ABSTRACT

Large scale generation of coal ash from varying kinds of coal fired plants has emerged as a major environmental threat in many countries of the world. To combat the situation, various possibilities of recycling this waste material are being envisaged. Since coal ash contains most of the plant nutrients in appreciable amount, its re-use in agriculture as a source of these nutrients constitutes an important component of such efforts. However, the major problem associated with supply of plant nutrients through coal ash is the low bio-availability of most of the nutrients in this material despite their good occurrence in total concentrations. This behavior is generally attributed to absence of organic matter and lack of microbiological activity in this burnt material. Under this context, we decided to assess the possibility of enhancing the availability of different plant nutrients in coal ash through adoption of vermicomposting biotechnology. Vermicomposting helps in accelerated degradation of various kinds of wastes with the help of gut microorganisms of some specific groups of earthworms. It was hypothesized that vermicomposting of organic waste mixed coal ash will help in accumulation of the much desired organic matter in this waste material and will also enhance the microbiological activity in the product resulting in release of larger amount of different plant nutrients to available forms. The results of a series of yard as well as on-farm studies showed introduction of epigeic earthworms in mixtures of coal ash and organic wastes to help in enhancing the microbiological activity in the substrates. These, in turn, facilitated improvement in the availability of three major nutrients viz. N, P and K and also several micro nutrients like Fe, Cu, Mn and Zn in the vermicomposted coal ash-organic waste mixture. It was further observed that substantial shares for such increments were derived from degradation of coal ash. Vermicomposting also helped in binding of several heavy metals from coal ash in earthworm flesh as organic compound, thus preventing their release in this composted product. On-farm trials conducted with vermicomposted coal ash on different crops like rice, potato, rape seed and tomato were found to generate crop yields comparable to those obtained by use of traditional organic manures.

KEY WORDS: Coal ash; Recycling in agriculture; Vermicomposting; Plant nutrient availability; Crop response.

INTRODUCTION

Consistent generation of huge amount of coal ash (CA) from different kinds of coal fired plants has now appeared as a serious threat to the global environment. To combat the situation, varying opportunities of recycling this waste material for productive purposes are being
explored at different levels. During these efforts, recycling of CA in agriculture as a source of plant nutrients has emerged as a possible option (Page et al., 1980). Owing to its plant origin, coal ash usually exhibits almost all the plant nutrients in appreciable concentrations, barring nitrogen and organic carbon. While Kumar et al. (2000) reported total occurrences of many of these plant nutrients to be almost at par with those commonly observed in arable soils (Table-1), some of these values may even be comparable to traditional organic manures also (Table-2). This behavior has prompted several workers to consider this material for use in agriculture related activities as a source of plant nutrients (Schutter and Fuhrman, 1999 and others). Appreciable studies have been carried out in agriculture and forestry sectors to assess the effect of CA as a source of plant nutrients which have shown that these ashes have some beneficial properties which can be utilized for agronomic purposes (Chattopadhyay and Bhattacharya, 2010). Positive effects of CA on yield levels of different crops have been reported by Mulford and Martens (1971), Hill and Lamp (1980) and many others.

Table 1. General properties of coal ash and arable soils.

<table>
<thead>
<tr>
<th>Properties</th>
<th>Fly Ash</th>
<th>Soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bulk density (g cm⁻³)</td>
<td>&lt; 1.0</td>
<td>1.33</td>
</tr>
<tr>
<td>Water holding capacity (%)</td>
<td>35-40</td>
<td>&lt; 20</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>50-60</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>P (%)</td>
<td>0.004-0.8</td>
<td>0.005-0.2</td>
</tr>
<tr>
<td>K (%)</td>
<td>0.19-3.0</td>
<td>0.04-3.0</td>
</tr>
<tr>
<td>S (%)</td>
<td>0.1-1.5</td>
<td>0.01-0.2</td>
</tr>
<tr>
<td>Fe (mg kg⁻¹)</td>
<td>36-133</td>
<td>10-300</td>
</tr>
<tr>
<td>Zn (mg kg⁻¹)</td>
<td>14-1000</td>
<td>2-100</td>
</tr>
<tr>
<td>Cu (mg kg⁻¹)</td>
<td>1-26</td>
<td>0.7-40</td>
</tr>
<tr>
<td>Mn (mg kg⁻¹)</td>
<td>100-3000</td>
<td>100-4000</td>
</tr>
<tr>
<td>B (mg kg⁻¹)</td>
<td>46-618</td>
<td>0.1-40</td>
</tr>
</tbody>
</table>

Source: (Kumar et al., 2000)

However, in spite of these encouraging results, low bio-availability of different nutrients forms a major constraint for wider acceptance of this material in agricultural use. Most of the plant nutrients present in CA do not remain in bio-available forms despite their total occurrence in considerably higher concentrations (Table-2). This behavior has been attributed to inert nature of this burnt material leading to absence of organic matter and consequently very poor microbiological activity in it (Roy et al., 2014). Under this context, it has been suggested by some workers that simultaneous use of CA and organic matter may appear as a wiser proposition for improving the nutrient supplying potential of this material. It has been visualized that incorporation of organic matter to such ash materials would help in extraction of more nutrient elements to available forms through acid extraction in one hand and encourage the microbial degradation of the ash on the other (Roy et al., 2018). In addition, this will also help to add a good amount of the much desired organic matter to the soil for improving its various health attributes. In fact, many of the significant beneficial effects of fly ash application in agriculture have been observed when the ashes were incorporated with organic materials (Wong and Wong, 1997; Mitra et al., 2000; Christy and Raghupathy, 2001). The physico-chemical properties of the soils improved in terms of decrease in bulk density, increase in pH, organic
carbon and available nutrients. While poor growth of various microorganisms in CA has been observed by Pitchel and Hayes (1990), beneficial effects of addition of organic matter on microbial activity in fly ash amended soils have been reported by workers like McCarty et. al. (1994) and others.

Table-2. Gross occurrence of primary nutrients in coal ash and farm yard manure

<table>
<thead>
<tr>
<th>Nutrients</th>
<th>Coal Ash</th>
<th>Farm Yard Manure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>50.0</td>
<td>5000.0</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>700.0</td>
<td>650.0</td>
</tr>
<tr>
<td>Potassium</td>
<td>5600.0</td>
<td>5000.0</td>
</tr>
<tr>
<td></td>
<td>Available</td>
<td></td>
</tr>
<tr>
<td>Nitrogen</td>
<td>30.0</td>
<td>1580.0</td>
</tr>
<tr>
<td>Phosphorus</td>
<td>27.0</td>
<td>125.0</td>
</tr>
<tr>
<td>Potassium</td>
<td>56.0</td>
<td>280.0</td>
</tr>
</tbody>
</table>

All these studies indicate that for increasing the efficiency of CA as a source of plant nutrients, the availability of the nutrients in this material need to be improved. Organic matter can supply food and energy to different heterotrophic microorganisms, extract various nutrients into soluble forms from different insoluble minerals through release of some organic acids (Rao and Chhonkar, 1998) and improve various physico-chemical properties of the soils. Therefore, combined use of CA and organic materials is likely to emerge as an effective proposition for increasing the nutrient supplying potential of CA and, at the same time, for maintaining the soil health. This practice is likely to be particularly beneficial for various tropical countries which have large areas of poor quality soils with low status of organic matter. Simultaneous application of organic materials and CA is likely to bring in positive effects on such soil health, which is difficult or practically not possible to achieve through use of CA alone. With this background, we made an effort to explore the possibilities of improving the nutrient supplying capacity of CA through simultaneous degradation with organic wastes using vermicomposting biotechnology.

Recycling of coal ash through vermicomposting

Like coal ash (CA), large scale generation of various kinds of organic wastes is also a major environmental problem throughout the world. A popular method of recycling these wastes in developing or under developed countries is to incorporate them in agricultural soils. However, the major problem of recycling the organic waste materials in agriculture is that, these organic materials should not be added to the soils directly and need to be composted or decomposed properly prior to their application. This composting process not only results in better release of different plant nutrients in bio-available forms but also helps to lessen the possibility of soil contamination through destruction of various pathogens, weed seeds etc. (Chattopadhyay, 2012).
We hypothesized that co-composting of CA and organic wastes may appear as a unique method of integrated inorganic and organic waste management leading to better release of the plant nutrients from CA through increased microbial activity, encouraged by the decomposition of the organic wastes.

Among different methods of composting of organic materials, vermicomposting biotechnology has now emerged as an important one owing to its simplicity as well as high efficiency in producing better quality compost (Kale, 1993, Chattopadhyay, 2012). This composting is carried out with the help of epigeic group of earthworms, which prefer to live on the upper layers of the soils and feed mostly on organic debris. These earthworms harbor rich concentrations of different kinds of microorganisms, enzymes etc. in their intestine (Edwards and Lofty, 1972). After feeding, these microorganisms get mixed with the wastes in the earthworm guts and thus help in rapid decomposition of the half digested excreta under aerobic condition. This results in the production of good quality compost in lesser period of time along with generation of different beneficial microorganisms in these compost materials (Chattopadhyay, 2004). In view of this efficiency of vermicomposting biotechnology in decomposing different kinds of organic wastes, we tried to assess the efficiency of this technology in facilitating plant nutrition through CA.

**Effects of vermicomposting on nutrient availability in coal ash**

Initial studies carried out to assess the hypothesis suggested that these earthworms can play a significant role in processing CA in combination with organic materials. While the earthworms could not survive in CA alone, their population increased considerably when organic waste, in the form of cow dung, was mixed with CA. The earthworm activity accelerated the population of different microorganisms in the CA and organic waste mixture that helped in rapid degradation of the waste materials (Table-3). The ultimate product was much darker in color and had been processed into a more homogenous mass after two months of earthworm activity, whereas the material without earthworms remained in compact lumps.

<table>
<thead>
<tr>
<th>Composting system</th>
<th>Bacteria ((10^6/g))</th>
<th>Fungi ((10^6/g))</th>
<th>Actinomycetes ((10^6/g))</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA only</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>CA+OW</td>
<td>39.5</td>
<td>9.8</td>
<td>15.3</td>
</tr>
<tr>
<td>CA+OW+EW</td>
<td>49.3</td>
<td>13.8</td>
<td>19.8</td>
</tr>
<tr>
<td>% increment due to vermicomposting</td>
<td><strong>24.8</strong></td>
<td><strong>40.1</strong></td>
<td><strong>29.4</strong></td>
</tr>
</tbody>
</table>

The studies were continued to assess the effects of incubating epigeic earthworm *Eisenia fetida* in mixtures of CA and cow dung on various chemical properties, including availability of various nutrient elements, in the vermicompost. It was found that adoption of this technology helped to maintain higher amount of plant nutrients in available form in the mixtures, as
compared to the materials without vermicomposting (Figure-1). It was also observed that CA contributed a good share for these increments in nutrient availability (Bhattacharya and Chattopadhyay, 2002, 2004). Moderate to high occurrences of some heavy metals in CA are commonly considered to be a major constraint for large scale use of CA in agricultural soils (Sims et al., 1995). It was interesting to observe that adoption of vermicomposting tended to reduce the solubility of metals like Cr, Cd, Pb etc. in the vermicomposted CA mixture. This behavior was attributed to transformation of these metals into complex metallothionein compounds in the earthworm tissues (Bhattacharya et al., 2012).

Figure 1. Changes in pH, organic C and availability of N, P and K in CA: organic waste systems after traditional composting and vermicomposting

(Source: Roy et al, 2018)

Effects on crop yield

The effect of vermicomposted coal ash (CA) and organic waste mixture on crop yield levels has also been assessed at field level. Use of vermicomposted CA resulted in substantial yield increments in case of potato (Bhattacharya et al., 2012). It was observed that integration of vermicomposted CA with mineral fertilizers played a very important role in production of potato in red and lateritic soils and this practice appeared to be statistically comparable to the crop yield with similar rate of application of traditional organic manure and mineral fertilizer (table-4).

Table-4: Potato yields (t ha⁻¹) under different treatments using vermicomposted ash in a red-lateritic soil of West Bengal, India.

<table>
<thead>
<tr>
<th></th>
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</tr>
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<tbody>
<tr>
<td>Control (NPK₁₀₀)</td>
<td>31.24c</td>
<td>31.95d</td>
</tr>
<tr>
<td>Treatment</td>
<td>Yield 1</td>
<td>Yield 2</td>
</tr>
<tr>
<td>-----------------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>FYM+ NPK&lt;sub&gt;100&lt;/sub&gt;</td>
<td>35.85a</td>
<td>36.08b</td>
</tr>
<tr>
<td>VC+NPK&lt;sub&gt;100&lt;/sub&gt;</td>
<td>36.29a</td>
<td>37.20a</td>
</tr>
<tr>
<td>VC+NPK&lt;sub&gt;75&lt;/sub&gt;</td>
<td>34.48b</td>
<td>35.36b</td>
</tr>
<tr>
<td>VC+NPK&lt;sub&gt;50&lt;/sub&gt;</td>
<td>31.68c</td>
<td>34.54c</td>
</tr>
</tbody>
</table>

(Values followed by different letters are statistically different)

NPK<sub>100</sub> = 100% recommended NPK fertilizer; NPK<sub>75</sub> = 80% recommended NPK fertilizer; NPK<sub>50</sub> = 60% recommended NPK fertilizer; FYM = Farm yard manure; VC = Vermicomposted ash (both added @ 10 t ha<sup>-1</sup>)

(Source: Bhattacharya et. al., 2012)

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**Epilogue**

The communication dealt with possibilities of utilizing the plant nutrient contents of coal ash (CA) in agriculture sector through vermicomposting in combination with organic wastes. Vermicomposting technology has long been used for recycling of different kinds of organic wastes in agriculture. The discussion indicated that this bio-technology may be effectively utilized for facilitating the re-use of inorganic resource like coal ash also. Good amount of insoluble nutrients of CA may be transformed into bio-available forms through combined vermicomposting of CA and organic wastes. This product has been observed to result in crop yields comparable to traditional organic manures. However, this is a new field of study and more information need to be collected on different aspects of this composting system.

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**References**


