Microbiology*, 167: 392-395.
- Brewer, L. J. (2001). Maturity and stability evaluation of composted yard debris. M.S. Thesis, Oregon State University, Corvallis, USA.
- Brodie, H. L. (1996). Exporting nutrients as compost. In: Animal Agriculture and the Environment: Nutrients, Pathogens and Community Relations, ed. M. Sailus, NRAES-96, Rochester, USA, pp. 277-284.
- Bulluck, L.R., Ristaino, J.B., 2002, : "Effect of synthetic and organic soil fertility amendments on southern blight, soil microbial communities, and yield of processing tomatoes", *Phytopathology*, 92, pp 181-189.
- Bundela P.S. , S.P. Gautam , A.K. Pandey , M.K. Awasthi, S. Sarsaiya (2010). Municipal solid waste management in

- Indian cities – A review, *International J. of Env. Sci.* Volume 1, No 4.
- Campbell, J. E. (1990). Dielectric properties and influence of conductivity in soils at one to fifty megahertz. *Soil Science Society of America Journal*, 54: 332-341.
- Cathcart, T. P., F. W. Wheaton, and R. B. Brinsfield (1986). Optimizing variables affecting composting of blue crab scrap. *Agricultural Wastes*, 15: 269-286.
- Characklis, W. G., and W. Gujer (1979). Temperature dependency of microbial reactions. *Prog. Water Technol. Suppl.*, 1:111-130.
- Cooney, C. L., D. I. Wang, and R. I. Materles (1968). Measurement of heat evolution and correlation with oxygen consumption during microbial growth. *Biotechnology and Bioengineering*, 11: 269-281.
- Crecchio, C., Curci, M., Mininni, R., Ricciuti, P., Ruggiero, P., 2001. Shortterm effects of municipal solid waste compost amendments on soil carbon and nitrogen content, some enzyme activities and genetic diversity. *Biol. Fert. Soils*, 34, 311-318.
- Crecchio, C., Curci, M., Pizzigallo, M., Ricciuti, P., Ruggiero, P., 2004. Effects of municipal solid waste compost amendments on soil enzyme activities and bacterial genetic diversity. *Soil Biol. Biochem.*, 36, 1595-1605.
- Daskalopoulos, E.O., Badr and S.D. Probert, (1998). An Integrated approach to Municipal solid waste management. *Resour. Conserv. Recycling*, 24 : 33-50.
- Dean, T. J., J. P. Bell, and A. J. B. Baty (1987). Soil moisture measurement by an improved capacitance technique (I): sensor design and performance. *Journal of Hydrology*, 93: 67-78.
- DeBertoldi, M., A. Rutili, B. Citterio, and M. Civilini (1988). Composting management a new process control through O₂ feedback. *Waste Management Research*, 6: 239-259.
- Dirksen, C. and S. Dasberg (1993). Improved calibration of time domain reflectometry soil water content measurements. *Soil Science Society of America Journal*, 57: 258-264.
- El-Fadel, M., A.N. Findikakis and J.O. Leckei, (1997). Environmental Impact of solid waste landfill. *J. Environ. Manage*, 50: 1-25.
- Ekinci, K. (2001). Theoretical and experimental studies on the effects of aeration strategies on the composting process. Ph.D. Dissertation, the Ohio State University, Columbus, USA.
- Ekinci, K. (2001). Theoretical and experimental studies on the effects of aeration strategies on the composting process. Ph.D. Dissertation, the Ohio State University, Columbus, USA.
- Ekinci, K. (2001). Theoretical and experimental studies on the effects of aeration strategies on the composting process. Ph.D. Dissertation, the Ohio State University, Columbus, USA.
- Eklind Y., Beck-Friis B., Bengtsson S., Ejlertsson J., Kirchmann H., Mathisen B., Nordkvist E., Sonesson U., Svensson B. H., and Torstensson L., 1997. Chemical characterization of source-separated organic household wastes. *Swedish Journal of Agricultural Researches*, 27: 167-178.
- EPA (1995). Decision maker guide to solid waste management. Vol. 2, United State Environmental Protection Agency. Washington D.C. Pp: 372.
- Epstein, E., 1997. The science of composting. Technomic Publishing, Lancaster,
- Eriksen, G., Coale, F., Bollero, G., 1999. Soil nitrogen dynamics and maize production in municipal solid waste amended soil. *Agron. J.* 91, 1009-1016.
- Faucette, B. (2004). Evaluation of environmental benefits and impacts of compost and industry standard erosion and sediment control measures used in construction activities. Ph.D. Dissertation, University of Georgia, Atlanta, USA.
- Finger, S. M., R. T. Hatch, and T. M. Regan (1976). Aerobic microbial growth in semisolid matrices: heat and mass transfer limitation. *Biotechnology and Bioengineering*, 18: 1193-1218.
- Finstein, M. S. and J. A. Hogan (1992). Integration of composting process microbiology, facility structure and decision-making. In: Proceedings of the International Composting Research Symposium, Renaissance Publications, Columbus, USA.
- Finstein, M. S. and M. L. Morris (1975). Microbiology of municipal solid waste composting. *Applied Microbiology*, 19: 113-151.
- Finstein, M.S., Miller, F.C. and Strom, P.F. 1986. Monitoring and Evaluating Composting Process performance. *Journal of Water Pollution and Control Federation*, 58(4): 272-278.
- Frankenberger WT, Dick WA 1983.: "Relationship between enzyme activities and microbial growth and activity indices in soil", *Soil Sci Soc Am J.*, 47, pp 945-951.
- Fromme, W. R. (1999). Characterization of changes occurring in natural organic matter during the composting of a synthetic compost and a municipal solid waste. Ph.D. Dissertation, University of Cincinnati, Cincinnati, USA.
- GallardoLara, F., Nogales, R., 1987.: "Effect of the application of town refuse compost on the soil-plant system: a review", *Biol Waste*, 19, pp 35-62.
- Garcia-Gil, J.C., Ceppi, S., Velasca, M., Polo, A., Senesi, N., 2004. Longterm effects of amendment with municipal solid waste compost on the elemental and acid functional group composition and pH-buffer capacity of soil humic acid. *Geoderma*, 121, 135-142.
- Garcia-Gil, J.C., 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.
- Giusquiani, P., Marucchini, C., Businelli, M., 1988. Chemical properties of soils amended with compost of urban waste. *Plant Soil*, 109, 73-78.
- Giusquiani, P.L., Gigliotti, G., Businelli, D., 1994. Long-term effects of heavy metals from composted municipal waste on some enzyme activities in a cultivated soil. *Biol. Fert. Soils*, 17, 257-262.
- Godden, B. (1983). Evolution of enzyme activities and microbial populations during composting of cattle manure. *European Journal of Applied Microbiology and Biotechnology*, 17: 306-310.
- Golueke, C. G. and L. F. Diaz (1996). Historical review of composting and its role in municipal waste management. In: The Science of Composting, eds. M. DeBertoldi, P. Sequi, B. Lemmes, and T. Papi, Blackie Academic and Professional, London, UK, pp. 3-13.
- Gotaas, Harold Benedict (1956). Composting: sanitary disposal and reclamation of organic wastes World Health Organization (Geneva) 101-184-886
- Gray K. R., Sherman K., and Biddlestone A. J., 1971a. A Review of Composting – Part I. *Process Biochemistry*. 6: 32-36.
- Gray, K. R., K. Sherman, and A. J. Biddlestone (1971). Review of composting part II. *Process Biochemistry*, 6(10): 22-28.
- Gregor, S. T., F. C. Miller, K. M. Psarianos, and M. S. Finstein (1981). Composting process control based on interaction between microbial heat output and temperature. *Applied and Environmental Microbiology*, 41 (6): 1321-1330.
- Haight (July 2006). Final Compost Training Presentation. Power Point Presentation. Baisha Hainan, China.
- Haight, Taylor (August 2000). A Manual for Composting in Hotels. A guide to Composting Yard and Food Waste for Hotels in Thailand. Canadian Universities Consortium Urban

- Environmental Management Project, Training and Technology Transfer program Funded by Canadian International Development Agency.
- Hall, S. G. (1998). Temperature feedback and control via aeration rate regulation in biological composting systems. Ph.D. Dissertation, Cornell University, Ithaca, USA.
- Hansen, R. C., H. M. Keener, C. Marugg, C. A. Dick, and H. A. J. Hoitink (1993). Composting of poultry manure. In: Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects, ed. Hoitink, H.A.J., Renaissance Publications, Columbus, USA, pp. 131-153.
- Hargreaves J.C., M.S. Adl , P.R. Warman (2007). A review of the use of composted municipal solid waste in agriculture, *Agriculture, Ecosystems and Environment*, 123 (2008) 1–14.
- Haug, R. T. (1980). Compost engineering: principles and practice. Ann Arbor Science, Ann Arbor, USA.
- Haug, R. T. (1986). Composting process design criteria part I: feed conditioning. *BioCycle*, 27: 38-43.
- Haug, R. T. (1993). The practical handbook of compost engineering. Lewis Publishers, Boca Raton, USA.
- Haug, R. T. (1993). The practical handbook of compost engineering. Lewis Publishers, Boca Raton, USA.
- Haug, R. T. (1996). Composting plant design and process management. In: The Science of Composting, eds. M. DeBertoldi, P. Sequi, B. Lemmes, and T. Papi, Blackie Academic and Professional, London, UK, pp. 60-70.
- Haug, R.T. 1993. The practical handbook of compost engineering / Boca Raton: Lewis Publishers, ISBN: 0873713737 (acid-free paper).
- Henis Y., 1987. Survival and Dormancy of Microorganisms. John Wiley & Sons Inc., New York.
- Hernando, S., Lobo, M., Polo, A., 1989. Effect of the application of a municipal refuse compost on the physical and chemical properties of soil. *Sci. Total Environ.*, 81/82, 589–596.
- Hoitink, H. A. J., M. J. Boehm, and Y. Hadar (1992). Mechanisms of suppression of soilborn plant pathogens in compost amended substrates. In: Proceedings of the International Composting Research Symposium, Renaissance Publications, Columbus, USA, pp. 154-167.
- Hoornweg, Thomas, Otten (1999). Composting and its Applicability in Developing Countries. World Bank, Urban Waste Management. Retrieved June 2006 from Urban Development Division, The World Bank.
- Houot, S., Chaussod, R., 1995, : “Impact of agricultural practices on the size and activity of the soil microbial biomass in a longterm field experiment”, *Biol Fert Soil*, 19, pp 309–316.
- Iglesias-Jimenez, E., Alvarez, C., 1993. Apparent availability of nitrogen in composted municipal refuse. *Biol. Fert. Soils*, 16, 313–318.
- Iglesias-Jimenez, E., Garcia, V., Espino, M., Hernandez, J., 1993. City refuse compost as a phosphorus source to overcome the P-fixation capacity of sesquioxide-rich soils. *Plant Soil*, 148, 115–127.
- Incropera, F. P., and D. P. DeWitt (1985). Fundamentals of heat and mass transfer. John Wiley and Sons, New York, USA.
- Iriarte, M. L. and P. Ciria (2001). Performance characteristics of three aeration systems in the composting of sheep manure and straw. *Journal of Agricultural Engineering Research*, 79 (3): 317-330.
- Jeris, J. S. and R. W. Regan (1973b). Controlling environmental parameters for optimum composting (II): moisture, free air space and recycle. *Compost Science*, 14(2): 8-15.
- Jeris, J. S. and R.W. Regan (1973a). Controlling environmental parameters for optimum composting (I): experimental procedures and temperature. *Compost Science*, 14 (1): 10-15.
- Keener, H. M., C. Marugg, R. C. Hansen, and H. A. J. Hoitink (1992). Optimizing the efficiency of the composting process. In: Proceedings of the International Composting Research Symposium, eds. H. A. J. Hoitink and H. Keener, Renaissance Publications, Columbus, USA, pp. 59-94.
- Kishimoto, M., C. Preechaphan, T. Yoshida, and H. Taguchi. (1987). Simulation of an aerobic composting of activated sludge using a statistical procedure. *MIRCEN Journal of Applied Microbiology and Biotechnology*, 3: 113-124.
- Lasoff, M. A. (2000). Composting industry. *Waste Age*, 31(8): 44-53.
- Lester J. N. and Birkett J. W., 1999. Microbiology and Chemistry for Environmental Scientists and Engineers. pp. 184-185. E & FN SPON., New York.
- Ljung, L. and T. Glad (1994). Modeling of dynamic systems. Prentice Hall, New Jersey, USA.
- Luis F. Diaz *et al.*, (2004). Hand Book of solid waste management, pp-12.4-12.5.
- Luong, J. H. T. and B. Volesky (1983). Heat evolution during microbial process - estimation, measurement, and applications. *Advances in Biochemical Engineering/Biotechnology*, 28: 1-40.
- Lyles S. T., 1969. Biology of Microorganisms. The C. V. Mosby Co., St. Louis.
- Macky, B. M. and C. M. Derrick (1986). Elevation of the heat resistance of salmonella typhimurium by sublethal heat shock. *Journal of Applied Bacteriology*, 66: 389-393.
- Maftoun, M., Moshiri, F., Karimian, N., Ronaghi, A., 2004. Effects of two organic wastes in combination with phosphorus on growth and chemical composition of spinach and soil properties. *J. Plant Nutr.*, 27 (9), 1635–1651.
- Mamo, M., Rosen, C., Halbach, T., 1999. Nitrogen availability and leaching from soil amended with municipal solid waste compost. *J. Environ. Qual.*, 28, 1074–1082.
- Miller, F. C. (1991). Biodegradation of solid wastes by composting. In: Biological Degradation of Wastes, ed. Martin, A. M., Elsevier Applied Science, London, UK, pp. 1-31.
- Mkhabela, M., Warman, P.R., 2005. The influence of municipal solid waste compost on yield, soil phosphorus availability and uptake by two vegetable crops, grown in a Pugwash sandy loam soil in Nova Scotia. *Agric. Ecosyst. Environ.*, 106, 57–67.
- Molla, A., Fakhru'l-Razi, A., Hanafi, M., and M. Alam (2005). Compost produced by solid state bioconversion of biosolids: a potential resource for plant growth and environmental friendly disposal. *Communications in Soil Science and Plant Analysis*, 36(11&12): 1435-1447.
- Montemurro, F., Maiorana, M., Convertini, G., Ferri, D., 2006. Compost organic amendments in fodder crops: effects on yield, nitrogen utilization and soil characteristics. *Compost Sci. Util.*, 14 (2), 114–123.
- Murillo, J., Cabrera, F., 1997. Response of clover *Trifolium fragiferum* cv Salina to a heavy urban compost application. *Compost Sci. Util.*, 5 (4), 15–26.
- Murphy, C., Warman, P.R., 2001. Effect of MSW compost applications on low-bush blueberry soil and leaf tissue trace elements. In: Proceedings of the 6th International Conference on the Biogeochemistry of Trace Elements, Guelph, ON, p. 166.
- Nakasaki, K. (1987). A new composting model and assessment of optimum operation for effective drying of composting material. *Journal of Fermentation Technology*, 65(4): 441-447.
- Nakasaki, K., and M. Shoda (1987). Oxygen diffusion and microbial activity in the composting of dehydrated sewage

- sludge cakes. *Journal of Fermentation Technology*, 56(1): 43-48.
- Nakasaki, K., K. Nag, and O. Ariga (2004). Degradation of fats during thermophilic composting of organic waste. *Waste Management & Research*, 22(4): 276-282.
- Nakasaki, K., K. Nag, and S. Karita (2005). Microbial succession associated with organic matter decomposition during thermophilic composting of organic waste. *Waste Management & Research*, 23 (1): 48-56.
- Oppenheimer, J. R. (1997). Compost process model development, validation, and simulation to assess moisture and energy management. M.S. Thesis, Cornell University, Ithaca, USA.
- Ozores-Hampton, M., Hanlon, E., 1997. Cadmium, copper, lead, nickel and zinc concentrations in tomato and squash grown in MSW compost amended calcareous soil. *Compost Sci. Util.* 5 (4), 40-46.
- Page, TO; Miller; DH and Keeney, Dr (Eds) 1982. Methods of Soil Analysis, Part 2, 2nd edn microbiological Chemical and properties. Agronomy Series 9 ROASTS SSSA, Madison, WI. The USA.
- Park, M., O. Singvilay, W. Shin, E. Kim, J. Chung, and T. Sa (2004). Effects of long-term compost and fertilizer application on soil phosphorus status under paddy cropping system. *Communications in Soil Science and Plant Analysis*, 35 (11&12): 1635-1648.
- 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, pp 1375-1382.
- Rand, T., J. Hankohl and V. Marxen (2000). Municipal solid waste incineration, Decision maker guide. Work Bank Washington D.C.
- Richard, T. L. (1992). Municipal solid waste composting: physical and biological processing. *Biomass and Bioenergy*, 3(3-4): 163-180.
- Richard, T. L. and L. P. Walker (1989). Temperature kinetics of aerobic solid-state biodegradation. *Proceedings of the IBE*, 1: A10-A30.
- Richard, T. L., L.P. Walker, and J. M. Gosset (1999). The effects of oxygen on solid-state biodegradation kinetics. *Proceedings of the IBE*, 2: A22-A39.
- RocaPerez, L., Martinez, C., Marcilia, P., Boluda, R., 2009, : "Composting Rice straw with sewage sludge and compost effects on the soilplant system", *Chemosphere*, 75, pp 781-787.
- Ryckeboer J., Mergaert J., Vaes K., Klammer S., De Clercq D., Coosemans J., Insam H., and Swings J., 2003. A survey of bacteria and fungi occurring during composting and self-heating processes. *Annals of Microbiology*, 53: 349-410.
- Ryckeboer, J. and J. Mergaert (2003). Microbiological aspects of biowaste during composting in a monitored compost bin. *Journal of Applied Microbiology*, 94(1): 127-137.
- Rynk, R. F., E. A. Johnson, and L. F. Whitney (1991). An expert system assisted control system for a composting process. In: *Automated Agriculture for the 21st Century*, Proceedings of the December 1991 Symposium, ASAE, St Joseph, USA.
- Seo, S.A., T. Aramaki, Y. Hwang and K. Hamaki (2004). Environmental Impact of solid waste treatment in Korea J. *Environ. Eng.*, 130: 81-89.
- Sesay, A. A. (1998). Aerated static pile composting of municipal solid waste (MSW): A comparison of positive pressure aeration with hybrid positive and negative aeration. *Waste Management and Research*, 16(3): 264-272.
- Sinha, R. K. and S. Heart (2002). A cost-effective microbial slurry technology for rapid composting of municipal solid wastes in waste dump sites in India and its feasibility for use in Australia. *The Environmentalist*, 22 (1): 12-19.
- Stentiford E. I., 1993. Diversity of Composting Systems. In: Hoitink A. J. and Keener H. M. (eds.) *Science and Engineering of Composting: Design, Environmental, Microbiological and Utilization Aspects.* pp. 100. Renaissance Publications, Worthington.
- Stentiford, E. I. (1996). Composting control: principles and practice. In: *The Science of Composting*, eds. M. DeBertoldi, P. Sequi, B. Lemmes, and T. Papi, Blackie Academic and Professional, London, UK, pp. 49-59.
- Swatek F. E., 1967. *Textbook of Microbiology*. The C. V. Mosby Co., St. Louis.
- Szmidt, R. and C. Fox (2001). Compost processes—Interdependencies for process control and compost quality. *Acta horticulture*, 549: 55-61.
- Teira, R.M. (2003) Class note of the subject environmental engineering. Department of Agricultural Engineering, Univeristy of Lieida (spain).
- Uif, S. (1998). Systems analysis of waste management-the ORWARE model, transport and compost sub-models. Ph.D. Dissertation, Swedish university of agricultural sciences, Uppsala, Sweden.
- USA.
- VanderGheynst, J. S. (1997). Experimentation, modeling and analysis of a high-solids aerobic decomposition process. Ph.D. Dissertation, Cornell University, Ithaca, USA.
- Vinci, B. J., S. T. Summerfelt, M. B. Timmons, and B. J. Watten (1996). Carbon dioxide control in intensive aquaculture: design tool development. *Proceedings of the Aquacultural Engineering Society*, 2: 399-419.
- Zhang, Z. (2000). The effects of moisture and free air space on composting rates. M.S. Thesis, Iowa state university, Ames, USA.
