Optimizing Soil and Crop Productivity Using Coal Fly Ash: A Study from Chhattisgarh, India

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Abstract: The uppermost layer of earth is called soil whereas the coal fly ash is byproduct generated by coal combustion in thermal power plants. India has got rich deposits of coal in which Chhattisgarh and contributes 15% of total coal cover of the country. The easy availability of coal in very low cost makes it the most useable and demandable fuel of the century. The agricultural soil and the coal fly ash have clear difference in their physicochemical properties and can subside their mutual deficiencies together. The waste byproduct coal fly ash has been recently recognized as a soil modifier. It has been investigated indifferent countries around the world and confirmed that coal fly ash has ability to alter the physical properties of soil providing better soil quality and yielding capacity due to its morphological and chemical features. Coal is the major source for energy production in Chhattisgarh, India hence there is no chance to flip the coin; we have to bear the hazardous byproducts with the valuable benefits of coal combustion. The only option left behind is to use this byproduct judicially in profitable manner to subside its ill elects of dumping in soil which give rise to various problems regarding soil health, environment quality and economics related to yield as the poor soil health results in less crop production. This paper deals with the physcio-chemical properties of soil and coal fly ash and evaluates the potential of coal fly ash as a soil conditioner with the approach to use a waste byproduct in a beneficial way for modifying the Physico-chemical properties of soil and utilize it in form of secondary source of fertilizer.

Key words: byproduct, Coal combustion, coal fly ash, , secondary source of fertilizer, soil modifier.

Introduction: In recent decades the rise in population in many folds had raised the industrialization along with need and demand of energy. The non -renewable resources for production of energy are decreasing at a remarkable rate hence demand for alternative fuel has risen up, in the same concern fossil fuel coal due to its availability on abundance ,long and easy storage, cost effective designate it as a fuel of the century. Thus, use of coal is an unavoidable deed the amount of coal burned will generate number of byproducts and residues in return which can pollutes air, water and soil in one or the other way and require large area, men power and energy for its proper management and safe disposal. The scientists had studied the structure, physical and chemical properties of coal fly ash and found that it has potential to modify the physcio-chemical properties of soil and can be used as soil modifier (Sikka and Kansal, 1995; Gangloff *et al.* 2000; Kalra *et al*. 2000; Gupta *et al*. 2006; Mishra *et al.* 2007). During combustion of coal all its constituent including macro and micro nutrients get condensed in form of ash and make it rich in chemical cover. After investigations and series of experiments many scientists reveled that coal fly ash in lower concentration could be beneficial for promoting growth and quality of many crop plants and has sound potential to be used as a cheap source of soil conditioner (Ghuman *et al.* 2006; Skousen *et al.* 2013; Gorai 2018).

The coal fly ash was considered as a waste but now it is catching the eye of scientists all over the world. Its disposal was the most problematic question of the century. Scientists and environmentalist are searching every possible aspect to reduce the burden of waste byproduct generated from coal combustion the coal fly ash. On earth, 70-75% of total coal combustion byproduct is coal fly ash hence the search was started to use this byproduct in all possible ways. The suggested use of fly ash includes construction of road, as liming material, use in combination with cement but when fly ash was examined morphologically and its properties were investigated it was found that it has immense capacity to change the physical properties of soil. It was found that coal fly ash has many macro and micro nutrients with its unique structure which can permanently change the physical properties of soil including its texture. The coal fly ash can alter the physical properties of soil like bulk density, particle density,porosity, moisture retention capacity and water holding capacity of soil in a beneficial way for soil health and growth of crop plants (Gangloff *et al*. 2000; Dzantor *et al*. 2013; Pradhan 2017). It can be used as soil modifier for reclamation of soil. Still the use of coal fly ash is not up to the speed needed in comparison to other developed countries like China, America, Germany and France. In India the industrialization has been increased in tremendous speed in last decades to make nation self -sufficient, establishing the concept of make in India. As the number of industries increases in the country the power demand also increases along with the industrialization and urbanization as the parallel consequences of development. Thermal power plants are the life line of the country to fulfil the increased demand of energy which is result of rise in population and industries in the country, these thermal power plants are based on coal combustion for production of energy which are generating coal combustion byproducts in an exceptionally large quantity requiring huge land area and ponds for its management. The safe disposal of coal fly ash had risen as a question of the decade. Some appropriate measures are immediately needed for its safe disposal and means of its utilization for sustainable management of this waste (Singh *et al*. 2010). In recent researches it has been noted that coal fly ash has soil amending, nutrient enriching and capabilities for reducing deficiencies of soil. Addition of coal fly ash increases the content of P, K,Ca, B, Mg, Zn, carbonated, bicarbonates and sulphates (Khan *et al*. 1996; Yunusa *et al*. 2006). Fly ash provides vital nutrients and minerals to crops so it can be used as potential fertilizer (Tiwari *et al*. 2016). Fly ash has ability to change the pH, electrical conductivity and chemical constitution of soil (Gupta *et al*. 2002; Skousen *et al*. 2013; Tejasvi 2017). This study was aimed to evaluate the potential of coal fly as amendment agent and to investigate its effect on physical and chemical properties of soil to and establish its use in form of a soil modifier.

MATERIALS AND METHODS:

Collection of samples

i. Collection and preparation of soil: The top most layer of soil from the agricultural fields of Raipur, Chhattisgarh up to depth of 25 cm was taken and filled in the collecting pots for the proposed investigations. The soil was air dried for two days in sunlight during the day time and in the shade during night, then sieved through the 2 mm sieve and packed in polythene bags for proposed investigations.

ii. Collection and preparation of coal fly ash: The coal fly ash for the investigation in this study was collected from ACC cement factory of Jamul, Durg district of Chhattisgarh. The fly ash collected was air dried for 2 days and passed through the 2 mm sieve and packed in separate air tight zip bags to prevent moisture absorbance.
In present investigation nine treatments of experimental soil with control were designed. The details constituents of each treatment have been described as follows:

C = 100% soil (Control)
T_1 = 5% Fly ash + 95% Soil
T_2 = 10% Fly ash + 90% Soil
T_3 = 15% Fly ash + 85% Soil
T_4 = 20% Fly ash + 80% Soil
T_5 = 25% Fly ash + 75% Soil
T_6 = 50% Fly ash + 50% Soil
T_7 = 75% Fly ash + 25% Soil
T_8 = 100% Fly ash

Then in the soil of these treatments the physical and chemical properties of the soil were determined for the selected parameters.

i. Texture: Texture of soil was measured by the total percentage of sand, silt and clay particles present in it. Particle size distribution of fly ash treated soil samples were assessed by following the method of Misra *et al.* (1970). Soil textures were determined by following soil texture triangle proposed by Palmer and Troeh (1977).

ii. Bulk density and particle density: Bulk density is the measure of oven dried mass per unit volume of soil with air spaces preserved with them. While particle density is the measure of oven dried mass per unit volume of soil without any air spaces in it and the values were expressed in g cm^{-3}.Bulk density and particle density of soil sample in all treatments were determined respectively by following the method of Black and Hartge (1986).

iii. Porosity (%) and soil solids (%): Porosity is the measure of number of pores in the total volume of soil, while soil solid is the total percentage of soil particles present in the total volume of soil. Porosity (%) and soil solids (%) were calculated in soil samples of all the treatments by following the methodology of Misra *et al.* (1970).

iv. Water holding capacity (WHC): Water holding capacity of soil is defined as the amount of water, which the soil can hold. Water holding capacity was estimated by following the method of Pandeya *et al.* (1968).

Chemical characteristics coal fly ash ameliorated soil samples: The chemical properties of experimental soil from different coal fly ash treatments were analyzed including the hydrogen ion concentration (pH), electrical conductivity and total dissolved salts.

i. Hydrogen ion concentration (pH): Hydrogen ion concentration is the measure of its acidity, which is measured in terms of pH having range of 0-14. A neutral solution has a pH 7.0, an acidic solution has pH less than 7.0 and an alkaline solution has pH greater than 7.0. Hydrogen ion concentration was estimated by the methods given by American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), (1992). Hydrogen ion concentration (pH) of soil samples of various treatments were determined by using digital pH meter after standardization of instrument with a buffer solution of 7.2 pH.

ii. Electrical conductivity: Electrical conductivity of soil is the measure of the amount of salts in soil. It is the ability is of soil to conduct electric current. Electrical conductivity of soil samples from all the treatments and control wereestimated by using conductivity meter by the methods prescribed by American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), (1992) and the results obtained were expressed in mS cm^{-1}.

iii. Total dissolved salts: Total dissolved salts in soil comprises of all-inorganic salts and small amount of organic matter present in liquid, molecular, ionized or small granular suspended form when soil is dissolved in water. Total dissolved salts in soil sample of all the treatments were determined by using digital salinity meter and was expressed in mg kg^{-1}, it was estimated by following the methods prescribed by American Public Health Association (APHA), American Water Works Association (AWWA) and Water Environment Federation (WEF), (1992).

Results & Discussion: The comparison of physico-chemical properties of coal fly ash and agriculture soil is done and following results are obtained. In physical characteristics of soil like texture, bulk density, particle density, porosity, soil solids and water holding capacity of soil and coal fly ash were analyzed. The soil used in experiment was found to be sandy loam texture class with 54.5% sand, 32.3% silt and 13.2% clay and coal fly ash was found to consist of silty clay texture class with 51.9% silt, 30.8% clay and 17.3% sand. Bulk density of soil was determined 1.49 g cm^{-3} and for coal fly ash 1.14 g cm^{-3}. The particle density was observed 2.74 g cm^{-3} in soil and 2.42 g cm^{-3} in coal fly ash. The porosity was observed 45.62% in soil and 52.89 % in coal fly ash. Soil solids (%) were observed 54.37 in soil and 47.10 in coal fly ash. The water holding capacity of soil was estimated 37.12% and of coal fly ash was 58.48%. (Table 1; Figure 1and 2). Similar results were obtained by Vijayan and Behera (1999); Gupta *et al.* (2002); Sharma *et al.*, (2002); Mishra *et al.* (2007); Shrivastava(2008); Surbhi (2017).

Table 1: Physico-chemical characteristics of soil and coal fly ash.

S. No.	Physico-chemical characteristics	Soil	Coal fly ash
1	Texture	Sandy loam	Silty clay
2	Bulk density (g cm^{-3})	1.49	1.14
3	Particle density (g cm^{-3})	2.74	2.42
4	Porosity (%)	45.62	52.89
5	Solids (%)	54.37	47.10
6	Water holding capacity (%)	37.12	58.48
7	Hydrogen ion concentration (pH)	7.31	5.52
8	Electrical conductivity (mS cm^{-1})	0.26	0.49
9	Total dissolved salts (mg kg^{-1})	272.8	398.3

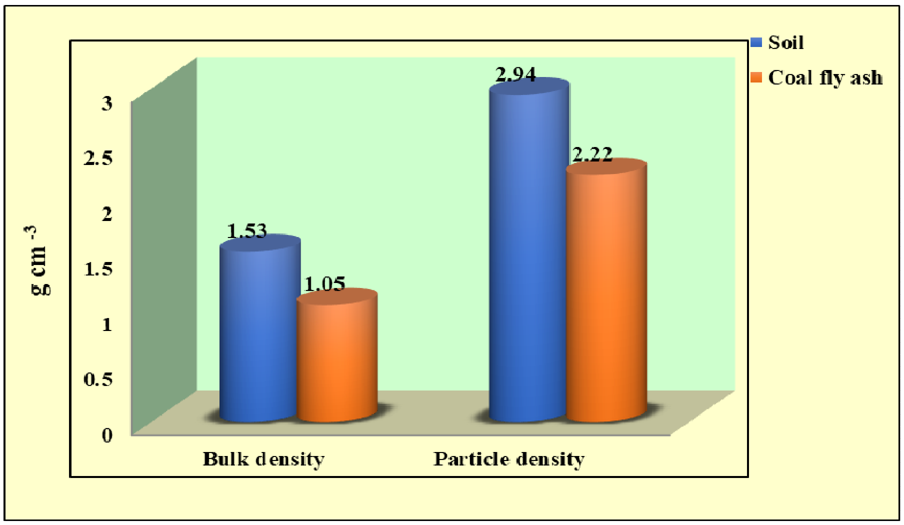

Figure 1 : Bulk density, particle density of soil and coal fly ash

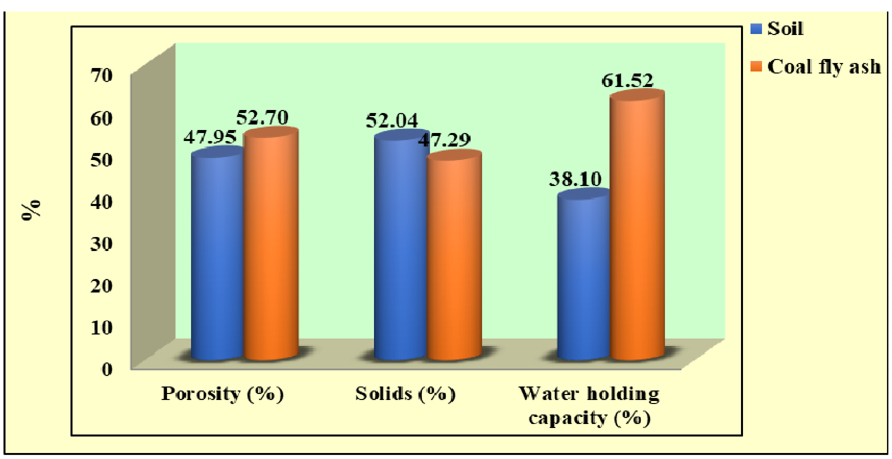

Figure: 2 Porosity, solids and water holding capacity of soil and coal fly ash

Chemical characteristics of soil and coal fly ash: Chemical characteristics of soil and coal fly ash viz. hydrogen ion concentration (pH), electrical conductivity, total dissolved salts were analyzed. The pH of soil and coal fly ash was determined7.31 and 5.52 respectively. 026 mS cm^{-1} electrical conductivity was determined in soil and 0.49mS cm^{-1} in coal fly ash. Total dissolved salts were estimated 272.80 mg kg^{-1} in soil and 398.30 mg

kg^{-1} in coal fly ash. (Table 1; Figure 3). These results were in accordance with results founded by Sharma *et al.*, (2002); Shrivastava (2008); Szponder and Trybalski (2011); Skousen *et al.* (2013); Tejasvi (2017); Gorai (2018).

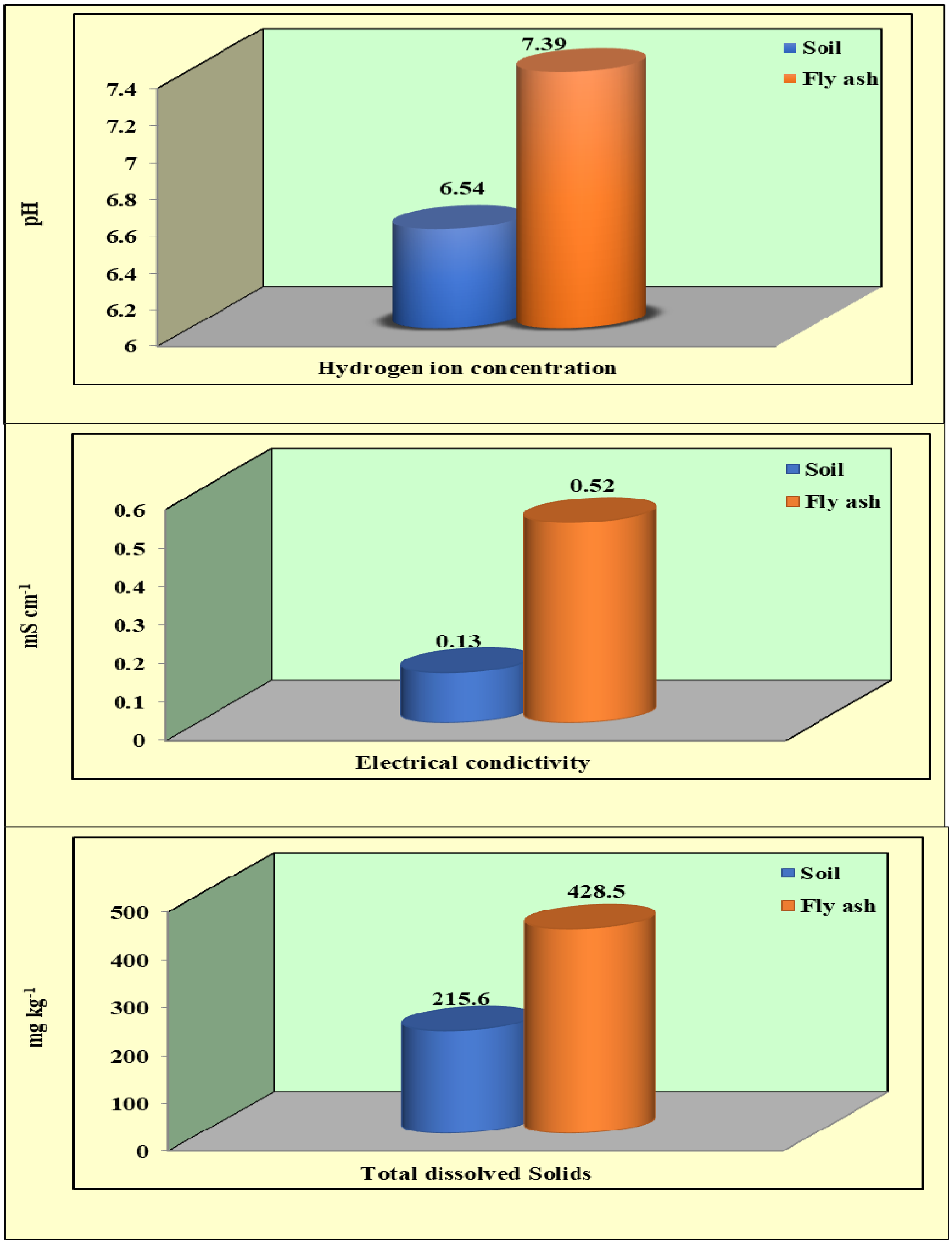

Figure 3: Hydrogen ion concentration, electrical conductivity and total dissolved solids of soil and coal fly ash

Physical characteristics of soil and coal fly ash:

Results for alteration in physical properties of soil: The results obtained by the analysis of soil of various treatments and coal fly ash reveled that coal fly ash can alter the physical and chemical properties of soil in a beneficial way for soil wellbeing along with its nutrient and structural modification.

i. Texture: Sandy loam texture of soil was observed in Control (C) and Treatment T_1 to $T_4$of soil sample, Silty sand texture was found in T_5 and Silty clay texture was obtained in $T_{6,}$ $T_{7,}$ T_8 treatments of soil. A gradual change in texture of soil from sandy loam (Control to Treatment T_4) to silty clay (T_5 to T_8) was observed (Table 2). This was similar to findings of Fail and Wochok (1977), Aitken *et al*.(1984), Summer *et al*.(1998) and Mishra *et al*.(2005).

Table 2: Texture of coal fly ash ameliorated soil.

S. No.	Treat-ments	Fly ash %	Sand (%)	Silt (%)	Clay (%)	Textural class
1	C	0	62.1	26.2	11.7	Sandy loam
2	T_1	5	58.2	29.3	12.5	Sandy loam
3	T_2	10	53.4	32.5	14.1	Sandy loam
4	T_3	15	49.6	34.2	16.2	Sandy loam
5	T_4	20	42.4	38.4	19.2	Sandy loam
6	T_5	25	36.2	40.7	23.1	Silty sand
7	T_6	50	26.1	45.2	28.7	Silty clay
8	T_7	75	18.4	49.1	31.5	Silty clay
9	T_8	100	11.1	53.3	34.6	Silty clay

ii. Bulk density and particle density: The bulk density decreased with increasing coal fly ash amount in the soil. Maximum bulk density was determined in C soil (1.53 g cm^{-3}) and minimum in T_8 (1.05 g cm^{-3}). Rest of the ameliorated soil recorded an intermediate value (Table 3; Figure 4). The results are in accordance with findings of Adriano *et al*. (1980), Kene *et al*. (1991) and Gupta *et al*. (2002).

The particle density decreased with increasing coal fly ash amount in the soil. Maximum particle density was observed in C soil (2.94 g cm^{-3}) and minimum was found in T_8 (2.22 g cm^{-3}). Rest of the ameliorated soil recorded an intermediate value (Table 3; Figure 4). Similar findings were obtained by Prabhaker *et al*. (2004)

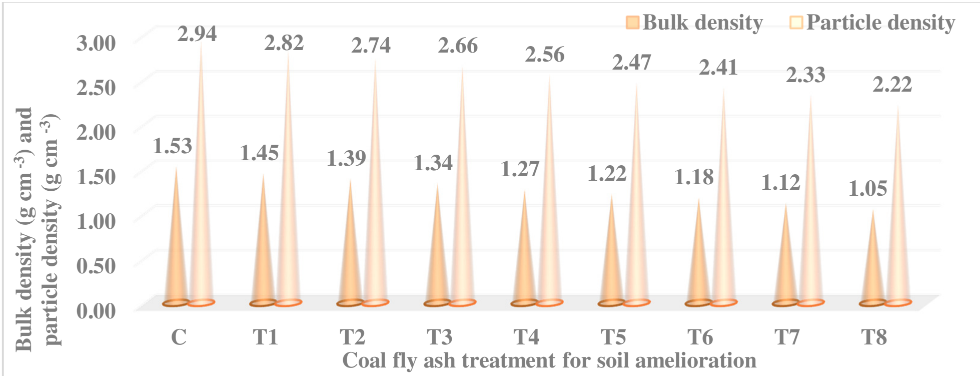

Figure 4: Bulk density and particle density of coal fly ash ameliorated soil.

iii. Porosity (%) and soil solids (%): Porosity was found to increase with increasing amount of coal fly ash in the soil. The maximum porosity was determined in T_8 (52.70%) and minimum was obtained in C(47.95%) soil. Rest of the ameliorated soil recorded an intermediate value (Table 3, Figure 5). These results are in accordance with Kene *et al*. (1991) and Vijayan and Behera (1999).

Soil solids (%) decreased with increasing amount of coal fly ash in soil. Highest percentage of soil solids was observed in C (52.04%) and lowest was found in T_8 (47.29%). Rest of the ameliorated soil recorded an intermediate value (Table 3, Figure 5). Similar findings were obtained by Adriano and Weber (2001) and Gupta *et al*. (2002).

Table 3: Physical characteristics of coal fly ash ameliorated soil.

S. No.	Treat-ments	Fly ash (%)	BD* (g cm^{-3})	PD* (g cm^{-3})	Porosity (%)	Solids (%)	WHC* (%)
1	C	0	1.53	2.94	47.95	52.04	38.10
2	T_1	5	1.45	2.82	48.58	51.41	41.51
3	T_2	10	1.39	2.74	49.27	50.72	48.67
4	T_3	15	1.34	2.66	49.62	50.37	49.99
5	T_4	20	1.27	2.56	50.39	49.60	53.16
6	T_5	25	1.22	2.47	50.60	49.31	56.42
7	T_6	50	1.18	2.41	51.03	48.96	58.79
8	T_7	75	1.12	2.33	51.93	48.06	60.12
9	T_8	100	1.05	2.22	52.70	47.29	61.52

* BD= Bulk density; PD = Particle density; WHC= Water holding capacity

iv. Water holding capacity: The capacity of soil to hold water increased with increasing amount of coal fly ash in soil. Highest value of water holding capacity was determined for T_8 (61.52%) and lowest value was found in Cof soil (38.10%). Rest of the ameliorated soil recorded an intermediate value (Table 3; Figure 5). Similar investigations and results were obtained by Campbell *et al*. (1983), Singh and Kumar (1997), Mishra *et al*. (2007) and Surbhi (2017).

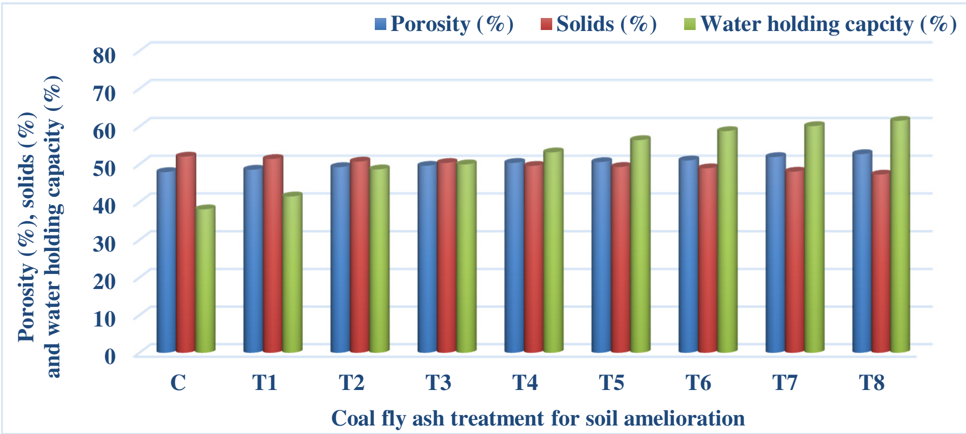

Figure 5: Porosity, solids and water holding capacity of coal fly ash ameliorated soil.

Results for alteration in chemical properties of soil

In present study Chemical characteristics of soil was analyzed for parameters like hydrogen ion concentration (pH), electrical conductivity and total dissolved salts in coal fly ash ameliorated soil.

i. Hydrogen ion concentration (pH) : The pH of samples ranged from 7.31 to 5.52. pH showed a decreasing trend with coal fly ash incorporation (Table 4; Figure 6). These results are in accordance with the results obtained by Pathan *et al*. (2003); Shrivastava (2008).

ii. Electrical conductivity: Electrical conductivity exhibited an increased trend with increasing fly ash content in soil. Minimum electrical conductivity was determined for C (0.26mS cm^{-1}) and maximum for treatment T_8 (0.49mS cm^{-1}) (Table 4; Figure 7). Similar results are obtained by Elseewi *et al*.(1978); Kalra *et al*.(2000); Gupta *et al*.(2002).

iii.Total dissolved salts: The values varied from272.8 mg kg^{-1} to 398.3mg kg^{-1}. Total Dissolved Salts were found to increase with increasing amount of fly ash in the soil. The maximum value was observed in treatment T_8 (398.3 mg kg^{-1}) and minimum in control C soil (272.8mg kg^{-1}) (Table 4; Figure 8). Similar results were obtained in study done by Mishra and Shukla *et al*. (1986); Sarangi *et al*. (2001).

Table 4:Chemical characteristics of coal fly ash ameliorated soil.

S. No.	Treatments	Fly ash %	pH*	EC* (mS cm^{-1})	TDS* (mg kg^{-1})
1	C	0	7.31	0.26	272.8
2	T_1	5	7.19	0.28	278.1
3	T_2	10	6.81	0.31	283.5
4	T_3	15	6.75	0.34	294.2

5	T_4	20	6.64	0.36	308.4
6	T_5	25	6.51	0.39	313.2
7	T_6	50	6.37	0.41	345.5
8	T_7	75	5.98	0.44	366.9
9	T_8	100	5.52	0.49	398.3

* pH= Hydrogen ion concentration; EC= Electrical conductivity; TDS = Total dissolved solids.

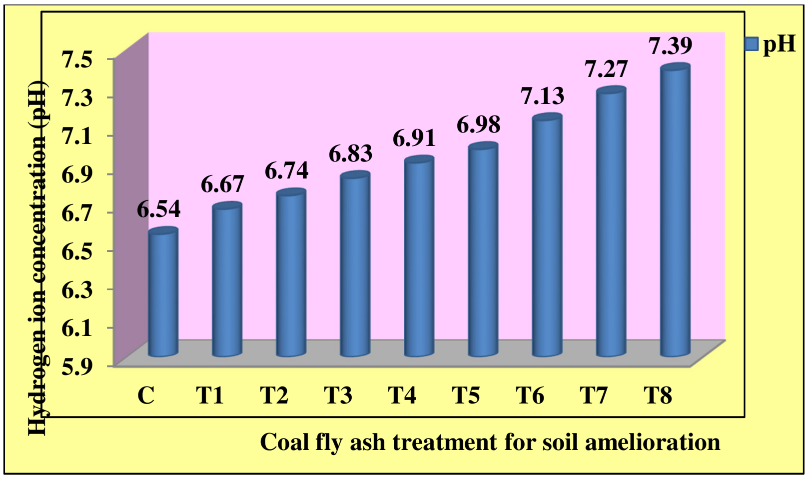

Figure 6: Hydrogen ion concentration of coal fly ash ameliorated soil.

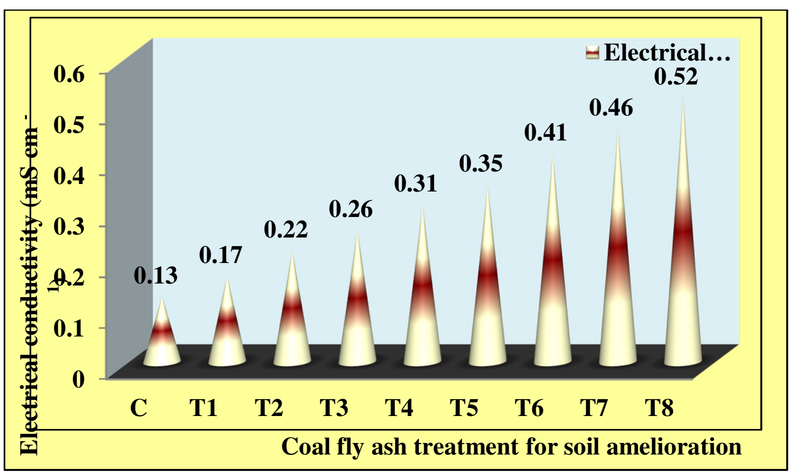

Figure 7: Electrical conductivity of coal fly ash ameliorated soil.

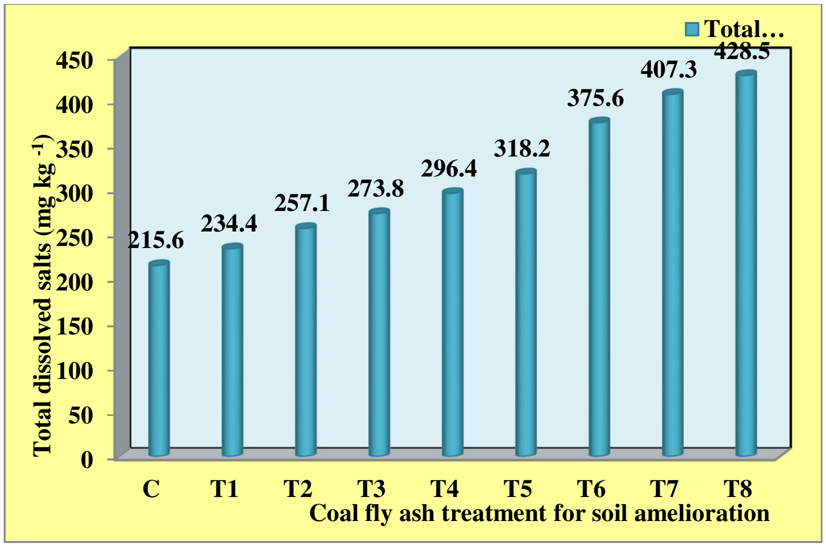

Figure 8: Total dissolved salts of coal fly ash ameliorated soil.

In present study all the values for different Physico-chemical characteristics showed remarkable variation in agricultural soil and coal fly ash because the coal fly ash has higher mineralogical and elemental concentration in comparison to pure soil. Fly ash consist of all essential macro and micro nutrients which are required for proper soil health and plant growth, the presence of these nutrients is the reason behind the difference in constituents of both soil and coal fly ash along with the fine texture of coal fly ash contributing for difference in values of various estimated parameters. Coal fly ash application in form of soil conditioner in agricultural soil decreases characteristics like bulk density, particle density and soil solids% while increases characteristics like porosity and water holding capacity. Similarly decreases pH, increase electrical conductivity and concentration of total dissolved salts, this changes in properties of soil elevates soil quality and yielding capacity also enhance growth and productivity of crop plants .Similar findings were made by Mishra *et al.* (2007); Shrivastava (2008); Skousen *et al.* (2013); Bisoi*et al.* (2017); Dash and Sahoo (2017); Surbhi (2017); Tejasvi (2017).

Coal fly has unique texture with large surface area and hollow structure it comprises fine particles, hence if applied in sufficient quantity it changes soil texture because fly ash replaces the bigger soil particle of soil so small size particles gets accumulated in voids which is responsible for good water holding capacity. Coal fly ash has higher concentration of minerals and required elements in comparison to soil which are needed for proper growth of plants. As coal fly ash is comprised of fine particles it can shift the pore size distribution thus porosity increases with increasing amount of fly ash in the soil, it was due to presence of clay particles and change in pore size due to addition of fly ash. Decrease in soil solid was observed as porosity is inversely proportional to soil solids. It decreases bulk density because bulk density is the measures of pore space and is affected by texture of soil and with increasing texture to clay, bulk density decreases porous soil always has lesser bulk density and particle density which was proved to be beneficial for the growth of various plants similar findings were made by Rai *et al*. (2004), Mishra *et al*. (2005), Tejasvi (2017) and Dash and Sahoo (2017).

In this study the values of pH of soil decreased and values for electrical conductivity and total dissolved salts were found to increase with increased concentration of coal fly ash thus pH shows negative correlation while electrical conductivity and total dissolved salts shows strong positive correlation with coal fly ash treatments. The ash produced by burning of bituminous coal is mostly acidic while sub-bituminous is alkaline with lower concentration of S and higher content of Ca and Mg than the bituminous coal as investigated by Fulekar *et al.* (1983).The electrical conductivity showed increase in values on addition of coal fly ash because fly ash has large quantity of soluble major and minor inorganic constituents which reflect binding of metal ions with soil particles as coal fly ash is mainly consisting of oxides of Si, Al, Fe, and Ca with trace elements these minerals constitutes are responsible for altering the chemical properties of soil which ae proved to be beneficial for growth of various crop plants. Mishra *et al.* (2007); Shrivastava (2008); Dash *et al.* (2015); Pradhan (2017).

Conclusion: The present study suggests that the physical characteristics of soil and coal fly ash including texture, bulk density, particle density, porosity, soil solids and water holding capacity of soil and chemical characteristics of soil and coal fly ash like hydrogen ion concentration (pH), electrical conductivity, total dissolved salts showed remarkable variation in values. The coal fly ash can be used to enhance and elevates the soil properties when used as soil conditioner providing benefits to farmers.

Fly ash when used in appropriate quantity according to the type and texture of soil selected can help in improvisation of soil physical properties including texture, water holding capacity, bulk density, particle density, porosity and soil solids as have beneficial effect on physical properties of soil it can be used as soil modifier for elevation of soil properties and soil quality. The use of coal fly ash as a soil amendment agent will also reduce the problem of fly ash disposal and will provide cheap soil modifier to farmers.

The present study revealed that the coal fly ash has the capability to improve the nutrient status of soil and can alter the pH, electric conductivity and concentration of total dissolved salts in soil, making it rich in various nutrients and more suitable for crop cultivation providing economic benefits to farmers .Thus the waste is no more designated as a waste but it has become a product of concern as can be used as soil amendment agent and secondary fertilizer to elevate the soil chemical characteristics.

Conflicts of interest: Here we certified that this research is original and do not copied from anyone, no copyright can be claimed. Here we certified that no affiliations with or entity with any financial interest is involved in this manuscript. All authors declare that they have no conflicts of interest.

References

1. Adriano, D.C. & Weber, J.T. (2001). Influence of fly ash on soil physical properties and turfgrass establishment. *Journal of Environmental Quality*, 30(2), 596-601.
2. Adriano, D.C., Page, A.L., Elseewi, A.A., Chang, A.C. & Straughan, I. (1980). Utilization and disposal of fly ash and other coal residues in terrestrial ecosystem: a review. *Journal of Environmental Quality*, 9(3), 333-344.
3. Aitken, R.L., Campbell, D.J. & Bell, L.C. (1984). Properties of Australian fly ashes relevant to their agronomic utilization. *Australian Journal of Soil Research*, 22(4), 443-453.

4. APHA (American Public Health Association), AWWA (American Water Works Association) & WEF (Water Environment Federation) (1992). *Standard methods for the examination of water and waste water*. 18th edition. Washington D.C.: American Public Health Association, American Water Works Association and Water Environment Federation.
5. Bisoi, S.S., Mishra, S.S., Barik, J. & Panda, D. (2017). Effects of different treatments of fly ash and mining soil on growth and antioxidant protection of Indian wild rice. *International Journal of Phytoremediation*, 19(5), 446-452.
6. Blake, G.R. & Hartage, K.H. (1986). Bulk density and Particle density. In Methods of soil analysis, Part I. 2nd edition. Edited by Klute, A., American Society of Agronomy, Crop Science Society of America & Soil Science Society of America: Madison, Wisconsin.
7. Campbell, D.J., Fox, W.E., Aitken, R.L. & Bell, L.C. (1983). Physical characterization of sands amended with fly ash. *Australian Journal of Soil Research*, 21(2), 147-154.
8. Dash, A.K., Pradhan, A., Das, S. & Moohanty, S.S. (2015). Fly ash as a potential source amendment in agriculture and a component of integrated plant nutrient supply system. *Journal of Industrial Pollution Control*, 31(2), 251-259.
9. Dash, S. & Sahoo, S.(2017). Effect of fly ash amendment on growth of mustard. *International Journal of Applied Environmental Sciences*, 12(9), 1617-1629.
10. Dzantor, E.K., Pettigrew, H., Adeleke, E. & Hui, D. (2013). Use of fly ash as soil amendment for biofuel feedstock production with concomitant disposal of waste accumulation. World of Coal Ash Conference, held on April 22-25 in Lexington, Kentucky.
11. Elseewi, A.A., Bingham, F.T. & Page, A.L. (1978). Availability of sulpher in fly ash to plants. *Journal of Environmental Quality*, 7(1), 69-73.
12. Fail, J.L. and Wochok, Z.S. (1977). Soybean growth on fly ash amended strip mine spoils. *Plant and Soil*, 48(2):473-484.
13. Fulekar, M.H., Naik, D.S.& Dave, J.M. (1983). Heavy metals in Indian coals and corresponding fly-ash and their relationship with particulate size. *International Journal of Environmental Studies*, 21, 179-182.
14. Gangloff, W.J., Ghodrati, M., Sims, J.T. & Vasilas, B.L. (2000). Impact of fly ash amendment and incorporation method on hydraulic properties of sandy soil. *Water, Air and Soil Pollution*, 119(1-4), 231-245.
15. Ghuman G.S., Sajwan K.S. & Paramasivam S. (2006). Potential of fly ash and organic wastes for uses as amendments to agriculture Soil. In *Coal Combustion Byproducts and Environmental Issues.* Edited by Sajwan, K.S., Twardowska, I., Punshon, T. & Alva, A.K.. New York: Springer.
16. Gorai, S. (2018). Utilization of Fly ash for sustainable environment management, *Journal of Material and Environmental Science*, 9(2), 385-393.
17. Gupta, D.K., Rai, U.N., Tripathi, R.D. & Inouhe, M. (2002). Impacts of fly ash on soil and plant responses. *Journal of Plant Research*, 115(6), 401-409.
18. Gupta, D.K., Tripathi, R.D., Rai, U.N., Dwivedi, S., Mishra, S., Srivastava, S. & Inouhe, M. (2006). Changes in amino acid profile and metal content in seeds of *Cicer arietinum* L. (Cheak pea) grown under various fly ash amendments. *Chemosphere*, 65(6), 939-945.

19. Kalra, N., Harit, R.C. & Sharma, S.K. (2000). Fly ash incorporation effect on soil properties in texturally variant soils. *Bioresource Technology*, 70(1), 91-93.
20. Kene, D.R., Lanjewar, S.A., Ingole, B.M & Chaphale, S.D. (1991). Effect of application of fly ash on physico-chemical properties of soil. *Journal of soils and crop*, 1(1),11-18.
21. Khan, S., Beghum, T. & Singh, J. (1996). Effect of fly ash on physiochemical properties and nutrient status of soil. *Indian Journal of Environmental Health*, 38(1), 41-46.
22. Mishra, L.C. & Shukla, K.N. (1986). Effect of fly-ash deposition on growth, metabolism and dry matter production of maize and soybean. *Environmental Pollution Series A, Ecological and Biological,* 42(1),1–13.
23. Mishra, M., Sahu, R.K. & Padhy, R.N. (2007). Growth, yield, metabolism and elemental status of rice (*Oriza sativa*) grown in fly ash amended soil. *Ecotoxicol*ogy, 16(2), 271-278.
24. Mishra, M., Sahu, R.K. & Padhy, R.N. (2005). Growth, yield, metabolism and elemental status of Green gram (*Phaseolus aureus*) and Til (*Sesamum indicum*) grown in soils amended with fly ash. *Fresenius Environmental Bulletin*, 14(7), 559-564.
25. Misra, K.C., Rao, D.N., Ambasht, R.S., Mukherjee, K.L., Dwivedi, R.S. & Ananthkrishnan, P.V. (1970). Ecology Study of Ecosystem, A.H. Wheeler Company Private Limited: Allahabad, India.
26. Palmer, R.G. & Troeh, F.R. (1977). *Introductory Soil Science Laboratory Manual*. Ames, Iowa, USA: Iowa State University Press.
27. Pandeya, S.C., Puri, G.S. & Singh, J.S. (1968). Research methods in plant ecology. Asia Publishing House: Bombay, India.
28. Pathan, S.M., Aylmore, L.A.G. & Colmer, T.D. (2003). Soil properties and turf growth on a sandy soil amended with fly ash. Plant and Soil, 256(1), 103-114.
29. Prabakar, J., Dendorkar, N. & Morchhale, R.K. (2004). Influence of fly ash on strength behaviour of typical soils. *Construction and Building Materials*, 18(4), 263-267.
30. Pradhan, B.C. (2017). Effect of fly ash on various crops productivity in amended soil in Angul, Odisha, India. *International Journal of Research in Engineering and Applied Science*, 7(1), 128-146.
31. Rai, U.N., Pandey, K., Sinha, S., Singh, A., Saxena, R. & Gupta, D.K. (2004). Revegetating fly ash landfills with *Prosopis juliflora* L.: Impact of different amendments and Rhizobium inoculation. *Environment International*, 30(3), 293-300.
32. Sarangi, P.K., Mahakur, D. & Mishra, P.C. (2001). Soil biochemical activity and growth response of rice (*Oryza sativa*) in fly ash amended soil. *Bioresource Technology*, 76(3), 199-205.
33. Sharma, S.K., Kalra, N. & Singh, G.R. (2002). Soil physical and chemical properties as influenced by fly ash addition in soil and yield of wheat. *Journal of Scientific and Industrial Research*, 61(8), 617-620.
34. Shrivastava, S.K. (2008). Impact of coal fly ash on properties of soil and germination and productive behaviour of *Andrographis paniculata* (Burm.f.) Wall. ex Nees. Ph.D. Thesis. Raipur, C.G: Pt. Ravishankar Shukla University.
35. Sikka, R. & Kansal, B.D.(1995). Effect of fly ash application on yield and nutrient composition of rice, wheat and on pH and available nutrients status of soils. *Bioresource Technology*, 51(2-3), 199-203.

36. Singh, G. & Kumar, S. (1997). Environmental evaluation on leaching of trace elements from coal ashes: a case study of Chandrapur thermal power station. *Journal of Environmental, Studies and Policy*, 2(2),135-142.
37. Singh, G., Sharma, P.K., Dudhe, R. & Singh, S. (2010). Biological activities of *Withania somnifera*. *Annals of Biological Research*, 1(3), 56-63.
38. Skousen, J., Yang, J.E., Lee, J. & Ziemkiewicz, P. (2013). Review of fly ash as a soil amendment. *Geosystem Engineering*, 16(3), 249-256.
39. Summers, R., Clarke, M., Pope, T. & Dea, O.T. (1998). Western Australian fly ash on sandy soils for clover production. *Communication in Soil Science and Plant Analysis*, 29(17-18), 2757-2767.
40. Surabhi (2017). Fly ash in India: Generation vis-à-vis Utilization and Global perspective. *International Journal of Applied Chemistry*, 13(1), 29-52.
41. Szponder, D.K. & Trybalski, K. (2011). Fly ash in agriculture- Modern applications of coal combustion by-product. *International Journal of Teka Commission of Motorization and Power Industries in Agriculture,*11(2), 373-385.
42. Tejasvi, A. (2017). Response of pea crop in fly ash amended soil. *Annals of Horticulture*, 10(1), 25-30.
43. Tiwari, M.K., Bajpai, S. & Dewangan, U.K. (2016). Fly ash utilization: A brief review in Indian context. *International Research Journal of Engineering and Technology*, 3(4), 949-956.
44. Vijayan, V. & Behera, S.N. (1999). Trace element analysis of fly ash by PIXE. *International Journal of PIXE*, 9(3-4), 417-422.
45. Yunusa, I.A.M., Eamus, D., DeSilva, D.L., Murray, B.R., Burchett, M.D., Skilbeck, G.C. & Heidrich, C. (2006). Fly ash: an exploitable resource for management of Australian agricultural soils. *Fuel*, 85(16), 2337-2344.