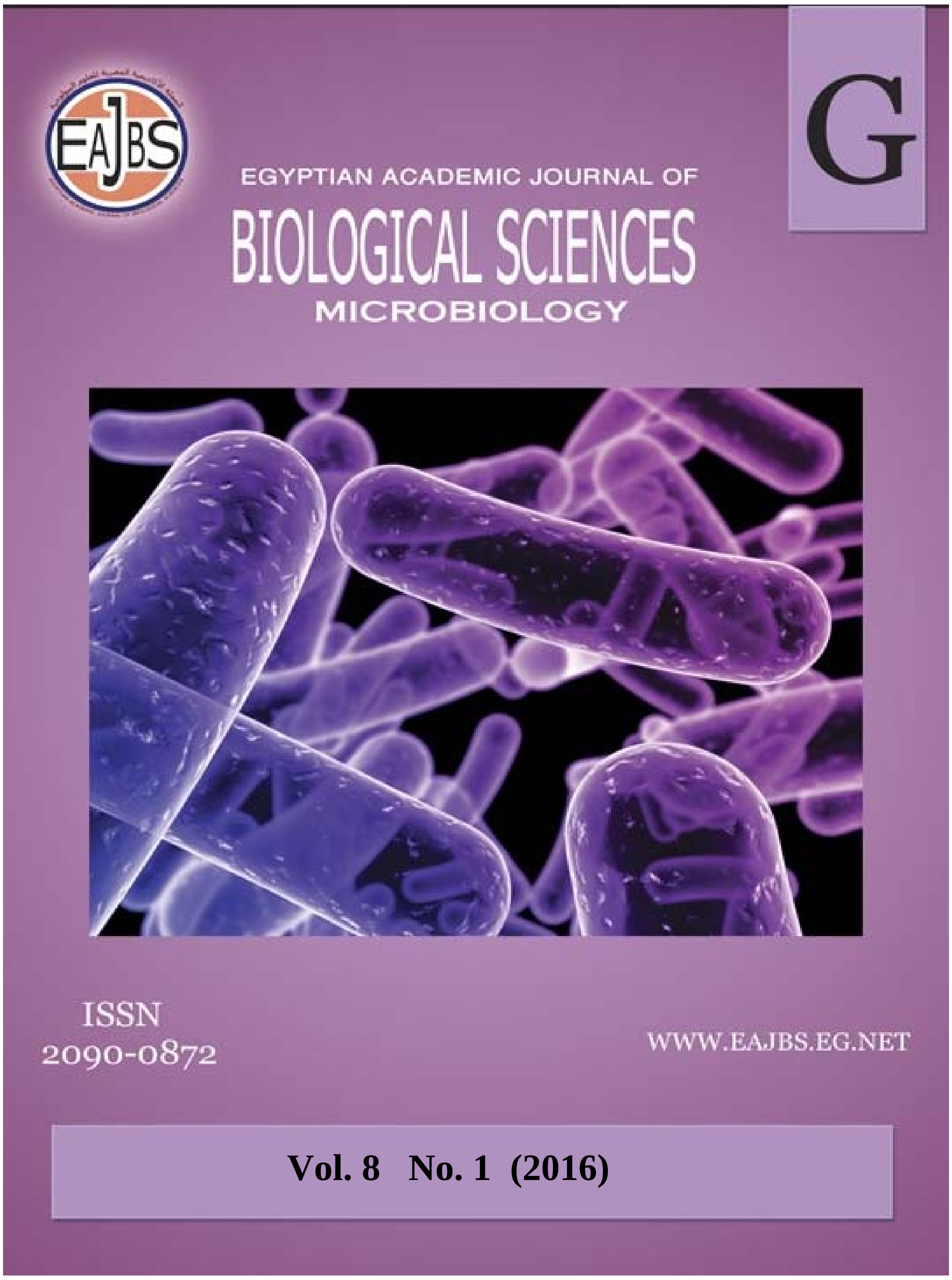

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Comparing The Biological And Chemical Properties Of Different Vemicomposts Made By Green Wastes (Prepared By Decomposing Fungi And *Eisenia Fetida* Earthworms)

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ABSTRACT

Annually, too much green wastes are produced that they should manage for being useful. One of their best using is composting. In this study the different green wastes were collected from Urmia, West Azerbaijan- Iran and Anzali lagoon. These green wastes were animal manure, hay debris, leaves of Maple and Platanus trees, the remains of Azolla ferns, apple and grape pruning waste and Herbal Essences. Compost formation was done in two processes including the inoculation of different plant residues with fungi *Trichoderma* strains (*T. ressei, T. viride* and *T. harzianum* and *phanerochaete Chrysosporium* and *Chaetomium globosum*) and followed by adding the *Eisenia Fetida* earthworms**.** Results of formed vermicompost analysis showed that pH and C/N ratio decreased, however the numbers of earthworm and cocoon significantly increased. At end of study, the vermicompost of apple and grape pruning wastes was selected as the favorite compost.

INTRODUCTION

In a world that resources are decreasing and needs are increasing, any way should be research to retrieve the waste material. There are very high amount of plant rows of trees in street, parks and gardens remain in large cities and other areas that reducing their volume is as a problem for the environment, so composting is presented technology for decreasing the weight and volume of these residual material. Composting is an aerobic process in which microorganisms convert the mixed organic matters to Carbon Dioxide (CO2), water, minerals and stable organic matter (Guisquiani *et al*., 1995). In another technology for the production of compost, earthworms are used and this produced compost is called Vermicompost.

In this method, an earthworm's species with name of *Eisenia Fetida* is used to decompose the cellulosic materials; and this process takes almost 6 months to carry out.

During the past two decades, the evolution of agricultural techniques for plant's growth and substrates has increased the market demands for peat, while the source of peat is falling (Inbar *et al*., 1990). Reducing these non-renewable resources has favorable the use of modified materials as growth substrates (Abad *et al*., 2001). Iran's arid and semi-arid soils that constitute more than 80% of agricultural land are poor in the terms of organic matters. To improve the fertility of agricultural soil, adding the organic matter is essential, but limited tradition resources of organic matters such as manure from livestock is not accountable to growing needs of agriculture to organic matter. Many studies have been done to find alternative materials instead of Peat. Domestic and industrial waste or scrap waste paper are components of waste products that are used in composting technology (Yu, 1996).From the other resource for composting can be noted to sewage sludge that sometimes is used with different rates of pruning wastes for composting (Ponsa *et al*., 2009). Between the residual organic matters, the green wastes are more functional than other organic matters for composting. Biodegradation of organic compounds looks as the proper treatment, which of its benefits can refer to reduce the volume and weight of waste, providing the compost of organic residues to improve the soil structure and increase of soil fertility and plant growth (Giusquiani *et al*., 1995). Compost can be used to improve the physical properties of soil by decreasing the bulk density and increasing the water-holding capacity (Guisquiani *et al*., 1995). Lignocellulosic materials are containing the polymer-cellulose, hemicellulose, pectin and lignin monomers and these polymers should be decompose to monomers that is done by physical, chemical and biological methods. The process of composting is the organic matter conversion into more simple organic units like organic carbon and nitrogen (Gigliotti *et al*., 2002). The Shortening of composting period with a significant decrease in the C/N, is of the remarkable operations for being useful of composting. To decompose the Lignocellulosic materials, it is needs to wide range of essential enzymes. Lignocellulose, such as wood, is mostly including a combination of cellulose (40% carbon), hemicellulose (20-30% carbon) and lignin (20-30% C) (Sjöström, 1993). Lignin is in the cell wall structure that makes resistant plants against the microbial degradation (Argyropoulos and Menachem, 1997). Composting is a dynamic process that is performed by the speed of the microbial population of microorganisms, and the main involved groups are included bacteria such as Actinomycetes and fungi (Golueke, 1991). Although the total number of microorganisms does not change significantly in the composting, but the compost microbial diversity can be change during the its different phases (Atkinson *et al*., 1996). The normal motions and the number of microorganisms in any phase of composting, is dependent on the substrate and microorganisms' Procedure (Crawford, 1983).When the agricultural waste convert to compost, usually lignocellulos is an important component of organic matter, which its decomposing is slowly (Shi *et al*., 2006; Tang *et al*., 2008; Tuomela *et al*., 2000; Yu *et al*., 2007). Inoculation of these organic matters with Lignocellulosic microorganisms is a strategy that exacerbates lignocellulosic materials decomposing, potentially. Fungi are organisms that clearly are accountable to the breakdown of lignocellulosic (Ten Have and Teunissen, 2001; Bennett *et al*., 2002; Rabinovich *et al*., 2004). The ability to the effectiveness break down of lignocellulosic is associated with mycelial growth that allows to fungi to transfer or import the rare nutrients such as nitrogen and iron to lignocellulosic substrates of poor of nutrients and forms its carbon source (Haddadin *et al*., 2009).

Temperature is one of the important factors in the growth of the fungus. Other important indicators are sources of carbon, nitrogen and pH. On average, the high amount of nitrogen for growing fungi is required, although some fungi, particularly white rot fungi, also grow in the low nitrogen levels (Eriksson *et al*., 1990; Dix and Webster, 1995). More fungi prefer the acidic environments, but they tolerate a wide range of pH, except Basidiomycota, which cannot grow well at pH higher than 7.5. The most fungi are mesophilic and grow at 5 to 37 degrees Celsius (Dix and Webster, 1995). Although, in composting environment the average temperature goes up, so the smaller group of mesophilic fungi being the break factor.

More mesophilic fungi are capable to degrade the wood or other Lignocellulosic material (cellulose, hemicellulose and lignin) (Fergus, 1964; Ofoso-Asiedu and Smith, 1973; Sharma, 1986). According to the results of Mouchacca (1997), the most effective fungi for lignin degradation are Basidiomycetes, which all are mesophilic. Addition to Basidiomycetes, a number of fungi belonging to Ascomycota are also causing to white rot (Eriksson *et al*., 1990). Basidiomycetes attack to hard and soft wood, while the Ascomycetes probably just degrade the hard wood (Krik and Ferrell, 1987). White rot fungi degrade the lignin by oxidized enzymes (Hattakka, 1994). Due to the structure and size of the lignin molecules, those enzymes that are responsible for the decomposition beginning are non-specific and extracellular (Krik and Ferrell, 1987; Hatakka, 1994). Including the effective white rot fungi can be referring to following species:

1. *Phanereochaete Chrysosporium*
2. *Trichoderma spp.*
   a) *Trichoderma harzianum*
   b) *Trichoderma viride*
   c) *Trichoderma reesei*
3. *Chaetomium spp.*

In general, it is accepted that earthworms have impact heavily on restoring the soil organic matter (SOM) in agricultural ecosystems (Edward, 1998). Earthworms' feed and high drilling power cause to strength the soil organic matter levels (Curry and Schmidt, 2007), that is because this drilling activity damages the soil again as the vortex. This activity of earthworms will eventually cause to alter the size and activity of soil microbial (Wolters and Joergensen, 1992; Bohlen *et al*., 1997; Brown *et al*., 2000; Tiunov *et al*., 2001; Ernst *et al*., 2008). Therefore, they modify highly the fertile and nutrient availability in the soil (Scheu and parkinson, 1994; Helling and Larink, 1998; Aira *et al*., 2003; Haynes *et al*., 2003). In addition, earthworms change the enzymatic degradation of organic matter that would lead to the strengthening of surface reactions in organic matter and release of extracellular enzymes in the intestinal tract (Lattaud *et al*., 1998; Satchell and Martin, 1984). In total, breaking the fresh plant material by earthworms and microbial mineralization is strongly dependent on the chemical properties of the plant material. Several studies have shown that fresh plant material with high C/N ratio is less digestible for earthworms (Flegel and Schrander, 2000; Curry, 2004).

One of the biggest environmental challenges that world is facing today is solid wastes management due to population growth and urbanization. The method applicable to carry out this environmental project is that degradation of organic wastes and treatment is performed in situ, until a useful end product has produced. Composting is the most important economic practice and applicable way of organic waste management that its method has been studied. It should to carry out in suitable place for best and right management. Composting is a natural process for treatment of organic wastes that normally have been tested with various modifiers technology (Nair *et al*., 2006).

MATERIALS AND METHODS

Preparing the studied fungi

The studied fungi, which were includes of three strains of *Trichoderma* fungi (*T. harzianum, T. viride, and T. ressei*), a strain of *basidiomycetes* (*Phanerocheat chrysosporium*) and *globosum Cheatomium,* were prepared from the Research Institute of

Industrial fungi, and were cultured in sterile PDF fungal strains in plates, and then were inoculated inside the target substrate with culture media.

Preparing the compost substrate and inoculation of fungi and earthworms

Plant residues including the leaves of platanus and maple, hay, wastes of essences plants and apple and grape pruning waste from gardens and around area of Urmia city, West Azerbaijan, and algae Azolla of Bandar Anzali Lagoon were collected and chopped to size of 1 to 2 mm, then were placed in 10-liter plastic containers, separately. Their humidity was retained in 60 to 70 percent of water holding capacity. Then three types of *Trichoderma's* strains including the *T. ressei*, *T. viride* and *T. harzianum* and two strains of *Phanerochaete chrysosporium* and *Chaetomium globosum* fungi were inoculated to the substrates of green wastes. To decompose of Lignocellulosic materials, first stage of composting and reduction of the carbon to nitrogen ratio (C/N) be done by these fungi at first. These green wastes substrates along with fungi were controlled in green house condition and 70 percent of water holding capacity. After that the initial decomposing were done by fungi and the C/N of substrates was moderated, the contents of the pots were transferred to the wooden box in dimension of 30 × 40 × 30 cm and at the same time the 50 earthworms (*Eisenia Fetida*) was released to each of the boxes. The substrates were under the effect of earthworms in appropriate temperature and humidity conditions for 4 months and half. After that vermicompost formed, the chemical and biological parameters such as salinity, pH, nitrogen, carbon, and the ratio of these two elements, the percentage of organic matter, minerals (such as calcium, magnesium, sodium, potassium and phosphorus), ash percent, the worm's Cocoon and the worm's number were counted and measured. This experiment was conducted in a completely randomized design with 7 treatments and 3 replications under greenhouse conditions. The variance Analysis (ANOVA) was done by SAS statistical software and mean comparison was performed with Duncan's multiple range test ($P < 5\%$).

RESULTS AND DISCUSSION

Tables 1 and 2, show the results of ANOVA in different treatments. According to the results and conducted analysis on different organic residues (animal's manure, hay debris, leaves of maple platanus trees, the remains of Azolla ferns, apple and grape pruning waste and wastes of essences plants), before the fungi and earthworms adding, waste organic had high C/N and was more than 40. But after applying the remarked treatments, some indices such as C/N were decreased, and the significant difference was observed in 5% possibility. At the end of composting process, no significant difference was observed between the mineral elements at the beginning and end of the composting process. The number of earthworms and Cocoon showed significant differences in different substrates. The pH decreased to 6.45in the treatment Azolla, whereas for other treatments, it was varied from 7 to 7/5.

Table 1: Variance analysis of made vermicompost from different vegetable substrate

Source of changes	Df	Mean squares						
		%k	%Na	%Mg	%Ca	C/N	%C	%N
treatment	6	0.459 ^{ns}	0.107 ^{ns}	0.01 ^{ns}	0.005**	133.366*	57.39*	0.263**
error	14	0.276	0.127	0.005	0	52.48	15.42	0.053
Coefficient of variation	-	23.71	13.442	101.345	16.85	54.14	92.19	17.25

Ns, *, ** are non-significantly, significant at 5%, and significant at 1% possibility respectively

Table 2: Variance analysis of made vermicompost from different vegetable substrate

Source of changes	Df	Mean squares				
		EC	pH	Cocoon's number	Worm's number	%P
treatment	6	0.161 ns	0.341 **	2930.6 *	207565 **	0.002 ns
error	14	0.199	0.028	743.952	38623.8	0.004
Coefficient of variation	-	21.09	2.346	78.03	39.66	29.22

Ns, * , ** are non-significantly, significant at 5%, and significant at 1% possibility respectively

Table 3 and 4 are the mean comparison results. Tables 3 and 4, show that the percentage of nitrogen (N) in the Platanus leaves and control was lower than the other treatments and showed a significant differences in $P<0.05$. In the case of organic carbon (OC), it was different between control and platanus, so that the highest degree of organic carbon was observed in the litter of platanus (26%) and lowest amount was in control (14%). The C/N amount for platanus wastes was higher than other treatments, so, differences could be due to the high amount of lignin and being woody of leaves in this sample. The calcium (Ca) in Maple leaves was higher than other treatments and pruning waste of apple and grape had more magnesium (Mg).Also the amount of potassium (K) was high in most treatments, but in the Maple leaves, this element was a bit lower. About the Phosphorus (P), no significant differences was observed between treatments.

Table 3: Mean comparison of made vermicompost from different vegetable substrate

treatments	Na%	Mg%	Ca%	C/N	C%	N%
Control*	2.38 a	0.06 ab	0.15 bc	7.15 b	13.8 c	57.1 b
hay	2.54 a	0.1 ab	0.14 bcd	11.8 b	17.9 bc	53.1 a
Platanus	2.51 a	0.04 b	0.17 b	30.5 a	26.4 a	96.0 b
Azolla	2.91 a	0.03 b	0.1 d	13.1 b	19.5 abc	53.1 a
Pruning wastes	2.64 a	0.19 a	0.12 cd	16.6 b	24.7 ab	53.1 a
Maple Leaf	2.83 a	0.04 b	0.23 a	11.3 b	17.7 bc	57.1 a
Distillates waste	2.75 a	0.04 b	0.16 cb	13.1 b	18 bc	38.1 a

The means with dissimilar letters in each column are significant statistically at p< 0.05 by Duncan test
*Manure, litter and straw

The number of earthworms in maple leaves and Azolla substrate was lower than others, but the number of cocoon in the maple leaves substrate was the highest. The pH value in Azolla substrate was lower than the rest, so this low amount of pH can has effect on the number of earthworms and cocoon.

Inoculation could be a useful tool to accelerate and to improve the compost maturity in agricultural wastes.

Table 4: Mean comparison of made vermicompost from different vegetable substrate

treatments	Ec	pH	Cocoon's number	Worm's number	P%	K %
Control*	1.8 a	7.5 a	34 b	332 c	0.29 a	2.42 ab
hay	2.2 a	7.4 a	25 b	541 bc	0.26 a	2.85 a
Platanus	2.1 a	7.2 a	48 b	972 a	0.25 a	1.84 ab
Azolla	2.4 a	6.4 b	15 b	319 c	0.33 a	1.96 ab
Pruning wastes	1.8 a	7.3 a	22 b	706 ab	0.33 a	2.29 ab
Maple Leaf	2.3 a	7.3 a	98 a	242 c	0.3 a	1.74 b
Distillates waste	2.1 a	7.2 a	3 b	356 bc	0.3 a	2.42 ab

The means with dissimilar letters in each column are significant statistically at p< 0.05 by Duncan test
*Manure, litter and straw

The C/N ratio is traditionally used to establish the maturity degree of compost. The C/N ratio decreased from the initial Value to lower levels, so that, the formed vermicompost be a suitable substrate growth the different plants. About the other analysis like other minerals that are in tables, it should to note that orepared vermicompost is rich of these minerals, and increasing the number of cocoon and earthworm in vermicompost show that this substrate is favorite environment to live for soil fauna. The presence of earthworm also indicate this issue that physical properties of this substrate like Water holding capacity and structure have been modified by these worms.

Conclusion:

There are many source of energy and nutrition in world that are produced daily by human, they are counted as waste material, but they have this potential to convert to useful substrates. The results show that various green wastes that decomposing fungi inoculation and earthworms have been imposed on them, could potentially be converted into compost through time and can be used in the cultivation of ornamental flowers and greenhouses, and be suitable substitute for chemical fertilizers.

REFERENCES

Abad, M., Noguera, P. and Bures, P. (2001). National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain. Biores. Technol. 77: 197–200.

Aira,M.,Monroy, F. and Domı´nguez, J. (2003). Effects of two species of earthworms (Allolobophora sp.) on soil systems: a microfaunal and biochemical analysis. Pedobiologia 47: 877–881.

Argyropoulos, D.S., and Menachem, S.B. (1997). Lignin. In: Eriksson, K.-E.L.(Ed.), Advances in Biochemical Engineering Biotechnology, vol. 57. Springer , Germany, pp. 127-158.

Atkinson, C.F., Jones, D.D., Gauthier, J.J. (1996). Biodegradabilities and microbial activities during composting of oxidation and ditch sludge. Compost Sci. Util., 4, 84–96.

Bennett, J. W., Wunch, K.G. and Faison, B.D., (2002). Use of fungi in biodegradation. In: Hurst, C.J. (Ed.), Manual of Environmental Microbiology. AMS press, Washington, DC, PP. 960–971.

Bohlen, P.J., Parmelee, R.W., McCartney, D.A. and Edwards, C.A. (1997). Earthworm effects on carbon and nitrogen dynamics of surface litter in corn agroecosystems. Ecol. Appl., 7:1341–1349.

Brown, G. B., Barois, I. and Lavelle, P. (2000). Regulation of soil organic matter dynamics and microbial activity in the drilosphere and the role of interactions with other edaphic functional domains. Eur. J. Soil Biol., 36: 177–198.

Crawford, J. H. (1983). Compostin g of agricultural wastes a review. Process Biochem., 18: 14-18.

Curry, J.P. (2004). Factors affecting the abundance of earthworms in soils. In: Edwards, C.A. (Ed.), Earthworm Ecology, second ed. CRC Press, pp. 91–113.

Curry, J.P. and Schmidt, O. (2007). The feeding ecology of earthworms. Pedobiologia, 50: 463–477.

Dix, N. J. and Webster, J. (1995). Fungal Ecology. Chapman & Hall, Cambridge, Great Britain.

Fergus, C. L. (1964). Thermophilic and thermotolerant molds and actinomycete s of mushroom compost during peakheating. Mycologia, 56: 267-284.

Edwards, C. A. (1998). The use of earthworms in the breakdown and management of organic wastes. In: Earthworm Ecology. CRC Press LLC, Boca Raton, Fl, pp. 327–354.

Eriksson,K.E.L., Blanchette, R. A. and Ander, P. (1990). Microbialand Enzymatic Degradatio n of Wood and Wood Components. Springer, Berlin, Germany.

Ernst, G., Müller, A., Göhler, H. and Emmerling, C. (2008). C and N turnover of fermented residues from biogas plants in soil in the presence of three different earthworm species (Lumbricus terrestris, Aporrectodea longa, Aporrectodea caliginosa). Soil. Biol. Biochem., 40: 1413–1420.

Flegel, M. and Schrader, S. (2000). Importance of food quality on selected enzyme activities in earthworm casts (Dendrobaena octaedra, Lumbricidae). Soil Biol. Biochem., 32: 1191–1196.

Gigliotti, G., Kaiser, K., Guggenberger, G. and Haumaier, L. (2002). Differences in the chemical composition of dissolved organic matter from waste materials of different sources. Biol. Fert. Soils., 36: 321–329.

Golueke, C.G. (1991). Principles of composting. In: The Staff of BioCycle Journal of Waste Recycling. The Art and Science of Composting. The JG PressInc., Pennsylvania, USA, pp. 14-27.

Guisquiani, P.L., Pagliali, M., Gigliotti, G., Businelli, D. and Benetti, A. (1995). Urban waste compost: effect on physical, chemical and biological soil properties. J. Environ. Qual., 24: 175–182.

Haddadin, M.S.Y., Haddadin, J., Arabiyat, O.I., and Hattar, B. (2009). Bioresource Technology Biological conversion of olive pomace into compost by using Trichoderma harzianum and Phanerochaete chrysosporium. Bioresource. Technol., 100: 4773–4782.

Hatakka, A. (1994). Lignin-modifying enzymes from selected white-rot fungi: production and role in lignin degradation. FEMS Microbiol. Rev., 13: 125-135.

Helling, B. and Larink, O. (1998). Contribution of earthworms to nitrogen turnover in agricultural soils treated with different mineral N-fertilizers. Appl. Soil. Ecol., 9: 319–325.

Haynes, R.J., Fraser, P.M., Piercy, J.E. and Tregurtha, R.J. (2003). Casts of Aporrectodea caliginosa (Savigny) and Lumbricus rubellus (Hoffmeister) differ in microbial activity, nutrient availability and aggregate stability. Pedobiologia, 47: 882–887.

Inbar, Y., Chen, Y., Hadar, Y. and Hoitink, H.A.J. (1990). New approaches to compost maturity. BioCycle., 31: 64–68.

Kirk,T.K. and Farrell, R.L. (1987). Enzymatic combustion: the microbial degradation of lignin. Ann. Rev. Microbiol., 41: 465-505.

Lattaud, C., Locati, S., Mora, P., Rouland, C. and Lavelle, P. (1998). The diversity of digestive systems in tropical geophagous earthworms. Appl. Soil. Ecol., 9: 189–195.

Mouchacca, J. (1997). Thermophilic fungi: Biodiversity and taxonomic status. Cryptogamie Mycol., 18: 19-69.

Nair, J., Sekiozoic, V. and Anda, M. (2006). Effect of pre-composting on vermicomposting of kitchen waste. Bioresource Technol., 97: 2091–2095.

Ofosu-Asiedu, A. and Smith, R.S. (1973). Some factors a ecting wood degradation by thermophilic and thermotolerant fungi. Mycologia, 65: 87-98.

Ponsa, S., Pagans, E. and Sa´nchez, A. (2009). Composting of dewatered wastewater sludge with various ratios of pruning waste used as a bulking agent and monitored by respirometer. Biosystems Eng., 102: 433–443.

Rabinovich, M.L., Bolobova, A.V. and Vasil'chenko, L.G. (2004). Fungal decomposition of natural aromatic structures and xenobiotics: a review. Appl. Biochem. Microb., 40: 1–17.

Satchell, J.E. and Martin, K. (1984). Phosphatase activity in earthworm faeces. Soil Biol. Biochem. 16: 191–194.

Scheu, S. and Parkinson, D. (1994). Effects of earthworms on nutrient dynamics, carbon turnover, and microorganisms in soil from cool temperate forests of the Canadian Rocky Mountains – laboratory studies. Appl. Soil Ecol. 1: 113–125.

Sjöström, E. (1993). Wood Chemistry, Fundamentalsand Applications, 2nd ed. Academic Press, New York/London.

Sharma, H.S.S. (1989). Economicimportance of thermophilous fungi. Appl. Microbiol. Biotechnol. 31: 1-10.

Shi, J.G., Zeng, G.M., Yuan, X.Z., Dai, F. and Wu, X.H. (2006). The stimulatory effects of surfactants on composting of waste rich in cellulose. World J Microbiol. Biotech. 22: 1121– 1127.

Tang, J.C., Maie, N., Tada, Y. and Katayama, A. (2006). Characteristics of the maturing process of cattle manure compost. Process Biochem. 41: 380–389.

Ten Have, R. and Teunissen, P.J.M. (2001). Oxidative mechanisms involved in lignin degradation by white-rot fungi. Chem. Rev., 101: 3397–3414.

Tiunov, A.V., Bonkowski, M., Alphei, J. and Scheu, S. (2001). Microflora, protozoa and nematoda in Lumbricus terrestris burrow walls: a laboratory experiment. Pedobiologia 45:46–60.

Tuomela, M., Vikman, M., Hatakka, A. and Itavaara, M. (2000). Biodegradation of lignin in a compost environment : a review. Bioresource Tech., 72: 169–183.

Wolters, V. and Joergensen, R.G. (1992). Microbial carbon turnover in beech forest soils worked by Aporrectodea caliginosa (Savigny) (Oligochaeta: Lumbricidae). Soil Biol. Biochem. 24:171–177.

Yu, P. (1996). Analysis of a municipal recyclable material recycling program. Resour. Conserv. Recy., 17:47–56.