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Co-application of biochar and lignite fly ash on soil nutrients and biological parameters at different crop growth stages of *Zea mays*

R. Ebhin Masto*, Md. A. Ansari, J. George, V.A. Selvi, L.C. Ram

Environmental Management Division, CSIR- Central Institute of Mining and Fuel Research, Digwadih Campus, PO: FRI, Dhanbad 828108, Jharkhand, India

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ABSTRACT

Worldwide, the fly ash, generated in huge quantities from thermal power plants is a menace, especially its handling and disposal. Utilization of fly ash as a soil amendment to improve soil quality has received a great deal of attention. Co-application of biochar with fly ash may further enhance soil quality and crop productivity. Field experiment was conducted in an acidic red soil, from Dhanbad, India, to investigate the effects of lignite fly ash (LFA) and biochar (BC) on soil nutrients, biological properties, and the yield of *Zea mays*. The treatments were (i) control, (ii) BC (4 t/ha), (iii) LFA (4 t/ha), and (iv) BC (2 t/ha) + LFA (2 t/ha). Soil samples were collected at three different crop stages of maize (vegetative, taselling and grain filling) and analyzed for pH, EC, organic carbon, N, P, K, soil enzymes, microbial biomass, and respiration. Soil bulk density and water holding capacity measured after the harvest of crop were not affected by the treatments. Soil P (+110%) and K (+64%) contents increased by LFA + BC application due to the presence of plant nutrient in BC and LFA. Soil enzymes like dehydrogenase activity (+60.7%), alkaline phosphatase (+32.2%), fluorescein hydrolases activity (12.3%) and microbial biomass (+25.3%) increased due to co-application of LFA and BC probably due to the pH-buffering and sorption of the organic matter to mineral surfaces to create a more reactive network for water, air and nutrient interactions in the soil. Available heavy metal (Zn, Ni, Co, Cu, Cd, and Pb) contents in soil decreased by LFA + BC application due to surface adsorption and precipitation caused by increase in soil pH. Maize grain yield increased by 11.4% for BC, 28.1% for BC + LFA treatment, and the yield was not significantly affected for the LFA alone treatment. Regression analysis showed soil P as the major factor for the increase in crop yield.

1. Introduction

Fly ash is the solid waste generated from coal combustion in thermal power plants and has been regarded as a problematic solid waste all over the world (Pandey and Singh, 2010). Coal accounts for 30% of global energy consumption. Global proven coal reserve is 8.6×10^5 million tonnes, out of which the Indian coal reserve is 6.0×10^4 million tonnes (BPSRWE, 2012). In India about 70% of the total energy requirement is met through coal, and this contribution is likely to continue long into the future in view of the enormous coal reserves in India and the country's steadily growing economy (Ram and Masto, 2010). The total amount of fly ash produced worldwide is enormous, which has been estimated to exceed 750 million tonnes per annum, but only less than 50% of world fly ash production is utilized (Blissett and Rowson, 2012). The generation of fly ash is progressively increasing in meeting the global demand of energy (Pandey and Singh, 2012; Pandey et al., 2012).

Soil application of fly ash could be an option for gainful fly ash utilization. The concept of fly ash application in agriculture and forestry because of its favourable physico-chemical properties including considerable content of plant nutrients has been advocated over the last four decades (Tripathi et al., 2009, Ram and Masto, 2010). Efforts are also been made to reclaim fly ash dumps with wide varieties of tolerant plant species (Kumari et al., 2013). For soil application, organic materials were used along with fly ash. Organic composts with high organic carbon and micronutrients on their application in combination with fertilizer nitrogen and fly ash, improved soil properties and slowly released nutrients in accordance with demand of growing crops. These blended materials in the form of organic-metal complexes reduced the bioavailability of metals applied through FA (Dar et al., 2012). Combined application of fly ash and farm manure amendments enhanced the rates of N transformation processes, plant available-N and paddy productivity (Singh and Pandey, 2013). Many studies support the beneficial effect of blending organic materials with FA. Biochar (BC) is another organic material that can be used along with FA. Biochar is the carbonaceous residue left in the pyrolysis process, which is even used by pre-Columbian farmers and recently being recognized as

* Corresponding author. Tel.: +91 326 2388339; fax: +91 326 2381113.
E-mail address: mastocfri@yahoo.com (R.E. Masto).

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an interesting material to store carbon in soils and to improve soil quality (Renard et al., 2012). Several studies have now highlighted the benefit of using biochar for mitigation of global climate change and as an effective strategy to manage soil quality and crop productivity (Lehmann, 2007). Fly ash blending with biochar could be a new ecological engineering option for sustainable utilization of FA.

Both biochar and fly ash have the potential to improve soil quality, crop yield and to expand terrestrial soil carbon pool (Palumbo et al., 2009). Sohi et al. (2009) stated that biochar may benefit crop production by three main mechanisms: (i) directly modifying the soil chemistry through its intrinsic elemental and compositional make up, (ii) providing chemically active surfaces that modify the dynamics of soil nutrients or otherwise catalyze useful soil reactions, and (iii) modifying physical character of the soil in a way that benefits root growth and/or nutrient and water retention and acquisition. The overall beneficial effects of FA are primarily associated with improvements in physico-chemical and biological characteristics of the soil. The presence of Ca–Si minerals with a pozzolanic nature, along with the soil moisture, fly ash promotes improvements in soil bulk density (BD), porosity, water holding capacity (WHC), and available water. The essential plant nutrients found in FA also encourage plant growth and increase crop yield (Ram and Masto, 2010).

It is hypothesized that co-application of fly ash and biochar may have synergistic benefits like enhanced nutrient availability, decreased bioavailability of toxic metals, pH buffering, organic matter addition, microbial stimulation, and overall improvement in the general health of the soil, etc. This study is focused on the evaluation of the agronomic potential of co-application of biochar and fly ash and its impact on soil quality, plant growth, and yield using maize (*Zea mays*) as an agricultural crop in a field experiment.

2. Materials and methods

2.1. Experimental site and treatments

Maize crop was cultivated in a field plot at Central Institute of Mining and Fuel Research, Digwadih Campus, erstwhile Central Fuel Research Institute, Dhanbad, India. The soil has sandy loam texture with the following properties: sand 75.5%, silt 6.5%, clay 18%, pH (1:2.5) 5.9, electrical conductivity 0.22 dS/m, cation exchange capacity (CEC) 10.8 cmol(P^+)/kg, soil organic carbon 0.86%, total nitrogen 0.11%, available P 4.64 mg/kg, available K 79 mg/kg. The experimental area is characterized as tropical with a mean annual precipitation of about 1598 mm, most of the rain falling between June and October and during these months 80-85% of the annual rainfall is achieved. The relative humidity during monsoon (July–September) varies between 60 and 100%, while in summer months (April–June) it decreases to as low as 20-25%. The summer and winter average temperatures being 44.5 °C and 20 °C respectively. The elevation of the area is 227 m above mean sea level.

Lignite fly ash (LFA) obtained from a lignite fired power station, Neyveli Lignite Corporation, Tamil Nadu, India was used for this study. The dry fly ash collected from the silo of the power plant was used for the study. Biochar (BC) was prepared from *Lantana camara*, an herbaceous weed growing abundantly in many parts of India and having no meaningful application till date. The weed was dried and carbonized to biochar through a local kiln. The pH of biochar (10.3) and fly ash (8.08) was alkaline (Table 1), whereas the pH of the experimental soil (5.9) was acidic. BC had the highest EC of 5.3 dS/m followed by LFA (2.46 dS/m) and soil (0.224 dS/m). Higher CEC observed for BC (41.7 cmol P^+/kg) is due to the high surface area and charge density of the biochar (Liang et al., 2006). The beneficial effect of LFA for improving soil physical quality is due to the high silt content (35.7%), water holding capacity, and the low bulk density than that of soil (Ram and Masto, 2010). Biochar contained significant amounts of plant nutrients (Table 1) like N (1.56%), K (711 mg/kg), Ca (5880 mg/kg), Mg (1010 mg/kg), Na (1145 mg/kg); while LFA had high Ca (4280 mg/kg), S (1140 mg/kg), Mg (989 mg/kg), and P (760 mg/kg). The scanning electron microscope (SEM) images (Fig. 1) for fly ash showed the presence of fine spherical ash particles and cenospheres. The SEM image for biochar showed the micro porous structure. During the preparation of biochar from *Lantana*, volatiles released out of the biomass create numerous micro pores on the surface, while the volatiles trapped inside the biomass expands the micro level structure. Thus the resulting biochar is highly porous (Fig. 1) and with high surface area. These two properties are much useful for soil application of biochar, especially for enhancing soil water holding capacity, nutrient retention, harbouring of micro organisms, increasing the fertilizer use efficiency, etc. The SEM-EDX illustrates the composition of biochar particle consisting of a combination of C > O > Mg > K, whereas fly ash consists of Al > O > Si > Ca > Mg > Fe > S > Na.

Table 1
Selected parameters of soil, fly ash and biochar used for the study.

Parameters	Soil	LFA	Biochar
Clay (%)	18	8.34	–
Silt (%)	6.5	35.7	–
Sand (%)	75.5	56	–
Bulk density (Mg/m^3)	1.39	1.065	–
Water holding capacity (%)	32.8	61.91	–
pH	5.9	8.08	10.33
EC (dS/m)	0.22	2.46	5.3
CEC (cmol P^+/kg)	10.8	14.3	41.7
C (%)	0.86	0.04	65.3
H (%)	0.26	0.18	2.62
Total N (%)	0.11	0.06	1.56
Available P (mg/kg)	4.64	760	0.64
Available K (mg/kg)	79.0	63.2	711
Available S (mg/kg)	65.5	1140	3150
Available Na (mg/kg)	25.3	312	1145
Available Ca (mg/kg)	1000	4280	5880
Available Mg (mg/kg)	150	989	1010

The treatments were (i) control, (ii) BC (4 t/ha), (iii) LFA (4 t/ha), and (iv) BC (2 t/ha) + LFA (2 t/ha). BC dose was fixed at 4 t/ha in view of the potential BC production from one hectare of land. Each treatment was replicated three times in a randomized block design (plot size 3 × 5 m). Required quantities of FA and BC were added to the randomly selected treatment plots and were mixed thoroughly with the soil using spade. The recommended dose of NPK (100:60:40) fertilizers were added to all the treatments (including control) through urea/diammonium phosphate (DAP), DAP/single superphosphate and muriate of potash, respectively. While full doses of P and K were applied as basal, 50% of the N dose was applied as basal and the remaining 50% top-dressed. After field preparation, maize crop was sown on 25 June 2011 with a crop spacing of 75 × 25 cm. The crop was irrigated as and when required, and was kept weed-free by hand weeding.

2.2. Soil sampling and analyses

Composite surface (0–15 cm) soil samples (i.e., 3 random core samples from each plot were thoroughly mixed together) were collected from each plot (i.e., replicate) at three physiological stages of the maize crop, viz. vegetative, tasselling, and grain filling. The composite samples were placed in plastic bags and brought to the laboratory, where field moist soil was sieved (2 mm mesh size),