Growth performance and metal concentration of rice (Oryza sativa l.) grown in three different soils amended with fly ash

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Growth performance and metal concentration of rice (*Oryza sativa* l.) grown in three different soils amended with fly ash

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Abstract. Fly-ash is largely alkaline in nature and contains many essential elements for plant growth along with toxic metals. Therefore, fly-ash is frequently applied for improving soil fertility. In this experiment, we studied growth performance of rice grown in three different soils (swampland, peatland, and irrigated-rice soils) amended with 20 ton fly-ash per hectare in the green-house experiment. The concentrations of metals in rice straw and grain were also measured at the end of the experiment. Result of soil analyses showed that the most distinctive property of soils used this experiment was the content of organic carbon (OC). The experiment also showed that fly-ash application significantly increased the number of rice tiller and dried-rice straw weight in peatland soils and rice production in swampland and peatland soils. Concentrations of aluminium (Al), lead (Pb), nickel (Ni), cadmium (Cd) and chromium (Cr) in the rice straw and grain of peatland soil were not influenced by fly-ash application. Results obtained in this study suggest that the effect of low level of fly-ash application on the growth performance and toxic element concentrations of rice cultivated in different soils is controlled by the OC contents of those soils.

1. Introduction

Main problem in rice cultivation in acid sulphate soils is low productivity. One of the factors limiting the growth of rice in acid sulphate soils is low soil pH. The observations in the province of South Kalimantan showed that the pH (H_2O) of the acid sulphate soils ranged between 3.96 and 4.88 [1]. Low soil pH results in low availability of soil phosphorus, calcium, magnesium, potassium and sodium [2, 3, 4], and this condition eventually result in unhealthy plant growth [5]. Improvements soil properties could be done by adding ameliorant material into the soil to increase soil pH and simultaneously improve the content of some nutrients such as Na, Ca, K and Mg [6, 7].

Fly ash, a byproduct of the utilization of coal as an energy source in steam power plants, contains a relatively high amounts of nutrients such as Ca, Mg, Na and K, and P in smaller amount [8, 9, 10]. Flay ash also encompasses relatively high contents of base and metal oxides [11, 12]. Therefore, fly ash is regularly applied to soils to improved soil properties such increasing the availability of soil nutrients [13, 14, 15] and counteract the soil acidity [16, 17]. Results of these studies show the important role of fly ash which is often considered as a waste material for improving soil quality.

Toxic elements such as Pb, Cr, Cd and Al are observed in high concentration in fly ash [18, 19]. Therefore, the application of fly ash as ameliorant materials for improving agricultural soils will be faced with the worry of the accumulation of toxic elements in plants. Several studies have shown an increase in the concentrations of metals in plants following fly ash application [18, 20]. However, there is a lack of information on the effect of fly-ash on plant growth and the accumulation of metals in biomass plant. In this study, we examined the effect of fly-ash application on the growth performance and the metal concentration of rice grown in three different soils amended with fly ash.

2. Materials and Methods

2.1. Sampling and characterization of soil and fly ash

Three different soils: swampland, irrigated-rice and peat soils were used in this study. Swampland soil was sampled from the Desa Tinggirian II, Sub-district of Tamban, District of Barito Kuala, South Kalimantan Province, Indonesia. Irrigated-rice soil was collected from the Desa Timbaan, Sub-district of Tapin Selatan, District of Tapin, South Kalimantan Province, Indonesia. Meanwhile, the peat was soil sampled from the Desa Kalampangan, Sub-district of Sebangau, District of Palangkaraya, Central Kalimantan Province, Indonesia. Each type of soil was sampled at a depth of 0-30 cm using 3 inch PVC pipe at several different points, and then the samples were homogenized. Plant debris was carefully removed from the collected samples and then the samples were stored in polyethylene vessels at 5 ^{o}C.

All three soils were characterized for soil physical and chemical properties. Determination of soil bulk density for all soils was carried out by the core method [21]. Particle size analysis for mineral soil was carried out using the hydrometer method [22]. Degrees of decomposition of peat were determined using the method of rubbed fibre content and pyrophosphate index [23]. Soil pH of all soils was determined using a glass electrode pH meter [24], organic carbon content determination was carried out by the Walkley and Black method [25], and total nitrogen was determined using the micro Kjehdahl method [26]. Determination of soil phosphorous contents was done by the method of perchloric acid [27]. Exchangeable bases (Na, K, Ca and Mg) of the soils were extracted using the ammonium acetate pH 7.0 and then quantified using atomic absorption spectroscopy (AAS) [28, 29]. Estimation of the cation exchangeable capacity (CEC) of soils was done by the ammonium acetate (pH 7.0) method [30].

Fly-ash used for the experiment was collected from the Asam-Asam Steam Power Plant, South Kalimantan Province, Indonesia. Dried fly ash was digested with a mixture of nitric, sulphuric, and perchloric acid (6:1:2 by volume) for 2 h at 100 ^{o}C and then subsequent digestion up to 120 ^{o}C until obtaining the white residue. Three replicates were prepared for digestion and analysis purposes. The solution was filtered through Whatman filter paper No. 41 and then was diluted with 50 mL deionized water. The concentration of nutrients and metals in the solution were determined using a Perkin Elmer 2380 atomic absorption spectrophotometer (AAS).

2.2. Greenhouse experiment

Ten kilograms of each soil (peat, swampland and irrigated-rice soils) was placed in a 15-L pot, then fly ash in equal to the amount of 20 Mg ha^{-1} was added to the pots, swirled gently until the fly ash evenly distributed to the soils. Water was added into each pot to obtain a 2-cm of water surface height in each pot. Soils in the pots without fly ash addition was also prepared in a similar procedure. The pots were then incubated for 15 days in the greenhouse. For each combination of soil and fly ash, four replicated pots were prepared and incubated. During the incubation period, tap water was added periodically to compensate for evaporative losses and ensure constant water surface height in each pot.

Rice varieties used for this experiment was the Ciherang. Rice plant was transferred to the pots after one month in the nursery. Urea was added into each pot gradually (25% at the time of planting, 25% was added 3 weeks after planting and 50% was added 5 weeks after planting. The amount of added nitrogen fertilizer to each pot is equivalent to the amount of urea for rice plant in Indonesia of 92 kg N ha^{-1}. Phosphorous (TSP) and potassium (KCl) fertilizers were also added to each pot with a dose of 100 kg ha^{-1}. Pot without fertilizers also prepared as control.

Observations on the plant height, the number of tillers, plant dry weight, root dry weight, and dry weight of rice grains were conducted at harvesting time. Harvested shoot and grain of rice were thoroughly washed and oven dried at 70 °C for 48 h, and the dried plant parts were ground to powders; lots of 1 g of the powders were digested with a mixture of nitric, sulphuric, and perchloric acid (6:1:2 by volume). Concentrations of aluminium (Al), lead (Pb), chromium (Cr), cadmium (Cd) and nickel (Ni) of digested plant samples were measured using an atomic absorption spectrophotometer (Perkin Elmer 2380).

2.3. Statistical analysis

Data of growth, production and metal contents in shoot and grain of rice was analyzed for variance to determine the influence of fly ash application on the growth performance and the metal contents of rice grown in different soils. In the case of variance analysis showed that the treatment had a significant effect, a different mean value was tested using the Least Significance Differences (LSD) Test at *P*<0.05. The statistical test was conducted using the GenStat 11th Edition [31].

3. Results and Discussion

3.1. Soil characteristics

Soils used for this study had significantly different characteristics. Swampland soil had a clay loam texture with a relatively low bulk density (0.54 g cm^{-3}), while irrigated rice soil had a clay texture with a high bulk density (1.07 g cm^{-3}). Differences in characteristics of soils used in this study were observed in available P, total K, CEC, total P and soluble Fe. All three soils has a similar soil pH (slightly acid). Results of soil analysis also showed that peatlands contained the highest organic carbon (OC), 75 times higher than that of irrigated rice soil and 7 times higher than that of swampland soil (Table 1). Therefore, it can be assumed that soils used for this study had a significantly different characteristics.

Table 1. Soil characteristics used in this experiment

Soil Characteristics	Swampland	Peatland	Irrigated Rice Soils
Soil texture (%)			
- Sand	0.99	-	19.97
- Loam	54.83	-	27.86
- Clay	44.18	-	52.17
Bulk Density (g cm^{-3})	0.54	0.28	1.07
Soil pH (H_2O 1 : 5)	4.41	3.27	4.10
Organic C (g C kg^{-1})	22.30	163.50	2.60
Total (g N kg^{-1})	1.70	2.60	0.80
Available P (mg P kg^{-1})	8.05	229.58	7.95
Total P (g P kg^{-1})	1.06	0.54	4.53
Total K (g kg^{-1})	4.86	0.97	0.08
CEC (cmol kg^{-1})	9.03	80.17	8.33
Soluble Fe (mg kg^{-1})	183.04	60.93	891.03

3.2. Growth and production of rice in response to fly ash application

Analysis of variance results showed that among the parameters observed in this study, number of tillers, shoot dried-weight and production were influenced by fly-ash application. Application of 20 Mg fly-ash on peatland soil increased the number of tillers from 3.92 to 6.17 (Figure1). However, application of fly-ash to swampland and irrigated-rice soils did not result in changes in the number of tillers (Figure 1). Similar response is also observed for shoot dried-weight. Fly-ash application only improved shoot dried-weight in peatland. These results indicating that the effect of fly-ash application on rice growth varied with the OC contents of soils used for the experiment.

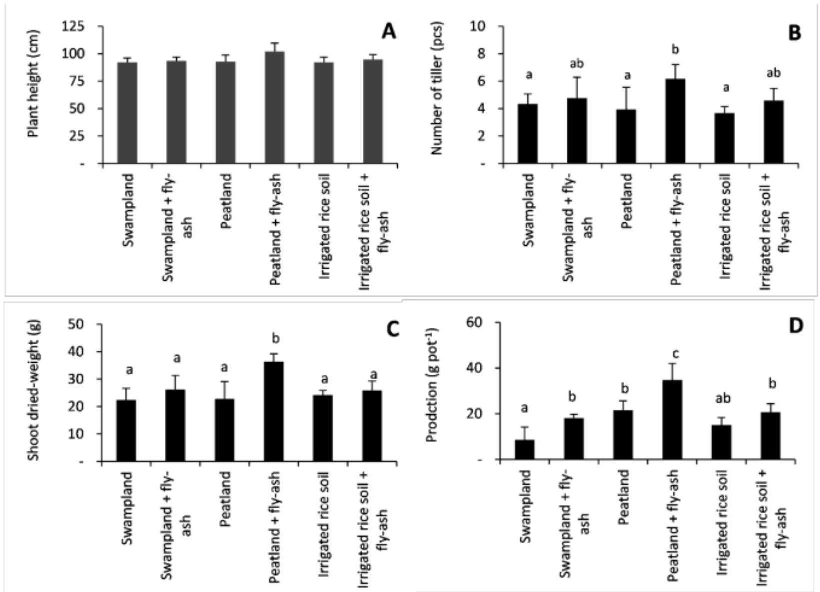

Figure 1. Changes in plant height (A), number of tillers (B), shoot dried-weight (C), and rice production per pot (D) of peatland, swampland and irrigated-rice soils applied with 20 Mg ha^{-1} fly ash. Vertical bar indicate standard error of the treatment (n=4). Similar letters above columns indicate no statistical difference between the treatments based on the LSD test at P<0.05.

Rice production of peatland also increased with fly-ash application. Rice production of peatland without fly-ash application only reached 21.56 gram per pot, increased 58% with 20 Mg ha^{-1} fly-ash application (Figure 1). Similar result was also observed for swampland in which fly-ash application was able to improve rice production as much as 115%. However, fly-ash application to irrigated rice soils did not result in improvement in rice production. These results demonstrate that effect of fly-ash application on rice production also controlled by the types of rice soils.

Improvements of tiller number, shoot dried-weight and rice production were attributed to the improvement of soil characteristics with fly-ash application. Ash application to soils increases mineralization of organic matter [32, 33], thereby increasing available nitrogen in soils [34]. Previous study showed that increase in available P of soils with fly ash application related to improvement of soil pH, the amount of silica and P supply from fly ash [13]. Fly ash application to soils increases 106-149% of nutrient adsorption [35]. Improvement of rice growth and production also related to larger access of rice root for nutrients. A relatively large of fly ash particles compared to soil particles results in larger soil pores (decreases in bulk density) when fly ash was applied to soils. Decrease in bulk density will make root easier to penetrate soils when fly-ash was applied to soils. Fly ash application to rice soils lead to reduction in bulk density from 1.65 g cm^{-3} to 1.59 g cm^{-3} [35].

3.3. Growth and production of rice in response to fly ash application

Results of the experiment showed that the application of 20 Mg ha^{-1} of fly-ash led to increase in the concentrations of metals in rice shoot. The concentration of metals of swampland and irrigated rice soils increased by 14-60% and 24-255% with fly-ash application. However, fly-ash application on peatland, soil containing the highest organic matter in this study, produced similar amount of metals in rice shoots to those without fly-ash application (Figure 2). Similar results were also observed for metal concentration in rice grain. Amount of metals in rice grain of swampland and irrigated rice soils increased significantly with fly-ash application (Figure 3).

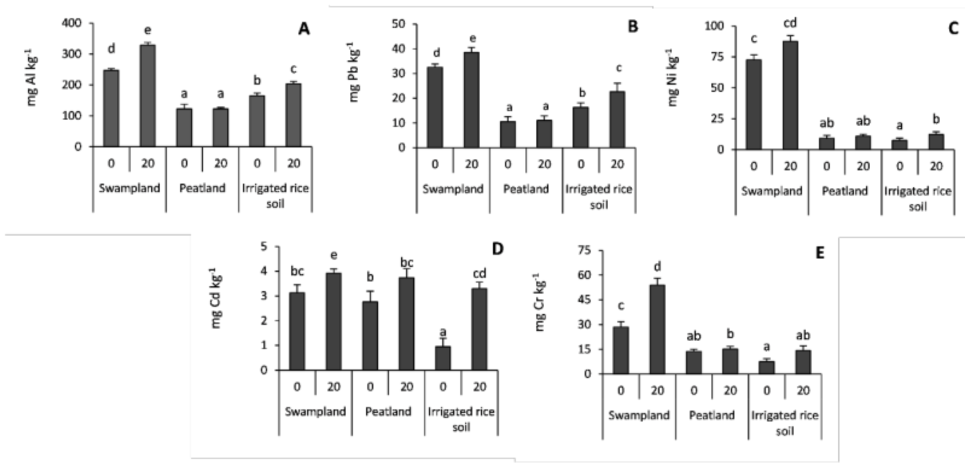

Figure 2. The amounts of aluminium (A), lead (B), nickel (C), cadmium (D) and chromium (E) in rice shoot of peatland, swampland and irrigated-rice soils applied with 20 Mg ha^{-1} fly-ash. Vertical bar indicate standard error of the treatment (n=4). Similar letters above columns indicate no statistical difference between the treatments based on the LSD test at P<0.05.

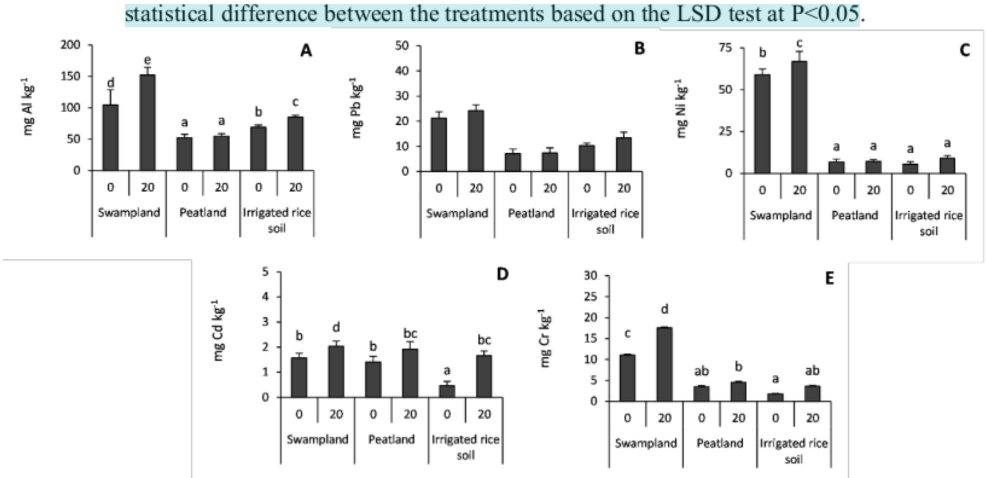

Figure 3. The amounts of aluminium (A), lead (B), nickel (C), cadmium (D) and chromium (E) in rice grain of peatland, swampland and irrigated-rice soils applied with 20 Mg fly-ash per hectare. Vertical bar indicate standard error of the treatment (n=4). Similar letters above columns indicate no statistical difference between the treatments based on the LSD test at *P*<0.05.

Increased metal contents in rice shoot and grain of swampland and irrigated rice soils is due to the increased solubility of metals derived from fly ash. Low amount of fly ash (≤ 10 Mg ha^{-1}) application to soils does not lead to accumulation of metal in plant tissue [36]. No significant differences in metal contents of peatland with and without fly-ash application are related to the high content of organic matter of peatland causes chemical reaction between organic matter functional groups of peat material with cations of metals from fly ash. The formation of chemical bonds between functional groups of organic materials with metal cations decreases the amounts of metals absorbed by the rice [16, 37].

Increased metal contents in rice shoot and rice grain with fly-ash application is also reported in other studies. Previous study reported an increase in metal contents of 12-21% on rice shoot and 15-21% on rice grain by the application of 200 Mg fly-ash per hectare to soils [38]. Various studies reported that fly-ash application increase metals accumulation in rice plants [36, 39, 40]. Study conducted by Vijayan [38] showed that increasing metal content in rice by fly-ash application remained in critical limits of metals in plants. In this study, an increase of metals in rice grains with the addition of fly-ash also remained below the critical limits of metals in plants [41, 42].

4. Conclusion

Observations on the growth and production of rice in paddy soils with different organic matter contents showed that the application of fly-ash increases the growth of rice in peatland and increase the production of rice in swampland and peatland. Concentrations of aluminium (Al), lead (Pb), nickel (Ni), cadmium (Cd) and chromium (Cr) in the rice straw and grain of peatland soil were not influenced by fly-ash application. Results obtained in this study suggest that the effect of low level of fly-ash application on the growth performance and toxic element concentrations of rice cultivated in different soils is controlled by the OC contents of those soils.

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References

[1] Saidy AR, Ifansyah H, and Yulianti H. 2005. Fertilizer efficiency of nitrogen on rice grown in soils with different chemical characteristics. *Agroscientiae* **12** 122-131.
[2] Jin Z, Chen C, Chen X, Jiang F, Hopkins I, Zhang X, Han Z, Billy G, and Benavides J. 2019. Soil acidity, available phosphorus content, and optimal biochar and nitrogen fertilizer application rates: A five-year field trial in upland red soil, China. *Field Crop Res* **232** 77-87.
[3] Bohn HL, McNeal BL, O'Connor G. 2001. Soil Chemistry. John Wiley & Sons, New York.
[4] Cerozi BdS, and Fitzsimmons K. 2016. The effect of pH on phosphorus availability and speciation in an aquaponics nutrient solution. *Bioresource Technol* **219**, 778-81.
[5] Callesen I, Clarke N, Lazdinš A, Varnagiryte-Kabasinskiene I, and Raulund-Rasmussen K. 2019. Nutrient release capability in Nordic and Baltic forest soils determined by dilute nitric acid extraction – Relationships with indicators for soil quality, pH and sustainable forest management. *Ecol Indic* **96** 540-7.
[6] Cai A, Xu M, Wang B, Zhang W, Liang G, Hou E, Luo Y. 2019. Manure acts as a better fertilizer for increasing crop yields than synthetic fertilizer does by improving soil fertility. *Soil Till Res* **189** 168-75.
[7] Singh R, Srivastava P, Singh P, Sharma AK, Singh H, and Raghubanshi AS. 2019. Impact of rice-husk ash on the soil biophysical and agronomic parameters of wheat crop under a dry tropical ecosystem. *Ecol Indic* **105** 505-15..
[8] Munda S, Nayak A, Mishra P, Bhattacharyya P, Mohanty S, Kumar A, Kumar U, Baig,M, Tripathi R, and Shahid M. 2016. Combined application of rice husk biochar and fly ash improved the yield of lowland rice. *Soil Res* **54** 451-9.
[9] Leclercq-Dransart J, Demuynck S, Bidar G, Douay F, Grumiaux F, Louvel B, Pernin C, and Leprêtre A. 2019. Does adding fly ash to metal-contaminated soils play a role in soil functionality regarding metal availability, litter quality, microbial activity and the community structure of Diptera larvae? *Appl Soil Ecol* **138** 99-111.

[10] García-Sánchez M, Siles JA, Cajthaml T, García-Romera I, Tlustoš P, and Száková J. 2015. Effect of digestate and fly ash applications on soil functional properties and microbial communities. *Eur J Soil Biol* **71** 1-12.
[11] Mushtaq F, Zahid M, Bhatti IA, Nasir S, and Hussain T. 2019. Possible applications of coal fly ash in wastewater treatment. *J. Environ. Manag.* **240** 27-46.
[12] Parab N, Sinha S, and Mishra S. 2015. Coal fly ash amendment in acidic field: Effect on soil microbial activity and onion yield. *Appl. Soil Ecol.* **96** 211-6.
[13] Lee H, Ha HS, Lee CH, Lee YB, and Kim PJ. 2006. Fly ash effect on improving soil properties and rice productivity in Korean paddy soils. *Bioresource Technol.* **97** 1490-7.
[14] Pandey VC, and Singh N. 2010. Impact of fly ash incorporation in soil systems. *Agri. Ecosys. Environ.* **136** 16-27.
[15] Schönegger D, Gómez-Brandón M, Mazzier T, Insam H, Hermanns R, Leijenhorst E, Bardelli T, and Fernández-Delgado Juárez M. 2018. Phosphorus fertilising potential of fly ash and effects on soil microbiota and crop. *Resour. Conserv. Recy.* **134** 262-70.
[16] Ram LC, and Masto RE. 2014. Fly ash for soil amelioration: A review on the influence of ash blending with inorganic and organic amendments. *Earth Sci. Rev.* **128** 52-74.
[17] Öğüt M, and Er F. 2015. Mineralizable carbon in biosolids/fly ash/sugar beet lime treated soil under field conditions. *Appl. Soil Ecol*. **91** 27-36.
[18] Jambhulkar HP, Shaikh SMS, and Kumar MS. 2018. Fly ash toxicity, emerging issues and possible implications for its exploitation in agriculture; Indian scenario: A review. *Chemosphere* **213** 333-44.
[19] Khan I, and Umar R. 2019. Environmental risk assessment of coal fly ash on soil and groundwater quality, Aligarh, India. *Groundwater Sustain. Dev.* **8** 346-57.
[20] Yu CL, Deng Q, Jian S, Li J, Dzantor EK, and Hui D. 2019. Effects of fly ash application on plant biomass and element accumulations: a meta-analysis. *Environ. Pol.* **250** 137-42.
[21] Blake GR and Hartge KH. 1982. Bulk Density, ed. Klute A (Madison WI.: American Society of Agronomy-Soil Science Society of America, Inc.) pp 363-375.
[22] Sheldrick B, and Wang C. 1993. Soil sampling and methods of analysis: Particle size distribution. Canadian Society of Soil Science, Lewis Publishers, Boca Raton, Florida, pp 499-511.
[23] Parent L, Caron J, and Carter M. 1993. Physical properties of organic soils. Soil sampling and methods of analysis, pp 441-458.
[24] McLean EO. 1982. Soil pH and Lime Requirement, eds. A.L. Page and D.R. Keeney Page AL and Keeney DR (Madison WI.: Soil Science Society of America Inc.) pp 199-224..
[25] Nelson DW and Sommers LE. 1982. Total Carbon, Organic Carbon, and Organic Matter, eds. Page AL and Keeney DR (Madison WI.: Soil Science Society of America Inc.) pp 961-1010.
[26] Bremer JM and Mulvaney CS. 1982. Nitrogen-total, eds. Page AL and Keeney DR (Madison WI.: Soil Science Society of America Inc.) pp. 595-709.
[27] Olsen SR, and Sommers LE. 1982. Phosphorus, eds. Page AL, Miller RH, and Keeney DR (Madison WI.: American Society of Agronomy, Inc.-Soil Science Society of America, Inc.) pp 403-430.
[28] Knudsen D, and Peterson GA. 1982. Lithium, Sodium dan Potassium, eds. Page AL, Miller RH, and Keeney DR (Madison WI.: American Society of Agronomy, Inc.-Soil Science Society of America, Inc.) pp 225-246.
[29] Lanyon LE, and Heald WR. 1982. Magnesium, Calcium, strintium and Barium, eds. Page AL, Miller RH, and Keeney DR (Madison WI.: American Society of Agronomy, Inc.-Soil Science Society of America, Inc.) pp 247-274.
[30] Rhoades JD. 1982. Cation Exchange Capacity, eds. Page AL, Miller RH, and Keeney DR (Madison WI.: American Society of Agronomy, Inc.-Soil Science Society of America, Inc.) pp 149-158.
[31] Payne R. 2008. A Guide to Anova and Design in Genstat VSN International, Hempstead, UK.

[32] Mortensen LH, Cruz-Paredes C, Schmidt O, Rønn R, and Vestergård M. 2019. Ash application enhances decomposition of recalcitrant organic matter. *Soil Biol. Biochem*. **135** 316-22.

[33] Singh JS., Pandey VC, and Singh D. 2011. Coal fly ash and farmyard manure amendments in dry-land paddy agriculture field: effect on N-dynamics and paddy productivity. *Appl. Soil Ecol*. **47** 133-40.

[34] Mupambwa HA, and Mnkeni PN. 2015. Optimization of fly ash incorporation into cow dung–waste paper mixtures for enhanced vermidegradation and nutrient release. *J. Environ. Qual.* **44** 972-81.

[35] Swain D, Rautaray S, and Ghosh B. 2007. Alkaline coal fly ash amendments are recommended for improving rice-peanut crops. *Acta Agric. Scan. B-S P* **57** 201-11.

[36] Nayak AK, Raja R, Rao KS, Shukla AK, Mohanty S, Shahid M, Tripathi R, Panda BB, Bhattacharyya P, Kumar A, Lal B, Sethi SK, Puri C, Nayak D, and Swain CK. 2015. Effect of fly ash application on soil microbial response and heavy metal accumulation in soil and rice plant. *Ecotox. Environ. Safe* **114** 257-62.

[37] Bhattacharyya P, Reddy K, and Attili V. 2011. Solubility and fractionation of different metals in fly ash of Powder River Basin Coal. *Water Air Soil Poll*. **220** 327-37.

[39] Dwivedi S, Tripathi RD, Srivastava S, Mishra S, Shukla MK, Tiwari KK, Singh R, and Rai UN. 2007. Growth performance and biochemical responses of three rice (Oryza sativa L.) cultivars grown in fly-ash amended soil. *Chemosphere* **67** 140-51.

[40] Padhy RN, Nayak N, Dash-Mohini RR, Rath S, and Sahu RK. 2016. Growth, metabolism and yield of rice cultivated in soils amended with fly ash and cyanobacteria and metal loads in plant parts. *Rice Sci*. **23** 22-32.

[41] Kabata-Pendias A, Pendias H. 1992. Trace Elements in Soils and Plants. CRC Boca Raton. Ann Arbor, London

[42] Alloway B. 1995. Heavy Metals in Soils .2nd Ed. Blackie Academic and Professional, London.

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