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Assessment of physico- chemical properties and microbial community during composting of municipal solid waste (Viz. KItchen waste) at Jhansi City, U.P. (India)

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Abstract

Rapid industrialization and population explosion in India has led to the migration of people from villages to cities, which generate thousands of tons of Municipal Solid Waste (viz. Kitchen waste) MSW (Viz. KW) daily. Jhansi City is well known district of Bundelkhand region of Uttar Pradesh (India) with a geographical area of 502.75 thousand hectare. The district is situated in the South West corner of the region at 24º11' - 25º57' N latitude and 78º10' - 79º23' E longitudes. Population of Jhansi city is near about 4,79, 612. A detail study was conducted in four consecutive years to assess the potential and possibilities of MSW (Viz. KW) composting generated from Jhansi city, Uttar Pradesh. In the present study, we studied physico-chemical parameters and succession of microbial populations during composting process of MSW (Viz. KW) and found that the pH ranged between 7.1-7.9, Temperature 14-65.2°C, Organic Carbon 20-26 %, moisture content 22-66.7 %, nutrients N – 1.16 %, P – 0.04 %, K – 0.34%, Na – 2.89 % and microbial colonies like Bacteria, fungi, and Actinomycetes were also present in large numbers.Temperature plays an important role in the growth of microbial colonies during composting of Municipal Solid waste (Viz. Kitchen Waste).

Keywords: Municipal Solid Waste, Organic Carbon, Microbial Population

INTRODUCTION

Composting is a biochemical process in which organic materials are biologically degraded (Eq. 1), resulting in the production of organic or inorganic by products and energy in the form of heat (Hogos et al. 2002). Heat is trapped within the composting mass, leading to the phenomenon of self-heating that is characteristics of the composting process (Semple et al., 2001).

$$\text{Organic Biodegradable Residue} + O_2 \xrightarrow{\text{Microbes}} \text{Stabilized organic Residue} + \text{Microbial Biomass} + CO_2 + H_2O + \text{Heat} \quad (1)$$

Composting is a microbiological process, little is known about microorganisms involved and their activities during specific phases of the composting process. Defining the diversity and structure of microbial communities of compost through their constituent populations has been of considerable interest to compost researchers in order to address basic ecological questions such as how similar are microbial communities in mature compost that were conducted from different feedstocks and using different composting methods (Tiquia and Michel, 2002).

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 humuslike substances (S.P. Gautam et al., 2010).

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) Arau´jo et al., (2008) Arau´jo and Monteiro (2006) Zucconi and Bertoldi (1987).

MATERIALS AND METHODS

Description of site and sampling

Jhansi City is well known district of Bundelkhand region of Uttar Pradesh with a geographical area of 502.75 thousand hectare. The district is situated in the South West corner of the region at 24º11' - 25º57' N latitude and 78º10' - 79º23' E longitudes.

Municipal Solid Waste (viz. Kitchen waste) was collected from door to door in 2008, 2009, 2010 and 2011 at Jhansi City Uttar Pradesh (India) and composted in biocomposter for 135 days. Before taking samples, the composting material were homogenized by daily turning a few times promote uniformity of the material inside the reactor. The sampling port located on the upper part of the biocomposter for collection of samples and the mixing of compost material. Samples were taken daily the first four days and weekly during rest of the time (120 days) at a deep of 15cm below the surface (Olynciw, 2002). From each pile three samples were taken from separated positions (about 10 cm distance). At each time of

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sampling, about 500 ml of compost material was taken and collected in a 500-ml beaker regardless of moisture content. Samples were transported to the laboratory rapidly and all the analysis (physico-chemical and microbiological) was made in the same day.

Analysis of Physico-Chemical Parameters

After the sampling from bioreactor, analysis conducted for physico-chemical parameters like pH, Temperature, Moisture Content, Electrical Conductivity, Organic Carbon, Nutrient (NPK), Sodium and Microbiological parameters on every 15 days during composting. The pH and electrical conductivity was determined in 1:50 extract after 30 minutes after stirring by using digital pH and EC meters, Samples were collected , dried and ground to pass through 1 mm sieve and used for chemical analysis. Carbon content was determined as wet digestion method by Walkley and Black as described by Jackson 1973, CEC by Bower method Richards, 1954). Total N content in the compost samples was determined by Micro jehldal method. Total P & K content was extracted by digestion with diacid and estimated the total P colorimetrically as Vanado-molybdophosphophosphate yellow colour complex and K by using Flame photometer (Jackson, 1973).

Isolation of microbial cultures from compost

The compost sample (10 g) was diluted in 90 mL of buffer solution (0.06M Na_2HPO_4/NaH_2PO_4) (1/9 v/v), pH 7.6. Decimal serials dilutions (10^{-1} to 10^{-10}) were made and inoculated aseptically in Petri dishes (10 µL for plate) with different culture media: Potato Dextrose Agar (PDA), Nutrient Agar (NA) and Starch Ammoniacal Agar (SAA); in order to facilitate the growth of fungi, bacteria and actinomycetes respectively. Petri dishes were incubated at 30°C(mesophilic microorganisms) and 50°C (termophilies) for 72h (PDA), 37°C or 50°C for 24h (NA) and 37°C or 55°C for 120 h (SAA), according to the phase were the isolation was carried out. After incubation isolated colonies of bacteria, fungi and actinomycetes were selected. The evaluation of cellular concentration in a compost samples was determined by plate counting of serials dilutions according to equation 1:

CFU/g = Colonies Numbers • dilution •100 ----------------------------Eq.1

RESULTS AND DISCUSSION

One hundred and thirty five days of the Municipal Solid weaste (Viz. Kitchen Waste) composting process were successfully conducted in four consecutive years at Jhansi City U.P. India, and details of the profiles of the physical, chemical and microbial parameters are changes during the composting process of MSW (Viz. KW) in biocomposter are presented in figure 1 (A-D), Table 1, and Figure 2 (A-C) respectively.

Physico-Chemical Properties of compost During Composting

Variation in pH value are presented in figure (1-A). The comparison of pH among different aged compost samples shadowed that during the early stage (first ten days) of decomposition pH was low (6.76), then it continued to increase slowly (Fig. 1-A). After 15th day of composting pH value were highest about 8.68 and after that it remain constant as 6.75 in all the four consecutive years. It could be explained as in the earliest stage of composting pH value decreases due to production of organic acids derived from the intense fermentation of carbohydrates. Afterwards, the pH begins to rise which results from the release of ammonia due to the start of proteolytic process (De Nobili and Petrussi, 1988). pH drop during thermophilic due to accumulation of organic acids reflects high rate of organic matter degradation and these acids are used later on as substrate by other microorganisms. During the cooling down and maturation stages the pH drops to a neutral value (Chefez et al., 1998). During the composting process, the pH dropped from 8.6 to 6.3, which may be due to the ammonification and mineralization of organic matter by the activities of microorganisms as found by Wong et al. (2001). 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).

Figure (1-B) shows that Electrical Conductivity was 2.15 mS/cm after 15 days of decomposition which increased to 2.32 mS/cm after one month. Thereafter, EC continued to decrease during the composting process and was stable (1.6 mS/cm) rest of the time in decomposition. The decrease of EC in the composting process is the direct consequence of the increased concentration of nutrients, such as nitrate and nitrite.

The moisture content in biocomposter was monitored, and the changes are shown in Figure 1 (C). In the 36-day composting process, the total moisture content dropped from 55.8 to 21.7% in biocomposter, and the greatest moisture loss was from days 30 to 90, when high temperatures dominated. Since the optimal moisture content in composting is 50.0 to 60.0%; a moisture content of over 65.0% can cause oxygen depletion (Gray et al. 1971b; Ryckeboer 2003).

The temperature characteristics of Municipal Solid waste (Viz. Kitchen Waste) compost during composting process are presented in figure 1 (D). The process of composting can be divided into three major steps, a mesophilic-heating phase, a thermophilic phase and a cooling phase (Alberti, 1984; Mustin, 1987, Leton and Stentiford, 1990). The highest temperature was about 64.°C in 2011, occurring between days 35 to 45. The temperature then cooled down to 35.5 ° C by day 120, and finally remained constant at about 32.7°C in 2011 for the rest of the composting process.

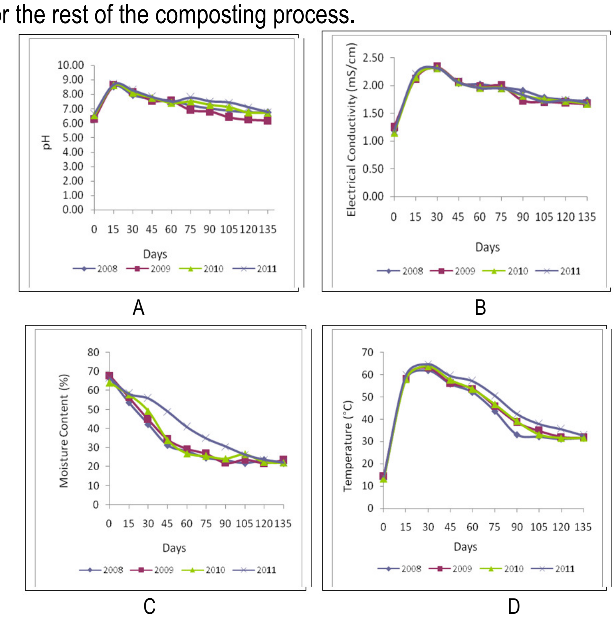

Fig1. (A-D). Shows the variations in pH (A), EC (B), Moisture Content (C) and

Temperature (D) during composting process of Municipal Solid waste (viz. Kitchen Waste)

Microbial Dynamics during Composting

The increase in the microbial count during Municipal Solid waste (Viz. Kitchen Waste) composting is shown in the figure 2 (A-C). In this experiment, the decline of temperature indicated that the compost had gone through the thermophilic stage and approached maturity, the microbial biomass also decreased with composting age, except in the case of actinomycetes. During composting, the microorganisms use the organic matter as a food source. The process produces heat, carbon dioxide, water vapour and humus as a result of growth and activities of microorganisms (Tiquia, 2005). Monitoring of the microbial succession is important in the effective management of the composting process as microorganisms play key roles in the process and the appearance of some microorganisms reflects the quality of maturing compost (Ryckeboer et al., 2003). The increase in bacterial and fungal concentrations evidenced during the mesophilic phase, was influenced fundamentally by temperature and pH. During initial phase of the composting process the substrate is at ambient temperature, the pH usually slightly acidic and easily available organic compound. Mesophilic fungi and bacteria are the dominant active degraders of fresh organic waste materials. Food waste containing vegetable residues often have a low initial pH (4.5-5), which stimulates the proliferation of fungi (Ryckeboer et al., 2003).

The interaction between various functional groups of microorganisms depends on nutrient resources and the biochemical mechanisms of organic and inorganic matter transformation changes (Insam *et al.,* 2002).

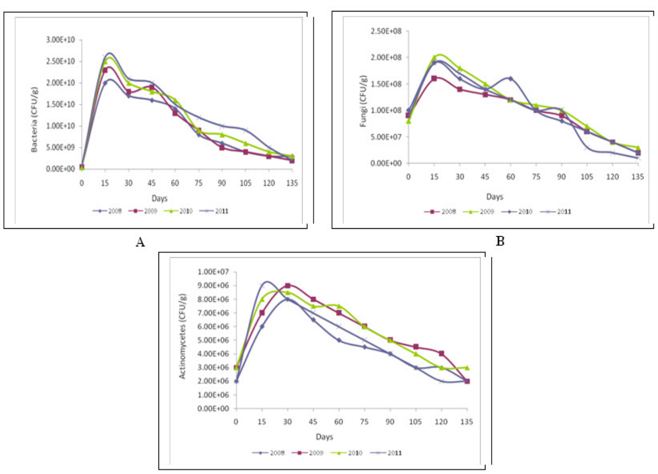

Fig 2 (A-C). Succession in microbial population (A=Bacteria, B=Fungi, C=Actinomycetes) during composting process of Municipal Solid waste (viz. Kitchen Waste).

Compost Characteristics

Physico-chemical characteristics of mature Municipal Solid waste (Viz. Kitchen Waste) compost are shown in table 1. pH of mature Municipal Solid waste (Viz. Kitchen Waste) compost are 7.51, 7.63, 7.10 and 7.79 in 2008, 2009, 2010 and 2011 respectively. EC (µS/cm) of mature Municipal Solid waste (Viz. Kitchen Waste) compost are 1288.0, 1324.0, 1277, and 1251.0 in 2008, 2009, 2010, and 2011 respectively. As with many properties of Municipal Solid waste compost, the EC content of MSW compost is likely related to the feed stock used in the compost and compost facility procedure (Hicklenton et al., 2001). Organic carbon (%) of mature Municipal Solid waste (Viz. Kitchen Waste) compost are 23.0, 24.0, 26.0 and 21.0 in 2008, 2009, 2010 and 2011 respectively.

The range of nitrogen concentrations that have been reported to be present in mature Municipal Solid waste (Viz. Kitchen Waste) compost is shown in table 1. While some studies showed that MSW compost increased soil N content, MSW compost is often reported to be less effective in supplying less available N in the first year of application to the soil-plant system than inorganic mineral fertilizars (Iglesias-Jimenez and Alvarez, 1993; Warman and Rodd, 1998; Eriksen et al., 1999).

The range of phosphorus that has been found in MSW composts is shown in table 1. Municipal solid waste compost has been reported to effectively supply P to soil with soil P concentration increasing with increasing application rates (Iglesias-Jimenez et al., 1993; Zhang et al., 2006). Some reports observed that MSW compost provided equivalent amounts of P to soil as mineral fertilizers (Iglesias-Jimenez et al., 1993). The range of K found in MSW compost in the literature is shown in table 1. Of the total K in MSW compost, 36–48% was found to be plant available (deHaan, 1981; Soumare et al., 2003).

Mn concentration in mature Municipal Solid waste (Viz. Kitchen Waste) compost are 212.3, 210.0, 208.5 and 213.1 in 2008, 2009, 2010 and 2011 respectively. Total soil Mn concentrations tended to increase with addition of MSW compost (Giusquiani et al., 1988; Murphy and Warman, 2001; Zheljazkov and Warman, 2004a,b). The largest portion of Mn in soil treated with MSW compost was found to be bound in the iron manganese fraction, which is unavailable to plants (Zheljazkov and Warman, 2004a). Maftoun et al. (2004) also reported interactions between Fe and Mn availability.

Cu concentrations in mature Municipal Solid waste (Viz. Kitchen Waste) compost is shown in table 1. Total and extractable soil Cu concentrations have been reported to increase when soil was amended with MSW compost and Cu has the potential to move down the soil profile (Ozores-Hampton and Hanlon, 1997; Warman et al., 2004; Zheljazkov and Warman, 2004a; Walter et al., 2006; Zhang et al., 2006).

Zn concentrations in mature Municipal Solid waste (Viz. Kitchen Waste) compost is shown in table 1. Municipal solid waste compost tended to increase total soil Zn concentrations when compared to unamended controls (Giusquiani et al., 1988; Pinamonti et al., 1999; Walter et al., 2006; Zhang et al., 2006).

Fe concentrations in mature Municipal Solid waste (Viz. Kitchen Waste) compost is shown in table 1. The application of MSW compost did not tend to increase soil and plant Fe concentrations. Municipal solid waste compost applied at 100 and 35–140 Mg ha1 did not increase available soil Fe concentrations nor did clover and blueberry leaves, respectively, show increased Fe concentrations compared to a control (Murillo and Cabrera, 1997; Warman, 2001).

The concentrations of other trace elements in MSW compost are shown in table 1. MSW compost can increase soil trace element concentrations (Pinamonti et al., 1999; Zheljazkov and Warman, 2004a).

Table 1. Physico-chemical analysis of mature Municipal Solid Waste (Viz. Kitchen Waste) compost

S.No.	Parameters	Years			
		2008	2009	2010	2011
1	pH	7.51 ± 0.03	7.63 ± 0.03	7.10 ± 0.02	7.79 ± 0.03
2	Electrical Conductivity (µS/cm)	1288.0 ± 5.51	1324.0 ± 5.57	1277.0 ± 6.67	1251.0 ± 5.51
3	Organic Carbon (%)	23.0 ± 1.0	24.0 ± 1.0	26.0 ± 1.0	21.0 ± 1.0
4	Nitrogen (%)	1.16 ± 0.02	1.18 ± 0.03	1.20 ± 0.01	1.17 ± 0.03
5	Phosphorus (%)	0.040 ± 0.01	0.030 ± 0.01	0.053 ± 0.01	0.043 ± 0.02
6	Potasium (%)	0.297 ± 0.02	0.340 ± 0.01	0.337 ± 0.02	0.377 ± 0.01
7	Sodium (%)	2.89 ± 0.02	2.76 ± 0.03	2.75 ± 0.04	2.81 ± 0.01
8	C/N Raio	24.00 ± 2.0	21.00 ± 1.0	22.00 ± 1.0	20.00 ± 2.0
9	Cr (mg/kg)	17.70 ± 0.18	17.36 ± 0.06	15.35 ± 0.25	16.79 ± 0.16
10	Cu (mg/kg)	47.11 ± 0.20	45.25 ± 0.17	48.39 ± 0.45	47.44 ± 0.46
11	Fe (mg/kg)	1134.8 ± 8.32	1246.6 ± 6.55	1274.2 ± 3.62	1329.5 ± 6.39
12	Zn (mg/kg)	51.1 ± 1.85	53.4 ± 1.09	52.5 ± 0.65	54.4 ± 1.44
13	Mn (mg/kg)	212.3 ± 0.53	210.0 ± 0.71	208.5 ± 0.85	213.1 ± 0.75

Values are Mean±SE

Conclusion

The present study of physico-chemical & microbiological characteristics of Municipal Solid weaste (Viz. Kitchen Waste) compost of Jhansi City U.P. India reveals reduction in microbial counts as well as microbial succession without a definite pattern and lower microbial counts at the end of the composting period. Municipal Solid weaste (Viz. Kitchen Waste) compost had significant amount of nutrients for plant growth. Composting of municipal solid waste has potential as a beneficial recycling tool. It's safe use in agriculture, however, depends on the production of good quality of compost, Especially, compost which is mature and low in metals and salt content sufficiently. The best method of reducing metal content and improving the quality of MSW compost is early source separation, perhaps separation required to occur before or at curbside collection.

REFERENCES

[1] Bergey´s Manual of Systematic Bacteriology. 1994. 9th Edition. Williams Wilkins, Baltimore, London.

[2] Bissett J. 1991. A revision of the genus Trichoderma. IV. Additional notes on section Longibrachiatum. Canada. *J. Bot.* 69:2418-2420.

[3] Ellis M. B. 1971. Demateaceous Hyphomycetes. Principal Mycologist. Common Wealth Mycological Institute. Kew, Surrey, England.

[4] Ellis M. B. 1976. More Dematiaceous Hyphomycetes. Mycological Institute. Kew, Surrey, England.

[5] Insam H., N. Riddech and S. Klammer. 2002. Microbiology of composting. – Springer edtion. Pp 99-108.

[6] Olynciw E. 2002. Cornell Composting. Compost Microorganisms. – Science & Engineering. Institute of Environmental Sciences.

[7] Ryckeboer J., J. Megaert , J. Coosemans , K. Deprins and J. Swings. 2003. Microbiological aspects of biowaste during composting in a monitored compost bin. – *J. Appl. Microbiol*., 94 (1): 127-137.

[8] Tiquia SM., Michel FC Jr. 2002. Bacterial Diversity in Livestock manure compost as characterized by terminal restriction fragment length polymorphisms (T-RFLP) of PCRamplified16S rRNA gene sequences.

[9] Wong JWC., K.F.Mak, N.W. Chan, A. Lam, M. Fang, L. X. Zhou, Q. T. Wu, X. D.Liao 2001. Co-compost of soybean residues and leaves in Hong Kong.*Biores Technol.* 76: 99-106.

[10] Hogos S.E.G., J.V. Juarez, C.A. Ramonet, J.G. Lopeg, A.A. Rios, and E.G. Uribe. 2002. Aerobic thermophilic composting of waste sludge from gelating-grenetine industry. *Resurces Conservation and Recycling,* 34, 161-173.

[11] Semple K.T., B.J. Reid and T.R. Fermor. 2001. Impact of composting stragies on the treatment of soils contaminated with organic pollutants. *Environmental Pollution*, 112, 269-283.

[12] Gray K. R., K. Sherman, and A. J. Biddlestone. 1971b. A Review of Composting − Part 2. The Practical Process. *Process Biochemistry.* 10: 22-28.

[13] Zucconi F., and M. De Bertoldi. 1982. Agricultural utilization of the product from the transformation of municipal solid waste. *Ingegnerta Ambientale*., 11:110-117.

[14] Gautam S.P., P.S. Bundela, A.K. Pandey, M.K. Awasthy, S. Sarsaiya, 2010. evolution of the Municipal Solid Waste Compost Phytotoxicity, and Maturation for ecofriendly organic forming system. *Journal of applied science in environmental sanitation,* 5 (4) : 397-402.

[15] Arau´jo, A.S.F., Monteiro, R.T.R., Abarkeli, R.B. 2003. "Effect of glyphosate on the microbial activity of two Brazilian soils", *Chemosphere*, 52, pp 799–804.

[16] Arau´jo, A.S.F., V.B. Santos, R.T.R. Monteiro, 2008. “Responses of soil microbial biomass and activity for practices of organic and conventional farming systems in Piauı´ state”, Brazil. Eur J Soil Biol., 44, pp 25–30.

[17] Bernal, M.P., J.A. Albuquereque, R. Moral. 2008. “Composting of animal manures and chemical criteria for compost maturity assessment: a review”, *Bioresour Technol*, 99, pp 3372– 3380.

[18] De Nobili M. and F. Petussi, 1988. Humification index as Evaluation of the stabilization Degree during compost. *J. Fermentation Technol*., 66: 557 – 583.

[19] Chefetz, B., Y. Chen and Y. Hadar, 1998. Water extractable components released during composting of Muncipal solid waste. *Acta Hort*., 469: 111 – 119.

[20] Benito, M; T.O. Masaguer,, Moliner; To Arrigo, N. and Palmmm M. 2003. Microbiological Chemical and parameters for the characterization of the stability and maturity of pruning waste compost. *Biol.Fertil. Soils* 37:184 – 189.

[21] Page, T.O., D.H Miller and Dr Keeney, (Eds) 1982. Methods of Soil Analysis, Part 2, 2nd edn microbiological Chemical and properties. Agronomy Series 9 ROASTS SSSA, Madison, Wi. The USA.

[22] Miller, F. 1993. Minimizing Odour Generation. In: Science and Engineering of Composting. *Hoitink and Keener*. pp. 219-241.

[23] deHaan, S., 1981. Results of municipal waste compost research over more than fifty years at the Institute for Soil Fertility at Haren/Groningen, the Netherlands. *Neth. J. Agric*. 29, 49–61.

[24] Eriksen, G., Coale, F., Bollero, G., 1999. Soil nitrogen dynamics and maize production in municipal solid waste amended soil. *Agron. J.* 91, 1009–1016.

[25] Giusquiani, P., C. Marucchini, M. Businelli. 1988. Chemical properties of soils amended with compost of urban waste. *Plant Soil* 109, 73–78.

[26] Hicklenton, P., V. Rodd, P.R. Warman. 2001. The effectiveness and consistency of source-separated municipal solid waste and bard composts as components of container growing media. *Sci. Hort.* 91, 365–378.

[27] Iglesias-Jimenez, E., V. Garcia, M. Espino, J. Hernandez. 1993. City refuse compost as a phosphorus source to overcome the P-fixation capacity of sesquioxide-rich soils. *Plant Soil* 148, 115–127.

[28] Maftoun, M., F. Moshiri, N. Karimian, A. Ronaghi, 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.

[29] Murillo, J., F. Cabrera,, 1997. Response of clover Trifolium fragiferum cv Salina to a heavy urban compost application. *Compost Sci. Util.* 5 (4), 15–26.

[30] Murphy, C., P.R. Warman, 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.

[31] Ozores-Hampton, M., E. Hanlon, 1997. Cadmium, copper, lead, nickel and zinc concentrations in tomato and squash grown in MSW compostamended calcareous soil. *Compost Sci. Util.* 5 (4), 40–46.

[32] Pinamonti, F., G. Nicolini, A. Dalpiaz, G.Stringari, G. Zorzi,, 1999. Compost use in viticulture: effects on heavy metal levels in soil and plants. Commun. *Soil Sci. Plan*. 30 (9–10), 1531–1549.

[33] Soumare, M., F. Tack, M. Verloo. 2003. Characterisation of Malian and Belgian solid waste composts with respect to fertility and suitability for land application. *Waste Manag*. 23, 517–522.

[34] Walter, I., F. Martinez, G.Cuevas, 2006. Plant and soil responses to the application of composted MSW in a degraded, semiarid shrubland in central Spain. *Compost Sci. Util.* 14 (2), 147–154.

[35] Warman, P.R., 2001. Municipal solid waste compost effects tomato leaf tissue: essential plant nutrients and trace elements. In: Proceedings of the 6th International Conference on the Biogeochemistry of Trace Elements, Guelph, ON, p. 167.

[36] Warman, P.R., C. Murphy, J. Burnham, L. Eaton, 2004. Soil and plant response to MSW compost applications on lowbush blueberry fields in 2000 and 2001. *Small Fruit Rev.* 3 (1/2), 19–31.

[37] Warman, P.R.,V. Rodd, 1998. Influence of source-separated MSWcompost on vegetable crop growth and soil properties: year 3. In: Proceedings of the 8th Annual Meeting of the Composting Council of Canada, Ottawa, Ontario, November 3–5, pp. 263–273.

[38] Zhang, M., D. Heaney, B. Henriquez, E. Solberg, E. Bittner, 2006. A fouryear study on influence of biosolids/MSW cocompost application in less productive soils in Alberta: nutrient dynamics. *Compost Sci. Util.* 14 (1), 68–80.

[39] Zheljazkov, V., Warman, P.R., 2004a. Source-separated municipal soil waste compost application to Swiss chard and basil. *J. Environ. Qual.* 33, 542–552.

[40] Zheljazkov, V.,Warman, P.R., 2004b. Phytoavailability and fractionation of copper, manganese, and zinc in soil following application of two composts to four crops. *Environ. Pollut.* 131, 187–195.