EFFECTIVE MICROORGANISMS ON ORGANIC MATTER WITH CARBON AND NITROGEN MINERALISATION FOR EMPTY FRUIT BUNCHES COMPOSTING

CASSENDRA BONG PHUN CHIEN

UNIVERSITI TEKNOLOGI MALAYSIA

EFFECTIVE MICROORGANISM ON ORGANIC MATTER WITH CARBON AND NITROGEN MINERALISATION FOR EMPTY FRUIT BUNCHES COMPOSTING

CASSENDRA BONG PHUN CHIEN

A thesis submitted in fulfillment of the

requirements for the award of the degree of

Master of Engineering (Bioprocess)

Faculty of Chemical Engineering

Universiti Teknologi Malaysia

APRIL 2015

Dedicated to my parents, brothers and friends for their love and understanding.

ACKNOWLEDGEMENTS

I want to take this opportunity to thank all the people at Institute of Bioproduct Development and Faculty of Chemical Engineering who supported and assisted me during my graduate studies in pursuit of my Master of Chemical Engineering degree. I would like to express my greatest gratitude and appreciation to my academic supervisor, Assoc. Professor Dr. Lee Chew Tin, for her encouragement, advises, critics and supports. I am also very thankful to my co-supervisors Dr. Chua Lee Suan and Prof. Dr. Mohamad Roji Sarmidi for their sincere supports and suggestions. This project would not be able to complete without their continued support and interest.

Special thanks to Pn. Siti Zulaiha Hanapi, Pn, Siti Hajar Mat Sarip, En. Aidee Kamal Khamis. Pn. Roslinda bt. Abd. Malek, Pn. Muna bte. Muhamed and all IBD members for their help and assistance with laboratory analysis to my research work. I would also like to thank Assoc. Professor Dr. Firdausi Razali for his valuable opinion and constructive suggestion for my work.

My fellow postgraduate students should also be recognised for their support. My sincere appreciation also extends to all my colleagues and others who have provided assistance at various occasions. Unfortunately, it is not possible to list all of them in this limited space. Finally, I would like to express my sincere appreciation to all my family members.

ABSTRACT

This project aims to investigate the effect of Effective Microorganisms (EM) on the composting of oil palm empty fruit bunch (EFB) through organic matter degradation with carbon (C) and nitrogen (N) mineralisation by comparing the control sample (CTL) of EFB with no EM treatment and the EM-treated EFB sample (ETC). The maximum C mineralisation for CTL and ETC was recorded as 671.4 ± 86.55 mg CO_2 $Ckg^{-1}d^{-1}$ on day one and 713.5 ± 68.5mg CO_2 $Ckg^{-1}d^{-1}$ on day two respectively. ETC had C mineralisation remained significantly higher than CTL from day 28 until day 40 before falling on day 41 and became on par with CTL. The total organic matter loss was 3.75 ± 1.35% for CTL and 10.78 ± 3.77% for ETC. This resulted in a total mineralised C of 32.97 ± 2.25% and 37.7 ± 2.53% total organic carbon for CTL and ETC, respectively. For N mineralisation, the presence of NH_4^+ in early stage followed by NO_3^- dominance on later stage indicated successful composting. CTL had final value of 0.1 and ETC had 0.04 for NH_4^+/NO_3^- ratio. For curve fitting, first order kinetic model and first order exponential model were chosen as they were showed to better describe mineralization for recalcitrant organic matter by other studies. The first order exponential model showed better fit with p-value of 0.275 as compared to the first order model with p-value of 0.981 in this work. First order kineitc model failed to describe the N mineralisation with a high p-value of 0.989. The unfitness of models could be due to insufficient data over limited experimental time and sampling error for heterogenous materials. This study showed that both CTL and ETC were able to produce mature compost but ETC had better performance on the efficiency of EFB composting based on organic matter degradation, C and N mineralisation coupled with several others parameters (C/N, temperature, pH and microbial profile).

ABSTRAK

Projek ini bertujuan untuk menyiasat kesan Mikroorganisma Efektif (EM) atas proses pengkomposan sisa tandan kosong buah kelapa sawit (EFB) melalui pengunaan bahan organik dengan pemineralan karbon (C) dan nitrogen (N). Sampel kawalan (CTL) yang tanpa tambahan EM manakala sampelETC ditambahkan dengan EM.Pemineralan C maksimumadalah671.4±86.55mgCO_2CKg^{-1}d^{-1} pada hari pertamabagi CTL dan 713.5±68mgCO_2CKg^{-1}d^{-1} pada hari kedua bagi ETC. ETC mempunyaipemineralan C yang lebih tinggi daripada CTL dari hari 28 hingga 40 sebelum ia menurun sehingga setanding dengan CTL pada hari41. BagiCTL, jumlah kehilangan bahan organik adalah 3.75±1.35% manakala ETC adalah 10.78±3.77%.Peratusan jumlah pemineralan C adalah 32.97±2.25% dan 37.7±2.53% untuk CTL dan ETC masing-masing. Bagi pemineralan N, dominasi NH_4^+ pada peringkat awal dan NO_3^-pada peringkap seterusnya menunjukkan pengkomposan yang berjaya. Nilai terakhir untuk nisbah NH_4^+/NO_3^- adalah 0.1 bagi CTL dan 0.04 bagi ETC. Bagi penyuaian lengkung, model kinetic terbib pertama and model terbib pertama eksponen dipilih kerana pengajian lain telah menunjukkan kesesuaian model bagi mineralasi bahan organik yang tidak mudah dikomposkan. Model eksponen dengan p-value 0.275 adalah lebih baik dari model tertib pertama dengan p-value 0.981. Model kinetic tertib pertama didapati tidak sesuai untuk mineralisasi N dengan p-value rendah 0.989. Ketidaksesuaian model disebabkan oleh data yang tidak mencukupi, masa ujikaji yang terhad dan kesilapan persampelan. Pengajian ini menunjukkan CTL and ETC dapat menghasilkan kompos yang matang tetapi ETC mempunyai prestasi yang lebih baik dalam pereputan bahan organik, peminralan C dan N bersama-sama dengan parameter lain (C/N, suhu, pH dan profil mikrob).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF EQUATIONS

LIST OF ABBREVIATIONS

ALA	-	5-Aminolevullic acid
C_0	-	Initial Organic Carbon
CHP	-	Combined Heat and Power Plant
C_m	-	Mineralised Carbon
EFB	-	Empty Fruit Bunches
EM	-	Effective Microorganisms
FFB	-	Fresh Fruit Bunches
GC-MS	-	Gas Chromatography and Mass Spectrometry
GHG	-	Greenhouse Gases
GWP	-	Global Warming Potential
IAA	-	Indole-3-Acetic Acid
LAB	-	Lactic Acid Bacteria
N_0	-	Initial Organic Nitrogen
N_2	-	Nitrogen gas
N_{bio}	-	Biological Nitrogen
N_m	-	Mineralised Nitrogen
NMR-	-	Nuclear Magnetic Resonance
OM	-	Organic Matter
PGPF	-	Plant growth promoting factor
PNSB	-	Purple non sulphur bacteria
SOC	-	Soil Organic Carbon
SOM	-	Soil Organic Matter
TOC	-	Total Organic Carbon
TON	-	Total Organic Nitrogen

LIST OF APPENDIX

LIST OF SYMBOLS

Al	-	Aluminium
C	-	Carbon
C/N	-	Carbon to Nitrogen
Ca	-	Calcium
CH_4	-	Methane
CO_2	-	Carbon Dioxide
Cu	-	Copper
H	-	Hydrogen
H_2O	-	Water
N	-	Nitrogen
N_2O	-	Nitrous Oxide
NH_3	-	Ammonia
NH_4^+	-	Ammonium ion
NO	-	Nitric Oxide
NO_2^-	-	Nitrite ion
NO_3^-	-	Nitrate ion
O	-	Oxygen
O_2	-	Oxygen gas
P	-	Phosphorus

CHAPTER 1

INTRODUCTION

1.1 Research Background

Oil palm (*Elaeis guineensis*) is one of the most versatile crops in tropical countries and is the major type of plantation in the palm oil industry in Malaysia. To date, Malaysia is one the world's largest producer and exporter of palm oil, contributing to 49.5% of total world production and 64.5% of world exports (MPOB, 2006). Around 13% of Malaysia total land bank, which is about 32.86 million hectar, is dedicated to oil palms plantation (Yusoff and Hansen, 2007).

The processing of oil palm fruits into palm oil produces an abundant volume of organic waste. The solid wastes from the palm oil extraction are normally 23% of empty fruit bunches (EFB), 7% of fruit bunches (FFB) and 13.5% of fiber. The EFB shares similarities with other agricultural wastes such as rice stalk and wheat stalk which are rich in cellulosic materials and are not readily biodegradable. For EFB handling, they are generally packed into fuel cell to feed incinerator. Incomplete incineration can lead to the production of unwanted gases such as hydrogen sulphide, nitrous oxide, acid gases, methane and carbon monoxide. Due to the abundant amount of EFB which can be produced yearly in Malaysia, it is worth to venture into the new potential of EFB that result in less environmental concern.

Composting is a bio-conversion process which converts organic wastes into an amorphous dark brown to black colloidal humus-like substance under conditions of optimum temperature, moisture and aeration (Ahmad *et al.*, 2007). It has gained a lot of attention as it can provide plants and soils with rich nutrients. This promotes better plant growth and development as well as replenishes soil nutrients, in which is of critical importance in order to have a reproducible and sustainable agricultural system.

Composting of EFB is not widely done due to the recalcitrant nature of EFB against microbial attack. As composting process is a microbial driven process, the type of microbes and the extend of microbial community present thus determine the time needed for complete degradation of organic matter (OM), the quality of the final composted product and the type of product released during composting process. The 'Effective Microorganism' is a commercialized microbial innoculant which was developed by Prof Higa from Japan in 1991. EM is claimed to have more than 80 species of microbes living in synchronization in which is dominated by lactic acid bacteria, photosynthetic bacteria, fungi, yeasts and actinomycetes (Higa and Parr, 1994).

It is rational to consider EM as a booster microbial inoculant to the composting process as diverse microbial communities allow the utilization of wide range of organic waste which speed up the composting process and offer a more complete degradation of organic waste, especially the positive effect that EM could exert on degradation of EFB, which consists more on recalcitrant carbon source. Furthermore, the presence of different microbes also resembles the decomposition of organic waste in actual environment where different microbes produce different metabolites which has either synergetic or antagonistic effect on each other.

1.2 Problem Statement

The main objective for composting is to convert organic waste into value added bioproduct such as biofertiliser. The application of compost as biofertiliser can only be carried out by using mature compost. The maturity of the compost can be evaluated via various parameters such as C/N ratio, temperature, pH, loss of organic matter and phytotoxicity test. These parameters can also be used to monitor the composting process in terms of microbial degradation. However, none of them is capable to determine the maturity compost individually (Tonetti *et al*., 2007).

As mentioned, due to the extremely high content of recalcitrant C in EFB, which is 44.7% cellulose, 33.5% hemicellulose and 20.4% lignin (Taherzadeh and Karimi, 2007), EFB is not widely used as raw materials for composting and thus the assessment of maturity for the EFB-based compost is also not well-established.

During composting, OM is being degraded by microbes into simpler form which could be assimilated easily by microbes and plant, thus exerting the positive effect on agricultural production of mature compost. During composting, organic C is mineralized into CO_2 or CH_4 whereas organic N is mineralized into inorganic ions such as ammonium (NH_4^+), nitrate (NO_3^-) and nitrite (NO_2^-), mostly by microorganisms (Khalil *et al*., 2005) via OM degradation. This could thus reflect more accurately on the intrinsic property of OM during composting which can be used to monitor the progression of OM degradation and the maturation of compost.

However, in order to better capture the composting of EFB as well as for better comparative measurements on the maturation and maturity presented by OM degradation as well as C and N mineralisation, other common operational parameters for compost maturity, including C/N ratio, temperature, pH and microbial count were also monitored.

1.3 Objective

The main objective of this research is to investigate the effect of Effective Microorganism (EM) on the composting of EFB with regards to OM degradation in parallel with C and N mineralisation.

1.4 Scopes of Study

The following scopes are studied in order to achieve the objective:

1. To monitor the composting process and evaluate the maturity of compost based on OM degradation coupled with C and N mineralisations in parallel with other operational parameters (C/N ratio, temperature, pH and microbial count).

2. To investigate the inter-relationships among operational parameters for compost monitoring and maturity.

3. To fit the obtained mineralised C and N data to available simple kinetic models as a means to evaluate the extend of the composting process.

REFERENCE

Abaye, D.A. and Brookes, P.C., 2006. Relative importance of substrate type and previous soil management in synthesis of microbial biomass and substrate mineralisation. *European Journal of Soil Science*. 57: 179-189.

Adani, F., Gondalonieri, R. and Tambone, F., 2004. Dynamic respiration index as a descriptor of the biological stability of organic wastes. *Journal of Environmental Quality*. 33: 186-1876.

Agehara, S. and Warncke, D.D., 2005. Soil moisture and temperature effects on nitrogen release from organic nitrogen sources. *Soil Science Society of America Journal*. 69: 1844-1855.

Agnew, J.M. and Leonard, J.J., 2003 The physical properties of compost. *Compost Science Uilisation*. 1: 238-264.

Ahmad, R., Jilani, G., Arshad, M., Zahir, Z.A. and Khalid, A., 2007. Bio-conversion of organic wastes for their recycling in agriculture: an overview of perspectives and prospects. *Annals of Microbiology*. 57(4): 471-479.

Aslam, D.N., VanderGheynst, J.S. and Rumsey, T.R., 2008. Development of models for predicting carbon mineralisation and associated phytotoxicity in compost-amended soil. *Bioresource Technology*. 99:8735-8741.

Baharuddin, A.S., Hock. L.S., Yusof, M.Z., Abdul, N.A., Shah, U., Hassan, M.A., Wakisaka, M., Sakai, K. and Shirai, Y., 2010. Effects of palm oil mill effluent (POME) anaerobic sludge from 500m^3 of closed anaerobic methane digested tank on pressed-shredded empty fruit bunch (EFB) composting process. *Africa Journal of Biotechnology*, 9: 2427-2436.

Baheri, H. and Meysami, P., 2002. Feasibility of fungi bioaugmentation in composting a flare pit soil. *Journal of Hazardous Material*. 89: 279-286.

Bailey, V.L., Smith, J.L. and Bolton, H. (2002). Fungal: bacterial ratios in soils investigated for enhanced C sequestration. *Soil Biology &Biochemistry*.34: 997-1007.

Balestrasse, K.B., Tomaro, M.L., Batlle, A. and Noriega, G.O., 2010. The role of 5-aminolevulinic acid in the response to cold stress in soybean plants. *Phytchemistry*. 71: 2038-2045.

Banitez, E., Nagales, R., Masciandraro, G. and Ceccanti, B., 2000. Isolation of isoelectric focusing of humic-urease complexes from earthworm (Eisenia foetida) processed sewage-sludges. *Biology and Fertility of Soils*. 31: 489-493.

Barrington, S., Choinière, D., Trigui, M. and Knight, W., 2002. Effect of carbon source on compost nitrogen and carbon losses. *Bioresource Technology*. 83: 189-194.

Bary, A., Cogger, C. and Sullivan, D., 2002. What does compost analysis tell you about compost? *Biologically Intensive and Organic Farming Research Conference*. Yakima, WA.

Basak, N. and Das, D., 2007. The prospect of purple non-sulfur bacteria (PNS) photosynthetic bacteria for hydrogen production: The present state of art. *World Journal of Microbiology and Biotechnology* .23(1): 31-42.

Bernal, M., Alburquerque, J. and Moral, R., 2009. Bioresource technology composting of animal manures and chemical criteria for compost maturity assessment. A review. *Bioresource Technology*. 100 (22): 5444-5453.

Bernal, M.P., Alburquerque, J.A., Moral, R., 2008.Composting of animal manures and chemical criteria for compost maturity assessment.A review.*Bioresource Technology*. 100(22): 5444-5453.

Bernal, M.P., Sanchez-Monedero, M.A., Parades, C. and Roig, A.,1998. Carbon mineralization from organic wastes at different composting stages during their incubation with soil. *Agriculture Ecosystems & Environment* .69: 175-189.

Bertoldi., M., Vallini, G. and Pera, A.,1983. The biology of composting: A review. *Waste Management & Research.* 1: 157-176.

Beck-Friis, B., Smars, S., Jonsson, H. and Kirchmann, H., 2001. Gaseous emissions of carbon dioxide, ammonia and nitrous oxide from organic household waste in a compost reactor under different temperature regimes. *Compost Science and Utilisation*. 11(10): 41-50.

Biey, E.M., Mortier, H. and Verstraete, W., 2000. Nitrogen transfer from grey municipal solid waste to high quality compost. *Bioresource Technology*. 73: 47-52.

Boulter-Bitzer, J.I., Boland, G.J., Trevos, J.T., 2000. Compost: a study of the development process and end product potential for suppression of tuftgrass disease. *World Journal of Microbiology Biotechnology*. 16: 115-134.

Butler, T.A., Sikora, L.J., Steinhilber, P.M. and Douglass, L.W., 2001. Compost age and sample storage effects on maturity indicators of biosolids compost. *Journal of Environmental Quality*. 30: 2141-2148б

Cácares, R., Flotats, X. and Marfä, O., 2006. Changes in the chemical and physicochemical properties of the solid fraction of cattle slurry during composting with and without mass inocula. *Compost Science and Utilisation*. 11: 6-15.

California Compost Quality Council (CCQC), 2001.Compost Maturity Index, Technical report.

Canali, S. And Benedetti, A., 2006.Soil nitrogen mineralization. In Ed Bloem, J., Hopkins, D.W., Benedetti, A., *Microbiological Methods for Assessing Soil Quality*, (pp 127-135). UK:CABI Publishing.

Canet, R., Pomares, F., Cabot, B., Chaves, C., Ferrer, R., Ribó, M. and Albiach, M.R., 2008. Composting olive mill pomace and other residues from rural southeastern Spain. *Waste Management*. 28: 2585-2592.

Castaldi, P., Alberti, G., Merella, R. and Melis, P., 2005. Study of the organic matter evolution during municipal solid waste composting aimed at identifying suitable parameters for the evaluation of compost maturity. *Waste Management*. 25: 209-213.

Cayuela, M.I., Mondini, C., Insam, H., Sinnico, T. and Franke-Whittle, I., 2009. Plant and animal waste composting: effects of the N source on process performance. *Bioresource Technology*. 100: 3097-3106.

Chagas, P.R.R., Tokeshi, H. and Alves, M.C., 2001.Effect of calcium on yield of papaya fruits on conventional and organic (Bokashi EM) systems.*6th International Conference of Kyusei Nature Farming*, South Africa.

Chaves, B., Neve, S.D., Hofman, G., Boecks, P. and Cleemput, O.V., 2004. Nitrogen biochcemical composition. European Journal of Agronomy. 21:161-170.

City, L. and Nevada, R. (2001). Compost maturity Index. C*alifornia Compost Quality Council*, June, CA.

Clemens, J. and Cuhls, C., 2003. Greenhouse gas emissions from mechanical and biological waste treatment of municipal waste. *Environmental Technology*. 24(6): 745-754.

Conti, M., Arrigo, N. And Marelli, H., 1997. Relationship of soil carbon light fraction, microbial activity, humic acid production and nitrogen fertilisation in the deacaying process of corn stubble. *Biology and Fertility of Soil*. 25: 75-78.

Dale, P., 2007. Isolation of cellulolytic fungi from waste paper gradual recycling materials. *Ekologia*. 53(4): 11-18.

Davide, Z. (Ed.) (2004). *Interactions between photosynthesis and respiration in facultative anoxygenicphototrophs*.In Davide, Z .*Respiration in Archaea and Bacteria* (pp. 279-295). USA: Springer.

Eggen, T. and Vethe, O., 2001.Stability indices for different composts.*Compost.Sci.Util*.9(2): 27-37.

Eiland, F., Klamer, M., Lind, A.M., Leth, M. and Baath, E., 2001. Influence of initial C/N ratio on chemical and microbial composition during long term composting of wheat straw. *Microbial Ecology*. 41(3): 272-280.

Eklind, Y. and Kirchmann, H., 2000. Composting and storage of organic household waste with different litter amendments.I: carbon turnover. *Bioresource technology*. 74: 115-124.

Fang, C., Smith, P., Smith, J.U. and Moncrieff, J.B., 2005. Incorporating microorganisms as decomposers into models to stimulate soil organic matter decomposition. *Geoderma*. 129(3-4): 139-146.

Fontaine, S., Mariotti, A. and Abbadie, I., 2003. The priming effect of organic matter: a question of microbial competition? *Soil Biology and Biochemistry*. 35: 837-843.

Forster, J.C., Zech and Würdinger, E., 1993. Comparison of chemical and microbial methods for characterisation of the maturity of composts from contrasting sources. *Biology and Fertility of Soils*. 16:93-99.

Francou, C., Linėres, M., Derenne, S., Le Villio-Poitrenaud, M. and Houot, S., 2008. Influence of green waste, biowaste and paper-cardboard initial ratios on organic matter transformations during composting. *Bioresource Technology*. 99: 8926-8934.

Fukumoto, Y., Osada, T., Hanajima, D. and Haga, K., 2003. Patterns and quantities of NH_3, N_2O and CH_4 emissions during swine manure composting without force aeration- effect of compost pile scale. *Bioresource Technology*. 89: 109-114.

Gajalakshmi, S. And Abbasi, S.A., 2008. Solid waste management by composting: state of the art. *Critical Review of Environmental Science and Technology*. 28: 311-400.

García-Gómez, A., Bernal, M.P. and Roig, A., 2003. Carbon mineralisation and plant growth in soil amended with compost samples at different degrees of maturity. *Waste Management Resource*. 21: 161-171.

Garrison, M.V., Richard, T.L., Tiquia, S.M. and Honeyman, M.S., 2001. Nutrient losses from unlined bedded swine hoop structure and as associated windrow composting site. *ASAE Annual International Meeting, Sacramento*, CA, 30 July-01 August 2002, St. Joseph, MI.

Gertsev, V.I. and Gertseva, V.V., 2004. Classification of mathematical models in ecology. *Ecological Modelling*. 178:329-334.

Ghazifard, A. Kermanshahi, R.K. and Far, Z.R., 2001. Identification of thermophyllic and mesophyllic bacteria and fungi in Esfahan (Iran) in waste compost. *Waste Management &Resouce* .19 (3): 257-261.

Gillis, J.D. and Price, G.W., 2011. Comparison of a novel model to three conventional models describing carbon mineralization from soil amended with organic residues. *Geoderma* .160: 304-310.

Goyal. S., Dhull, S.K. and Kapoor, K.K., 2005. Chemical and biological changes during composting of different organic wastes and assessment of compost maturity. *Bioresource Technology*. 96: 1584-1591.

Grigatti, M., Cavani, L. and Ciavatta, C., 2011. The evaluation of stability during the composting of different starting materials: comparison of chemical and biological parameters. *Chemosphere*. 83(1): 41-48.

Guardia, A., Petiot, C., Rogeau, D. and Druilhe, C., 2008. Influence of aeration rate on nitrogen dynamics during composting. *Waste Management*. 28: 575-587.

Hamoda, M.F., Abu Qdais, H.A. and Newnam, J., 1998. Evaluation of municipal solid waste composting kinetics.*Resources, Conservation and Recycling*,.23: 209-223.

Hanekon, D., Prinsloo, J.F. and Schoonbee, H.J., 2001. A comparison of the effect of anolyte and EM on the faecal bacterial loads in the water and on fish produced in pig cum fish integrated production units. *6th International Conference on Kyusei Nature Farming*, South Africa.

Hanet, R.L. and Franzluebbers, A.J., 2009. Soil CO_2 evolution: response from arginine additions. *Applied Soil Ecology*. 42: 324-327.

Haney, R.L., Franzluebbers, A.J., Hons, F.M., Hossner, L.R. and Zuberer, D.A., 2001. Molar concentration of K_2SO_4 and soil pH affect estimation of extractable C with chloroform fumigation-extraction. *Soil Biology and Biochemistry*. 33; 1501-1507.

Hao, X., Chang, C. and Larney, F.J., 2004. Carbon, nitrogen balances and greenhouse gas emission during cattle feedlot manure composting. *Journal of Environmental Quality*. 33: 37-44.

Higa, T. and Parr, J.F., 1994.Beneficial and Effective Microorganisms for a sustainable agriculture and environment.*International Farming Research Centre, Atami, Japan*, 16.

Highley, T.L. and Illman, B.L., 1991. Progress in understanding how brown-rot fungi degrade cellulose, *BiodeteriorationAbstract.*5 (3): 232-241.

Horwath, W.,2007. *Carbon cycling and formation of soil organic matter*. In Paul E.A. (Ed.) *Soil Microbiology, Ecology and Biochemistry*, 3rd edition, Oxford, UK : Elsevier.

Hu, Z.H., Liu, Y.L., Chen, G.W., Gui, X.Y., Chen, T.H. and Zhan, X.M., 2011. Characterisation of organic matter degradation during composting of manure-straw mixtures spiked with tetracyclines. *Bioresource Technology*. 102 (15): 9239-7234.

Huang, G.F., Wu, Q.T., Wong, J.W.C. and Nagar, B.B., 2006. Transformation of organic matter during co-composting of pig manure with sawdust. *Bioresource Technology*. 97: 1834-1842.

Iannotti, D.A., Pang, T., Toth, N.L., Elwell, D.L., Keener, H.M. and Hoitink, H.A.J., 1993. A quantitative respirometirc method for monitoring compost stability. *Compost Science Utilisation*. 1: 52-65.

Janssens, I.A, Lankrejier, H., Matteucci, G., Kowaiski, A.S., Buchmann, N. and Epron, D., 2001. Productivity overshadows temperature in determining soil and ecosystem respiration across European forests. *Global Change Biology*. 7: 269-278.

Janssens, I.A., Kowalski, A.S., Longdoz, B. and Ceulemans, R., 2000. Assessing forest soil CO_2 efflux: an in site comparison of four techniques. *Tree Physiology*. 20: 23-32.

Jiménez, I. and Garcia, P., 1992. Composting of domestic refuse and sewage sludge.II.Evolution of carbon and some "humification" index.*Resourse, Conservation and Recycling* , 6: 243-257.

Jones, C.A. (1998). Estimation of an active fraction on soil nitrogen.*Commun.Soil.Science and Plant Analysis*.15: 23-32.

Kala, D.R., Rosenani, A.B., Fauziah, C.I. and Thohirah, L.A., 2009. Composting oil palm wastes and sludge sewage for use in potting media of ornamental plants. *Malaysia Journal of Soil Science*, 13: 77-99.

Kantha, T., Chaiyasut, C., Kantachote, D., Sukrong, S. and Muangprom, A., 2010. Selection of photosynthetic bacteria producing 5-aminolevuliniv acid from soil of organic saline paddy fields from the Northeast region of Thailand. *African Journal of Microbiology Research*. 4(17): 1848-1855.

Khaliq, A., Abbasi, M.K. and Hussain, T., 2005. Effects of integrated use of organic and inorganic nutrient sources with effective microorganisms (EM) on seed cotton yield in Pakistan. *BioresourceTechnology* .97: 967-972.

Kim, B.H. and Gadd, G.M., 2008. *Glycolysis*. In Kim, B.H. and Gadd, G.M. (Ed.). *Bacterial Physiology and Metabolism* (pp 60-84), Cambridge University Press: UK.

Koh, R.H. and Song, H.G., 2007. Effects of application of *Rhodopseudomonas sp*. on seed germination and growth of tomato under axenic conditions.*Journal of Microbial Biotechnology*.17: 1805-1810

Komilis, D.P., Ham, R.K. and Park, J.K., 2004. Emission of volatile organic compounds during composting of municipal solid waste. *Water Research*. 38: 1707-1714.

Kulcu, R. and Yaldiz, O., 2004. Determination of aeration rate and kinetics of composting some agricultural wastes. *Bioresource Technology*. 93:49-57.

Kumar, R., Verma, D., Singh, B.L., Kumar, U. and Shweta, 2010. Composting of sugar-cane waste by-products through treatment with microorganisms and subsequent vermicomposting. *Bioresource Technology*. 101: 6707-6711.

Larney, F.J. and Hao, X., 2007. A review of composting as a management alternatie for beef cattle feedlot manure in southern Alberia, Canada. *Bioresource Technology*. 98: 3221-3227.

Lei, F. and Gheynst , J.S.V., 2000. The effect of microbial inoculation and pH on microbial community structure changes during composting. *Process in Biochemustry*. 35: 923-929.

Lekasi, J.K., Tanner, J.C., Kimani, S.K. and Harris, P.J.C., 2003. Cattle manure quality in Maragua District, Central Kenya: Effect of management practices and development of simple methods of assessment. *Agriculture, .Ecosystem and.Environment*. 94: 289-298.

Levin, D.B., Lawrence, P. and Murry, I., 2004. Biohydrogen production: prospects and limitations to practical application. *International Journal of Hydrogen Energy*. 29:173-185.

Liu, K. And Price, G., 2011. Evaluation of three composting systems for the management of spend coffee grounds. *Bioresource Technology*. 102(17): 7966-7974.

Lo, C.W., Lai, N.S., Cheah, H.Y., Wong, N.K.I. and Ho, C.C., 2002. Actinomycetes isolated from soil samples from the crocker range Sabah. *ASEAN Review of Biodiversity and Environmental Conservation (ARBEC)*, September issue, pp 1-7.

Lu, A.I., Kumar, M., Tsai, J.C. and Lin, L.G., 2008. High-rate composting of barley dregs with sewage sludge in a pilot scale bioreactor. *Bioresource Technology*. 99: 2210-2217.

Maboeta, M.S., Renburg and Van, 2003. Vermicomposting of industrially produced wood chips and sewage sludge utilising Eisenia Foetida. *Ecotoxicology and Environment*. 5: 25-270.

Manna, M.C., Singh, M., Kundu, S., Tripathi, A.K. and Takkar, P.N., 2003. Growth and reproduction of vermicomposting earthworm Perionyx excavates as influenced by food materials. *Biology and Fertility of Soils*. 24(1): 129-132.

Mari, I., Ehaliotis, C., Kotsou, M., Chatzipavlidis, I. And Georgakakis, D., 2005. Use of sulphur to control pH in composts derived from olive processing by-products. *Compost Science Utilisation*. 13: 281-287.

Marinari, S., Abate, Dell Abate, M.T., Brunetti, G. And Dais, C., 2010. Differences of stabilised organic carbon fraction and microbiological activity along Mediterranean Vertisols and Alfisols profiles. *Geoderma*. 156:379-388.

Mason, I.G., 2006. Mathematical modeling of the composting process: a review. *Waste Management* .26: 3-21.

Milala, M.A., Shehu, B.B., Zanna, H. and Omosioda, V.O., 2009. Degradation of agrowaste by cellulose from Aspergillus candidus. *Asian Journal of Biotechnology*. 1: 51-56.

Miller, F.C., 1992. Composting as a process based on the control of ecologically selective factors. In: Metting, F.B., Jr. (Ed.), *Soil Microbial Ecology, Applications in Agricultural and Environmental Management* (pp515-544), New York: Marcel Dekker.

Mondini, C., Dell Abate, M.T., Leita, L., Benedetti, A., 2003. An integrated chemical, thermal and microbiological approach to compost stability evaluation. *Journal of Environmental Quality*. 32: 2379-2386

Malaysia Palm Oil Board (MPOB), 2013. FFB processed by Mill 2013. Available at http://bepi.mpob.gov.my/index.php/statistics/sectoral-status/120-sectorial-status-2013/626-ffb-processed-by-mill-2013.html. [accessed on 13 Dec 2014]

Muhle, S., Balsam, I. and Cheeseman, C.R., 2010. Comparison of carbon emissions associated with municipal solid waste management in Germany and the UK. *Resources Conservation and Recycling*. 54(11): 793-801.

Murwira, H.K., Kirchmann, H. and Swift, M.J., 1990. The effect of moisture on the decomposition rate of cattle manure. *Plant and Soil*. 122: 197-199.

Nair, J. and Okamitsu, K., 2010. Microbial inoculants for small scale composting of putrscible kitchen wastes. *Waste Managemen.* 30(6): 977-982.

Nakasaki K., Sasaki, M., Shoda, M. and Kubota, H.,1985. Change in microbial numbers during thermophyllic composting of sewage sludge with reference to CO_2 evolution rate. *Applied and Environmental Microbiology*. 1 (49): 37-41.

Nakasaki, K., Tran, L.T.H., Idemoto, Y., Abe, M. and Rollon, A.P., 2009. Comparison of organic matter degradation and microbial community during thermophilic composting of two different types of anaerobic sludge. *Bioresource Technology*. 100(2): 676-682.

Nedgwa, P.M. and Thompson, S.A., 2001. Integrating composting and vermicomposting in treatment and bioconversion of biosolids. *Bioresource Technology*. 76: 107-112.

Ohkuma, M., Maeda, Y., Johjima, T. and Kudo, T., 2001. Lignin degradation and roles of white rot fungi: Study on an efficient symbiotic system in fungus-growing termites and its application to bioremediation. *Microbiology Laboratory,* Riken, JST-ICORP.

Osada, T., Kuroda, K. and Yonaga, M., 2000. Determination of nitrous oxide, methane and ammonia emissions from a swine waste composting process. *Journal of Material Cycles Waste Management*. 2: 51-56.

Pagans, E., Barrena, R., Font, X. and Sánchez, A., 2006. Ammonia emissions from the composting of different organic wastes: Dependency on process temperature. *Chemosphere*. 62:1534-1542.

Paredes, C., Bernal, M.P., Cegarra, J., Roig, A. and Navarro, A.F., 1996. Nitrogen transformation during the composting of different organic wastes. In: Van Cleemput, O., Vermoesen, G., Hofman, A. (Eds.). *Progress in Nitrogen Cycling Studies* (pp121-125), Dordrecht :Kulwer Academic Publisher.

Parkinson, R., Gibbs, P., Burchett, S. and Misselbrrok, T., 2004. Effect of turning regime and seasonal weather conditions on nitrogen and phosphorus losses during aerobic composting of cattle manure. *Bioresource Technology*. 91: 171-178.

Pérez-Murcia, M.D., Moreno-Caselles, J., Moral, R., Pérez-Espinosa, A., Paredes, C. and Rufete, B., 2005. Use of composted sewage sluge as horticultural growth media: effects on germination and trace element extraction. *Communications in Soil Science and Plant Analysis*. 3: 571-582.

Petric, I. and Selimbaśić, V., 2008.Development and validation of mathematical model for aerobic composting process. *Analysis*. 139:304-317.

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. *Annual Microbiology*. 53: 349-410.

Richard, T.L., Hamelers, H.V.M., Veeken, A.H.M. and Silva, T., 2002. Moisture relationships in composting process. *Compost Science Utilisation*. 10: 286-302.

Ros, M.M., García, C. and Hernández, T., 2006. A full-scale study of treatment of pig slurry by composting: Kinetic changes in chemical and microbial properties. *Waste Management*. 26: 1108-1118.

Sangakkara, U.R. and Weerasekera, P., 2001.Impact of EM on nitrogen utilization efficiency in food crops.*6th International Conference of Kyusei Nature Farming*, South Africa.

Saviozzi, A., Levi-Minzi, R. and Riffaldim, R., 1993. Mineralisation parameters from organic materials added to soil as a function of their chemical properties. *Bioresource Technology*. 45,131-135.

Scholwin, F. and Bidlingmaier, W., 2003. Fuzzifying the composting process: a new model based control strategy as a device for achieving a high grade and consistent product quality. In: Proceedings of the Fourth International Conference of ORBIT Association on Biological Processing of Organics: *Advances for a Sustainable Society* (pp 739-751), 30th April to 2nd May, 2003, Perth. ORBIT Association, Weimar, Germany.

Schumacher, B.A.,2002. Methods for the determination of total organic carbon (TOC) in soils and sediments. *Environmental Science Division National Exposure Research Laboratory*, United States Environmental Protection Agency, Las Vegas, NV.

Sehy, U., Ruser, R. and Munch, J.C., 2003. Nitrous oxide fluxes from maize fields: relationship to yield, site-specific fertilisation and soil conditions. *Agriculture, Ecosystem and Environment*. 99:97-111.

Semple, K.T., Reid, B.J. and Fermor, T.R. (2001). Review: Impact of composting strategies on the treatment of contaminated with organic pollutants. *Environmental Pollution* ,112 (2), 269-283.

Senesi, N.,1989. Composted materials as organic fertilizers. *The Science of the Total Environmen*t. 81/82: 521-542.

Singh, A. and Sharma, S., 2002. Composting of a crop residue through treatment with microorganisms and subsequent vermicomposting. *Bioresource Technology*. 85: 107-111.

Taherzadeh, M.J. and Karimi, K., 2007. Acid-based hydrolysis processes for ethanol from lignocellulosic materials: A review. *Bioresources*. 2: 472-499.

Takei, T., Yoshida, M., Hatate, Y., Shimori, K. and Kiyoyama, S. (2008). Lactic acid bacteria-enclosing poly (ε-caprolactone) microcapsules as soil bioamendment. *Journal of Bioscience and Bioengineering* .106 (3): 268-272.

Thambirajah, J.J., Zulkali, M.D. and Hashim, M.A., 1995. Microbiological and biochemical changes during the composting of oil palm empty fruit bunches. Effect of nitrogen supplementation on the substrate. Bioresource Technology, 52: 133-144.

Ting, A.S.Y., Hermanto, A. and Peh, K.L., 2014. Indigenous actinomycetes from EFB compost of oil palm: evaluation on enzymatic and antagonistic properties. *Biocatalysis and Agricultural Biotechnology*, 3(4): 310-315.

Tiquia, S.M., Tam, N,F,Y. and Hodgkiss, I.J., 1996. Microbial activities during composting of spent pig-manure sawdust litter at different moisture contents. *Bioresource Technology*. 55: 201-206.

Tontti, T., Heinonen-Tanski, H., Karinen, P., Reinikainen, O. and Halinen, A., 2010. Maturity and hygiene quality of compost and hygiene indicators in agricultural soil fertilized with municipal waste or manure compost. *Waste Management Resource*. 29(2): 197-207.

Tremier, A., de Guardia, A., Massiani, C., Paul, E. and Martel, J.L., 2005. A respirometry method for characterising the organic composition and biodegradation kinetics and the temperature influence on the biodegradation kinetics for a mixture of sludge and bulking agent to be co-composted. *Bioresource Technology*. 96(2): 169-180.

Trias, R., Baneras, L., Montesinos, E. and Badosa, E., 2008. Lactic acid bacteria from fresh fruit and vegetables as biocontrol agents of phytopathogenic bacteria and fungi.*International Microbiology* .11: 231-236.

Tuomela, M., Vikman, M., Hatakka, A., Itävaara, M., 2000. Biodegradation of lignin in a compost environment: a review. *Bioresource Technology*. 72: 169-183.

Valaskova, V. and Petr, D., 2006. Degradation of cellulose and hemicelluloses by the bwon rot fungus Piptoporus betulinus production of extracellular enzymes and characterisation of the major cellulases. *Microbiology*. 152: 3613-3622.

Vargas-Gárcia, M.C., Suárez-Estrella, F.F., López, M.J., Joaquin, M., 2007. Effect of inoculation in composting process: modifications in lignocellulosic fraction. *Waste Management*. 27: 1099-1107.

Veijalainen, A.M., 2007. Suitable organic waste management in tree-seedling production.Natural and *Environmental Sciences.Doctoral Dissertaion*. Kuopio University Publications C, vol.217, pp 114.

Wang, P., Changa, C.M., Watson, M.E., Dick, W.A., Chen, Y. and Hoitink, H.A.J., 2004. Maturity indices for composted dairy and pig manures. *Soil Biology and Biochemistry*. 36: 767-776.

Weber, J., Karczewska, A., Drozd, J., Licznar, M., Licznar, S., Jamroz, E. and Kocowica, A., 2007. Agricultural and ecological aspects of a sandy soil as affected by the application of municipal solid waste composts. *Soil Biology and Biochemistry*. 39: 1294-1302.

Wrage, F.L., Velthof, G.L., Laanboek, H.J. and Oenema, O., 2004. Nitrous oxide production in grassland soils: Assessing the contribution of nitrifier denitrification. *Soil Biology and Biochemistry* .36 (2): 229-236.

Wu, L.K. and Ma, L.Q., 2002. Relationship between compost stability and extractable organic carbon. *Journal of Environment Quality*. 31: 1323-1328.

Xi, B., Zhang, G.Z. and Liu, H., 2005. Process kinetics of inoculation composting of municipal solid waste. *Journal of Hazardous Materials* . *124*: 165-172.

Xu, H.L., 2000. Effect of microbial inoculation, organic fertilization and chemical fertilization on water stress resistance of sweet corn :In nature farming and microbial application. *Journal of Crop Production.* 3: 223-234

Yamada, Y. and Kawase, Y., 2006. Aerobic composting of waste activated sludge : Kinetic analysis for microbiological reaction and oxygen consumption. *Waste Management*. 26: 49-61.

Yahya, A., Sye, C.P., Ishola, T.A. and Suryanto, H., 2010. Effect of adding palm oil mill decanter cake slurry with regular turning operation on the composting process and quality of compost from oil palm empty fruit bunches. *Bioresource Technology*, 101: 873-8741.

Zainudin, M.H.M., Hassan, M.A., Tokura, M. and Shirai, Y., 2013. Indigenous cellulolytic and hemicellulolytic bacteria enhanced rapid co-composting of lignocelluloses oil palm empty fruit bunch with palm oil mill effluent anaerobic sludge. Bioresource Technology, 147: 632-635.

Zeng, Y., de Guardia, A., Daumoin, M. and Benoist, J.C., 2012. Characterising the transformation and transfer of nitrogen during the aerobic treatment of organic wastes and digestates. *Waste Management*. 32(12): 2239-2347.

Zhang, H.J., and Matsuti, T., 2010. Mass and element balance in food waste composting facilities. *Waste Management.* 30(8-9): 1477-1485.

Zhang, Y., Lashermes, G., Houot, S., Doublet, J., Steyer, J.P., Zhu, Y.G., Barriuso, E. and Garnier, P., 2011. Modelling of organic matter dynamics during the composting process. *Waste Management*. 32
(1): 19-30.

Zhou, L.X., Yi, W.M., Yi, Z.G. and Ding, M.M., 2002. Soil microbial characteristics of several vegetations at different elevation in Dinghushan Biosphere Reserve.*Trop Subtrop for EcosystRes* ,9: 169-174.

Zmora-Nahum, S., Markovitch, O., Tarchitzky, J. and Chen, Y., 2005.Dissolved organic carbon (DOC) as a parameter of compost maturity. *Soil Biology and Biochemistry*. 37: 2109-2116.

Zucconi, F. and de Bertoldi, M., 1987. Compost specification for the production and characterisation of compost from municipal solid waste, in: de Bertildi, Ferranti, P.L., Hermite and Zucconi, F. (Ed), *Compost: Production, Quality and Use* (pp 20-29). London: Elsevier.