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Review Research Paper

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The Implications of Fly Ash Remediation Through Vermicomposting: A Review

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ABSTRACT

Generation of fly ash (FA) occurs in huge amounts during the combustion of coal for energy production and is recognized as a serious environmental pollutant. Fly ash management is a major concern of the century. Disposal of FA by various conventional methods leads to degradation of arable land and contamination of the groundwater. Attention is now being paid to the recycling of FA through biological methods. FA has availability of plant nutrients and it also contains some toxic heavy metals. Remediation of metals from FA and an increase in its NPK content enhances its applications in agricultural sector. Vermitechnology is one of the promising options for improving the nutrient status of FA and also reducing the metal content. Biologically modified form of fly ash is used for its chemical composition for agricultural purposes or upgrading the wastelands. An exhaustive review of several studies was done in this paper, which, systematically covers the importance, scope and benefits of remediating the fly ash using different species of earthworms. Changes in the content of N, P and K along with the reduction of metal content in the substrates were observed as per the literature survey thus proving vermiremediation, a sustainable technique.

INTRODUCTION

Industrialization and urbanization at a rapid rate has led to an increase in dependence on coal based thermal power plants for power generation in most of the developing countries. In India, about 79% of the entire electricity is met by these coal fired power plants (Singh & Siddiqui 2003). The annual per capita energy consumption ranges between 5-11 KW in developed countries like USA while its range is very low at about 1-1.5 KW in developing countries. India is a large consumer of non-coking coal having a high ash content of about 30-40% (Senapati 2011). FA, also referred to as flue ash is generated as small dark flecks by the burning of powdered coal at high temperature. FA contains silica, aluminium and oxides of iron, calcium, magnesium, arsenic, chromium, lead, zinc and other toxic metals. It has been regarded as a problematic solid waste all over the world.

Disposal, management and proper utilization of FA has been a major concern for the scientists and environmentalists. Engineers nowadays are making efforts to take advantage of these coal byproducts. Extensive research is being carried out in order to use FA in various sectors as FA does not come under the category of hazardous wastes (Latifi et al. 2015). Hence, FA is being used in many other applications in civil engineering, construction of roads and manufacture of bricks, cement, ceramics, distempers and roads due to its pozzolanic nature. Use of FA in agriculture is also being explored by researchers, mainly because it contains essential plant nutrients except N, P, and K. FA maintains pH, better aeration and percolation of the soil, provides nutrients to the soil and enhances the growth and yield of crops as biofertilizers. In India, only 2% of FA generated is being utilized in the agricultural sector (Kumar et al. 2005-12). FA has certain limitations regarding its use in agricultural ecosystems because of the low availability of most of the nutrient elements and lower rate of degradation after application in soils. The presence of heavy metals in their soluble forms in FA is the major constraint in its utilization for agricultural purposes (Pandey et al. 2009, Pandey & Singh 2010). The treatment of FA polluted sites and the reduction of heavy metal exposure by conventional procedures is expensive and time-consuming (Gonzalez & Gonzalez-Chavez 2006).

Vermicomposting is one of the most promising techniques to dispose the wastes like FA and also remediate and amend the soil (Edwards & Bater 1992). The prime benefits of vermicomposting of FA are (a) capable of handling very low to very high quantities of FA, (b) simple and cost-effective process effective both in case of small scale and large scale utilization, (c) the vermicasts provide popular and ready markets as enrichers of soil (Abbasi & Ramasamy 1999). Earthworms form an important part of soil fauna in most global soils and comprises a significant proportion of the soil biomass, thus serving as a useful indicator of soil health

Table 1: Physico-chemical properties of fly ash of different countries.

Parameters	India[a]	USA[b]	China[c]	Gobal Scenario[d]
pH	6.0-11.0	5-12	4-10	4.5-12.0
Bulk Density (g/cm^3)	0.85-1.2	1.04-1.76	531-1261	1.01-1.43
Specific gravity (g/cm^3)	1.66-2.55	2.1-2.9	-	1.6-3.1
Water holding capacity (%)	45-60	-	89-130	35-40
Porosity (%)	45-55	0.40-0.50	-	50-60
Grain size distribution	Sandy silt to silt loam	Silty loam	Silty loam	Silt loam
Electrical Conductivity (ds/m)	0.15-0.45	-	-	

Source: [a](ICAR 1996; CFRI 2000a; 2000; Goyal et al. 2002; Ram & Masto 2010)
[b](EPR 2005; EPR 2009); [c](Lan & Yuansheng 2007); [d](Jala & Goyal 2006; Basu et al. 2009)

and quality (Edwards 2004). Earthworms enhance the fertility of soil treated with coal FA by increasing availability of mineral nutrients such as nitrogen (N), phosphorus (P) and potassium (K) in the ash and minimizing the toxic heavy metal contents from FA by these metal accumulation in their gut.

This review considers the (i) basic physico-chemical properties of FA of several developed and developing countries, (ii) potential of FA to be used in agriculture, (iii) vermitechnology technique for remediating FA by worms. This technique has also been validated with the results of the on-going vermicomposting experiment, (iv) changes in nutrient content of different mixtures before and after vermicomposting, (v) changes in the metal content of FA due to metal accumulating earthworm species. Thus management of FA through biological means is the basic concern of the paper.

Fly Ash

Fly ash generation: FA is a coal combustion residue obtained from coal burning power generation plants (Gitari et al. 2013). It is a powdery material. An estimated amount of 550 Mt per year of FA is produced by combustion of coal in thermal power plants around the world (Querol et al. 2001, Ram & Masto 2010). As per Fly-Ash Utilization Programme (FAUP), Department of Science and Technology, New Delhi, India, during 2011-2012, 220 million tonnes FA was generated and FA generation can further increase to about 1000 million tonne by 2032. Countries such as China, United States, Europe, South Africa, Australia, Greece, Japan and Italy also have high rates of FA production (ACAA 1998, Koukouzas et al. 2005, Yunusa et al. 2006, Skordas et al. 2007). There are significant differences between the generation and utilization rates of FA in various developing and developed countries (Fig. 1).

Physico-chemical properties of fly ash: FA is an amorphous mixture of ferroaluminosilicate minerals generated from the combustion of ground or powdered coal at 440-1500ºC (Mattigod et al. 1990). It is a mixture of fine, spherical particles, size ranging between 0-100 microns. FA has a light texture with high surface area and low bulk density (Asokan et al. 2005, Jala & Goyal 2006) (Table 1). FA particles constitute hollow, empty spheres (cenospheres) comprising of smaller amorphous particles and crystals (pleospheres). The cenosphere fraction comprises 1% of the total mass and gets easily air borne (Jala & Goyal 2006). Major fraction of FA, about 90-99% comprises of Si, Al, Fe, Ca, Mg, Na, K, Si, Al, Fe and Ca as the major elements present in most compounds along with minor amounts of Mg, Ti, K and traces of silicates, oxides, sulphates and borates, along with lesser amounts of phosphates and carbonates (Schumann & Sumner 2000). FA consists of metals like As, Cd, Ca, Cr, Co, Cu, Pb, Mn, Hg, Ni, F, Zn, Al, B, Ba, Be, Mo and some trace metals associated with the basic elements. According to the amount percentage of the basic constituent, FA is categorized as class C (high CaO content) or class F (low CaO content). The physicochemical and mineralogical characteristics of FA vary with coal source and quality, combustion process, types of emission, control devices storage and handling methods, extent of weathering, particle size and age of the ash (Mc Carthy & Dhar 1999, Mohapatra & Rao 2001). Thus, there is a wide variation in the physical properties, chemical properties, radioactivity, the occurrence of major nutrient elements and the toxic heavy metals, depicting a comparative scenario of physico-chemical properties of FA of different countries. Table 2 gives a detailed knowledge about the various oxides and micronutrients present in FA. Table 3 focuses on the presence of toxic heavy metals occurring in FA of several developed and developing countries.

FA is an industrial waste and if not utilized properly, it would be disposed off in land-fills, ponds or rivers (Khan et al. 2013). FA is a serious source of air pollution since it remains air-borne for a long period of time and causes health hazards (TERI 1998). FA interferes with the photosynthesis of aquatic plants and thus disturbs the food chain. FA also degrades the environment. It clogs natural drainage and re-

Table 2: Chemical composition of fly ash of different countries and global scenario of major nutrients in fly ash.

Chemical Composition[a]			
Oxide (%)	India	China	USA
Na_2O	0.07-0.43	0.2-1.1	1.9-3.4
MnO	0.1-0.5	0.27	0.009-0.7
Al_2O_3	27.0-44.0	16.5-35.1	5-35
Fe_2O_3	3.3-6.4	1.5-19.7	4-40
K_2O	0.04-0.9	0.6-2.9	0.62-2.1
CaO	0.2-8.0	0.8-10.4	1-40
TiO_2	0.4-1.8	1.36	0.43-0.9
SiO_2	38.0-63.0	33.9-59.7	15-60
(Major Elements)[b] (mg kg^{-1})			
Elements		Global Scenario	
P		0.004-0.8	
K		0.15-3.5	
Ca		0.11-22.2	
Mg		0.04-7.6	
N		-	
S		0.1-1.5	
Al		0.1-17.3	
Na		0.01-2.03	

(-): not mentioned
Source: [a](ICAR 1996; CFRI 2000a, 2000b, 2001a, 2002a, 2003; Kumar et al. 2005; Ram & Masto 2010)
Source: [b](Jala & Goyal 2006; Basu et al. 2009)

duces the pH and portability of water, making it turbid. FA poses a serious problem for its disposal. Therefore, it is important to overcome these problems not only by proper and safe disposal, but also through transformation of these materials to value-added products (Bhattacharya & Chattopadhyay 2002).

FA in agriculture: FA has great potential as a resource material in construction, agriculture and other related areas. Agricultural utilization of FA has been proposed due to its considerable content of K, Ca, Mg, S and P (Singh et al. 1997). FA, having both the soil amending and nutrient-enriching properties, is helpful in improving crop growth and yield even in low fertility acid lateritic soils. FA contains both macro and micro-nutrients (S, Ca, Mn, P) which can sustain plant growth (Negi & Meenaxi 1991) but is deficient in nitrogen and phosphorus. FA amendment with soil, various organic materials (sewage sludge, bioprocess materials) or microbial inoculants like mycorrhizae leads to enhancement of plant growth. Possible agronomic uses of FA such as, a fertilizer (Giedrojc et al. 1980), a liming material (Hoodgsen et al. 1982) and as a physical amendment (Campbell 1983) have been stated by authors. FA generally decreases the bulk density of soils leading to improved soil porosity, workability and enhanced water-retention capacity. Improved water-holding capacity is necessary for the growth of plants, especially under rainfed agriculture.

Many research studies have reported that FA increased the yield of crops such as: wheat (*Triticum aestivum*), alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), bermuda grass (*Cynodon dactylon*), sabai grass (*Eulaiopsis binata*), mung (*Vigna unguiculata*) and white clover (*Trifolium repens*) and have further improvised the physical and chemical characteristics over the physical and chemical characteristics of the soil. The use of FA as a soil amendment or soil conditioner in agricultural fields is the most common topic of research (Anon 2002). However, there are certain limitations regarding the use of FA in agricultural ecosystem. FA contains certain heavy metals which may enter the soil. The overall growth and metabolism of plants is affected by metals like Lead (Pb), Zinc (Zn) Chromium (Cr) and Cadmium (Cd) and bioaccumulation of such toxic metals in the plant poses a risk to animal and human health.

Earthworms

Worm technology: Worm technology or vermitechnology is a low cost, on-site method of remediating heavy metal soil contamination (Dabke 2013). It is the process in which earthworms remove toxins from the soil/FA through bioaccumulation of heavy metals from coal ash or contaminated site/land. Red earthworms (*Eisenia fetida*) are generally subjected to ash filled with heavy metals as they are able to withstand a wide range of environmental conditions. Vermiculture biotechnology involves a cost-effective and modern technique of harnessing the ecosystem for effective utilization of the organic wastes with the help of earthworms, leading to generation of useful organic manure.

Vermicomposting

Vermicomposting is an eco-biotechnological process that converts energy rich and complex organic substances into a stabilized humus-like product involving the help of earthworms (Benitez et al. 2001). Vermicomposting results in degradation of organic wastes due to consumption by earthworms, thus converting the material into worm castings (Shanthi et al. 1993). Most commonly used earthworm species for composting is *Eisenia fetida*, the tiger or brandling worm (Haimi & Huhta 1900). Other suitable species include *Lumbricus rubellus, Eudrilus eugeniae* and *Perionyx excavatus*, an Asian species (Edwards et al. 1995) and *Eisenia andrei* (Haimi & Huhta 1900). Ideal earthworm species for vermicomposting should be prolific breeder, healthy eater, resistant, etc. They are therefore a useful tool for ecological assessment of soil and land (Rombke et al. 2005). Vermicompost is a natural fertilizer produced as an end prod-

Table 3: Comparison of heavy metal content in fly ash of some developed and developing countries.

Metals#	India[1]	Canada USA[2]	China[3]	Phillipines[4]	Greece[5]	Spain[6]	UK[7]	Australi[8]	Europe[9]	Global Scenario[10]
Cd	5-10	0.7-11.7	0.6-0.75	<1	11.6-14.4	60	0.13-0.82	0.2-1.3	1.0-6.0	0.7-130
Cu	40-80	34-131	74-81.4	22-34	31.8-62.8	71.8	-	28-151	39.0-254	14-2800
Zn	50-150	49-479	3.5-7.3	23-138	59.6-86.9	221.3	-	67-283	70-924	10-3500
Pb	10-70	31-84	38.0-70.4	8-22	123-143	52.0	17-176	48-81	40-1075	3.1-5000
Mn	500-750	237-1307	-	122-308	213-330	324.6	-	88-1630	250-750	58-3000
Ni	50-145	13-799	240.8-322.5	6-50	-	87.9	-	11-242	49-377	6.3-4300
Cr	50-225	15-229	-	6-49	110-160	134.2	-	18-130	47-281	10-1000
Fe	3.30-6.40	3-13	-	-	-	-	-	-	-	36-1333
Co	10-50	6-43	-	6-25	-	29.2	-	6-100	20-112	7-520
B	17-38	-	-	-	-	-	-	7-89	24-534	10-618
As	1.0-4.0	8-304	-	8.4-41.8	-	60	40-205	5-44	22-162	2.3-6300
Hg	bdl	0.01-0.22	-	1.2-1.9	-	0.01	-	0.02-0.23	<0.01-1.40	0.02-0.1
Se	0.6-2.6	2-25	-	-	-	-	-	1-5	3-30	0.2-134
V	-	49-479	-	-	-	-	-	49-274	154-514	-
Mo	2.2-6.7	7-103	-	-	-	-	-	5-21	5.0-22.0	7-160

USA: United States of America, UK: United Kingdom, (-): not mentioned, (-): not determined; #Metals: Total (Acid digestion)
[1](ICAR 1996; CFRI 2000a, 2000b, 2001a, 2002a, 2002b, 2003; Kumar et al. 2005); [2,8,9](Riley 2007); [3](Zhang et al. 2007); [4](Brigden & Santillo 2002); [5](Fytianos & Tsaniklidi 1998); [6](Llorens at al. 2001); [7](Wadge et al. 1986); [10](Jala & Goyal 2006; Basu et al. 2009)

uct of vermicomposting. Vermicomposts prepared from different organic wastes, possessed considerably higher levels of major nutrients - N, P, K, Ca and Mg compared to that of the other wastes; these findings are in conformity with those of earlier authors (Edwards 2004, Garg et al. 2006, Kitturmarth et al. 2007, Pattnaik & Reddy 2009). The environmental factors mostly affecting the biodegradation of organic wastes are pH, temperature, moisture content, particle size, nutrients and oxidation-reduction potential (Reinhart & Townsend 1998, Sethi et al. 2013). Earthworms lead to nutrient enrichment on ingestion of FA or organic matter along with organic matter incorporation and metal sequestration and also performs gut associated processes due to passage of FA and organic matter through the gut as seen in Fig. 2.

This figure is an illustration of earthworm's body divided into four compartments depicting: mouth, foregut, midgut, hindgut and anal region. Changes in physico chemical properties increase in microbial population and different metabolic activities occur in each of these compartments. Earthworms harbour millions of 'nitrogen-fixing' and 'decomposer microbes' in their gut. Nutrients required for microbial growth include carbon, hydrogen, nitrogen, phosphorus, oxygen, sodium, potassium, calcium, magnesium and many trace elements.

Earthworms in Fly Ash Management

Earthworms belonging to class Oligochaeta of phylum Annelida are one of the foremost components of soil communities and have great ecological importance in forming and maintaining soil structure. They are potentially important agents involving the transfer of inorganic and organic toxicants by virtue of their habitation in a site possessing contaminated soils (Cooke et al. 1992). They have been considered an interesting biological indicator of many metals in soils (Lee 1985). They can degrade 'FA' from the coal power plant which has a serious disposal problem due to heavy metal content. Earthworms ingest the heavy metals from the FA while converting them into valuable vermicompost. The combination of FA and organic amendment improves the microbial functions and further the efficiency of FA as a source of plant nutrients in agriculture (Mohapatra & Rao 2001, George et al. 1998).

Earthworms enhance the N, P, K content of FA thereby enhancing its availability. There is considerable difference in N, P, K content of FA before and after introduction of earthworms as seen in Table 4 and thus can be used as a potent fertilizer (Bhattacharya & Chattopadhyay 2004, Ananthakrishnasamy et al. 2009) in agricultural fields. Mineralization of nitrogen is regulated by the availability of dissolved organic nitrogen and ammonium, the activity of the microorganisms and their relative requirements for C and N. They enhance nitrogen mineralization through modifications of the environmental conditions and their interactions with microbes, thereby producing conditions in the organic wastes that favour nitrification, leading to immediate conversion of ammonium-nitrogen into nitrates (Aira & Dominguez 2008, Lazcano et al. 2008).

Moreover, earthworm reduces the heavy metal content in FA by accumulating these toxic metals in their gut. Their inherent tendency to accumulate heavy metals make them potent for remediation of FA. The greatest advantage of the vermiremediation technology is that it is 'on-site' treatment and there are no additional problems of 'earth-cutting', 'excavation' and 'transportation' of contaminated soils to the landfills or to the treatment sites incurring additional economic and environmental cost. Vermicomposting can be conducted all year-round, providing environmental conditions remaining within acceptable limits.

Metal Accumulation by Earthworm Species

This is the process by which the chemical concentration in tissues of an earthworm achieves a level that exceeds that in the FA/ soil, as a result of chemical uptake through all possible routes of chemical exposure (e.g., dietary absorption). These detrivorous animals are relatively efficient accumulators of certain essential and non essential metals (Suthar & Singh 2008). Species of earthworms such as *Eisenia fetida, Eudrilus eugeniae, Perionyx exacavatus* and *Perionyx sansibaricus* are considered to be important bioaccumulators and bioindicators of environmental contamination of persistent pollutants like heavy metals (Udovic et al. 2007, Suthar et al. 2008, Wang et al. 2009) and have been successfully demonstrated in mitigating the toxicity of FA and increasing its nutrient content (N, P, K) (Gupta et al. 2005, Bhattacharya & Chattopadhyay 2006).

Metal accumulation in the earthworm tissues depend partially on the absolute concentration of the metal within the FA. Limited mobility of earthworms make them an appropriate species for monitoring the potential impact of contaminants and changes in soil structure (Suthar et al. 2008). Bioaccumulation is strongly influenced by physicochemical edaphic interactions, including factors such as organic matter content, C/N ratio, Ca concentration, cation-exchange capacity (Morgan & Morgan 1999, Kizilkaya 2005). Accumulation of these metals depend mostly on the interaction of earthworms with these local edaphic factors. Lukkari et al. (2006) reported that metals bounded to organic matter reduces the availability of metals for earthworms. The differences in dietary metal intake of two physiologically contrasting species *Lumbricus rubellus* and *Aporrectodea caliginosa* were observed and its physiological utilization affect the patterns of metal accumulation in earthworms of inter-specific species (Suthar et al. 2008, Morgan & Morgan 1999). Dai et al. (2004) reported that bioaccumulation of metals in worms is their ability to eliminate excess of metals. Past studies done by Gupta et al. (2005) and Suthar et al. (2008) have suggested that during the vermicomposting process, earthworms accumulate heavy metals in their tissues. Numerous authors, reviewed by Hughes et al. (1980) and Beyer (1981) have reported that earthworms uptake and accumulate heavy metals such as Cd, Hg and Au in their tissues, while living both in contaminated and non-contaminated environments (Ireland 1983). Biota to soil accumulation factor (BSAF) can be evaluated with respect to relative toxicity and bioaccumulation determinations based on metal bioavailability to earthworms (Cortet et al. 1999). Remediation of metals from FA using earthworms has gained much attention. Earthworms have proved to be an important tool in FA management by reducing the metal content in FA by accumulating the metals in their gut as indicated in Table 5. Thus, there is considerable reduction in the concentration of heavy metals in FA before and after vermicomposting (Table 5).

Gupta et al. (2005), in his investigation, performed vermicomposting of FA using different mixtures of FA and cow-dung. The vermicomposted samples obtained showed 30-50% reduction in heavy metals up to 60% FA and 10-30% reduction in 80% FA. He also observed the feasibility of *E. fetida* for mitigating toxicity of metals and concluded that up to 60% FA and cow-dung mixtures can be used for sustainable vermicomposting. Suthar et al. (2008) indicated that earthworms have an inherent potential for bioaccumulation of metals in their tissues and thus can be used as an ecological indicator of soil contamination. Bhattacharya et al. (2012) took various combinations of FA and cow dung along with and without (control) epigeic earthworm, *Eisenia fetida*. He observed that vermicomposted FA on application to red and lateritic soil brought about enhancement of three major nutrient elements N, P and K and also helped to maintain low solubility of heavy metals like Pb, Cr and Cd in soil due to their bioaccumulation property. Wang et al. (2013) also emphasized on the ability of *Eisenia fetida* to accumulate body metals in their tissues. Niyazi et al. (2014) inoculated different feed mixtures of FA and pressmud with *Eisenia fetida*. They observed that *Eisenia fetida* could not tolerate 100% FA and addition of other organic waste was essential. A decrease in heavy metal concentrations of the final vermicompost was observed by him. The trials done by them demonstrated that vermicomposting can be an alternative technology for management of FA. Maximum accumulation of different metals by earthworms was found in feed mixture having FA+PM in the ratio 1:4. Similar results were observed by Morgan & Morgan (1992), Anderson & Laursen (1982), Das et al. (2012), implying that metal accumulation patterns in tissues of earthworms are affected by inter-specific differences in dietary metal intakes and physiological utilization. Variability of metals in worm tissues may vary with respect to the type of species, ecological category of earthworm species, worm age, season and several other factors. Thus, source

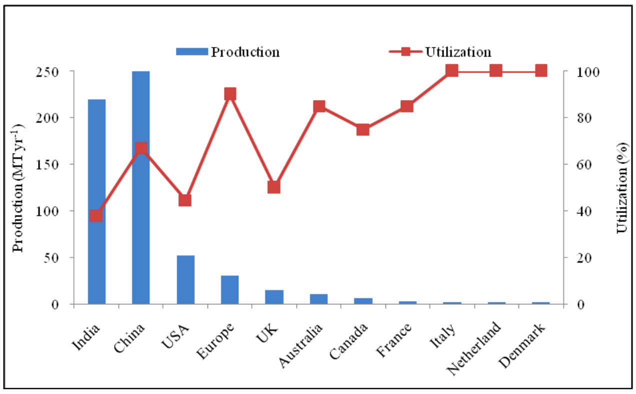

Fig. 1: Current scenario of fly ash production and utilization in different countries.
(Source: (ACAA 1998; Kumar et al. 2005; Tang et al. 2013; Vieira-Caldos & Feuerborn 2013; Adopted and modified from http://www.tifac.org.in [accessed 26.07.08])

of metals, species of earthworms and metal-metal interaction may influence tissue metal concentration.

Mechanism of Metal Accumulation

The major area responsible for metal accumulation in earthworms is the chloragogenous tissue surrounding the posterior alimentary canal (Morgan & Morgan 1982). Earthworms, when exposed to metals synthesize metallothioneins. These are low-molecular weight, cysteine-rich proteins having a high affinity towards certain trace metal ions like copper, cadmium and zinc (Dallinger 1994). These proteins play an important function in protecting the cells and organisms against toxic metal stress. These proteins are marked as indicators of pollution.

Earthworms on utilizing the superfluous heavy metals for physiological metabolism reduce their possible toxic effects. Metals interact with many chemicals and lead to detoxification processes, as part of the enzymes of the antioxidant systems, such as superoxide dismutase (SOD), and in metallothioneins (MT). The availability of heavy metals decreases due to bioaccumulation of metals and organo-complex formation during this process (Li et al. 2008). Heavy element fractionation among soil/FA components represents one of the most significant factors affecting their mobility in soil/FA and uptake of metals by soil organisms such as isopods, amphipods and earthworms (Lanno et al. 2004, Becquer et al. 2005, Hobbelen et al. 2006, Gal et al. 2008). Earthworms accumulate highest concentrations of Cd, Pb, Zn and Ca within their posterior alimentary canal (PAC), a tissue fraction containing the major proportion of the entire worm burdens of the respective metals. Intracellular vesicles are prime regions for Pb and Zn accumulation within the PAC and excess metals get associated with P ligands within the chloragosome matrix (Morgan & Morgan 1990). Ca distribution pattern in *Aporrectodea caliginosa* differs from the previous observations on the earthworms *Lumbricus rubellus* and *Dendrodrilus rubidus*, where alimentary canal had the greatest concentrations, approximately up to 70% of the total body burden of Ca in association with this tissue fraction (Ireland 1975, Morgan & Morgan 1990). The epigeic species of earthworms possess 'active' calciferous glands, containing numerous excretory or secretory calcium rich spherites in their extensive lumina. *Aporrectodea caliginosa* in turn possesses 'inactive', non-mineralizing glands (Piearce 1972, Morgan 1982). The accumulation of Ca within the PAC may be related to chloragosomal storage linked to an acid-base buffering function (Prento 1979, Morgan 1981, Morgan 1982, Morgan & Morgan 1990). Cation-exchange properties are present in chloragosomes (Fischer 1973 and Fischer 1977) and this exchange was considered to be an integral part for performing the physiological function of these intracellular organelles (Prento 1979, Morgan 1981, Fischer & Trombitts 1980). The relationship between calcium and phosphorus has been observed and documented for chloragosomes of several other earthworm species (Prento 1979, Morgan 1981, Morgan 1982, Morgan & Morgan 1982). Morgan & Morris (1982) performed microprobe x-ray analysis of chloragogenous tissue that were air-dried. They concluded that metals were specifically compartmentalized into two distinct organelles in the worms. Ca, Pb and Zn were found in the chloragosomes (in association with sulphur) while Cd was found in Cadmosome that was an electron-lucent vesicular component. Cadmosome is quite similar to debris vesicles present in the form of characteristic inclusions in chloragocytes.

Advantages/Apprehensions and Future Research Scope

Vermicomposting reduces waste bulk density, and research also showed that it reduces populations of pathogenic microorganisms' up to a great level. During the composting process, the thermophilic stage eliminates human pathogens. Human pathogens are also removed during vermicomposting by means of an antagonism mechanism. The potential of FA for its use in agriculture is familiarizing nowadays. Although, FA amendment in soil cannot substitute the chemical fertilizers or organic manure, but it can be used in addition to these amendments in order to get additional benefits in terms of improvement in soil physical characteristics, increased yields. FA is used for stabilization of erosion promoting soils. Moreover, FA is a good substitute for lime which is a costly amendment for acid soils and contributes to global warming by emission of carbon-dioxide, unlike FA. FA contains some amount of radioactivity. Due to this radioactivity and heavy metal content in FA, its

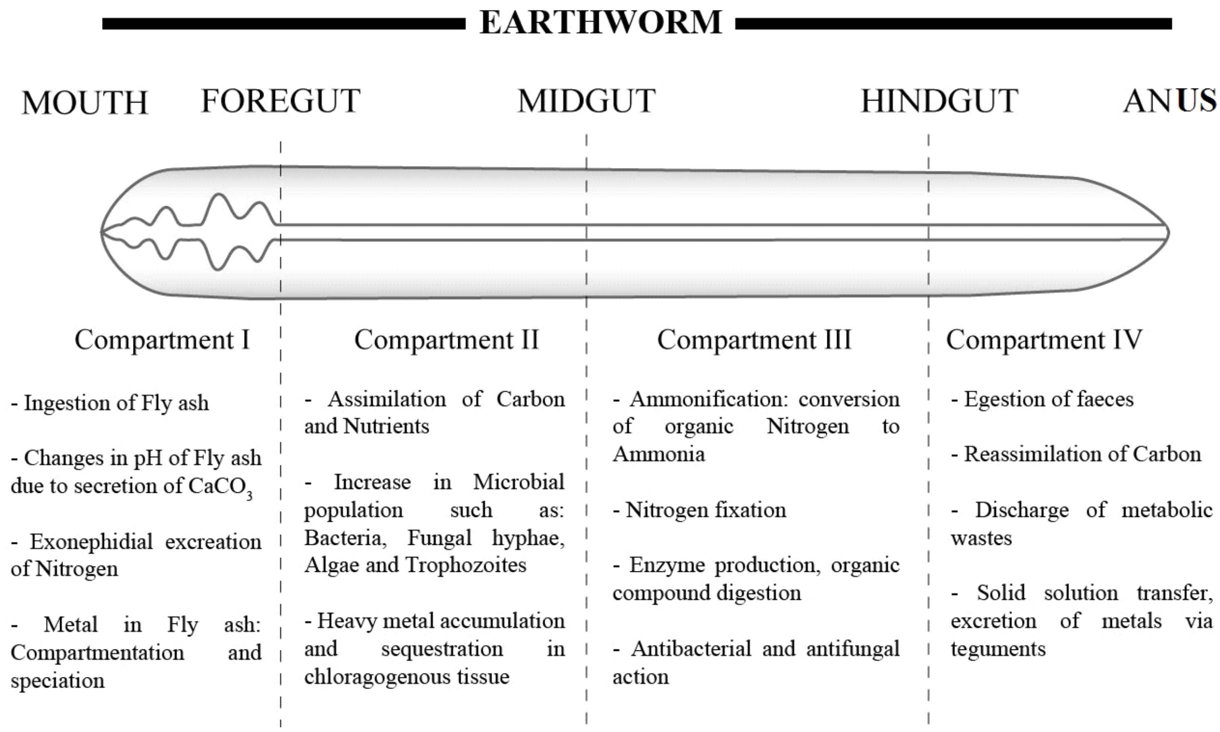

Fig. 2: Physico-chemical changes occurring in different compartments of earthworm including variation in nutrient concentration and heavy metal sequestration on ingestion of fly ash.

use in agricultural fields is limited. Vermicomposting systems may be an alternative, cheap way to avoid environmental issues and at the same time obtain a valuable organic fertilizer.

On the contrary, researchers should obtain convincing results for FA application in agriculture in order to popularize it on small scale level first and then in a broader scenario. Moreover, earthworms forms the base of several food chains, they can potentially mediate metal transfer from FA added to soil to a range of predators, including birds, thus posing a risk to terrestrial food chain (Suthar & Singh 2008). According to Abbasi & Soni (1983), earthworm *Octochaetus pattoni* suffered significant mortality at all levels of exposure to metals such as Cr and Hg. Thus, these metals become toxic to the worms after a prescribed limit. The metals identified to be most toxic to a wide range of earthworms are Cd, Cu, Ni, Pb and Zn. More research studies should be promoted in order to see the effect of heavy metals on genes of earthworms and to know the defined concentration of metals that is safe for metal accumulating earthworms.

CONCLUSION

Electricity in the current world is the basic necessity of mankind. Thermal power plants generate electricity but at the cost of pollution. FA is responsible for causing pollution of entire soil, air and water. Even though the FA has negative environmental impact, the current energy demand in India will not lower the FA generation in immediate future. Hence, the FA disposal and management has achieved a significant importance. FA management has taken considerable strides over the last few decades. Researchers are trying to convert this coal waste into wealth by exploring viable avenues for FA management. FA contains the basic mineral nutrients, which are necessary for plant growth. It is very evident from experimental study performed that vermicomposting is an effective technique for reducing the metal content in FA substrates as well as in enhancing the N, P, K content of substrates. This study also depicts that the values of the different physico-chemical properties and the heavy metals content of FA shows quite similarity with the Indian scenario thus lying within the range. The final outcome aids in converting the burden of FA disposal into an opportunity to produce high-potential organic fertilizers capable of enhancing soil fertility, bioremediation and improving crop quality, thus causing economic growth and environmental protection. Thus FA utilization in agricultural fields should be enhanced in order to reduce the problem of its disposal.

Table 4: Study of nutrient composition before and after vermicomposting using different earthworm species.

Species	Study site	Substrate	Study	Exposure (Days)	Combinations	Nutrient composition								Reference
						Before Vermicomposting				After Vermicomposting				
						OC (mg kg^{-1})	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	OC (mg kg^{-1})	N (mg kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})	
Eisenia fetida	Durgapur TPP	FA	Field	45-75	FA : OM 1:0 0:1 1:1 1:3 3:1	ns	470 ± 5.4 640 ± 2.2 517 ± 1.5 628 ± 1.9 544 ± 1.9	18.3 ± 1.0 29.0 ± 0.5 26.7 ± 0.7 24.5 ± 0.5 23.1 ± 0.6	51 ± 0.5 80 ± 0.4 102 ± 0.7 80 ± 0.8 50 ± 0.8	ns	518 ± 2.2 120 ± 7.6 1078 ± 6.5 924 ± 4.5 742 ± 4.5	24.2 ± 0.4 33.0 ± 0.7 38.5 ± 0.3 19.8 ± 0.4 18.5 ± 0.2	62 ± 0.4 118 ±1.0 138 ± 0.7 138 ± 0.6 110 ± 1	(Bhattacharya et al. 2012)
Lampitto mauritii	NLC, Tamil Nadu	FA	Lab	50	CD: FA 1:1 2:1 3:1	15.7 ± 0.7 31.8 ± 1.7 44.8 ± 1.3	0.41 ± 0.1 0.72 ± 0.1 1.12 ± 0.2	0.5 ± 0.07 1.0 ± 0.07 1.2 ± 0.45	0.10 ± 0.1 0.19 ± 0.1 0.24 ± 0.1	13.2 ± 0.9 25.7 ± 2.1 27.65 ± 2	0.69 ± 0.07 1.01 ± 0.2 1.65 ± 0.4	0.8 ± 0.08 1.5 ± 0.06 1.8 ± 1.1	0.15 ± 0.1 0.27 ± 0.1 0.38 ± 0.1	(Ananthakrishnasamy et al. 2009)
Lampitto mauritii	ns	FA	Lab	ns	FA: PM: CD 1:1:8 2:2:6 3:3:4 4:3:3 3:4:3	437.7 ± 18 437.7 ± 18 422.3 ± 11 416.4 ± 18 420.4 ± 11	11.5 ± 1.2 11.8 ± 3.1 11.6 ± 2.4 11.3 ± 1.6 11.9 ± 2.7	5.1 ± 0.1 4.7 ± 0.2 4.5 ± 0.1 4.2 ± 0.2 4.6 ± 0.4	14.5 ± 1.2 14.1 ± 1.4 13.5 ± 1.2 12.4 ± 1.3 12.9 ± 1.1	351.6 ± 29 351.6 ± 29 353.3 ± 21 381.5 ± 15 379.3 ± 12	21.3 ± 1.0 20.1 ± 1.7 20.1 ± 1.7 15.4 ± 3.2 16.6 ± 2.4	9.6 ± 0.3 8.8 ± 0.2 8.5 ± 0.5 7.1 ± 0.4 7.2 ± 0.3	13.3 ± 1.2 12.6 ± 1.5 12.2 ± 0.6 12.2 ± 0.6 11.3 ± 0.7	(Manivannan et al. 2012)
Eudrilus eugeniae	Raichur TPP, Karnataka	FA	Lab	28	FA:PM:CD:CO2: 2:2:1 2:2:0:1 2:0:2:1 2:2:0:0 2:0:2:0	ns	1.87 1.08 0.38 1.42 0.96	0.89 0.15 0.36 0.15 0.58	ns	ns	ns	ns	ns	(Senappa 2012)
Eisenia fetida	Panki TPP	FA	Lab	60	FA:PM 1:0 3:2 2:3 1:4 4:1 0:1	1.26±0.14 6.34±0.12 13.84±0.29 20.72±0.66 27.44±1.04 53.23±10.6	0.13±0.04 0.31±0.06 0.54±0.09 0.81±0.07 1.09±0.08 1.28±0.11	0.28±0.03 0.51±0.04 0.79±0.08 1.09±0.08 1.40±0.10 1.60±0.15	0.06±0.01 0.09±0.02 0.12±0.03 0.16±0.05 0.20±0.03 0.23±0.05	0.94±0.13 3.56±0.30 7.04±0.20 1.19±0.09 14.08±0.2 15.48±0.29	0.16±0.03 0.42±0.03 0.77±0.04 1.19±0.09 1.53±0.11 1.81±0.10	0.34±0.05 0.63±0.03 1.07±0.09 1.56±0.10 1.93±0.18 2.37±0.14	0.05±0.01 0.11±0.03 0.14±0.02 0.21±0.05 0.24±0.03 0.29±0.03	(Niyazi & Chaurasia 2014)

FA: fly ash, OM: organic matter; CD: cow dung, PM: press mud, CO: cocopith, OC: organic carbon, ns: not specified, TPP: thermal power plant, Lab: Laboratory, NLC:

Table 5: Studies depicting metal uptake by earthworms from Fly ash before and after vermicomposting.

Species	Site	Substrate	Study	Exposure (days)	Combinations/ Concentration	Concentration of metals (mgkg^{-1}) (FA)										References
						Before Vermicomposting					After Vermicomposting					
						Cu	Cr	Pb	Zn	Cd	Cu	Cr	Pb	Zn	Cd	
Eisenia fetida	Panki TPP	FA	Lab	ns	FA:PM											(Niyazi & Chaurasia 2014)
					1:0	79	124	52	84	-	73	110	52	74	-	
					4:1	86	101	41	107	-	79	84	41	85	-	
					3:2	91	83	34	128	-	74	63	33.5	92	-	
					2:3	66	61	27	147	-	41	43	26	92	-	
					1:4	66	41	21	169	-	40	25	21	95	-	
					0:1	56	28	20	186	-	52	15	20	94	-	
	Durgapur, India	FA	Field	45-75	FA:OM											(Bhattacharya et al. 2012)
					1:0	-	0.86	1.8	-	0.36	-	0.84	2.48	-	0.3	
					0:1	-	0.38	0.9	-	0.92	-	0.35	0.45	-	0.14	
					1:1	-	0.22	1.0	-	0.14	-	0.19	0.67	-	0.92	
					1:3	-	0.35	0.7	-	0.23	-	0.27	0.60	-	0.12	
					3:1	-	0.29	1.3	-	0.28	-	0.24	0.92	-	0.19	
	TPP (ns)	FA	Lab	180	FA:CD											(Gupta et al. 2005)
					1:4	22.1	23.7	-	-	-	13.9	12.8	-	-	-	
					4:1	57.9	81.3	-	-	-	51.1	60.9	-	-	-	
Eudrilus eugeniae	Tamil Nadu, India	FA, HD	Lab	ns	FA:HD in different ratios	-	High	High	-	High	-	Low	Low	-	Low	(Dharani et al. 2010)

TPP-Thermal Power Plant, FA- Fly ash, OM-Organic matter, PM- Press mud, HD-Horse Dung, Lab- Laboratory; ns-not specified, (-): not mentioned

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