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Fly ash application in nutrient poor agriculture soils: Impact on methanotrophs population dynamics and paddy yields

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ABSTRACT

There are reports that the application of fly ash, compost and press mud or a combination thereof, improves plant growth, soil microbial communities etc. Also, fly ash in combination with farmyard manure or other organic amendments improves soil physico-chemical characteristics, rice yield and microbial processes in paddy fields. However, the knowledge about the impact of fly ash inputs alone or in combination with other organic amendments on soil methanotrophs number in paddy soils is almost lacking. We hypothesized that fly ash application at lower doses in paddy agriculture soil could be a potential amendment to elevate the paddy yields and methanotrophs number. Here we demonstrate the impact of fly ash and press mud inputs on number of methanotrophs, antioxidants, antioxidative enzymatic activities and paddy yields at agriculture farm. The impact of amendments was significant for methanotrophs number, heavy metal concentration, antioxidant contents, antioxidant enzymatic activities and paddy yields. A negative correlation was existed between higher doses of fly ash-treatments and methanotrophs number ($R^2=0.833$). The content of antioxidants and enzymatic activities in leaves of higher doses fly ash-treated rice plants increased in response to stresses due to heavy metal toxicity, which was negatively correlated with rice grain yield ($R^2=0.944$) and paddy straw yield ($R^2=0.934$). A positive correlation was noted between heavy metals concentrations and different antioxidant and enzymatic activities across different fly ash treated plots.The data of this study indicate that heavy metal toxicity of fly ash may cause oxidative stress in the paddy crop and the antioxidants and related enzymes could play a defensive role against phytotoxic damages. We concluded that fly ash at lower doses with press mud seems to offer the potential amendments to improving soil methanotrophs population and paddy crop yields for the nutrient poor agriculture soils.

1. Introduction

The rise in demand for power in domestic, agricultural and industrial sectors has increased the pressure on coal combustion and thus aggravated problem of fly ash (FA) generation/disposal. According to current estimates, the FA production may increase to ~170 million tons yr^{-1} by 2012, and 225 million tons by 2017 (Singh, 2012). Therefore, FA management remains the great concern of the current century. FA contains traces of toxic elements and heavy metals (Pandey and Singh, 2010), but also has some macro- and micro-nutrients and thus can be used as soil amendments/conditioner to boost the soil health and crop productivity (Singh et al., 2011). Toxic effect of FA is insignificant, and concentration of toxic elements within permissible limits at its low doses in some plantation work (Pandey et al., 2009). Hence, major initiatives have been taken in India and elsewhere to use such a cost effective resource in large volumes in agriculture (Lee et al., 2007; Pandey and Singh, 2010; Singh et al., 2011).

The Indian subcontinent has been affected worst by humans since long. This could be the reasons climate formations being altered and/or destroyed for paddy agriculture and even other similar purposes in the region. In the dry tropical region, low soil moisture status due to scanty rainfall and higher temperature affects soil functioning and paddy crop productivity (Singh et al., 2011). The soils of most of the dry-land rice agro-ecosystem are nutrient poor (Singh et al., 2010). It is here that micro-elements in the FA and press mud could be crucial to paddy crop productivity.

Abbreviations: ANOVA, Analysis of variance; APX, Ascorbate peroxidase; CAT, Catalase; DAS, Day after sowing; EDTA, Ethylene di-amine tetra acetic acid; EC, Electrical conductivity; FA, Fly ash; FYM, Farm yard manure; GSSG, Glutathione disulfide; NADPH, Nicotinamide adenine dinucleotide phosphate; MB, Methanotrophic bacteria; MMO, Methane mono-oxygenase; PM, Press mud; ROS, Reactive oxygen species; SPSS, Statistical package for the social sciences; SM, Soil moisture; NTPP, National thermal power plant; MPN, Most probable number; PVP, Poly vinyl pyrrolidone; GR, Glutathione reductase

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For achieving maximum crop productivity the importance has been attached to the application of FA, press mud (PM), farm yard manure (FYM) and other organic manures to conserve soil moisture and improve fertility of the nutrient poor agriculture soils (Odlare and Pell, 2009; Pandey and Singh, 2010).

Paddy is an important crop of Indian agriculture. Owing to the shrinking cultivable land resources, and the demand to produce more and more food per unit area, has made agriculture heavily dependent on chemical fertilizers. The indiscriminate use of chemical fertilizers affects soil health and, leads to a negative impact on soil productivity by eliminating diverse types of beneficial microorganisms such as methanotrophic bacteria (MB) (Singh et al., 2010). Thus for sustainable paddy agriculture, all our efforts should be streamlined to protect and sustain soil health. In this context, that FA amendment is gaining importance in rice agriculture (Singh et al., 2011).

FA contains heavy metals such as Cu, Ni, Cr, Cd, etc., that exhibit metal toxicity in plants (Lee et al., 2007; Pandey and Singh, 2010). These metals at supra-optimal condition become phytotoxic due generation of reactive oxygen species (ROS) and affect growth, development, and yield of the plants (Pandey et al., 2010). It is well known that heavy metals particularly redox metals may provoke oxidative stress with over production of ROS such as superoxide radicals (O_2^-), hydroxyl radicals (OH^-), hydrogen peroxide (H_2O_2) etc., (Foyer et al., 1997). The ROS react very rapidly with DNA, lipids and proteins causes the plant cell damage (Navari-Lazzo and Quartacci, 2001). The tolerance capacity of plants to heavy metals depends on an interrelated network of physiological and molecular mechanisms (Bah et al., 2011). One of the mechanisms that make a plant species tolerant to heavy metal stress is the presence of strong antioxidant defence system (Pandey et al., 2010). In response to oxidative stress due to heavy metal toxicity the plants produces antioxidants to detoxify ROS that includes carotenoids, ascorbate, glutathione, tocopherols, anthocyanins and antioxidants enzymes such as superoxide dismutase, catalase, glutathione peroxidise, peroxidase, as well as enzymes involved in the different antioxidants enzymatic cycles (Bah et al., 2011; Pandey et al., 2010; Upadhyay et al., 2012). Although, a number of experiments have been conducted to demonstrate the application of FA as a soil amender to enhance the crop productivity (Pandey et al., 2009, 2010; Singh et al., 2011), but the information regarding the antioxidative defense response in the paddy crop amended with FA is still in incipient stage. Therefore, a precise knowledge would be useful about the change in Cu, Ni, Cr and Cd, induced oxidant stress and enzymatic antioxidant system in rice plants.

FA is recognized as the useful resource and not just a waste, and could be the potential inorganic soil amendment to raise rice productivity and also to restore the soil nutrient balance in paddy soils (Lee et al., 2007). There are reports that the application of FA, compost and PM or a combination thereof, improves plant growth, soil microbial communities and their activities (Bougnom et al., 2010). Also, FA in combination with FYM or other organic amendments improves soil physico-chemical characteristics, rice yield and microbial processes in paddy fields (Pandey and Singh, 2010; Singh et al., 2011). However, the knowledge about the impact of FA inputs alone or in combination with other organic amendments on soil methanotrophic bacteria (MB) population in paddy soils is almost lacking.

MB are the only known biological sink for the potent greenhouse gas methane (Singh et al., 2010). Therefore, population size of MB in the paddy agro-ecosystem soil is the important factor in influencing the regional/global methane oxidation. With the FA input in soils, the physical and chemical changes within the soil first may affect the microbial communities including MB as the latter are the first to be exposed to the soil changes. However, the experimental proofs for influence of FA and organic manure application on MB population in faddy fields are lacking. Further, it is still to be ascertained whether the FA application alters the population structure of the MB. Therefore, estimates of the methanotrophic population in paddy agriculture soil could be the effective means of assessing the impact of FA inputs on rice productivity and so also the abundance of MB following such treatments.

The most important attribute, which makes FA and PM appropriate for farming, is its texture and the fact that it contains almost all the essential crop plant nutrients, the amendments improves the soil physico-chemical properties and microbial diversity (Kohli and Goyal, 2010; Singh et al., 2011). In view of this, it seemed important to assess the role of FA and PM amendments on soil physico-chemical properties, paddy crop yield and the methanotrophic population.

Keeping in view the implication of the FA application on the improvement of various soil microbial properties and crop yield, an experiments was conducted on dry land paddy field, with the objectives: (a) to assess the effect of FA and PM inputs on MB population, heavy metal contents, antioxidants, antioxidative enzymatic activities, paddy yields and, (b) to examine the statistical correlation between treatments, MB population and paddy crop productivity.

2. Materials and methods

2.1. Experimental sites and climate

This study was conducted at the agriculture farm (26°52′21″N; 80°57′20″E; 110 m msL) of the Department of Environmental Science, Babasaheb Bhimrao Ambedkar (Central) University, Lucknow, Uttar Pradesh, India. The soil was slightly alkaline, sandy loam, nutrient poor with moderate water holding capacity and grey in colour (Singh et al., 2010). Lucknow has a hot sub-tropical climate with warm summers and cool, dry winters. Summers (April to May) are quite hot with the temperature reaching 45 °C. Winters (December to February) are relatively cool with the maximum temperature 21 °C and minimum as low as 4 °C or even less. Fog formation is very often during the winter. The average annual rainfall ranged from 900 to 1100 mm during wet season of late June to October. However, during the last few years, it is extremely variable and random and at times, causing drought spells of varying degree and duration. The average monthly temperature and rainfall for the study area are presented in Fig. 1.

2.2. Set-up of experimental plots for paddy crop cultivation

Field experiments were conducted in the rainy paddy crop season (July to November 2010) adopting a high-yielding rice (*Oryza sativa*) variety HUBR 2–1 (Malviya Basmati Dhan 1). The rice variety is semi-dwarf, with stiff stems, has fairly strong tillering ability, and tolerant to several paddy diseases such as blast, bacterial leaf blight, stem borer etc. The dry-land rice variety used presently was from the Department of Genetics and Plant Breeding, Institute of Agriculture Sciences, Banaras Hindu University, Varanasi.

The methods for the preparation of experimental plots were according to our earlier investigations performed in the same area (Singh et al., 2010).

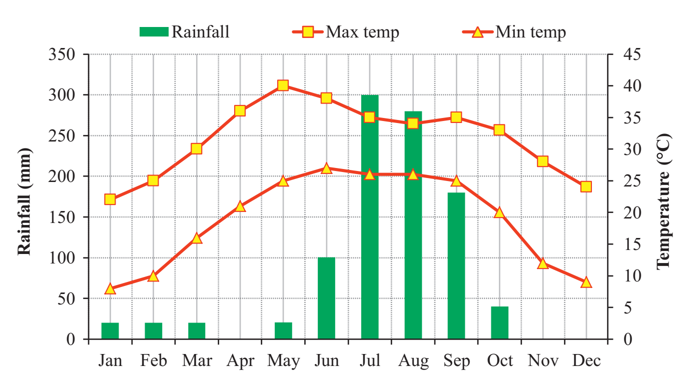

Fig. 1. Metrological data of study area during the year 2010.