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Growth, Metabolism and Yield of Rice Cultivated in Soils Amended with Fly Ash and Cyanobacteria and Metal Loads in Plant Parts

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Abstract: Soil amendment with fly ash (FA) and combined supplementation with N_2-fixing cyanobacteria masses as biofertilizer were done in field experiments with rice. Amendments with FA levels, 0, 0.5, 1.0, 2.0, 4.0, 8.0 and 10.0 kg/m^2, caused increase in growth and yield of rice up to 8.0 kg/m^2, monitored with several parameters. Pigment contents and enzyme activities of leaves were enhanced by FA, with the maximum level of FA at 10.0 kg/m^2. Protein content of rice seeds was the highest in plants grown at FA level 4.0 kg/m^2. Basic soil properties, pH value, percentage of silt, percentage of clay, water-holding capacity, electrical conductivity, cation exchange capacity, and organic carbon content increased due to the FA amendment. Parallel supplementation of FA amended plots with 1.0 kg/m^2 N_2-fixing cyanobacteria mass caused further significant increments of the most soil properties, and rice growth and yield parameters. 1000-grain weight of rice plants grown at FA level 4.0 kg/m^2 along with cyanobacteria supplementation was the maximum. Cyanobacteria supplementation caused increase of important basic properties of soil including the total N-content. Estimations of elemental content in soils and plant parts (root and seed) were done by the atomic absorption spectrophotometry. Accumulations of K, P, Fe and several plant micronutrients (Mn, Ni, Co, Zn and Cu) and toxic elements (Pb, Cr and Cd) increased in soils and plant parts as a function of the FA gradation, but Na content remained almost unchanged in soils and seeds. Supplementation of cyanobacteria had ameliorating effect on toxic metal contents of soils and plant parts. The FA level 4.0 kg/m^2, with 1.0 kg/m^2 cyanobacteria mass supplementation, could be taken ideal, since there would be recharging of the soil with essential micronutrients as well as toxic chemicals in comparative lesser proportions, and cyanobacteria mass would cause lessening toxic metal loads with usual N_2-fixation.

Key words: soil property; cyanobacteria; fly ash; growth; heavy metal; rice; toxic element; yield

The amount of fly ash (FA) generated by a thermal power station depends on the quality of used coal (Pluss and Ferrel, 1991), and, in India, comparatively more FA is generated per unit amount of coal because of low quality, compared to that in America (Warren and Dudas, 1984; Sen and Kumar, 1995; Haque, 2013). Moreover, the eco-friendly methods of disposal are not enough to sustainably manage/dispose the vast mass of FA generated in Indian conditions (Sen and Kumar, 1995), and those lie as unclaimed and burdened heaps at thermal power stations, with eventual contamination of adjacent rice fields (Mishra et al, 2007; Samy et al, 2010).

The rice field ecosystem in Asian countries, particularly in low lands, provides a flooded condition for three or four weeks before soil puddling and seedling transplantation, suitable for the natural growth of blue-green algae or cyanobacteria, which are unique

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for *in situ* aerobic N_2-fixation and contribute to the nitrogen economy of rice soil (Padhy, 1985; Paudel et al, 2012). This is the natural mechanism of recharging of rice soils with combined nitrogen sources in areas where chemical nitrogen fertilizers are not used. Firstly, algalization is the farm practice of separately growing N_2-fixing cyanobacterial mass for mixing them in soil during puddling before transplantation of seedlings (Nayak and Prasanna, 2007; Saadatnia and Riahi, 2009; Dash et al, 2015). Secondly, cyanobacteria have the capacity to invade, colonize and at times dominate at extremes of environmental nooks, for example, volcanic soils (Schmidt et al, 2008), and contribute to the process of soil binding as pioneer organisms.

Heavy metals (Fe, several micronutrients and toxic metals) are abundant in FA, with the deficiency of fixed C- and N-compounds (Martens et al, 1970; Parab et al, 2012). Several heavy metals are useful in minute quantities to plants and classified as micronutrients, which nonetheless are toxic at higher levels. Moreover, metal contents in FA are known to cause the enhancement of crop growth in amended soils. FA has been used in amending soils supporting several crops, rice, cabbage, barley, corn, alfalfa, til and a few more (Korcak, 1995; Mishra et al, 2005a, 2007; Samy et al, 2010), as a method of sustainable waste disposal and soil fertilization, worldwide (Dick et al, 2000).

N_2-fixing cyanobacteria can be used during amendment of rice soil with FA, for a supplementary N-nutrition. Obviously, the decay of grown cyanobacteria would help the soil in enrichment of C-compounds (Tripathi et al, 2008; Dash et al, 2015). Furthermore, cyanobacteria are known to be highly tolerant to heavy metals (Rai et al, 1981; Kiran and Thanasekaran, 2011). Thus, it is worthwhile to examine the value of algalization with commercially available cyanobacteria for growth and yield of rice as well as a check to the expected heavy metal contamination of soil and plant parts from FA. Further, it is an extension of earlier attempts in the use of FA with rice, green gram and til with estimations of heavy metal toxicity (Mishra et al, 2005a, b, 2007). Moreover, unwitting contamination of rice fields by FA-leachate near thermal power stations (Samy et al, 2010), especially in wet season each year, cause a fear of far-reaching health problems from the metal contaminations in India. Similar contamination from toxic metals in soils by FA-leachated from adjacent coal incinerating power stations should also be a commonplace problem in other Asian countries. As toxic metals are not degraded to innocuous substances, those get biomagnified in trophic levels and are the causes of metal poisoning in human body through food (Jan et al, 2011). Thus, it becomes logistically essential to examine combined effects of both amendants in experimental rice agriculture, for an aim to achieve a 'nutrient enrichment module with a waste material and a biofertilizer for rice fields', since FA is an intrinsic source of an array of wanted and unwanted elements for soil without any C- or N-compounds as well as both amendants might be mutually inclusive factors for holistic crop-soil nutrition. Such a module would be the disposal of an industrial waste sustainably for the most important crop, rice, used by more 50% people globally. About 50% rice-area globally is grown under intensive farming, which accounts for 75% global rice production (Samy et al, 2010), and about 80% farm-land in the wet season (*Khariff* crop) and about 35% farm-land in winter season (*Rabi* crop) are used for rice in India (Samy et al, 2010).

In this study, growth, metabolism and yield of rice, physical properties of soil, and heavy metal loaded in plant parts after simultaneous amendments of FA and cyanobacteria were recorded. Further, rice straw was routinely used in commercial cultivation of several popular edible mushroom varieties in India. Therefore, assessing heavy metal loaded in rice stem/whole plant would be regarded as a pertinent attempt.

MATERIALS AND METHODS

Analysis of fly ash and soil

The composition of electro-statically precipitated FA obtained from Talcher Thermal Power Station in Odisha, India, an unweathered condition, is as follows: sand, 15.5%; silt, 72.5%; clay, 13.0%; and pH, 7.4. The amounts of elements are (mg/kg): Na, 800; K, 840; Fe, 425; P, 68; Ni, 190; Co, 670; Pb, 20; Zn, 340; Mn, 450; Cu, 700; Cr, 505 and Cd, 131. About 30%–40% of FA is generated from the used coal in Odisha, India (Sen and Kumar, 1995).

The soil of the experimental field was sandy loam with pH 6.8, in a soil/water mixture at the ratio of 1:2.5. The electrical conductivity (EC) of soil samples 269 [μmol/(L·cm)] was determined by a digital conductivity meter (Digison model D1-909, Elico, Bombay, India). Nitrogen content (0.3%) was estimated with 8 g sun-dried soil by the Kjeldahl method