Tropical and Subtropical Agroecosystems, 14 (2011): 949-963

REVIEW [REVISIÓN]

VERMICOMPOSTING AS A PROCESS TO STABILIZE ORGANIC WASTE AND SEWAGE SLUDGE AS AN APLLICATION FOR SOIL

[EL VERMICOMPOSTEO COMO PROCESO ESTABILIZADOR DE RESIDUOS ORGANICOS Y LOS LODOS RESIDUALES COMO UNA APLICACIÓN A SUELOS]

Pedro Del Aguila Juárez*, Jorge Lugo de la Fuente, Rocío Vaca Paulín

Laboratory of Edaphology and Environment, Faculty of Sciences, Autonomous University of the State of Mexico, Instituto Literario 100. Toluca Mexico
Email: daguila@uaemex.mx,*
** Corresponding author*

SUMMARY

The issue of organic waste generation is a constant nowadays; recycling and reduction are expensive physical and chemical processes, so the use of vermicomposting techniques reduces production costs and decontaminates the environment. Earthworms decompose organic matter and generate a product called vermicompost. Vermicompost is obtained from a wide variety of organic waste including residual sludge; when sewage sludge is managed with vermicomposting techniques, the resulting product supplies nutriments, more stable organic matter and works as a soil conditioner. The present bibliographic review underscores its importance via the use of diverse sorts of organic waste to reincorporate them into the environment. The parameters considered to produce vermicompost are: pH, temperature, moisture, total solid contents, nitrogen, carbon, C/N ratio and humic acids. The importance of this text is to be found in the need to use vermicompost amendments from the use of sewage sludge to be transformed into fertilizer and be utilized in the growth of plants, thus turning it into an alternative in agricultural soils and a solution for its final end. Separately, earthworms take part as agents that bio-accumulate heavy metals and reduce the levels of toxicity in the environments; thereby these organisms, in addition to produce vermicompost, are considered an agent that bio-accumulates heavy metals from the environment.

Key words: vermicompost; earthworm; sewage sludge.

RESUMEN

La problemática que se presenta en la generación de los residuos orgánicos es una constante de esta época, las acciones de reciclamiento y reducción son procesos físicos y químicos que resultan costosos, por lo que el emplear técnicas de vermicomposteo reduce costos de producción y descontamina al ambiente. La lombriz de tierra descompone la materia orgánica y genera un producto que se denomina vermicomposta. La vermicomposta se obtiene a partir de una gran variedad de residuos orgánicos incluyendo a los lodos residuales. Cuando el lodo residual se maneja con la técnica de vermicomposteo, el producto que se forma aporta nutrimentos, materia orgánica más estable y sirve como mejorador del suelo. La presente revisión bibliográfica resalta la importancia por el empleo de diversos tipos de residuos orgánicos para su reincorporación al ambiente. Los parámetros que se consideran para preparar una vermicomposta son: el pH, temperatura, humedad, contenido de sólidos totales, nitrógeno, carbono, relación C/N y ácidos húmicos. La importancia de este texto reside en la necesidad de utilizar enmiendas vermicomposteadas, a partir del empleo de lodos residuales para su uso como abono y para el crecimiento de la planta y de esta manera sea una alternativa en suelos agrícolas y una solución a su disposición final. Por otra parte la lombriz de tierra participa como agente que bioacumula metales pesados y reducen los niveles de toxicidad en el ambiente, por lo que este organismo además de elaborar vermicomposta es considerado un agente que bioacumula metales del ambiente.

Palabras claves: Vermicomposteo; lombriz de tierra; lodo residual.

INTRODUCTION

In sustainable development one of the greatest challenges is to have an integrated system of organic solid waste, both in the city and the countryside (Armijo *et al*., 2007). The "General Law for Conservation and Integral Management of Residues" (*Ley General para la Conservación y Gestión Integral de Residuos*) proposes to make a better management of urban solid waste so that it is incorporated into nature in the short and medium term, hence reduce environmental pollution (Rodríguez and Córdova, 2006; Montenegro *et al*., 2007).

There is a wide variety of worms that decompose organic matter (OM) and among them one finds *Eisenia fetida*, an organism that produces stable humus and nutriments available for the plants (Garg *et al*., 2005). Vermicompost requires a good balance of C and N that is beneficial for the worm (in biomass, reproduction and reduction of mortality rates). There is a broad spectrum of organic waste in the diet of the worm that comes from animals, vegetables, alimentary, textile, winemaking industries and sewage sludge (SS) (Gupta and Garg, 2008).

SS generation is a problem that appears because of population growth in the cities and waste from industry (Bernache, 2007). In Mexico, 1.6 million metric tons (henceforth only ton) of SS are produced every year (Colin *et al*., 2006) which is below the 7 million tons a year produced by the United States (Adegbidi and Briggs, 2003); these differences are due to the fact that the U.S. has a higher index of urbanization than Mexico (López, 1994). A good management of SS has to undertake techniques that work as compost amendment for soil (Quincha and Carmona, 2004). The product from vermicompost is useful for regeneration of soils, energy as liquids and combustible gases (López, 1994). During the process to produce vermicompost, it is considered important to monitor the routine parameters, namely: temperature, moisture, pH and airing that predict stability, quality and the maturity of the vermicompost (Sharma *et al*., 2005).

Vermicompost has substances such as humic acids (HA) and hormones that together regulate the growth and production of plants (Atiyeh *et al*., 2000), and in the environmental field the worm helps alleviate environmental pollution and takes part into bio-accumulation and bio-remediation processes (Delgado *et al*., 2004).

The need to use SS as amendments arose from the interest of the governments in implementing environmental policies to reduce the effect of the pollution that comes from this sludge; in Europe, SS recycling practices are carried out by means of composting and vermicomposting, and the product is considered good quality manure (Mora, 2000; Khwairakpan and Bhargava, 2009), which favors the reduction of heavy metals and mitigates their effect in the environment (Soto and Muñoz, 2002; Cabrera *et al*., 2007).

The earthworm

Earthworm belongs to *Annelida* phylum and to *Oligochaeta* class that comprises more than 1300 species; most of the species belong to *Lumbricidae* family, than comprehends the genera: *Allolophora, Aporrectodea, Bimastos, Dendrobaena, Eisenia, Lumbricus* and many more. Until the end of the XX century, there was a counting of 3500 earthworm species known to man (Bohlen, 2002; García, 2006). *E. fetida* (Savigny, 1826) is known as redworm, brandling worm, red wiggler worm and it is classified as shown in Table 1 (Manna *et al.,* 2003).

Table 1. Taxonomic classification of *Eisenia fetida* (Cuevas, 2005)

Phylum	*Annellida*
Class	*Oligochaeta*
Subclass	*Clitelata*
Order	*Haplotaxia*
Suborder	*Lumbricina*
Superfamily	*Lumbricoidea*
Family	*Lumbricidae*
Subfamily	*Lumbricinae*
Genus and species	*Eisenia fetida*

On the basis of its feeding habits, the worm is classified into two types: detritivore and geophagous. The former feeds on leaves, dead roots, plant residues and animal scats on the ground surface; the latter only consumes large amounts of organic soil and is located under the surface. The worms that produce humus are divided into epigeal and anecic. The epigeal live on the surface and feed on organic matter and detritus, an instance of them are *E. fetida, E. andrei, Perionyx excavatus*, *P. sansibaricus,* and *Eudrilus eugenie*. The anecic live in vertical burrows, an instance of them is *Lumbricus terrestris* (Sharma *et al*., 2005).

The main systemic characteristic of earthworms is that they possess an internal and external bilateral symmetry, extremely segmented. They do not have a skeleton and are hermaphrodite; their gonads are located in a specific manner with variations according to their taxa (Edwards and Bohlen, 1996). The maturity of the worm is reached at 90 days and when mating, two worms make ventral contract in opposing directions and adhere at the clitellum, which is located in the fore third and the contact sends sperm to the other worm in order to fecundate (García, 2006). The clitellum is a thickened area and the region where two to five cocoons are produced weekly, they might produce from one to seven individuals that undergo an incubation process in the soil, where they develop from a juvenile stage to maturity or adulthood (Sharma *et al*., 2005). *E. fetida* can produce 12.3 cocoons per organism with 88.3% of viability and each cocoon produces on average 3.8 individuals (Holmstrup, 2001; Domínguez *et al.*, 2003).

The size of the adult organism is 8-10 cm in length on average, and it weighs a gram; the color of the organism ranges from pale pink to white, passing through brown or gray (García, 2006). The reddish coloration in *E. fetida* comes from the presence of hemoglobin, which appears because of the existence of two blood vessels that run along its body (Bohlem, 2002). Its body has spines called bristles or setae, which have a ringed appearance, these are separated by grooves called septa and in the fore end there is the mouth called prostomium and at the rear end there is the anus, located in the last segment called periproctal (Cuevas, 2005).

Physiology of earthworm and sorts of organic residues in its diet

Vermicomposting consists in a bio-oxidative process where the earthworm takes part (Santamaría and Ferrera, 2002; Aira *et al.*, 2008). The conversion of OM by the worm in its digestive tract occurs in two stages (figure 1); in the first stage (physical-mechanical) one notices airing, mixing and milling of OM; in the second (biochemical) labile substrates (sugars, amino acids, lipds and cellulose), which are decomposed by bacteria, are produced. In this second stage the maturing of C sources and recalcitrant substances and materials (hemicellulose and lignin) is finished, as well as the formation of stable humic substances (Soto and Muñoz, 2002; Moreno *et al.*, 2005).

As the earthworm uses OM as food source, it requires help from protozoans, rotifers, nematodes, bacteria and fungi to acquire its nutriments; its digestive system is composed of oral cavity, pharynx, crop, esophagus, gizzard, calciferous glands, intestine and anus (Edwards and Bohlen, 1996; García, 2006). Each earthworm consumes about 100-300 mg/g dry weight a day of food and can increase its live weight in circa 300-450 mg in 90 days (Sharma *et al*., 2005). The material eaten by the worm is distributed between 5-10% for growth and metabolic activities; the other 85% is excreted as vermicompost that contains urine (as ammonia) and mucoproteins (Blair *et al*. 1997). There are, in the digestive tract, enzymes and microflora that carry out the digestion of OM; enzymes such as amylase, endoclunease, protease, lipase, cellulose, alkaline phosphate, acid and nitrate reductase, all of them turn proteins and carbohydrates into energy and unfold other organic components with structural complexity (Cuevas, 2005; Prabna *et al.*, 2007).

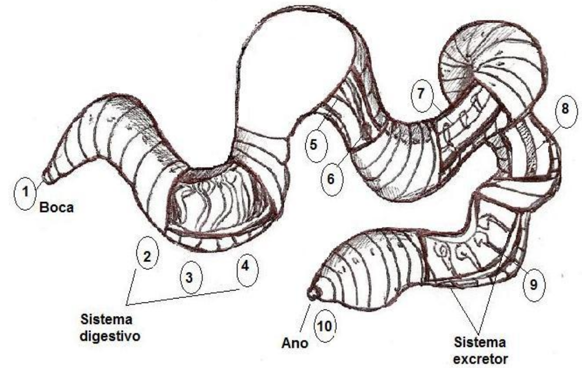

Figure 1 General schema of OM processing by the earthworm: (1) sucks OM; (2) triturates and grinds particles; (3) mix substrates; (4) modifies and levels acidity; (5) inoculates with microorganisms; (6) promotes and multiplies microorganisms; (7) creates regulating compounds; (8) homogenizes and homogeniza y palletizes; (9) covers proteins in muco; and (10) excretes organic manure (source of Capistrán *et al.* 2001, modified by Del Aguila, 2010).

The alimentary requirements of the worm are composed of four basic elements, namely: green residues (high N content), brown residues (high C content), water (moisture) and air (oxygen and ventilation) (Sharma *et al*., 2005). The largest content of organic C comprises proteins, hemicellulose, cellulose and lignin. Proteins are the most abundant form of N in organisms and are the main constituent of every life form (Paul and Clark, 1996). The contents of C and N have to be adequate dosages to perform a good process (Ndegwa and Thompsom, 2000); if there is too much C, it becomes slow, and if there is more N, it creates bad odors and produces a viscous mixture (Rodríguez and Córdova, 2006). In table 2 we describe the sort of source, organic residue, and the cares necessary to produce compost and vermicompost.

Earthworms can feed on conventional organic residues (vegetal and animal), and to a lesser extent on those non-conventional, which are residues from alimentary and paper industries, winemaking, wild animals, including SS (municipal origin) (Sharma *et al*., 2005). A good selection of food in quantity and quality (N source) determines the good development of earthworms as for biomass, fertility and mortality rate (Lowe and Butt, 2005). The worm chooses the sort of food based on its enzymatic activity, works by Prabna and collaborators (2007) measured the enzymatic activity of cellulose in two worm species, *E. fetida* and *M. guillelmi*, finding that *E. fetida* (152.8±18 μg cellulose g^{-1} of dry weight worm) had preference for wheat in relation to *M. guillelmi* (18.9 ± 1.3 μg glucose g^{-1} of dry weight worm) due to a higher enzymatic activity. Other studies report a biomass increase of 250% in the case of water hyacinth (*Eichhornia crassipie*, Mart. Solm) and *E. euginaea* (Gajalaksmi *et al.,* 2001). The increase in reproductive rate and egg production in *P. sensibaricus* yielded satisfactory results using vegetal residues and dead leaves (Suthar, 2007). The same researcher (Suthar, 2009b), two years later however, worked with *E. fetida* and mixtures of market vegetal residues and wheat (1:1) to amend and the obtained product improved the C/N ratio (20) and the content of N (31.3 g kg^{-1}), available P (8.7 g kg^{-1}) and interchangeable K (20.7 g kg^{-1}).

There are differences in residues from animals to favor the increment of biomass, the manure which the worm (*E. fetida*) assimilates best to obtain larger biomass comes from ovine (55.3 ±1.9 mg/g) and the least from camel (32.5 ± 1.4 mg/g), out of a series of manures under study and in ascending biomass order they were: sheep>donkey>buffalo>goat=cow=horse>camel. In egg production, the largest number was obtained with sheep manure (0.44± 0.052), being 25.3% higher than with buffalo manure (0.19±0.072) in ascending order we have: sheep>cow=horse=goat>camel>donkey>buffalo (Garg *et al*., 2005). Cow, horse, goat and sheep scats adequately respond to the growth and reproduction of *E. fetida*, however there is very little experience in studies that employ wild animal organic residues so it is required to have more nonconventional sources of C and N to be recycled and used.

Organic residues that are generated in the city and the countryside can be used as a mixture; works by Sangwan and collaborators (2008) are based on the use of mixtures of animal and vegetal residues, thus they achieved a maximal growth of *E. fetida*, for instance, when they use a proportion of 90% horse manure and 10% of sugar residue. Other studies mention mixtures of residues from textile industry and bird feces (40% textiles, 60% bird feces) that favor the development and reproduction of *E. fetida* (Garg and Kaushik, 2005). Both a good selection of residues and a good balance of them in the worm diet have as a result a good development, biomass production and vermicompost; however, if the organic residues have potentially toxic substances, such as ammonia and salts present in animal manure or tannins and acid substances, found in vegetal residues, the problem has to be sold carrying out a pre-composting on the organic residues (Gunadi *et al*., 2002).

Table 2. different sorts of organic residues used in the process of vermicomposting (Rodríguez and Córdova, 2006).

	Reside	Observation
Brown residues	Sawdust,	Do not use if they come from wood treated with chemical products,
	Wood chip,	best if they are chopped
	Perennial leaves,	Gathered in autumn to be used
	Dry leaves,	Mince and wet
	Straw and hay,	Favor airing
	Cut and dry grass	They must be cut as splinters smaller than 1cm
	Tree pruning	
Green residues	Citrus	Good airing is required
	Manure from Herbivores	Very useful if green materials are needed
	Fruits and vegetables, food leftovers	Mince in small pieces, mainly peels
	Green weeds	Pasteurize under the sun inside a black plastic bag for 7 - 10 days
Small amounts	Green grass	Mix with dry materials. Do not use if they contain pesticides
	Oils and fats	They generate bad odors as they rot
	Meat,bone, fish	
	Paper with no inks	They generate bad odors and attract rodents and flies
		It degrades slowly, cut in stripes
Sanitary risk	Feces of carnivores and humans	They contain microorganisms noxious for health
	Diseased plants	Vermicompost may become infected
	Weeds and resistant plants	Plants with persistent roots and weed with seeds difficult to pasteurize

Physical and chemical characteristics that govern the development of vermicomposting

In order to learn whether a vermicompost meets the standards for its use as a soil conditioner, there is need for the monitoring of parameters such as: temperature, moisture, pH, airing, particle size, capacity of cationic interchange (CCI), organism matter (OM), nitrogen (N) and C/N ratio (García, 2006). These parameters regulate all the biological activities of the worm; temperature helps manipulate the lifecycle of the worm (Lowe and Butt, 2005), the optimal temperature for the development of *E. fetida* is between 15º C and 25º C. At low temperatures (3-5ºC) the incubation of *L. terrestres* is inhibited, this worm gains weight if temperature rises (2.6 g) to 20ºC from the 16^{th} week and it loses weight if temperature drops (0.25 g) to 5ºC (Mangrich *et al*., 2000; Santamaría and Ferrera, 2002).

Moisture helps the worm (*E. fetida*) to have a thin film of water to carry out gas interchanges, the optimal moisture level is between 60 and 80% which prevents the worm from losing weight and dehydration (Manna *et al*., 2003; Lowe and Butt, 2005). Moisture is also related to the age of the worm, if there are moistures between 70% and 80% they are adults, and with 60% and 70% they are juvenile (Gunadi *et al.*, 2002).

Airing favors the increase of the population of worms due to the high requirements of oxygen and this process of the physical and manual kind that facilitates the passive diffusion of air. The recommended particle size is 5 cm, for it supplies a larger exposure surface; large fragments of manure favor airing, yet they take longer to degrade (García, 2006).

The habitat of the worm requires a pH from 6.8 to 7.8 to grow and reproduce (Garg *et al*., 2006); if pH decreases by the end of the process, it is due to the production of CO_2 and organic acids (Premuzic *et al*., 2002; Kaushik and Garg, 2004). In an acid environment, the worm secretes calcium carbonate to neutralize the acidity of the environment and so avoid mortality (Dekker, 2002). It is also recognized that changes in pH take place during microbial decomposition, mineralization of N and P in nitrite/nitrate and orthophosphates (Sutarh, 2009a).

The capacity of cationic interchange (CCI) increases by the end of the process (Garg *et al.,* 2005) and it is considered an indicator of the degree of maturity and stability due to the presence of radical groups (carboxylic and phenolic), which helps increase the interchange places to improve the enriching of the humic fraction (Yagi *et al*., 2003; Romero *et al.*, 2007). In the compost CCI (400 meq $kg^{-}1$) is larger than that in a mineral soil (150 meq kg^{-1}) (Mathur *et al*., 1993).

As the worm processes OM, it modifies the sources of C, N and by means of the C/N ratio, it reports on the quality of the obtained product. Organic C decreases by the end of vermicomposting, from different factors, namely: i) the worm consumption of organic C; ii) the transformation into CO_2 by the respiratory activity; iii) the formation of humic fraction that makes room for mature vermicompost (Singh *et al*., 2005; Garg *et al*., 2006; Suthar, 2009a). On the other side N increases by the end of the process and responds to i) the elaboration of products (metabolites) that contain N by the worm; ii) the excrete of mucus that is a fluid rich in N eliminated by the worm; iii) the substratum enzymes, NH_4^+, dead tissue rich in N; and iv) the mineralization process during vermicomposting (Chaudhuri *et al.,* 2000; Aira *et al*., 2006; Muthukumaravel *et al*., 2008). C/N ratio expresses the quantity of C and N that has to be included to elaborate a vermicompost and it decreases by the end of the process (Yadav and Garg, 2009). The optimal C/N ratio is between 20:1 and 30:1, according to Soto and Muñoz, (2002); Orozco and collaborators (2000). Works by García (2006), Palsania and collaborators (2008) mention that the process shall begin with a C/N ratio of 60 and end with a value of 20; moreover, the C/N ratio determines the age of the worm, a value under 20 indicates the presence of mature organisms (60%) and above 20 indicates the presence of juvenile organisms (70%) and an incubation period (Aira *et al*., 2007).

A faulty management of the aforementioned parameters brings along a bad quality vermicompost, and it can pollute the ground, plants and animals, due to the presence of noxious substances. Nowadays the General Law of Prevention and Integral Management of Residues does not consider a specific regulation that analyzes a regulation to produce composts, however the Mexican Norm of humus, worm, specifications and testing methods (*Norma Mexicana de humus, lombriz, especificaciones y métodos de prueba, SAGARPA, 2007*) takes into account the characterization of the most important parameters that shall be considered to sell composts (table 3). The sale of vermicompost must be certified and supported by laboratories that indicate that said product can be used as a soil improver or organic fertilizer.

The importance of humic acids

Worm stabilize OM, and in it one finds humic acids (HA) which are substances that provide vermicompost with an aliphatic character (Mangrich *et al*., 2000; Campitelli and Ceppi, 2008) and that benefit the development and growth of the plants (Suthar, 2008). Vermicompost has complex organic structures (Santamaría and Ferrera, 2002; Romero *et al*., 2007), which undergo chemical and enzymatic degradation and become a complex mixture that in the laboratory is broken into three fractions based on their aqueous solubility: (1) humic acids (HA), (2) fulvic acids, and (3) humic substances. HA are amorphous mixtures of heavy molecular weight, black in color and it is the main constituent of humic substances (Porta *et al*., 2003).

Table 3. Characteristics of chemical and physical parameters of the Mexican Official Norm NMX-FF-109-SCFI, (SAGARPA, 2007) worm humus.

Characteristic	Value
Total Nitrogen	From 1 to 4% (dry base)
Organic matter	From 20% to 50% (dry base)
C/N ratio	≤20
Moisture	From 20 to 40% (on wet matter)
pH	From 5.5 to 8.54
Electric conductivity	≤ 4 dS m^{-1}
Cationic interchange capacity	> 40 cmol kg^{-1}
Apparent density on dry matter	0.40 to 0.90 g mL^{-1}
Added materials	Absent

Depending on the origin of the organic residue (sheep, goat, cow and rabbit), the vermicompost will present a variety of functional groups in HA and rich in N, O, and H, such as chemical structures (aromatic rings, carboxylic, phenolic, hydroxyl and alcoholic groups). The total acidity of HA determines the addition of carboxylic and phenolic groups (Masini *et al*., 1998).

HA restitute the fertility potential of the soil when it is present in vermicompost and modify the physical and chemical properties of the soil (Cuevas, 2005; Pramaik *et al.*, 2007). HA have their diverse origin in different organic residues (animal, vegetal, sewage sludge, paper industry, etc.) and their use as a remedy in cultivation soils yields satisfactory results (table 4); studies in the agricultural field point out that HA improve the germination and growth of seeds and increase the production of ornate plants and also for human consumption, which besides act together with auxins, gibberellins and cytokinins as growth regulating hormones (Canellas *et al*., 2002).

Currently the mechanisms that unleash the growth of a large variety of ornate and human consumption plants are not known in HA, so this field of study demands attention (Atiyeh *et al.*, 2002). The use of HA (from a vermicompost) as a liquid fosters a better development of the plants and roots in a barley cultivation in relation to chemical fertilizer (Ortega and Fernández, 2007); works that evaluate mono- and poly-cultivations in the field and relate HA, N, P, K choose poly-cultivations because this systems favors the increment of the production of the plant by adding HA and nutriments (Kankan and Balasubramanian, 2007). Other benefits of HA are of the environmental kind, as they sequestrate heavy metals and herbicides by means of chemical complexation and adsorption of toxic organic compounds (Mangrich *et al.*, 2000; Atiyeh *et al*., 2002).

Composting of sewage sludge and its use

Vermiculture is an agricultural activity that has been on the increase as from the 1990's in Mexico (Cardoso, 2002). In China vermicomposting techniques have been known for more than 6000 years; nowadays, vermicomposting techniques are commercially applied in countries such as the United States, Canada, Japan and the Philippines; as an instance, the city of Ontario, Canada, processes near 75 tons a week (Rodríguez and Córdova, 2006).

Table 4. Application of HA in vermicompost of different types of organic residues to cultivations

Residue type	Plant	Observation	Source
Bovine HA vermicompost	Maize (*Zea mays*)	Plant growth with hormone help (auxins group)	Pasqualato *et al.* (2002)
Pig and residue HA vermicompost	Tomato (*Lycupersicum esculentum*), cucumber (*Cucumus sativus*)	50-500 mg Kg^{-1} dosages of HA. Plant growth increase	Atiyet *et al.* (2002)
Bovine, domestic residue and paper industry HA vermicompost	Sunflower (*Helicantus annus*), cucumber (*Cucumus sativus*), Tomato (*Lycupersicum esculentum*), strawberry (*Fragania vesca*)	250-1000 mg Kg^{-1} dosages of HA. Plant increase and better yields	Arancon *et al.* (2006)
Bovine and domestic residue AH vermicompost	Cucumber (*Cucumus sativus*)	100 mg L^{-1} of HA . Increase of Root length, weight, stem, number of leaves and flowers	López *et al.* (2006)

The organic residues that are used in the elaboration of vermicompost are mainly manures; the accumulation of manure generates pollution from odors, nitrates and salts. In Mexico there is a variety of manures, namely: bovine, from fowl, pigs, rabbits and goats. Bovine manure is one of the residues that contain good levels of N and some 3 thousand tons a week are produced (Luévano and Velásquez, 2001). In Table 5 we show studies that employ different sorts of organic residues as ameliorations, where bovine manure and *E. fetida* species are the most reported, as this species presents a broad adaptation to the environment (Suthar, 2009b).

Vermicomposting techniques represent and important alternative to solve many of the pollution problems in disposing SS (Velasco and Wolke, 2003); in the past SS were sent to the seabed and to the open; nowadays however, they are treated and are utilized as soil improvers and conditioners. In the frame of sustainable development, the use of organic products with high content of stabilized OM and nutriments that increase the quality of depleted agricultural soils is required (Cuevas and Walter, 2004). In the United States and Europe SS are subject to composting techniques to reduce pollution from this sludge, under programs and environmental policies that order to recycle them and dispose of them in the soil (Smith, 2009). In the United Kingdom, 44% of the total sludge production is composted; in France 7% and in the United States only 33% (Cedú *et al.*, 2005). In Mexico there are no precise figures for this process, yet the pioneering studies on vermicomposting of SS date back to the end of the 1970's (Cardoso, 2002).

The practice of using organic fertilizers in Mexico goes back to ancient times; nevertheless, during the Green Revolution and the widespread use of soil fertilization was focused on applying chemical fertilizers of N and P, marginalizing organic manures, which were the base and sustain of agriculture for several centuries (López *et al*., 2001). Although plenty of information on the use of SS has been generated in different countries, the valuing of their use as organic fertilizer in Mexico has been both scantly explored and documented (Salcedo *et al*., 2007). Composting and vermicomposting techniques are processes to stabilize organic residues; in composting two stages are distinguished: (i) the first one is called thermophilic, in which OM is decomposed with great intensity; and (ii) the second is a maturity stage, in which a mesophilic phase which consists in slowly degrading organic compounds (Boyle, 1990).

Vermicomposting involves bio-oxidation and stabilization of organic residues by the action of the worm which stimulates the microorganisms that take part in biochemical activities degrading OM (Lazcano *et al.*, 2008). As from recent decades the stabilization and maturity processes of the compost have been based on determining volatile solids (Boyle, 1990); nevertheless, nowadays parameters that measure stability have been increased, namely: plant growth, respiration speed, humification index, C/N ratio, content of pathogens, metal bio-availability, bad odor, toxic organic substances and production of methane (Tognetti *et al.*, 2007).

Table 5. summary of experiments that contain diverse results and worm species

Sort of organic residue	Amendment	Worm species	Source
Sewage sludge	Sugarcane residues	*E. fetida*	Suthar, (2009a)
Kitchen residues and coffee-sowed soil	Bovine manure	*Lumbricus rubellus*	Adir and Nor (2009)
Olive soil	Bovine manure	*E. andrei*	Plaza *et al.*, (2008)
Domestic residues	Bovine manure	*P. excavatus, P. sansibaricus,, D. veneta*	Sutarh and Sing (2008), Frederickson *et al.* (1997)
Sewage sludge	Bovine manure	*E. fetida*	Sutarh (2007)
Domestic residue	Bovine manure	*E. fetida, P. excavatus*	Sutarh and Singh (2008), Sutarh (2007),
Agricultural cultivation residue	Bovine manure	*E. fetida, P. excavatus*	Sutarh (2007)
Sewage sludge	Bovine manure	*E. foetida*	Garg *et al.*(2006)
Turkey manure	Bovine manure	*Lumbricus terretris*	Kizilkaya (2005)
Textile industry residues	Chicken manure	*E. fetida*	Kaushik and Garg (2004)
Sewage sludge	Food leftovers	*E. fetida*	Maboeta and Rensbourg (2003)
Paper industry residues	Bovine manure	*E. andrei*	Elvira *et al.* (1998)

The stabilization of SS via vermicomposting or composting generates a series of advantages which are:

- Turn SS in an article with added value;
- Measure and control pollutants (Campitelli and Ceppi, 2008);
- Attenuate the content of metals available in the soil by means of the complexation of these on organic residues;
- Reduce the availability and adsorption of metal in plants (Boyle, 1990);
- Decrease the levels of pathogens in organic residues; and,
- Facilitate enzymatic and microbial activities, and make the nutriments for plants available (Nair *et al*., 2006).
-

Some works point out the benefits of stabilized SS and the use of pre-composted amendments which improve the quality of OM and favor mineralization between 25.4 and 39.8% (Adegbidi and Briggs, 2003). Another field study demonstrated that when 50 t kg^{-1} of composted SS are applied, maize production increases (*Zea mays L*) and the metals do not pose a threat to plants and livestock feeding because of their low mobility and bio-availability (Cuevas and Walter, 2004). In the present day, the application of mixed type organic amendments based on SS and organic residues, as a mixture of 20% SS and 80% bovine manure provides better stability to the soil aggregates (Suthar and Singh, 2008) and when SS and urea are used with a dosage from 12 to 40 t ha^{-1} of SS and 350 kg ha^{-1} of urea, for cultivations of tomato (*Lycopersicon esculentum Mill*), spinach (*Spinacia oleracea L.*), lentil (*Lens esculenta Moench*) and maize (*Zea mays L*) improve the productivity of cultivation and it has been demonstrated that metal contents do not do harm to the plant (Albiach *et al.,* 2001). Mix amendments in the diet of the worm (*E. fetida*) favor the increase of biomass and the number of eggs when mixtures with 70% of SS and 30% of water lily (Cardoso, 2002).

The importance of applying composting and vermicomposting technology to organic residues is that mainly decreases the chemical extractability and solubility of metals (Smith, 2009); the combination of both techniques leads to a better stabilization of organic residues and also to sustainability, because it improves the economic cost to produce organic fertilizers due to their easy and environmental operation (Nair *et al*., 2006). These experiences in the agricultural sphere are oriented to the culture of organic fertilizers use, since the countryside is still invaded by chemical fertilizers that cause soil degradation. The use of SS composted by worms will favor the reduction of pollution, fostering the reuse and recycling of solid organic residues that are generated on a daily basis both in the countryside and the city (López, 1994). The management of SS must consider there is a metal transit via the trophic chain of the worm, which may pose a risk and the probability that the metal moves toward other organisms, such as birds (Suthar, 2008).

Heavy metals in sewage sludge and their impact on the worm and environment

Any kind of municipal solid waste contains more heavy metals than those existing in the ground (Smith, 2009); because of this the Mexican Official Norm NOM-004 (SEMARNAT, 2002) regulates the application of sewage sludge in function of its content of heavy metals and pathogens.

Heavy metals are in the environment, soil, food and their use is widespread in the manufacture of these service products, so they need to be recycled and transferred as composted organic residues (Smith, 2009). It is important to know the contents of heavy metals in SS before being applied to agricultural soils due to their high risk and toxicity (Jamali *et al.,* 2009).

These considerations come from taking into account the application of SS in the soil and the how metals are found:

- As ions in solution;
- As interchange ions;
- Bound to the surface of organic colloids; and,
- Occluded or co-precipitated with metallic rusts, carbonates, phosphates, and other secondary minerals (Smith, 2009).

Pathogens such as bacteria (*Salmonellae*), viruses and parasitic worms (*Ascaris* spp) are to be taken into account when applying SS, the persistence of these agents is favored by low temperatures, alkaline pH, a high OM content and moisture (Boyle, 1990).

Metals are known as potentially toxic elements (PTE) and the most likely to be found in SS are: Zn, Cu, Ni, Cd, Pb, Hg and Cr, being their origin the contribution of urban and industrial sort. The PTE that are shown in table 6 are found booth in the city and countryside and with a higher frequency they are Cu with 589 mg kg^{-1} and Zn with 1144 mg kg^{-1} (Delgado *et al*., 2002).

Table 6. PTE content in sewage sludge (mg kg^{-1}) used in agricultural soils (Smith, 1996)

Element	Minimum	Maximum	Mean	Median
Zinc (Zn)	279	27600	1144	1205
Copper (Cu)	69	6140	589	625
Nickel (Ni)	9	932	61	59
Cadmium (Cd)	<2	152	9	9
Lead (Pb)	43	2644	398	418
Mercury (Hg)	<2	140	4	3
Chromium (Cr)	4	23195	197	124
Molybdenum (Mo)	<2	154	5	5
Selenium (Se)	<2	15	3	3
Arsenic (As)	<2	123	6	5

PTE = potentially toxic element

PTE can pose high risk when they enter into the trophic chain of human beings and affect the primary and secondary producers who are exposed to them (Suthar and Sing, 2008). The damage in the plant is determined by the sort of metal, availability and content (Sandoval *et al.*, 2001). Zn, Cu and Ni present in SS must be regulated to be agriculturally applied; Zn and Cu affect the growth of many vegetal species within a range of 200-300 mg of Zn kg^{-1} and 15-20 mg of Cu kg^{-1} dry weight. Cu tends to be heavily absorbed by the soil and the plant regulates its absorption. The reduction of the phytotoxicity of Zn, Cu, and Ni in the plant tissue is improved if there is a fine texture and a pH of 6.8 (Smith, 2009). Ni, Cd and Pb are phytotoxic in contents of 10-100 mg kg^{-1},5-30 mg kg^{-1} and 30-300 mg kg^{-1} (dry weight), respectively. Zn in excess favors the presence of yellow stripes and brown spots on the leaves; this metal moves fast into the plant tissue (Smith, 1996). Ni in excess provokes the appearance of brown spots on the leaves and white stripes along them. If Cd surpasses the permissible, brownish-reddish spots appear on the leaves and damage the stem (Pereira *et al*., 2003). Cr does not have adverse effects, yet if it is found as Cr (VI), it is highly toxic for plants (Smith, 1996). Phytoavailability is corrected if the soil presents a slightly alkaline pH and the composted SS amendment is applied (Smith, 2009).

If PTE enter into the diet of human beings, they harm health. Zn does not represent a toxic effect (Zhou and Wong, 2001; Volke *et al*., 2005). Cd is toxic in human diets; however the tolerance value for human consumption is 16.2 µg of Cd a day (Pereira *et al.*, 2003). Pb poses a risk in child diets, causing serious problems of encephalitis and neuronal damages (Acarasquero *et al.*, 2006). Pb shows a low availability in cultivations for human consumption and if SS is applied to cultivation soils there is an increase of 25000 mg of Pb kg^{-1} of soil. Cu only presents toxic effects in grazing animals (Smith, 1996).

Industrial activities still damage the environment, which makes a reflection on the ameliorating technologies necessary (Fernández *et al*., 2006), and to do so one can resort to composting and vermicomposting techniques where the former performs a chemoremediation, sequestering heavy metals, being Pb the one with the strongest chemical binding, above Ni, Zn, Cu and Cd. In vermicomposting the worm is known as a bioremediation agent (Boyle, 1990; Baker, and Kryson, 2002). In organisms bioavailability is determined in a laboratory and in the field by means of geochemical techniques of sequential extraction, and more recently using bio-indicators; these last are based upon the determination of a metal in the tissue of the organisms by exposure to pollutants (Sandoval *et al.*, 2001). The function of the bio-remediating agent consists in removing (extracting), degrading (biodegrading) or transforming (biotransforming) toxic organic compounds into less toxic or innocuous metabolic products (Velasco and Wolke, 2003). An instance of bioremediation is the earthworm (*E. fetida*) that removes metals from SS from sugar industry and reduces the content of Zn (20.5-43.8%), Fe (23.6-34%), Mn (18-45%), and Cu (29-58.1%) (Suthar, 2008).

The worm presents selectivity between metals and the tissue where it is absorbed; the bioaccumulation of Cd and Ni in the worm tissue represents a linear relation between the metal in the tissue and time (Aleagha *et al*., 2009). Chronic exposure to Cd and Cu generates changes in metabolism and decreases the production of carbohydrates, lipids, proteins in the worm (Shukla and Kumar, 2006; Prabna *et al.*, 2007). The chemical selectivity in adsorbing metals in the tissue presents the following ascending order Zn>Cu>Pb>Hg (Maboeta and Rensburg, 2003): an instance of this is in the bioaccumulation in the tissue of *E. fetida* for Cu (16 - 27 mg kg^{-1}), Fe (42-89 mg kg^{-1}), Zn (58 -75 mg kg^{-1}) and Pb (1.7-12.4 mg kg^{-1}) analyzing SS that underwent vermicomposting and the most frequently selected tissue was from kidney and liver (Carpene *et al*., 2005; Renoux *et al*., 2007).

Because of the great importance that the environment has in correcting the problem of pollution from organic residues promoted by industrialization and urbanization, which have generated a large amount of organic residues, it is necessary to implement techniques where worm, in addition to produce biomass (providing), performs another task that consists in being a bio-remediation to regulate the environment via reducing and bio-transforming organic residues and making them useful, in benefit of society.

CONCLUSIONS

From the previous revision earthworm is considered an organism that decomposes and stabilizes OM, due to the contribution of nutriments available to the soil and plant. Vermiculture reduces the production costs of organic fertilizers and in the agricultural sector, requires experiences where new nonconventional sources of C and N are studied, such as SS, in which the biological, physical and chemical parts of the worm are known so that with the help from practitioners, can attack the problem from the productive and environmental viewpoint. Because of this, it is necessary to continue testing dosages and different mixtures, and apply them as an alternative in the short and middle terms in the agricultural and forest spheres in Mexico. The Mexican Official Norm NMX-FF-109-SCFI (SARPA, 2007) states that the product can be commercialized and become a sustainable industry to solve pollution problems where organic residues are involved (SS included). The worm has to be seen as a bio-remediating organism as it accumulates and cleanses polluted soils, so it is required to carry out new studies that respond to the challenges of bio-remediation, when one works with residues that contain heavy metals and other compounds from SS and conventional organic residues. In Mexico, the use of conventional organic residues from the agricultural sector (manure from bovines, horses, pigs, birds) have been successful in its application, however the use of nonconventional residues generated in the city and industry (residues from alimentary, textile, paper, winemaking industries and municipal sludge) have been very sporadically used. So it is needed to continue working and testing these sorts of residues in benefit of the environment and meeting the environmental criterion as for the reduction of weight and volume, hence favoring the reduction of pollution in the planet.

REFERENCES

Acarasquero, D., Flores, I., Perozo, C., Permaleto, Z. 2006. Immobilization of lead by a vermicompost and its effect on white bean (*Vigna Sinenis* var. Apure) uptake. International Journal Environmental Science. Technology. 3:203-210.

Adegbidi, H.G., Briggs, R.H. 2003. Nitrogen mineralization of sewage sludge and composted poultry manure applied to willow in a greenhouse. Journal Biomolecular. Bioenergy. 25: 665-673.

Adir, A.J., Nor, Z.M. 2009. Waste recycling: Utilization of coffee grounds and kitchen waste in vermicomposting. Bioresource Technology. 100:1027-1030.

Aira, M., Monroy, F., Domínguez, J. 2006. C to N ratio strongly affects population structure of *Eisenia fetida* in vermicomposting systems. Europan Journal Soil Biology. 42: s127-s131.

Aira, M., Monroy, F., Domínguez, J. 2007. *Eisenia fetida* (*Oligochaeta Lumbricidae*) modifies the structure and physiological capabilities of microbial communities improving carbon mineralization during vermicomposting of pig manure. Microbiology Ecology. 54:662-671.

Aira, M., Sampdero, L., Monroy, F., Domínguez, J. 2008. Detritivorous earthworms directly modify the structure, thus altering the functioning of a microdecomposer food web. Soil Biology & Biochemistry. 40:2511-2516.

Albiach, R., Canet, R., Pomares, F., Ingelmo, F. 2001. Organic matter components and aggregates stability after the application of different amendments to a horticultural soil. Bioresource Technology.76: 125-129.

Aleagha, M.H., Pedrau, H., Omani, G. 2009. Bioaccumulation of heavy metals by Iranian earthworms (*Eisenia fetida*) in the process of vermicomposting. Europan Journal Agricultural Environmental Science. 4: 480-484.

Arancon, Q. N., Clive, A., Stephen, L.E., BYrne, R. 2006. Effects of humic acids from vermicompost on plant growth. Europan Journal Biology. 42: S65-S67.

Armijo, V., Ojeda, B.S., Ramírez, B. M.E. 2007. Caracterización de residuos sólidos el potencial de reciclaje para una institución de educación superior. Encuentro Nacional de Expertos en Residuos Sólidos. Universidad Autónoma de Baja California, México. ISBN 970-735-075-X: pp. 66-77.

Atiyeh, R. M. Subler, S., Edwards, C. A., Bachman, G., Metzger, J. D., Shuster, W. 2000. Effects of vermicomposts and composts on plant growth in horticultural container media and soil. Pedobiologia. 44: 579-590.

Atiyeh, R.M., Lee, S., Edwards, C.A., Arancon, N.O., Metzge, J.D. 2002. The influence of humic acids derived from earthwoms-proced organics wastes on plant growth. Bioresource Technology. 84: 7-14.

Baker, V.A., Kryson, G.M. 2002. Bioremediation of heavy metals and organic toxicants by composting. Science. World Journal. 2: 407-420.

Bernache, G. 2007. Los Estudios de Basura en México. Una Retrospectiva. Encuentro Nacional de Expertos en Residuos Sólidos. Universidad Autónoma de Baja California, México. ISBN 970-735-075-X. pp. 7-30.

Blair, J.M., Parmelee, R.W., Allen, M.F., McCartney, D.A., Stinner, B.R. 1997. Changes in soil N pools in response to earthworm population manipulations in agroecosystem with different N sources. Soil Biology & Biochemistry. 29: 361-367.

Bohlen. 2002. Earthworms.. Encyclopedia of Soil Science. R. Lal (ed). Florida, United State American. pp 370-373.

Boyle, M. 1990. Biodegradation of land-applied sludge. Journal Environmental Quality. 11:640-643.

Cabrera, C R.E., Gordillo M. A.J., Hernández M. A. 2007. Propuesta de planificación para la gestión integral de residuos sólidos en el estado de Hidalgo, México. Encuentro Nacional de Expertos en Residuos Sólidos. Universidad Autónoma de Baja California, México. ISBN 970-735-075-X. pp. 313-324.

Campitelli, P., y Ceppi, P. 2008. Chemical, physical and biological compost and vermicompost characterization: A chemometric study. Chem. Intell. Lab. Syst.90: 64-71s.

Canellas, L.P., Olivares, F.L.; Okokrokova-Facanha, A.L., Fancanha, A.O. 2002. Humic acids isolated from earthworms compost enhance root elongation, lateral root emergence and plasma membrane H+-ATPase activity in maize roots. Plant Physiololgy . 30: 1951-1957.

Capistrán, F., E. Aranda, Romero, J.C. 2001. Manual de reciclaje, compostaje y lombricompostaje. Instituto de Ecología, A.C. Xalapa, México. 150 p.

Cardoso, V.L. 2002. Sistema de vermiestabilización para plantas de tratamientos municipal. Congreso Interamericano de Ingeniería Sanitaria y Ambiental. 28. Cancún, México. 27 oct-1 nov.

Carpene, E., Andreana, G., Morani, M., Gastote, C., Isari, G. 2005. Distribution of Cd, Zn, Cu, and Fe among selected tissues of the earthworm (*Allolophora caliginoasa*) and Eurasian Wordcok (*Scolopax raticula*). Science Total Environmental. 363:126-135.

Cedú, F., Oitrenaud, M., Houot, S. 2005. Stabilization of process and feedstock compost. Science Utilization. 13: 72-73.

Chaudhuri, P.S., Pal, T.K., Bhattacharjee, G., Dey, S.K. 2000. Chemical changes vermicomposting (*Periony excavatus*) of kitchen waste. Tropical Ecology. 41:107-110.

Cuevas, G.R. 2005. Desarrollo de la lombriz *Eisenia fetida* Sar. En dos localidades y efecto de la lombricomposta en maíz en el Soconusco Chiapas. Tesis de Maestría. Universidad Autónoma del Chiapas. México. 64 p.

Cuevas, G., Walter, I. 2004. Metales pesados en maíz (*Zea mays L.*) cultivado en un suelo enmendado con diferentes dosis de compost de lodo residual. Revista Internacional de Contaminación Ambiental. 20: 56-68.

Colín, C.A., Ayesterán, H.L.M., Gutiérrez, S.E.F., Torres, P.J. 2006. Nuevas aplicaciones de lodos residuales. Revista Internacional de Contaminación Ambiental.1-10.

Dekker, H. 2002. Earthworms. Encyclopedia of Soil Sci. pp. 370-373.

Delgado, A. M.D.H., Porcel, C.M.A., Millarez, D.I.H.R., Beltrán, R.F., Beringola, B. L., Martín, S.J.V. 2002. Sewage sludge compost fertilizer effects on maize yield and soil heavy metal concentration. Revista Internacional de Contaminación Ambiental. 8: 47-50.

Delgado, A. M.D.H., Porcel, C.M.A., Millares, D.I.H.R., Beltrán, R.F., Beringola, B. L., Martín, S.J.V. 2004. Efecto de la vermicultura en la descomposición de residuos orgánicos.

Revista Internacional de Contaminación Ambiental. 18: 147-150.

Domínguez, J., Velando, J., Aira, M., Monroy, F. 2003. Uniparental reproduction of *Eisenia fetida* and *E. Andrei* (Oligochaeta: Lumbricidae): evidence of self-insemination. Pedobiologia. 47: 530-534.

Elvira, C., Sampedro, L., Benítez, E., Nogales, R. 1998. Vermicomposting of sludge from paper mill and dairy industries with *Esenia andrei*: A pilot-scale study. Bioresource Technology. 3:205-211.

Edwars, C.A., Bohlen, P.J. 1996. Biology and Ecology of earthworms. Chapman & Hall. Third edition. Great Britain. 426 p.

Fernández, L. L.C., Rojas, A. N.G., Carrillo, R. T.G., Islas, R. M. E., Martínez, Z. H.G., Hernández, U. R., Ávila, R. J.R., Hernández, F.D., Ortega, AJ.M. 2006. Maual of analysis techniques of soils applied to remediation of polluted places. SEMARNAT, INE, IMP. 177p.

Frederickson, J., Kevin, R., Butt, R., Morris, M., Daniel, C. 1997. Combining vermiculture with traditional green waste composting systems. Soil Biology and Biochemistry. 29: 725-730.

Gajalaksmi, S., Rasamany, E.V., Abbasi, S.A. 2001.Potencial of two epigeic and two anecic earthworm species in vermicommposting of water hyacinth. Bioresource Technology. 76: 177-181.

García, P. R. E. 2006. La lombriz de tierra como biotecnología en agricultura. Tesis de licenciatura. Universidad Autónoma de Chapingo. Mexico. 177p.

Garg, V.K., Chand, S., Chhillar, A., Yadav, A. 2005. Growth and reproduction of *Esenia foetida* in varios animal waste during vermicomposting. Applied Ecology and Environmental Resource. 3: 51-59.

Garg, V.K., Kaushik, K.P. 2005. Vermistabilization of textile mill sludge with poultry dropping by an epigeic earthworm *Eisenia foetida*. Bioresource Technology. 96:1063-1071.

Garg, P., Gupta, A., Satya, S. 2006. Vermicomposting of different types of waste using: A comparative study. Bioresource Technology. 97: 391-395.

Gunadi, B., Blount, C., Clive, A.E. 2002. The growth and fecundity of *Eisenia fetida* (Savingny) in cattle solids pre-composted for different periods. Pediobiologia. 46: 15-23.

Gupta, R., Garg.V.K. 2008. Stabilization of primary sewage sludge during vermicomposting. Journal Hazard Material. 153: 1023–1030.

Holmstrup, M. 2001. Sensitivity of life history parameters in the earthworm *Aporrectodea caliginosa* to small changes in soil water potential. Soil Biology & Biochemistry . 33, 1217-1223.

Jamali, M.K., Kazi, T.G., Arain, M.B., Afruidi, H.I., Jalnbani, N., Kandhru, G.A., Shah, A.Q., Baig, J.A. 2009. Heavy metal accumulation in different varieties of wheat (*Triticum aestivum*) grown in soil amended with domestic sewage sludge. Journal Hazard Material. 164:1386-1391.

Kannan, R., Balasubramanian, A. 2007. Efficacy of vermicomposting in relation to humic acid and NPK content. Pollution Resource. 26: 719-724.

Kaushik, O., y Garg, V.K. 2004. Dynamics of biological and chemical parameters during vermicomposting of solid textile mill sludge mixed with cow dun and agricultural residues. Bioresource Technology. 94:203-209.

Khwairakpan, M., Bhargava, R. 2009. Vermitechnology for sewage sludge recycling. Journal Hazard Material.1:1-7.

Kizilkaya, R. 2005. The role of different organic waste on zinc bioaccumulation by earthworm *Lumbricus terrestris L.* (Oligochaeta) in successive Zn added soil. Ecology Engenery. 25: 322-331.

Lazcano, C., Brandón, G. M., Domínguez. 2008. Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. Chemosphere. 22: 1013-1019.

López, B.D. 1994. El medio ambiente. Ed. Cátedra. Madrid. España. 385p.

López, M.J.D., Díaz, E.A., Martínez, R.E., Valdez, C.R.D. 2001. Abonos orgánicos y su efecto en propiedades físicas y químicas del suelo y rendimiento en maíz. Terra.4: 293-299.

López C.R., Gallegos, A., Peña, E., Castro, R., Franco, J., Chávez, J.F.J. 2006. Sustancias húmicas de origen diverso en algunas propiedades físicas de un suelo. Terra. 24: 303-310.

Lowe, C. N., Butt, K.R. 2005. Culture techniques for soil dwelling earthworms: A Review. Pedobiologia. 49: 401-413.

Luévano, G.A., Velásquez, G. N. E. 2001. Ejemplo singular en los agronegocios estiércol vacuno: de problema ambiental a excelente recurso. Revista Mexicana de Agronomía .9: 306-320.

Maboeta, M.S., Rensbourg, L. 2003. Vermicomposting of industrially produce woodchips and sewage sludge utilizing *Eisenia fetida*. Ecotoxology Environmental Safety. 65:265-270.

Mangrich, A. S., Lobo M.A., Tanck, C.B., Wypych, F. E., Toledo, B. S., Guimarães E. 2000. Criterious Preparation and Characterization of Earthworm-composts in View of Animal Waste Recycling. Part I. Correlation Between Chemical, Thermal and FTIR Spectroscopic Analyses of Four Humic Acids from Earthworm-composted Animal Manure. Journal Brazil Chemistry Society. 2: 164-169.

Manna, H.C., Jha, C., Ghosh, P.K., Acharya, C.L. 2003. Comparative efficacy of three epigeic earthworms under deciduous forest litters decomposition. Bioresource Technology. 88:197-206.

Masini, J.C., Abate, G., Lima, E.C., Hahn, L.C., Nakamura, M.S., Liehtig, J., Nagatomy, H.D. 1998. Comparison of methodologies for determination of carboxylic and phenolic groups in humic acids. Analitycal Chemistry . 364:223-233.

Mathur, P., Owen, G., Dinel H., Schnitzer, M. 1993. Determination of compost biomaturity. Biology, Agricultural & Horticultural. 10. 65-85.

Montenegro, M. M. Y., Ojeda, B. S., Hidalgo, S. H. 2007. Identificación de patrones de comportamiento ambiental por tipología familiar en la generación de RSD: Estudio de Caso. Encuentro Nacional de Expertos en Residuos Sólidos. Universidad Autónoma de Baja California, México. ISBN 970-735-075-X. pp. 40-53.

Mora, D.J.R. 2000. Contribuciones del compost al mejoramiento de la fertilidad del suelo. Univ. De Caldas Manizales-Colombia. Revista Luna Azul. 5: 87-99.

Moreno, R.A., Valdés, P.M.T., Zarate, L.T. 2005. Desarrollo de tomate en sustratos de vermicompost/arena bajo condiciones de invernadero. Revista de Agricultura y Técnica de Chile. 65: 26-34.

Muthukumaravel, K., Amsath, A., Sukumaran, M. 2008. Vermicomposting of vegetable waste using cow dung. European Journal Chemistry. 5:810-813.

Nair, J., Seckiozoic, T., Anda, M. 2006. Effect of pre-composting on vermicomposting of kitchen waste. Bioresource Technology. 97: 2091-2095.

Ndegwa, P.M., Thompson, S.A. 2000. Effects of C-to-N ratio on vermicomposting of biosolids. Bioresource Technology. 75: 7-12.

Orozco, F. H., Cegarra, J., Trujillo, L. M., Roig, A. 2000. Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: Effects on C and N contents and the availability of nutrients. Bioresource Fertility and Soils. 22:162-166.

Ortega, R., Fernandez, M. 2007. Agronomic evaluation of liquid humus derived from earthworm humic substances. Journal, Plant Nutrition.30: 2019-2104.

Palsania, J., Shrama, R., Srivastava, J.K., Sharma, D. 2008. Effects of moisture content variation over kinetic reaction rate during vermicomposting process. Application Ecology Environmental Resource. 6: 49-61.

Pasqualalto, L., Lopez, O.F., Okorokova, F.L., Rocha, F.A. 2002. Humic acids isolated from earthworms compost enhance toot elongation, lateral root emergence and plasma membrane M+-ATPasa activated in maize roots. Plant Physiology.130:1951-1957.

Plaza,C., Nogales, R., Senesi, N., Benítez. E., Polo, A. 2008. Organic matter humification by vermicomposting of cattle manure alone and mixed two-phase olive pomace. Bioresource Technology. 99-5085-5089.

Paul, E.A., Clark, F.E. 1996. Soil microbiology and biochemistry. Academic Pres. United State Americam.340 p.

Prabna, M.L., Jayaraai, I. A., Jeyaraai, R., Rao, S. 2007. Comparative studies on the digestive enzymes in the gut of earthworms, *Eudeilus eugeniae* and *Eisenia fetida*. Indian Journal Biotechnology. 6: 567-569.

Pereira, M., Azura, M. A. 2003. vermicompost as a natural absorbent material: Characterization and potentialities for cadmium adsorption. Chemistry Society. 4:39-47.

Pramaik, K.O., Ghosh, G.K., Ghosal, P.K., Bonik, P. 2007. Changes inorganic-C, N,P and K and enzyme activities in vermicompost of biodegradable organic wastes under liming and microbial inoculants. Bioresource Technology. 98:2485-2494.

Premuzic, Z., Brichta, J.P., Rendina, A.E., Louo, A.F. 2002. Fertility and toxicity parameters for the commercialization of a soil additive using muds from the Mantanza river in Argentina. Información Tecnológica. 13: 25-29.

Porta, C. J., López, A. R. M., Roquero, L.C. 2003. Edafología: para la agricultura y el medio ambiente. Ed. Mundi-Prensa. España.849 p.

Quincha, A. M., y Carmona, D. M. 2004. Factibilidad de disposición de los biosólidos generados en una planta de tratamiento de aguas residuales combinada. Revista EIA. 2: 89-108.

Renoux, A., Rocheleau, S., Surrazin, M., Sunahara, G.I., Blair, J.F. 2007. Assessment of sewage sludge treatment of cadmium, copper and zinc bioavailability in barley, ryegrass and earthworms. Environmental. Pollution. 145:41-50.

Rodríguez, S.M.A., Córdova, V.A. 2006. Manual de compostaje municipal: tratamiento de residuos sólidos urbanos. SEMARNAT, INE Y GTZ. México. 101 p.

Romero, E., Plaza, C., Senesi., N., Nogales, R., Polo, A. 2007. Humic acid-like fractions in raw and vermicomposted winery and distillery wastes. Geoderma. 139: 397-406.

SAGARPA. 2007. Norma Mexicana de humus y lombriz, especificaciones y métodos de prueba. Web site: www: Ordenjuicio.gob.mx/FEDERAL/PE/ADF/SAGARPA/Normas/Oficiales/nmx-ff-109-scfi-2007.pdf. (Consultada 5/junio/2010).

Salcedo, P.E., Vázquez, A.A., Krishnumurthy, L., Zamora, H. F., Hernández, A.E., Rodríguez, M.R. 2007. Evaluación de lodos residuales como abono orgánico en suelos volcánicos de uso agrícola y forestal en Jalisco. México. InterCiencia. 32: 115-120.

Sandoval, C.M., Veiga, M., Hilton, J., Klein, B. 2001. Review of biological indicators for metal mining effluents: a proposed protocol using earthworm. Proceeding of the 25th Annual British Columbia Reclamation Symposium. Sep.23-27. pp 67-79.

Sangwan, P. Kauship, C.P., Garg, V.K. 2008. Feasibility of utilization of horse dung spiked filter cake in vermicomposts using exotic earthworms *Eisenia foetida*. Bioresource Technology. 99: 2442-2448.

Santamaría, R. S., Ferrera, C. R. 2002. Dinámica poblacional de *Eisenia andrei* (bouche, 1972) en diferentes residuos orgánicos. Terra. 20: 303-310.

SEMARNAT. 2002. Norma Oficial Mexicana NOM-004, Protección ambiental. - lodos y biosólidos- Especificaciones y límites máximos permisibles de contaminantes para su aprovechamiento y disposición oficial. Diario Oficial viernes 15 de agosto de 2003. Pagina en red: www.semarnat.gob.mx/.../NOM-004-SEMARNAT-2002. pdf. (Consultada el 5 de febrero del 2010).

Sharma, S., Pradham, K., Satya, S., Vasudevan, P. 2005. Potentiality of earthworms for waste management and in other Use-A Review. Journal American Science. 1:4-16.

Shukla, V., Kumar, K. 2006. Toxic effect of heavy metals (cadmium and copper) or biochemical parameters of earthworms. Journal Ecobiology.19: 347-354.

Singh, N.B., Khare, A.H., Bhargava, D.S., Bhattacharya, S. 2005. Effect of initial substrate pH on vermicomposting using *Perionyx excavatus* (Perrier, 1872). Application Ecology Environmental Resource. 4: 85-97.

Smith, S. R. 1996. Agricultural recycling of sewage sludge and the environment. CAB international. United King. 382 p.

Smith, S. R. 2009. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste compost compared to sewage sludge. Environmental International. 35: 142-156.

Soto, G., y Muñoz, C. 2002. Consideraciones teóricas y prácticas sobre el compost y su empleo en la agricultura orgánica. Manejo Integrado de Plagas. Costa Rica. 65:123-129.

Suthar, S. 2007. Vermicomposting potential of *Perionyx sansibaricus* (Perrier) in different waste materials. Bioresource Technology. 98: 1231-1237.

Suthar, S., Sing, S. 2008. Vermicomposting of domestics waste by using two epigei earthworms (*Perionyx excavatus* and *Perionyx sansibarious*). International Journal Environmental Technology. 5: 99-106.

Suthar, S. 2009a. Vermistablization of municipal sewage sludge amended with surgarcane trash using epigeic *Eisenia fetida* (Oligochaeta). Journal Hazard Material. 163: 199-206.

Suthar, S. 2009b. Vermicomposting of vegetable-market solid waste using *Eisenia fetida*: Impact of bulking material on earthworm growth and decomposition rate. Ecology Enginery. 35: 914-920.

Tognetti, C., Mazzarino, H.J., Laos, F. 2007. Improving the quality organic municipal waste compost. Bioresource Technology. 98: 1067-1076.

Velasco, J.A., Wolke, S.T.L. 2003. El composteo una alternativa tecnológica para la biorremediación de suelos en México. Gaceta Ecológica. 66:41-53.

Volke, S. T., Velasco, T.J.A., de la Rosa, P. D.A. 2005. Suelos contaminados por metales y metaloides: muestreo y alternativas para su remediación. Secretaria de Medio Ambiente y Recursos Naturales. Instituto Nacional de Ecología. México.141 p.

Yagi, R., Ferreira, M.E., Pessoôa, D.L. C.M.C., Barbosa, J.C. 2003. Organic matter fractions and soil fertility unde the influence of liming vermicompost and cattle manure. Ciencia Agrícola.60:549-557.

Yadav, A., Garg, V.k. 2009. Feasibility of nutrient recovery from industrial sludge by vermicomposting technology. Journal Hazard Material.168:262-268.

Zhou, L., Wong, J. 2001. Effects of dissolved organic matter from sludge and sludge compost on soil Koper sorption. Environmental Quality Journal. 30: 878-883.

Submitted March 17, 2011– Accepted May 04, 2011
Revised received July 11, 2011