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Original Research

Effect of Fly Ash as an Admixture in Agriculture and the Study of Heavy Metal Accumulation in Wheat (*Triticum aestivum*), Mung Bean (*Vigna radiata*), and Urad Beans (*Vigna mungo*)

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Abstract

A huge amount of fly ash is being generated from coal-based thermal power plants (TPPs). Fly ash is a waste product from TPPs that creates environmental problems due to improper utilization or disposal. Use of coal fly ash in agriculture is a good way to dispose of fly ash, and it will improve the yield of variety of agricultural crops. In the present study a pot experiment was carried out to study the effects of fly ash as an admixture in agriculture and on the growth and accumulation of heavy metals in wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*). In this the fly ash was applied at ratios of 10-60% (w/w). It was found that the application of fly ash enhances the seed germination rate considerably, whereas in the absence of fly ash (control) rate of seed germination was very slow. The use of fly ash as an admixture in agriculture up to 60% for the wheat (*Triticum aestivum*), 10-20% for mung bean (*Vigna radiata*), and 20% for urad beans (*Vigna mungo*) is suitable for maximum growth and yield. Cd, Cu, Fe, Mn, Mg Ni, Pb, and Zn were accumulated in the plants under study, but at very low concentrations and below the permissible limits provided for human consumption.

Keywords: fly ash, heavy metal accumulation, wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), urad bean (*Vigna mungo*)

Introduction

Coal is the most abundant, extensively used, and important source of energy for power generation in the world [1]. Among the total power generated annually in India, about 70% is produced by thermal power plants [2]. About 112 million tons of fly ash is being generated annually in India by thermal power plants [3] that will reach 170 million tons by the year 2012 [4]. The generation of fly ash depends on the type and ash content of the coal being used. Generally, lower quality coal is used in Indian power plants, which contains a high percentage of ash [5].

In India, studies have been carried out toward management of fly ash disposal and utilization [6, 7]. Fly ash is utilized in the cement and construction industries, with the remainder trucked to landfills or piped to settling ponds [8]. However, the rate of production is greater than consumption. The disposal of such a huge amount of fly ash is one of the major problems of developing countries. Dumping of fly ash affects the quality of the surface and ground water, soil, and vegetation of the area. Besides these, the use of fly ash in agricultural fields is a good alternative.

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Fly ash contains essential nutrients such as K, Ca, and Mg, which has an alkaline effect [9]. Amending such alkaline fly ash can reduce soil acidity at a certain level and it is suitable for agriculture [10], and it can increase the availability of important nutrients [11]. The use of fly ash can promote plant growth by increasing soil conductivity, organic carbon contents, and microbial activity [12], soil porosity and water holding capacity [13]. Fly ash contains essential nutrients for plant growth and it can be used as a fertilizer to complete the deficiencies of several elements. Fly ash application in agricultural soil has shown promising results in crop production due to its high mineral contents and unique physicochemical properties [14]. The application of fly ash changes the soil properties and it may increase or decrease crop yields [4].

Fly ash contains a high concentration of toxic heavy metals such as Cu, Zn, Cd, Pb, Ni, Crs, etc. [15]. Concentrations of heavy metals in various ecosystems has increased in recent decades [16]. Heavy metals can bioaccumulate in the environment and may have toxic effects on human health. Heavy metal accumulation in agriculture is a great concern with respect to environmental and food safety. Fly ash contains toxic heavy metals that may accumulate in plant bodies and may enter the food chain. Therefore, study of the application of fly ash as a soil amendment in agriculture is important.

In the present study an attempt has been made to evaluate the effect of fly ash as an admixture on plant growth in agriculture and the study of heavy metal accumulation in wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*).

Experimental Procedures

All chemicals and reagents used in this research work were of analytical reagent grade supplied from Fischer Scientific India. De-ionized water was used for the preparation of solutions and analysis throughout the research work. The concentration measurements of the heavy metals were carried out with an atomic absorption spectrophotometer (Thermo Scientific, U.K. make, Solaar S series model). The pH measurements were done with an electronic pH meter (Elico LI 120), calibrated with standard buffer solutions.

The fly ash investigated in this study was obtained from the Bhusawal thermal power plant, which uses the pulverization technique for the incineration of coal. The incineration temperature in the combustion chamber was between 1,000º and 1,400ºC. The fly ash was sampled from the electrostatic precipitator of the plant. The sampling period represented normal process conditions for the plant. A coning and quartering method was applied repeatedly to reduce the wet ash sample to a size suitable for laboratory analysis. After sampling, the sample was stored in a polyethylene bottle in a refrigerator (4ºC).

A black cotton soil was collected and it was churned for further study. The fine fly ash was mixed with soil in the ratios of 10%, 20%, 30%, 40%, 50%, and 60% in w/w proportion. 7 pots were plotted, including one control for each crop. Three crops were selected, i.e. wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*). The height of each plant was recorded properly at each 5-day interval. The study was continued for one month and after one month these plants were taken for the heavy metal accumulation study.

To study the heavy metal accumulation by plants, the plants were oven dried (110ºC) for 24 h. The different parts of the plants were separated and mechanically ground. The ground samples (0.3 g) were digested in 1:3 HNO_3 and HCl mixture. Digested samples were filtered through Whatman filter paper (No. 42) before metal analysis, and the concentration of metals were determined on an atomic absorption spectrophotometer.

Results

The physicochemical properties and the heavy metal contents of fly ash depend on the parent coal composition from which it is produced and on its coal combustion conditions [3]. It is difficult to generalize the composition of ashes due to the varying nature of coal. Fly ash contains approximately 95-99% oxides of Si, Al, Fe, and Ca, and about 0.5 to 3.5% of Na, P, K, and S [17]. Fly ash consists of minute glass-like particles of 0.01 to 100 mm size [18]. Physicochemical properties and heavy metal content of soil and fly ash are shown in Table 1.

Discussion of Results

Physicochemical Properties of Soil and Fly Ash

Fly ash is generally gray in colour and mostly alkaline in nature. It was found that the pH of the soil and fly ash is 9.2 and 8.1, respectively. The alkaline pH of fly ash may be due to the presence of Ca, Na, and Mg, along with other trace metals. CaO is a major constituent of the fly ash that forms $Ca(OH)_2$ with water and thus attributes to alkalinity [19]. Acidic soil can be neutralized by the addition of fly ash because it contains hydroxide and carbonate salts, which have the ability to neutralize the soil [20]. Fly ash has higher electrical conductivity (0.220 mhos/cm) than soil (0.082 mhos/cm). This property will help increase the conductivity of the soil. The bulk density of the fly ash is 1.17 gm/cm^3. Fly ash has less organic matter (1.96%) compared to soil (17.68%). All the metals present in soil are also present in the fly ash, but in a higher amount as compared to soil. Fly ash contains all the important metals needed for plant growth and metabolism.

Effects of Fly Ash Application on Plant Growth

The fly ash disposal problem can be solved by the application of fly ash in agriculture, which would also it will save the large amount of land required for landfilling.

Table 1. Physicochemical characteristics of soil and fly ash.

Parameter	Soil	Fly Ash
pH	8.1	9.2
Conductivity	0.082 mhos/cm	0.220 mhos/cm
Bulk Density	0.951 gm/cm^3	1.17 gm/cm^3
Moisture	13.6 %	2.3 %
Alkalinity	8.5 m eq/10gm	3.5 m eq/10gm
Chloride	0.0127%	0.099%
Organic Matter	17.68%	1.96%
Nitrate	0.096%	0.106%
Phosphate	0.35%	0.03%
Na (exchangeable)	2.38%	0.684%
K (exchangeable)	2.78%	0.279%
Ca	0.257 %	0.428%
Total heavy metal content of soil and fly ash (Concentration in %)		
Cd	BDL	0.004
Cu	0.008	0.014
Fe	0.159	0.500
Mn	0.017	0.066
Mg	0.182	0.262
Ni	0.008	0.011
Pb	BDL	0.004
Zn	0.049	0.039

BDL – below detectable level

Generally, fly ash application in soil increases nutrient uptake [21]. Soil texture, bulk density, and water-holding capacity of the soil can be changed by the addition of fly ash [22].

The experiment was carried out in a laboratory using various ratios of fly ash such as 0%, 10%, 20%, 30%, 40%, 50%, and 60%. Normal soil without fly ash addition was treated as control. For this study three types of plant species were selected: wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*). The data of these plants was collected for one month.

The application of fly ash in agriculture resulted in higher germination rates. Experimentally it was found that the application of fly ash enhances the seed germination rate considerably, whereas in the absence of fly ash (control) rate of seed germination was slow. Germination rate of wheat seeds was decreased with the increasing application ratio of fly ash as compared to control. This might be due to the higher concentration of trace elements such as Cu, Co, Ni, Se, Al, and Cr, etc. at higher application rates, which delayed or inhibited the process [23]. A higher germination rate was observed in case of mung and urad, with the increasing application ratios of fly ash, maximum germination was observed at 60% fly ash application. The germination rate of mung and urad was delayed by 1 day in the case of control as compared to the higher application rate of fly ash.

The growth obtained for wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*) is shown in Fig. 1.

Fig. 1 (a) shows the growth of wheat (*Triticum aestivum*). In this case the growth of the plant was slower ini-

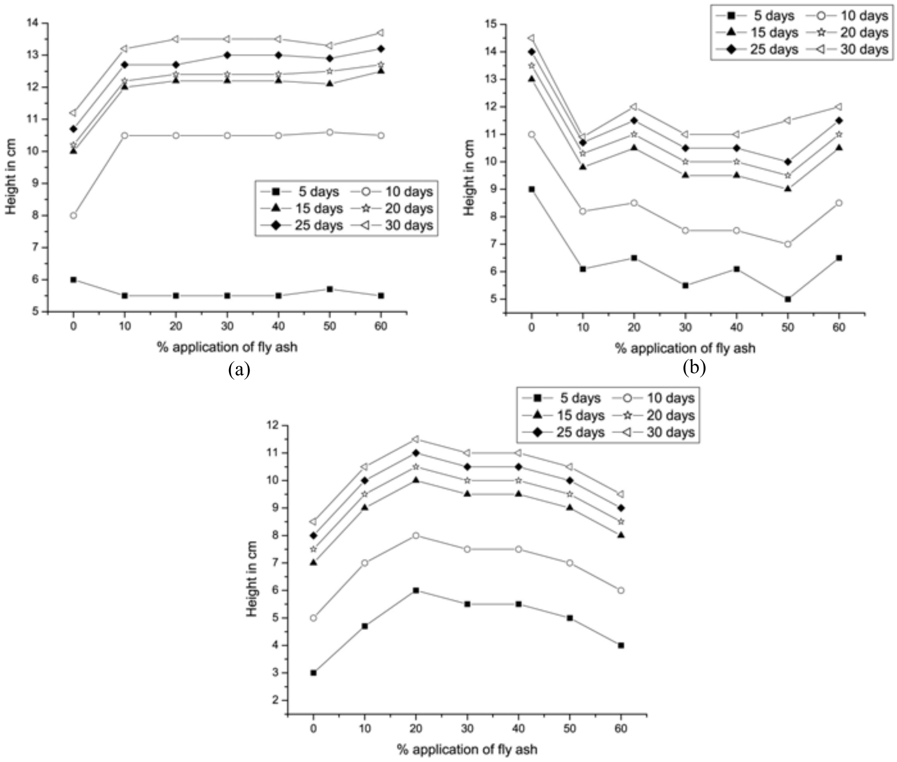


Fig. 1. Growth rate in (a) wheat (*Triticum aestivum*), (b) *mung bean* (Vigna radiata), (c) urad beans (*Vigna mungo*)

Table 2. Heavy metal uptake by wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*) at different fly ash application ratios.

Element	Crop	Control	10%	20%	30%	40%	50%	60%
Cd	Wheat	BDL	BDL	BDL	0.0013	0.0017	0.0031	0.0043
	Mung beans	BDL	BDL	BDL	BDL	0.0011	0.0023	0.0037
	Urad beans	BDL	BDL	BDL	0.0021	0.0029	0.0033	0.0047
Cu	Wheat	0.0064	0.0061	0.0067	0.0089	0.0119	0.0131	0.0157
	Mung beans	0.0089	0.0071	0.0066	0.0097	0.0129	0.0151	0.0183
	Urad beans	0.0071	0.0063	0.0073	0.0081	0.0121	0.0148	0.0161
Fe	Wheat	0.1431	0.0159	0.1258	0.1569	0.2139	0.2771	0.3891
	Mung beans	0.1143	0.0109	0.1387	0.1391	0.2363	0.2897	0.3354
	Urad beans	0.1236	0.1136	0.1345	0.1492	0.2231	0.2653	0.3539
Mn	Wheat	0.0083	0.0069	0.0089	0.0109	0.0391	0.0698	0.0971
	Mung beans	0.0079	0.0095	0.0013	0.0185	0.0283	0.0568	0.0832
	Urad beans	0.0051	0.0072	0.0079	0.0117	0.0279	0.0424	0.0528
Mg	Wheat	0.1073	0.1036	0.1379	0.1481	0.2521	0.3167	0.3983
	Mung beans	0.1182	0.1251	0.1275	0.1364	0.2352	0.3367	0.4129
	Urad beans	0.1203	0.1178	0.1267	0.1399	0.2151	0.2793	0.3478
Ni	Wheat	0.0051	0.0069	0.0061	0.0093	0.0109	0.0129	0.0131
	Mung beans	0.0038	0.0053	0.0057	0.0083	0.0113	0.0135	0.0148
	Urad beans	0.0049	0.0041	0.0053	0.0081	0.0128	0.0135	0.0142
Pb	Wheat	BDL	BDL	BDL	BDL	0.0019	0.0021	0.0047
	Mung beans	BDL	BDL	BDL	0.0012	0.0027	0.0033	0.0039
	Urad beans	BDL	BDL	BDL	BDL	0.0016	0.0025	0.0032
Zn	Wheat	0.0112	0.0147	0.0179	0.0278	0.0373	0.0399	0.0437
	Mung beans	0.0137	0.0127	0.0159	0.0236	0.0321	0.0379	0.0482
	Urad beans	0.0113	0.0142	0.0166	0.0253	0.0299	0.0327	0.0467

Concentrations in µg/g; BDL – below detectable limit

tially at the high application rate of fly ash as compared to control, but after 10 days it was observed that the growth of wheat (*Triticum aestivum*) was increasing with increased leaf area and plant height as compared to control. The growth of wheat (*Triticum aestivum*) is about same for all 10-60% fly ash application pots. Hence it can be concluded that up to 60% application ratios, fly ash is suitable in agriculture for maximum growth and yield of wheat (*Triticum aestivum*).

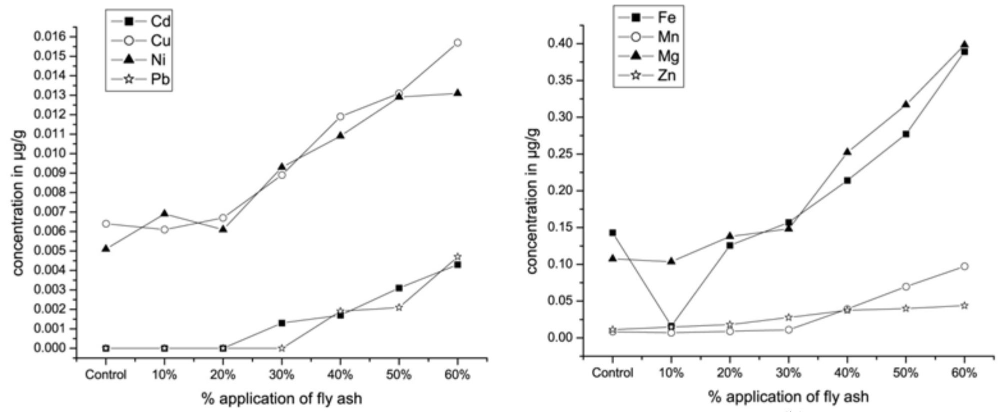
Fig. 1 (b) shows the growth of mung bean (*Vigna radiata*). In this case the growth of the plant is slower at the high application rate of fly ash as compared to control. It was observed that the growth of mung bean (*Vigna radiata*) was slow as compared to control. Plant height was reduced in the case of mung bean (*Vigna radiata*), but the leaf area was increased over control. Hence it can be concluded that the application of fly ash reduces stem height but does not affect plant growth. 10-20% fly ash can be applied for maximum growth and yield of the mung bean (*Vigna radiata*).

Fig. 1 (c) shows the growth of urad beans (*Vigna mungo*). In this case the growth of the urad bean (*Vigna mungo*) plant increased at higher application rates of fly ash. The maximum growth of urad beans (*Vigna mungo*) was achieved by 20% fly ash the application. Though the growth of the plant was good even at the application rate of 60% as compare to control, the application rate of 30% and above this the growth of the urad beans (*Vigna mungo*) was inhibited with a decrease in plant height and leaf area. Hence it can be concluded that the 20% application ratio of fly ash is suitable in agriculture for the maximum growth and yield of urad beans (*Vigna mungo*).

Effects of Fly Ash Application on Heavy Metal Uptake by Plants

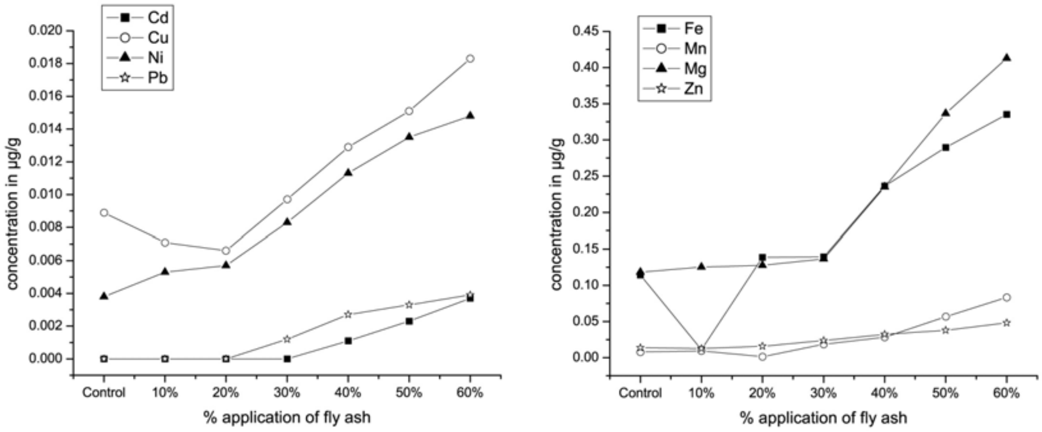
The effects of fly ash application on the uptake of various nutrients and heavy trace elements in various crops have been studied for the safe use of crops produced for human consumption. Accumulation and translocation of heavy metals depends on fly ash application ratios. Lower ratios of fly ash application showed positive results in growth and yield as compared to control [24]. Metal availability in soil, rather than total metal concentration, is the main concern, because it has been reported that the available metal concentration is an indication of the amount available for plant uptake. Table 2 shows the heavy metals uptake observed in wheat (*Triticum aestivum*), mung bean (*Vigna radiata*), and urad beans (*Vigna mungo*).

Fig. 2 shows heavy metals accumulation in wheat (*Triticum aestivum*) at different application ratios of fly ash. From the growth results it was found that at up to 60% application ratios the fly ash is suitable in agriculture for the maximum growth and yield of wheat (*Triticum aestivum*). At the 60% fly ash application rate Fe was accumulated at



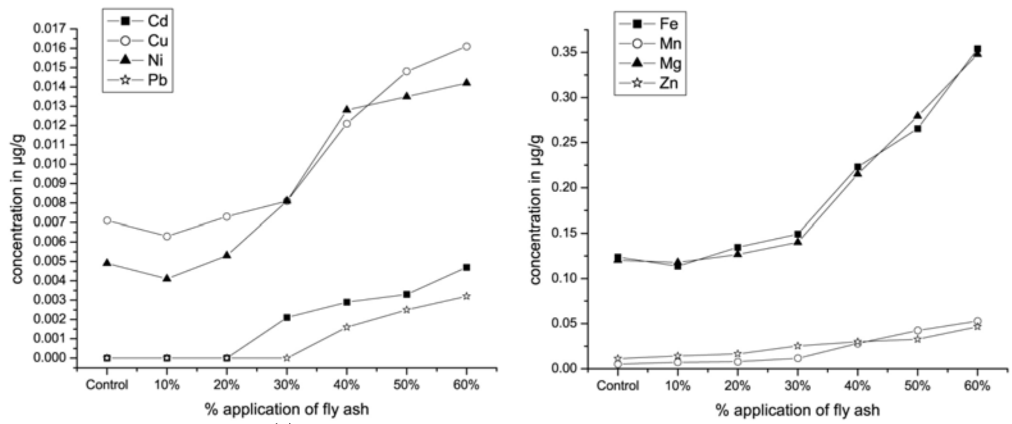
(a) (b)

Fig. 2. (a) Uptake of Cd, Cu, Ni, and Pb by wheat (*Triticum aestivum*); (b) Uptake of Fe, Mn, Mg, and Zn by wheat (*Triticum aestivum*).



(a) (b)

Fig. 3. (a) Uptake of Cd, Cu, Ni, and Pb by mung bean (*Vigna radiata*); (b) Uptake of Fe, Mn, Mg, and Zn by mung bean (*Vigna radiata*).



(a) (b)

Fig. 4. (a) Uptake of Cd, Cu, Ni, and Pb by urad beans (*Vigna mungo*); (b) Uptake of Fe, Mn, Mg, and Zn by urad beans (*Vigna mungo*).

the higher concentration but not above the permissible limits of Indian standards and WHO. The other heavy metals under study were also accumulated in wheat (*Triticum aestivum*), but below the permissible limits for human consumption. Therefore, the use of fly ash as an admixture up to 60% in agriculture for wheat (*Triticum aestivum*) is safe.

Fig. 3 shows the comparison between heavy metals accumulated in mung bean (*Vigna radiata*) at different applied concentrations of fly ash. From the growth results it was found that only 10-20% application ratios of fly ash are suitable in agriculture for maximum growth and yield of mung bean (*Vigna radiata*). At this application rate Cd and Pb was not accumulated in the plant, and Cu, Mn, and Ni was accumulated but at low concentrations. Fe, Mg, and Zn were accumulated at higher concentrations as compared to control, but not above the permissible limits of Indian standards and WHO. Therefore, the use of fly ash as an admixture up to 10-20% in agriculture for the mung bean (*Vigna radiata*) is safe.

Fig. 4 shows a comparison between heavy metals accumulated in urad beans (*Vigna mungo*) at different applied concentrations. From the growth results it was found that up to 20% application ratios of the fly ash are suitable in agriculture for the maximum growth and yield of urad beans (*Vigna mungo*). At this application rate Cd and Pb was not accumulated in the plant, and Cu, Fe, Mn, Mg, Ni, and Zn were accumulated at higher concentrations as compared to control, but not above the permissible limits of Indian standards and WHO. Therefore, the use of fly ash as an admixture up to 20% in agriculture for the urad beans (*Vigna mungo*) is safe.

Our heavy metal accumulation study shows that the application of fly ash in agriculture does not adversely affect plant growth, rather it enhance the quality and growth of plants.

Conclusions

From this study the following conclusions can be drawn,

- It was found that the application of fly ash enhances the seed germination rate considerably, whereas in the absence of fly ash (control) the rate of seed germination was very slow.
- The use of fly ash as an admixture in agriculture up to 60% for wheat (*Triticum aestivum*), 10-20% for mung bean (*Vigna radiata*), and 20% for urad beans (*Vigna mungo*) is suitable for maximum growth and yield.
- Cd, Cu, Fe, Mn, Mg Ni, Pb, and Zn were accumulated in the plants under study, but at low concentrations and below permissible limits for human consumption.

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