PalArch's Journal of Archaeology of Egypt / Egyptology

Fly Ash Amendment for Sustainable Agriculture through Vermicomposting

[1]*Sunita Satapathy*, [2]*Yashaswi Nayak*, [3]*Kunja Bihari Satapathy*

[1,2,3] Department of Zoology, School of Applied Science, Centurion University of Technology & Management, Odisha, India

Email: [1]sunita.mishra@cutm.ac.in, [2]yashaswi.nayak@cutm.ac.in, [3]kunjabihari.satapathy@cutm.ac.in

Sunita Satapathy, Yashaswi Nayak, Kunja Bihari Satapathy: Fly Ash Amendment for Sustainable Agriculture through Vermicomposting -- Palarch's Journal Of Archaeology Of Egypt/Egyptology 17(9). ISSN 1567-214x

Keywords: Fly ash (FA); Heavy metals; Remediation; Earthworms; Agriculture; Vermicomposting

ABSTRACT

The process of coal combustion for energy production in thermal power plants (TPPs) generates huge amount of Fly Ash (FA) is one of a major source of environmental pollution. FA is considered as a serious pollutant throughout the globe from two decades. Safe disposal is the major concern of the century under the management and utilization of FA. Various conventional methods of FA disposal leads to landfill and contamination of the ground water. FA contains plant nutrients for enhancing agriculture production but it still contains heavy toxic metals. Recycling of FA is necessary to convert toxic metals with increasing of NPK content for enhancing agriculture yields. Researchers are paying attention for remediation of FA by using biological methods. Vermitechnology is an active and faster method for converting heavy metal toxic content of FA into organic manure by the action of certain species of earthworm. Biologically modified FA is suitable for agricultural application. The present review studies was done including several papers that correlates with the use of FA with it's importance, benefits and scope of remediation by using different species of earthworm. Conversion of toxic metals to organic manure adding with NPK content due to the biological activity of earthworm were recorded as per literature survey with an evidence of sustainable technique is vermicomposting.

1. Introduction

Huge increase of industrialisation and urbanisation has led to meet the demand of electricity, generated from coal based thermal power plants (TPPs) throughout the globe. It has been suggested that coal is the dominant source of fuel for power generation in India is expected to grow electricity upto twofold to threefold more by 2030. Approximately 79% of the entire electricity is produced yearly by these coal fired power plants [1]. According to report of Central Electricity Authority (CEA) of India with an average of 730 MT of coal consumed by the power plants which generated to an average of 210 MT of Fly Ash (FA) in the year 2018-2019 and may reached upto 437MT by 2030. Non-coking coal is largely consumed in India having a high ash content of about 30-40% [2]. However, the generated fly ash from TPPs had resulted in achieving just 59% of utilisation (CEA, 2019). The amount of electricity that generated from the thermal power industries in turn it exploits with FA as a serious disposal solid waste. It is otherwise referred as flue gas or Powered fuel ash (PFA) inorganic residue and pavement materials is formed by the burning of powdered coal as small dark flecks at high temperature. The first notification was issued on 1999 in India by Ministry of Environment, Forest and climate change on utilization of FA and it is amended subsequent years. FA is an amorphous mixture of ferroaluminosilicate minerals contain silica, aluminium and oxides of iron, calcium, magnesium, arsenic, chromium, lead, zinc and other toxic metals. It is a heavy toxic material cause of serious health hazards being practiced in recent years by scientists environmentalists for it's proper management and safe disposal. The research has been carried in various sectors such as construction of roads and manufacture of bricks, cement, ceramics and distempers is not categorized as hazardous wastes [3]. It is also being revealed from various research that FA has contain essential nutrients of plant except NPK for the purpose of agriculture. It is explored by researchers that FA provides nutrients to the soil enhances the growth and yield of crops as bio fertilizers. Approximately 0.7%-2% of generated FA is being utilized in the agricultural sector [4].The heavy metals in soluble form presence in FA has the potency for agricultural utilization [5,6], but has certain limitations due to lower rate of degradation after application in soils. The treatment of FA by conventional procedures is expensive and time-consuming for reduction of heavy metal [7]. Direct implementing of FA maintains pH, better aeration and percolation of the soil, but lower rate of degradation in heavy metal content is the major limitation for agricultural ecosystem.

Vermicomposting is an eco-friendly, low cost simple biotechnology technique for safe disposal and management of solid wastes. It is the technique that used for remedial and disposal of FA with soil amendment [8]. Vermicomposting process effective in both small scale and large scale utilization. The end product vermicasts are enriched with soil nutrients provide agricultural use and commercial approaches [9]. Earthworm is an important soil fauna related to different earth soils serving as an indicator of soil health and quality [8,10]. The fertility of soil increases after treating with FA and metal accumulation by earthworm in their gut minimize the heavy toxic metal with enhancement of NPK.

This present review article focus on the areas includes physico-chemical properties of FA of several developed and developing countries, the role of FA in plant growth and remediation of FA through vermicomposting by the activity of worms for agriculture production. Thus management of FA through biological means is the basic concern of the paper.

2. Fly Ash Details

A. Fly Ash Production

Fly ash is the finest inorganic residue as by product resulted from coal combustion in thermal power industries [11].The nature of fly ash is mainly dependent upon the type of coal that is burnt. When coal is burnt in pulverized coal boilers, the minerals dragged in the coal, are thermally transformed into chemical species that are reactive or could be chemically activated, for example by the addition of calcium hydroxide. It is called "fly ash" because it is being transported from the combustion chamber by the exhaust gases [12]. It is produced approximately of 550 Mt per year around the world ([13],[14]). In India FA production was about 220 Mt during 2011-2012 which further estimated to increase about 1000 Mt by 2032 according to the report of FAUP (Fly-Ash Utilization Programme) under DST (Department of Science and Technology), New Delhi. The production and utilization rates of FA are found significantly distinguishable in various developing and developed countries. The countries like Europe, United States, Australia, South Africa, China, Japan, Greece and Italy also have reported with huge amounts of FA production ([15],[16],[17],[18]) (Fig.1.1).From different studies the content of various fly ash was estimated that it is composed of oxides as major components [19]. A comparison study of yearly production FA is presented in Table-1 and demand of coal for it is tabulated in Table-4. Due to presence of its fine powdery form pozzolanic and cementitious nature, has many established applications in the production of concrete-related constructions.

B Properties of Fly Ash.

Fly ash has a characteristic spherical microscopic structure observed through scanning electron microscope photograph was published on the cover of Science magazine, 7 May 1976, vol 192, no 423r9; and again on 19 December 1980, Vol. 210, no 4476. It is an extreme polished material contains silt and glass-like particles, heterogeneous in nature whose size varies from 0.01- 150 µm. It is light in colour and the clay-sized glassy spheres provides fly ash a consistency somewhat like talcum powder.

It constitutes hollow, empty spheres known as cenospheres comprising of smaller amorphous particles and crystals pleospher. The mineralogy and composition of fly ash vary from one sample to next depending on the source of the coal; design, type and operation of the power plant boiler unit ([20], [21]). FA consist about 90-99% of "Si, Al, Fe, Mg ,Ca,,Na, K, and Ca" as the major elements of oxides like present in most compounds along with minor amounts of Mg, Ti, K and traces of silicates, oxides, sulphates and borates. Other 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 of FA along with lesser amounts of phosphates and carbonates [22]. Analysis of basic elements is categorized FA into Class C (high CaO content) or class F (low CaO

content). Because of variation in the physical properties, chemical properties, radioactivity, the occurrence of major nutrient elements and the toxic heavy metals gives a detailed knowledge about the various oxides and about micronutrients present in FA.
The industrial waste Fly Ash is treated as major pollutant should be utilized properly to prevent it's predisposed into land-fills, ponds or rivers [23]. FA is considered as an air pollutant since it remains air-borne for a long period of time and causes health hazards [24]. FA becomes an obstacle for photosynthesis mostly of aquatic plant and breaks the food chain system. FA degrades the environment, increases the turbidity of water bodies and reduces pH. Therefore it is highly required to proper and safe disposal of FA for overcoming from unavoidable problems and on version of these materials into value-added products [25]. To convert the burden of FA disposal into high-potential organic fertilizers capable of enhancing soil fertility, bioremediation and improving crop quality[26]. Hence it should be enhanced to utilized FA in agricultural fields in order to reduce the problem of its disposal.

C. Fly ash in plant growth

The soil amendment with fly ash was reported by Abassi et al. caused significant role in enhancement of soil properties and seed germination. The study was carried out in sunflower plant with application of 25% of amended fly ash enhanced the oil content in seed and overall growth of plants. [27]. Gorai studied the effect of alkaline fly ash on plant growth. Along with fly ash grass was used that increased the soil pH due to addition of phosphate and borate. However higher quantities of Fly ash effected plant growth due to toxicity [28]. Singh et al. reported about the Fly Ash amendment of soil and it's effect on various crop plants like chilly, mung, bean and beat. The experiment was conducted by taking various concentration of Fly Ash from 0-30%.Th maximum amount of seed germination was recorded in 25% of Fly Ash with increasing biomass, healthy growth and perfect yielding of plants [29]. Pathan et al. studied plant growth in Western Australia using Fly ash amended in soil. Different concentrations of Fly Ash 0, 75, 150, 300 tons per hectare was used in this experiment. The soil pH was subsequently increased by adding Fly Ash and it was observed that a huge amount of heavy metal s accumulated such as cadmium, zinc and selenium in the soil [30]. *Yunsa et al.* reported about plant growth using Fly Ash obtained from sub bituminous and alkaline coal. The fly ash amended soil was applied at 5 ton per hectare and experimented on canola, radish, parsley, field pea, barley and rye. The plant had shown favourable effect on growth, increase in chlorophyll pigment, transpiration rate and reduction in carotenoid levels with improving yield [31]. Nayak et al. reported the effect of fly ash on the growth of plants and soil microbial population. Different concentration from 0-100% of fly ash was amended with soil and rice seedlings were tested [32]. The significant higher growth in plant was observed upto 20% whereas accumulation of high toxic metal was inhibit the growth of soil microbes as well as plant. Near about 550 Mt of FA is generated per year by coal combustion in thermal power plants around the world ([13], [14]). The lignite FA substantially improved soil fertility and productivity of rice in mine spoils for long term field application [14].Increase in plant growth by amendment of FA in soil in Table -3.

D. Agricultural utilization of Fly Ash

Utilization of fly ash in agriculture sector has been proposed by many scientists because of its considerable content of K, Ca, Mg, S and P [29,33].Addition of Fly ash normally increases plant growth and nutrient uptake [34]. Weinstein reported that fly ash ameliorant with soil increased crop production of barley (*Hordeum vulgare*), Bermuda grass (*Cynodon dactylon*), alfalfa (***Medicago sativa)*** and white clover (*Trifolium repens*) [35]. Unweathered western US fly ash up to 8% higher Se grown on a deep bed of fly ash. Approximately 125 mt ha^{-1} of unweathered fly ash was treated with a slightly acidic soil (pH 6.0) could be enhanced the growth of sorghum ***(Sorghum bicolor***), field corn (*Zea mays*), millet (*Echinochloa crusgalli*), millet (*Echinochloa crusgalli*), carrots (*Daucas carota*), onion (*Allium cepa*), beans (*Phaseolus vulgaris*), cabbage (*Brassica oleracea*), alfalfa, potatoes (*Solanum tuberosum*) and tomatoes (*Lycopersicon esculentum*) [36]. These plants exhibited higher contents of As, B, Mg and Se. Application of 2-4% fly ash significantly increased N, S, Ca, Na and Fe contents of rice (*Oryza sativa*) plants through a greenhouse experiment [37].The photosynthetic pigments of crops like maize and soybean enhanced along with their growth and metabolic rates with the application of foliar fly ash. Khan et al. reported that the yield of tomato was increased by 81% after application of fly ash at 40% and market value (mean fruit weight) [38].Accumulation of Se content increased in plant tissue by increasing the amount of fly ash [39]. About 5-20% fly ash on w/w basis is applied in the plough layer (0-15 cm) increased both grain and straw yield of pearlmillet (*Pennisetum* sp.) followed by wheat [40]. Weathered coal fly ash at 5% resulted in higher seed germination rate and root length of lettuce (*Lactuca sativa)* (Lau and Wong, 2001)[41]. (Goyal *et al*., 2002) reported that **amino acid** content in soybean (*Glycine max*) increased when grown in fly ash amended soils in pot cultures[42]. (Neelima *et al*., 1995) reported that high yield of aromatic grasses particularly palmarosa (*Cymbopogon martini*) and citronella (*Cymbopogon nardus*) was increased with major plant nutrients while treated with different fly ash-soil combinations[43]. High yield of brinjal (*Solanum melongena*), tomato and cabbage produced with application of fly ash at 25%, oil seed crops such as sunflower (*Helianthus* sp.) and groundnut (*Arachis hypogaea*) also responded favourably to fly ash amendment. Sharma *et al*., reported medicinal plants such as cornmint (*Mentha arvensis*) and vetiver (*Vetiver zizanoides*) were successfully grown in combination of fly ash with 20% farmyard manure (FYM) and mycorrhiza [44,45]. Management of root knot disease in tomato caused by *Meloidogyne* sp. was treated with 40% of fly ash have nematicidal effect and providing available nutrition. Khan and Singh reported tomato cultivars grown on fly ash amended soils had high hence tolerance to wilt fungus *Fusarium oxysporum*[38]. The FA amendment in soil is enhanced in crop growth Moreover, high percentage of humic acids in vermicompost contributes to plant health, as it promotes the synthesis of phenolic compounds such as anthocyanin and flavonoids which may improve the soil fertility and plant nutrition.

3. Vermicomposting

Vermicomposting is an effective and faster method for producing organic rich fertilizer from waste material. It is a simple, eco-friendly biotechnological process that produce stabilized humus like organic product by the action of earthworms on complex organic substances [12]. Various species of earthworms, white worms and microorganisms act together on waste materials to produce nutrient rich organic fertilizer as vermicasts. Vermicasts nothing but the end product of organic matter that consumed and excrete by earthworm [46]. The earthworm species that used most commonly for vermicomposting are *Eisenia foetida*, the tiger or brandling worm [47]. Other species like *Lumbricus rubellus, Eudrilus eugenia. Perionyx excavates* an Asian species[48] and *Eisenia andrei* [47] are used in vermicomposting. These ideal species are excellent in vermicomposting as well as tool for ecological assessment having the characteristics as prolific breeder, healthy eater, resistant, etc. [49]. Vermicompost contained major nutrients such as N, P, K, Ca and Mg in maximum level prepared from various organic wastes are findings of some earlier authors ([10], [50], [51], [52]). The parameters like pH, temperature, moisture content, particle size, nutrients and oxidation-reduction potential are influenced by environmental factors during degradation ([53], [54]). Earthworms capable for degradation of FA incorporated with other organic matter that passage through gut. Millions of 'nitrogen-fixing' and 'decomposer microbes' are generated by earthworms in their gut during vermicomposting. The metabolic activities in earthworm change according to changing of physico chemical properties that increase in microbial population. A comparison study of uncomposted and composted Fly ash is explained in Table-2

A. Role of Earthworms in Fly Ash Management

Earthworms play a great role to maintain the soil composition, soil structure and soil fertility. They are one of the ancient group of soil organism belongs to phylum Annelida and class Oligochaeta have potency for rapid and efficient decomposition of waste materials [55] into mineralized forms as vermicompost. Earthworms are potential agents that convert inorganic and organic toxicants in respect to their habitation of site possessing contaminated soils [56]. These are considered as biological indicators of many metals in soil [57]. Heavy metal content FA generates from coal combustion in thermal power plants is a serious disposal able to degrade by earthworms. Earthworms consume the heavy metal from FA during conversion into vermicompost. The incorporation of FA and organic material improves the microbial function and the FA contents enhance the plant nutrient for agriculture ([21], [58]).

Earthworms consume the heavy metal of FA and enhance the NPK content as a potent fertilizer applicable in agriculture fields that less in FA content before vermicomposting ([59], [60]). Earthworms enhance nitrogen mineralization through modifications of different environmental conditions. It is regulated by the availability of dissolved organic nitrogen and ammonium, the activity of the microorganisms and their relative requirements for C and N. The interactions of microbes with nitrogen mineralization, thereby producing conditions in the organic wastes that favour nitrification, leading to immediate alteration of ammonium-nitrogen into nitrates ([61], [62]).

However, consumption of heavy metal content in FA is reduced by earthworms through accumulating the toxic metals in their gut .The potency of remediation of FA is contributed by the inherent tendency of earthworm. The major advantage of applying vermitechnology for FA remediation is an 'on-site' treatment over other additional problems like 'earth-cutting', 'excavation' and 'transportation of contaminated soils to the landfills or to the treatment sites incurring additional economic and environmental cost was reported by [63] ,sources from CFRI, Dhanbad, India [64]. Hence for vermin-remediation is the better opportunity for FA amendment throughout the globe and enhancement of agriculture utility.

B. Advantages of vermicomposting on Fly Ash

Management of huge production of FA and it's utilization is being carried out by many researchers. The contents of FA is adding cultivation benefits in terms of improvement in soil physical characteristics and enhanced agriculture production. However, FA amendment in soil cannot replace organic manure or chemical fertilizer but it's additional use in agriculture is becoming popularised. FA is good source for amendment of acid soils and used for stabilization in soil erosion. Vermicomposting may be a cheap and alternative way for degradation of FA into fine granular organic manure.

Many researchers are contributed their results on application of FA in agricultural purpose became familiarized .Biological activities of earthworm transfer heavy metal contents of FA into enriched soil nutrient by amendment with organic matters through small scale level initially to large scale production. The heavy metal contents of FA significantly increase the mortality rate of earthworm after a prescribed limit [65].The metals Cd, Cu, Ni, Pb , Zn, Cr and Hg are identified as toxic impact on food chain of vermicomposting from base level earthworm to peak level of bird [66]. More research studies should be carried out on effect, amount and accumulation of earthworm after using heavy metal from FA during vermicomposting process. The research will obtain with required concentration of FA for amendment and sustainable agriculture production.

4. Conclusion

The huge generation of FA from thermal power plants has negative impact on environment as major source of pollution. The production of FA in India is high nearer to production of China compare to other developed or developing countries. It will not be decreased in quantity within near future as increase of electricity demand. Subsequent management of FA has taken considerably from last few years. Researchers are involving to explore the conversion of FA into suitable productivity under FA management by using an effective technique vermicomposting. The degradation of heavy metal of FA due to consumption of earthworm increased the addition of NPK content in substrates. This review study reflects on the changes in physico-chemical parameters, survivability of earthworm, and conversion of heavy metal content of FA into sustainable organic product .The ultimate outcome from the conversion of FA into an opportunity to produce high yield organic fertilizers capable of enhancing soil fertility, improving crop quality, economic growth, bioremediation and the major issues for environment protection. This study reveals that the utilization of fly ash in agriculture sectors should be enhanced for safety disposal and proper management.

Production and utilization of FA in India during the period of year 2010-11 to 2018-19 (CEA reports 2019)

Descriptions	2010-11	2011-12	2012-13	2013-14	2014-15	2015-16	2016-17	2018-19
Fly ash production	131.09	145.42	163.56	172.87	184.14	176.74	169.25	176.26
Fly ash utilization	73.13	85.05	100.37	99.62	102.54	107.77	107.10	115.08
% Utilization	55.79	58.48	61.37	57.37	55.69	60.97	63.28	67.72

Comparison Study of uncomposted (Initial) and composted (Final) fly ash through different parameters (source from Ranveer et al., 2015)

Parameter	Initial	Final compost
pH	7.3	7.5
Organic matter %	49.6	47
Organic carbon%	26.67	27.26
Nitrogen%	2.17	2.23
Phosphorous%	1.97	2.15
potassium%	0.52	0.61
Calcium%	1.8	2.34
Sulphur%	0.7	0.54
Iron(ppm) 350 390		
Zinc(ppm)	353	354
Magnesium(ppm)	132	142

Yield increase of various plants grown in fly ash amended soils (Source fromMurugan and Vijayarangam, 2013).

Crops	Yield increase in %
Banana	30
Paddy, Potato	31
Pearl millet	32
Seed Cotton, Gram, Sorghum, Soybean	10-46
Sunflower, Groundnut	10-26
Sugarcane	22
Wheat, Mustard, Rice, Maize	6-18
Vegetables	15

Projected coal demand (Million Tons) (Source India Energy Book, 2012)

Sectors	2005-06	2006-07	2011-12	2016-17	2021-22	2026-27	2031-32
Electricity (A)	310	341	539	836	1040	1340	1659
Iron & Steel	43	43	69	104	112	120	150
Cement	20	25	32	50	95	125	140
Others	53	51	91	135	143	158	272
Non-Electrical (B)	116	119	192	289	350	403	562
Total of (A) + (B)	426	460	731	1125	1390	1743	2221

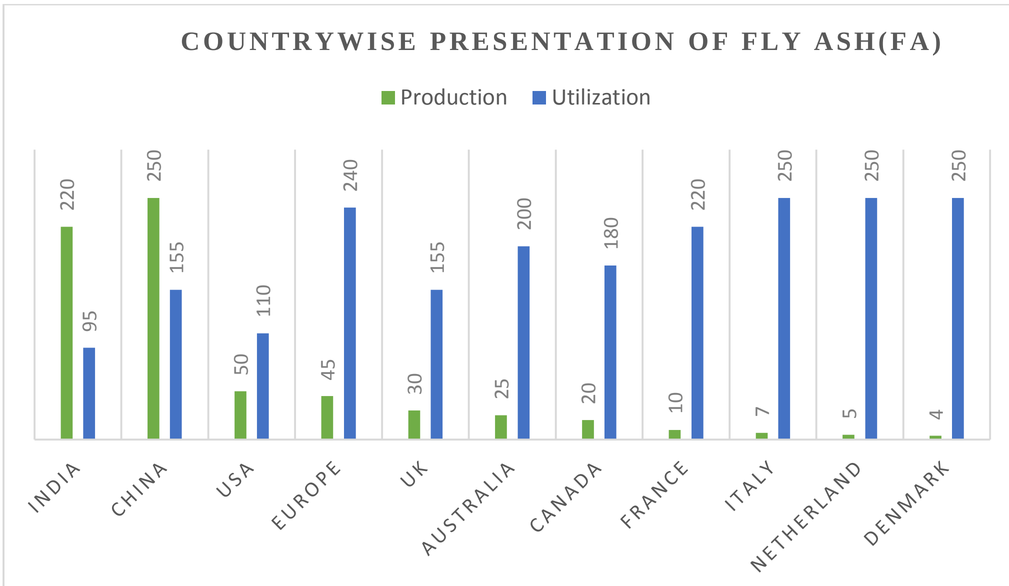

Fig 1: Graphical presentation of current scenario of different countries for FA production and utilization.
(Source: (ACAA 1998; Kumar et al. 2005; CEA 2019; Adopted from http://www.tifac.org.in)

References

L.P Singh,. and Siddiqui, Z.A., " Effects of fly ash and Helminthosporium oryzae on growth and yield of three cultivators of rice", Bioresource Technology 86(1), Dec. 2003,pp-73-78,DOI: 10.1016/S0960-8524(02)00111-6

M.R. Senapati, "Fly Ash from Thermal Power Plants – Waste Management and Overview." Current Science, vol. 100, no. 12, 2011, pp. 1791–1794. JSTOR, www.jstor.org/stable/24077549

N.Latifi, , A.Marto, , A. S. A. Rashid, and J. L. J. Yii, "Strength and Physico-chemical Characteristics of Fly Ash–Bottom Ash Mixture".Arab J Sci Eng,Vol. 40, pp.2447–2455 (2015). https://doi.org/10.1007/s13369-015-1647-4

V.Kumar, G .Singh,. and R.Rai, 2005-2012. "Fly ash another material for green revolution. Fly Ash Utilization Programme (FAUP)", TIFAC, DST, New Delhi.

V.C. Pandey, and N.Singh, “Impact of fly ash incorporation in soil systems”, Agric. Ecosyst. Environ, Vol.136,pp. 16-27,Feb. 2010 DOI: 10.1016/j.agee.2009.11.013

V.C.Pandey, Abhilash, P.C., Upadhyay, N. and Tewari, D.D. “Application of fly ash on the growth performance, translocation of toxic heavy metals within Cajanus cajan L., implication for safe utilization of fly ash for agricultural production”. J. Hazard. Mater, Vol.166, 2009,pp.255-259, doi.org/10.1016/j.jhazmat.2008.11.016

R.C. Gonzalez, and M.C.A. Gonzalez-Chavez, 2006. “Metal accumulation in wild plants surrounding mining wastes”. Environ. Pollut., Vol.144,2006, pp.84-92., https:// doi.org /10.1016/j.envpol.2006.01.006

C.A. Edwards, and J.E. Bater,. “The use of earthworms in environmental management”. Soil Biol. Biochem”., Vol.24, 1992, pp.1683-1689. https://doi.org/10.1016/0038-0717(92)90170-3

S.A. Abbasi, and E.V. Ramasamy, “Biotechnological Methods of Pollution Control”. Orient Longman, Hyderabad, 1999,pp. 168.

C.A. Edwards, Earthworm Ecology (2nd Edn). CRC Press L.L.C, Boca Raton, Florida, USA. 2004,pp. 12-23.

W.M.Gitari, L.F Petrick, D.L. Key, and Okujeni, “Inorganic contaminants in attenuation in acid mine drainage by fly ash and its derivatives: Column experiments”, Int. J. Environ. Pollut., Vol.51(1/ 2), Jan.2013.,pp. 32-56, DOI: 10.1504/IJEP.2013.053177

E.Benitez, M.Romero, M.Gomez, , F.Gallardolaro, and R.Nogales, 2001. “Biosolid and biosolid ash as sources of heavy metals in plant-soil system”. Water Air Soil Pol, Vol.132, ,2001,pp.75-87, DOI: https://doi.org/10.1023/A:1012012924151

X.Querol, J.Umana, A.Alastuey, A.Lopez-Soler, and F.Plana, “Extraction of soluble major and trace elements from fly ash in open and closed leaching system”. Fuel, Vol.80, 2001, pp.801-813, https://doi.org/10.1016/S0016-2361(00)00155-1.

L.C.Ram, and R.E. Masto, “An appraisal of the potential use of fly ash for reclaiming coal mine spoil. J. Environ. Manage., Vol.91, 2010, pp.603-617. https://doi.org/ 10.1016 /j.jenvman.2009.10.004

ACAA (American Coal Ash Association). Coal Combustion Product (CCP): Production and Use. ACAA, 1998, Alexandria, VA.

N.R.Koukouzas, , R., Zeng, V.Perdikatsis, , W.Xu, and E.Kakarasm,. “Mineralogy and geochemistry of Greek and Chinese coal fly ash: research for potential applications”. In: Proceedings, (World of Coal Ash), Kentucky,2005.

I.A.M Yunusa, D.Eamus, D.L. De silva, B.R Murray,., M.D. Burchett, G.C. Skillbeck, C.Heidrich,. “Fly ash: an exploitable resource for management of Australian agricultural soils. Fuel”,Vol. 85, Jan.2006,pp. 2337-2344, https://doi.org/10.1016/j.fuel.2006.01.033

G.Skordas, P.Grammelis, E.Kakaras, D.Karangelos, M.Anagnostakis, and E.Hinis, “Quality characteristics of greek fly ashes and potential uses”.

Fuel Process. Technol., Vol.88,2007, pp. 77-85, https://doi.org/10.1016/ j.fuproc.2006.09.001.

K.Nataraja, “Feasibility of Using Salvinia molesta (D. S. Mitchell) For Composting, Vermicomposting and Biogas Generation. Agronomy”. University 0f Agricultural Sciences, Dharwad - 580 005, Thesis,2008, http://krishikosh.egranth.ac.in/handle/1/82343.

M.J. McCarthy, and R.K. Dhar, “Towards maximizing the use of fly ash as a binder”. Fuel, Vol.78,1999 ,pp.121-132. https://doi.org/10.1016/S0016-2361(98)00151-3

R.Mohapatra, and J.R. Rao, “Some aspects of characterization, utilization, and environmental effects of fly ash”. J. Chem. Technol. Biot., Vol.76, 2001,pp.9-26. https://doi.org/10.1002/1097-4660(200101)76:1.

A.W. Schumann, and M.E. Sumner, “Chemical evaluation of nutrient supply from fly ash-biosolids mixtures”. Soil Sci. Soc. Am. J., Vol.64,2000, pp419-426. DOI: 10.2136/sssaj2000.641419x

M.S.Khan, , J.Prasad, and H.Abbas, “Effect of high temperature on high-volume fly ash concrete”, Arab J Sci Eng ,Vol.38, 2013.,pp. 1369-1378, DOI:https://doi.org/10.1007/s13369-013-0606-1

TERI 1998. Reclaiming ash pond by means of mycorrhizal-organo biofertilizer: Quarterly reports submitted to fly ash mission. TIFAC, DST, Tata Energy Research Institute, New Delhi, India.

S.S. Bhattacharya, and G.N. Chattopadhyay, “Bioavailability of phosphorus from fly ash through vermicomposting”. J. Environ. Qual., Vol.31(6), 2002,pp. 2116-2119, DOI: 10.2134/jeq2002.2116

Z.Usmani, V.Kumar, “The implications of Fly Ash remediation through vermicomposting: A Review”, Vol.16, 2017,pp.363-374.

S.A. Abbasi, and R.Soni, “Stress-induced enhancement of reproduction in earthworm octochaetus pattoni exposed to chromium (vi) and mercury (ii) - implications in environmental management”, International Journal of Environmental Studies, Vol.22(1), 1983,pp. 43-47. https://doi.org/10.1080 /00207238308710100.

S.Gorai, “Utilization of Fly ash for sustainable environment management”,J. Mater. Environ. Sci.,Vol. 9, 2018 , pp. 385-393, https://doi.org/10.26872/jmes. 2018.9.2.42

S.N.Singh, K.Kulshreshtha, and K. J Ahmad, “Impact of fly ash soil amendment on seed germination, seedling growth and metal composition of Vicia faba L.” Ecol. Eng., Vol.9, 1997,pp. 203-208, https://doi.org/ 10.1016/ S0925-8574(97) 10004-0

S.N Pathan., L.A.G Aylmore., T.D. Colmer “ Fly ash amendment of sandy soil to improve water and nutrient use efficiency in turf culture”, International Turfgrass Society, Vol 9,2001,pp.33-39

I.A.M.Yunusa, D. Eamus, , D.L. De silva, , B.R.Murray, M.D. Burchett, G.C. Skillbeck, C. Heidrich,. “Fly ash: an exploitable resource for management of Australian agricultural soils”, Fuel, Vol.85, 2009,pp. 2337-2344, https://doi.org/10.1016/j.fuel.2006.01.033

A.K.Nayak, R.Raja ,K.S.Rao, A.K.Shuklaa, Sangita Mohanty, Mohammad Shahid ,R.Tripathi, B.B.Panda, P.Bhattacharyya, Anjani Kumara, B.Lala, S.K.Sethi, C.Puri, D.Nayak, C.K.Swain. "Effect of fly ash application on soil microbial response and heavy metal accumulation in soil and rice plant". Ecotoxicol Environ Saf Vol.114,2015,pp.257–262, https://doi.org/10.1016/ j.ecoenv.2014.03.033.

N Kalra , HC Joshi, A Chaudhary, R Chaudhary, SK Sharma (1997) "Impact of flyash incorporation in soil on germination of crops".Biotreseurce technology,Vol. 61,1997,pp.39-41.

R.L.Aitken, D.J.Campbell, & L.C. Bell, "Properties of Australian fly ashes relevant to their agronomic utilization", Australian Journal of Soil Research", Vol.22, 1984,pp. 443–453, https://doi.org/10.1071/SR9840443.

L.H.Weinstein, J.F.Osmeloski, M. Rutzke, A.O. Beers, J.B. McCahan, C.A. Bache and D.J. Lisk,. "Elemental analysis of grasses and legumes growing on soil covering coal fly ash landfill sites". J. Food Safety, Vol.9, 1989,pp. 291-300 https://doi.org/10.1111/j.1745-4565.1989.tb00529.x.

A.K.Furr, T.F. Parkinson, R.A. Hinrichs, D.R. Van Campen and C.A. Bache,. "National survey of elements and radioactivity in fly ashes. Absorption of elements by cabbage grown in fly ash soil mixtures". Environ. Sci. Technol., Vol.11, 1977pp.1194-1201, https://doi.org/ 10.1021/es60136a006

R.Sikka, B.D.Kansal, "Characterization of thermal power1143 plant fly ash for agronomic purposes and to identify pollution 1144 hazards", Bioresour. Technol. Vol.50, 1994, pp.269–273, DOI:10.1016/0960-8524(94)90101-5

M.R Khan, M.W.Khan, K.Singh, "Management of root-knot 992 disease of tomato by the application of fly ash to soil". Plant Pathol. 993, 1997,Vol. 46, pp.33–43, https://doi.org/10.1046/j.1365-3059.1997.d01-199.x.

I.Straughan, , A.A.Elseewi, A.L. Page,. Mobilization of 1183 selected trace elements in residues from coal combustion with 1184 special reference to fly ash. In: Hemphill, D.D. (Ed.), Trace 1185 Substances in Environmental Health—XII. A Symposium. Uni1186 versity of Missouri, Columbia, 1978,pp. 389–402.

K.S.Grewal, P.S. Yadav, S.C. Mehta and M.C. Oswal, 2001. "Direct and residual effect of fly ash application to soil on crop yield and soil properties", Crop Res., Vol.21,2001,pp: 60-65.

S.S.S. Lau, and J.W.C. Wong, "Toxicity evaluation of weathered coal fly ash amended manure compost". Water, Air Soil Pollut., Vol.128, 2001,pp. 243-254, https://doi.org/10.1023 /A:1010332618627.

D.Goyal, K.Kaur, R.Garg, V.Vijayan, S.K.Nanda, A.Nioding, S.V. Khanna, and V.Ramamurthy, "Industrial fly ash as a soil amendment agent for raising forestry plantations". In: Taylor, P.R. (Ed.), EPD Congress and

Fundamental of Advanced Materials for Energy Conversion. TMS Publication, Warrendale, PA, 2002, pp. 251-260.

M.R.Neelima, S. Khandual, , A.Tripathy, R.K.Sahu,. " Fly ash Management in the State of Orissa", Conference Proceedinhg,April. 1995. RRL, Bhubhaneshwar, India, pp.76-89.

M.P.Sharma, U.Tanu, A.Adholeya, , "Growth and yield of Cymbopogon martinii as influenced by fly ash, AM fungi inoculation and farmyard manure application". In: 7th International Symposium on Soil and Plant analysis", Edmonton, AB, Canada., 2001a.

M.P. Sharma, U.Tanu, G. Reddy, A.K Shyam, A. Adholeya,. "Herbage yield of Mentha arvensis DC. Holms as influenced by AM fungi inoculation and farmyard manure application grown in fly ash over burdens amended with organic matter". In: (Ed.), International Ash Utilization Symposium, KY, USA.,2001b

N.R. Shanthi, R.V. Bhoyar, and A.D.Bhide, "Vermicomposting of vegetable wastes". Compost Science & Utilization, Vol.1(4),1993,pp. 27-30, https://doi.org/10.1080/1065657 X.1993.10757900.

J.Haimi, and V.Huhta, "Effects of earthworms on decomposition processes in raw humus forest soil: A microcosm study", Biol. Fert. Soils, Vol.10,1990,pp. 178-183, https://doi.org/10.1007/BF00336132.

C.A., Edwards, P.J., Bohlen, Linden, D.R. and Subler, S.. "Earthworms in agro ecosystems". In: Earthworm Ecology and Biogeography in North America (P. F. Hendrix, Ed.), Lewis, Boca Raton, 1995, pp. 185-213,

J., Rombke, S.Jansch, and W.Didden, "The use of earthworms in ecological soil classification and assessment concepts". Ecotoxicol. Environ. Safe., Vol.62,2005, pp.249-265, https://doi.org/10.1016/j.ecoenv.2005.03.027

P. Garg, A.Gupta, and S.Satya,. "Vermicomposting of different types of waste using: A comparative study". Bioresour. Technol., Vol.97, 2006,pp. 391-395, https://doi.org/10.1016/j.biortech.2005.03.009

M.S., Kitturmath, R.S. Giraddi, and B.Basavaraj, "Nutrient changes during earthworm, Eudrilus eugeniae (Kinberg) mediated vermicomposting of agro-industrial wastes Karnataka". J. Agric. Sci., Vol.20, 2007,pp. 653-654.

S.Pattnaik, and M.Reddy, "Assessment of municipal solid waste management in Puducherry (Pondicherry)", India. Resour. Conserv. Recyc., Vol.54,2010,pp. 512-520, https://doi.org/10.1016/j.resconrec.2009.10.008

D.Reinhart, and T.G. Townsend,. "Landfill Bioreactor Design and Operation". Lewis Publisher, Boca, 1998

S.Sethi, , N.C. Kothiyal, and A.K. Nema,. "Stabilisation of municipal solid waste in bioreactor landfills - an overview". Int. J. Environ. Pollut., Vol.51(1/2), Jan.2013,pp.57-78, DOI: 10.1504/IJEP.2013.053175.

G. J. Romanes, "The Formation of Vegetable Mould, through the Actions of Worms, with Observations on Their Habits", Nature, Vol. 24,1881, pp553–556, https://doi.org/ 10.1038/024553a0

A. S. Cooke, P. W.Greig-Smith, and S. A. Jones,. "Consequences for vertebrate wildlife of toxic residues in earthworm prey". Ecotoxicology of Earthworms, 1992,pp. 109-115, DOI: 10.1007/s11356-014-3180-5

K.E. Lee,. "Earthworms: Their Ecology and Relationship with Soils and Land Use", Academic Press, Australia, 1985,pp. 56-57.

V.T., George. S.R., Prabhu, M.Z. Reeny, and B.M. Bopaiah, "Evaluation of lignocellulosic biomass from coconut palm as substrate for cultivation of Pleurotus sajor cajii" (Fr.) Singer. World J. Microb. Biotechnol., Vol.14, 1998,pp. 879-882, DOI:10.1023/A:1008881124903

S.S. Bhattacharya, and G.N. Chattopadhyay, "Effect of vermicomposting on the transformation of some trace elements in fly ash". Nutr. Cycl. Agroecosys., Vol.75, 2006.pp. 223-231, https://doi.org/10.1007/s10705-006-9029-7

S.Anantha krishnasamy, S.Sarojini, G.Gunasekaran, and G.Manimegala, "Fly ash - A lignite waste management through vermicomposting by indigenous earthworms Lampito mauritii." Am. Eur. J. Agric. Environ. Sci., Vol.5, 2009. pp.720-724.

M.Aira, and J. Dominguez, "Optimizing vermicomposting of animal wastes: effects of dose of manure application on carbon loss and microbial stabilization." J. Environ. Management, Vol.88, 2008,pp. 1525- 1529, https://doi.org/10.1016/j.jenvman.2007.07.030

C.Lazcano, , M.Gomez-Brandon, and J. Domýnguez, 2008. "Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure". Chemosphere, Vol.72,2008,pp.1013-1019, https:// doi.org/ 10.1016/j. chemosphere. 2008.04.016

Z.Usmani, V.Kumar, "The implications of Fly Ash remediation through vermicomposting: A Review",Vol.16, 2017,pp.363-374.

CFRI, Dhanbad, Jharkhand, CFRI Report No. TR/CFRI/3.04/1999-2000. CFRI (Central Fuel Research Institute). 2001a. Utilization of Fly Ash from Chandrapur and Bhusawal TPPs in Agriculture and for Reclamation of Degraded Land. CFRI TR/CFRI/1.08/2002-2003.

S.A. Abbasi, and R.Soni,. "Stress-induced enhancement of reproduction in earthworm octochaetus pattoni exposed to chromium (vi) and mercury (ii) - implications in environmental management". International Journal of Environmental Studies, Vol.22(1), 1983,pp.43-47, https://doi.org/10.1080/00207238308710100

S.Suthar, , S.Singh, and S.Dhawan,. "Earthworms as bioindicator of metals (Zn, Fe, Mn, Cu, Pb and Cd) in soils: is metal bioaccumulation affected by their ecological category?" Ecol. Eng., Vol.32, 2008,pp. 99-107, https://doi.org/10.1016/j.ecoleng.2007.10.003