Growth performance and yield of rice grown in three different types of soil collected from rice fields with coal fly ash application

by Bambang Joko Priatmadi

Submission date: 11-Aug-2023 06:04PM (UTC+0700)
Submission ID: 2144394081
File name: ld_of_rice_grown_in_three_different_types_of_soil_collected.pdf (849.61K)
Word count: 7304
Character count: 35822

Original Paper *Plant, Soil and Environment, 69, 2023 (7): 314–323*

https://doi.org/10.17221/245/2022-PSE

Growth performance and yield of rice grown in three different types of soil collected from rice fields with coal fly ash application

Bambang J. Priatmadi[1], Meldia Septiana[1], Akhmad R. Saidy[1,2]*

[1]Department of Soil, Faculty of Agriculture, Lambung Mangkurat University, Simpang Empat Banjarbaru, Kalimantan Selatan, Indonesia

[2]Doctoral Program of Agricultural Science, Postgraduate Program Lambung Mangkurat University, Simpang Empat Banjarbaru, Kalimantan Selatan, Indonesia

**Corresponding author: bj_priatmadi@ulm.ac.id*

Citation: Priatmadi B.J., Septiana M., Saidy A.R. (2023): Growth performance and yield of rice grown in three different types of soil collected from rice fields with coal fly ash application. Plant Soil Environ., 69: 314–323.

Abstract: The improvement of rice production to meet food needs for the increasing population is a general problem faced in wetland development for agriculture. The use of industrial waste, such as coal fly ash (CFA), could effectively improve the soil properties of wetlands. In this study, CFA with an amount of 2% (weight/volume) or 240 g was added to 12 L of three different soils collected from the rice fields (peatland, swampland, and rainfed field) in a 15-L pot, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of NH_4^+-N, NO_3^--N, exchangeable calcium (Ca) and magnesium (Mg) and available phosphorus in the soil were quantified following the completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in peatland and swampland, the rice fields that contain high organic carbon (C), which ultimately leads to increasing rice growth and yield. The application of CFA to rice fields containing low organic carbon did not improve available nitrogen and phosphorus nor enhance the growth and yield of rice. Results of this study indicate an important role of soil organic C content in the rice fields in controlling the effect of CFA on nutrient availability, growth and yield of rice.

Keywords: available nutrients; mineralisation; soil fertility; toxic element; contamination

Coal fly ash (CFA) is a byproduct using coal as an energy source in power plants. The long-term storage of this industrial waste in open, indiscriminate disposal sites without further consumption poses environmental issues. Khan and Umar (2019) showed an increase in the concentration of several heavy metals in groundwater near CFA disposal sites, which exceeded the World Health Organisation's (Dowhower et al. 2020) recommended drinking water standards. Several studies have also shown toxic contamination elements in soil and groundwater around the disposal sites (Kicińska 2019, Seki et al. 2021). The aforementioned results show the need for CFA management to prevent soil and groundwater exposure to toxic elements originating from leached CFA.

The mineral and chemical properties of CFA allow the reuse of CFA to have a better economic value while simultaneously reducing environmental risks. CFA is used in manufacturing ceramic tiles and producing high-volume concretes (Luo et al. 2021). It also treats wastewater through adsorption, filtration, the Fenton process, photocatalysis, and coagulation (Mushtaq et al. 2019). Premkumar et al. (2017) reported that CFA is an effective stabiliser in enhancing the erosion resistance of dispersive soils. This industrial waste is also used in agriculture to improve soil properties and increase the yield of crops (Saidy et al. 2020, Haris et al. 2021, Ukwattage et al. 2021).

The presence of oxides, which neutralise acidic soils, and trace elements, that provide nutrients for

https://doi.org/10.17221/245/2022-PSE

plant growth, is highly advantageous for using CFA as a soil ameliorant (Jambhulkar et al. 2018). Dwivedi et al. (2007) discovered that the application of CFA at a high concentration of 50% (weight of soil:weight of CFA) reduces rice growth but promotes rice growth at low concentrations of 10–25%. Furthermore, other studies have demonstrated the beneficial effect of CFA treatment on rice growth (Munda et al. 2016, Padhy et al. 2016). However, Lee et al. (2019) observed that CFA application does not enhance rice growth due to lowering nitrogen (N) and phosphorus (P) uptakes. Although the application of CFA does not diminish grain yield, it inhibits the tillering process and reduces rice plant biomass (Lim et al. 2017). The results of these studies indicate that the effect of CFA application on the growth and yield of rice may vary depending on the soil conditions employed in the studies. Therefore, this study aimed to investigate the effect of CFA treatment on the growth and production of rice grown in three distinct soil collected from rice fields. In this study, rice fields with varying levels of organic carbon were utilised so that the influence of the CFA on nutrient availability from the mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

MATERIAL AND METHODS

Sampling and characterisation of soil and coal fly ash. Based on the soil formation process and organic carbon content, the samples used in this study consist of three distinct rice fields: peatland, swampland, and rainfed. Peatland samples (Sapric Histosols) were collected from Pangkoh Hilir Village, Central Kalimantan Province, Indonesia (3°06'01.2"S, 114°08'40.5"E). Swampland soils (Thionic Fluvisols) were obtained from Desa Tinggiran II Luar, South Kalimantan Province, Indonesia (3°17'25.5"S, 114°32'23.3"E). Meanwhile, rainfed rice fields (Argic Fluvisols) were sampled from Desa Timbaan, South Kalimantan Province, Indonesia (2°58'37.9"S, 115°07'16.5"E). In each type of rice field, soil samples were collected using a PVC pipe (12.5 cm in diameter) squeezed to a depth of 30 cm. Following the removal of plant debris, soil samples were homogenised, sealed in plastic bags, and transferred to the laboratory for soil characterisation and greenhouse experiments. Characteristics of the soils used for this study are described in Table 1.

Coal fly ash was collected from the disposal site of the Asam Asam Power Plant located in the Asam Asam Village, Jorong Sub-district, Tanah Laut Regency, South Kalimantan Province, Indonesia. After being transported to the laboratory, the CFA was air-dried, sieved through a 2.00 mm sieve, and a portion was used for the characterisation, while another was stored at 4 °C until used for the experiment. The characteristics of CFA used for this study are shown in Table 1.

Greenhouse experiment. A 240 g of CFA was added to 12 L of soil samples collected from each type of rice in a 15-L (25 cm in diameter) pot and mixed homogeneously. The amounts of CFA added to the soils were equivalent to 2% (weight/volume) or 20 g/L. Control soil was prepared from each type of rice field without the CFA addition. There were 24 experimental units with three types of rice fields with and without CFA application and four replicates per treatment. Water was added to each pot to obtain a water level of 1 cm above the soil surface in the pot, and then the soil and CFA combination was incubated for 15 days in the greenhouse. The water level in the pot during the incubation period was maintained by watering daily.

A sub-sampling was performed by collecting 250 g of soil from each experimental pot on the 15th day after the CFA application (after the completion of the incubation period) for the characterisation of amended soils. The characterisation includes soil pH measured using a glass electrode method (McLean 1982) and the concentration of NH_4^+-N and NO_3^--N in soil (Bundy and Meisinger 1994), available phosphorus in Bray extract (Jackson 1967), and exchangeable Ca and Mg (Lanyon and Heald 1982). Rice seedlings (30 days old) previously prepared at the nursery were planted as many as three seedlings in each experimental pot. The rice cultivar used for this research was Ciherang. Finally, the rice harvest was carried out 90 days after planting, and then the growth (plant height, number of tillers, and shoot dry weight) and rice yield were determined. Measurement of plant height (cm) was carried out using a metric scale, and the number of tillers was calculated manually. All parts of the rice plant above the ground from each pot were cut (2–3 cm above the ground), washed with equates, and then rice shoots and grains were separated from each other. Rice shoots and grains were oven-dried at 70 °C for 48 h, weighed immediately, and expressed as grams per pot (g/pot). Rice shoots were then grind to powder for the determination of N and P contents. The content of N in shoot rice was quantified using the micro Kjeldahl method (Hafez

https://doi.org/10.17221/245/2022-PSE

Table 1. Characteristics of the soil and coal fly ash (CFA) used for the study

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal fly ash
Texture[a]				
Sand (%)	–	18.23 ± 1.23	21.36 ± 2.34	–
Silt (%)	–	34.56 ± 3.45	34.23 ± 2.45	–
Clay (%)	–	47.21 ± 4.32	44.41 ± 3.56	–
Bulk density (g/L)[b]	379.60 ± 70.21	629.50 ± 90.23	735.90 ± 92.34	1 170.30 ± 80.45
Particle density (g/L)[c]	1 340.23 ± 120.34	1 980.65 ± 110.78	1 450.45 ± 80.76	2 340.45 ± 80.23
pH_{H_2O}[d]	3.23 ± 0.09	4.72 ± 0.21	4.17 ± 0.08	7.43 ± 0.09
Organic C (g C/kg)[e]	214.54 ± 1.76	93.34 ± 1.32	4.60 ± 0.34	1.45 ± 0.08
Total N (g N/kg)[f]	22.60 ± 1.21	10.70 ± 0.96	5.70 ± 0.12	0.97 ± 0.05
P (g P/kg)[g]	12.90 ± 0.65	6.24 ± 0.34	3.13 ± 0.12	0.17 ± 0.08
Ca (mg Ca/kg)[h]	3.21 ± 0.23	2.58 ± 0.23	1.67 ± 0.43	1 453.67 ± 9.76
Mg (mg Mg/kg)[h]	4.56 ± 0.13	3.23 ± 0.34	1.87 ± 0.12	1 362.66 ± 8.54
Na (mg Na/kg)[h]	3.23 ± 0.08	2.34 ± 0.08	2.54 ± 0.09	365.87 ± 6.76
K (mg K/kg)[h]	3.23 ± 0.12	2.19 ± 0.08	1.44 ± 0.05	768.55 ± 8.87
Fe (mg Fe/kg)[h]	14.12 ± 0.07	22.55 ± 0.12	7.23 ± 0.60	1 124.65 ± 7.88
Al (mg Al/kg)[h]	5.66 ± 0.12	17.56 ± 2.34	4.23 ± 0.09	865.54 ± 7.54
Cr (mg Cr/kg)[i]	–	–	–	121.32 ± 4.67
Pb (mg Pb/kg)[i]	–	–	–	98.78 ± 9.65
Ni (mg Ni/kg)[i]	–	–	–	176.78 ± 9.45
Cd (mg Cd/kg)[i]	–	–	–	4.02 ± 0.15
CEC ($cmol_+$/kg)[j]	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	–

Numbers after ± represent the standard deviation of the mean (n = 3). [a]Sieving and sedimentation methods (Gee and Bander 1986); [b]soil core sampling method (Blake and Hartge 1986a); [c]volumetric flask method (Blake and Hartge 1986b); [d]electrode glass method (1:5, mass:volume) (McLean 1982); [e]Walkley and Black method (Nelson and Sommers 1996); [f]Kjeldahl method (Bremer and Mulvaney 1982); [g]digestion of soil and CFA with 60% $HClO_4$ and measurement at 660 nm using a spectrophotometer (Olsen and Sommers 1982); [h]digestion of soil and CFA using a mixture of HNO_3 and $HClO_4$ and determination of digested solution using an atomic absorption spectrophotometer (Barnhisel and Bertsch 1982, Knudsen and Peterson 1982, Lanyon and Heald 1982, Olson and Ellis 1982); [i]digestion of CFA in the tri-acid mixture (10:1:4, HNO_3:H_2SO_4:$HClO_4$ acids) and measurement using an atomic absorption spectrophotometer (Baker and Amacher 1982, Burau 1982, Reisenauser 1982); [j]ammonium acetate (pH 7.0) method (Rhoades 1982); CEC – cation exchangeable capacity

and Mikkelsen 1981), while the content of P in shoot rice was determined using ascorbic acid-molybdate method after the digestion of rice shoot with 60% concentrated HNO_3 (Haradus and Snaydon 1987).

Data analysis. The analysis of variance (ANOVA) was conducted to determine the effect of CFA application on changes in the properties of amended soils and the growth and yield of rice. Previously, data normality and variance homogeneity were verified using the Shapiro-Wilk and Bartlett tests, respectively. The ANOVA results were significant; hence, the analysis was continued with the mean difference test using the procedure of least significant difference multiple comparisons at $P < 0.05$. All the analyses were performed using the GenStat 11th Edition package (Hempstead, UK).

RESULTS AND DISCUSSION

Characteristics of soils and coal fly ash. The three rice fields used in this study have different bulk densities (BD). The highest and lowest values were observed in peatlands and rainfed rice fields at 0.38 t/m^3 and 1.17 t/m^3, respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen, and phosphorous contents. Table 1 shows that values of investigated soil characteristics were higher at peat-

https://doi.org/10.17221/245/2022-PSE

land and swampland than at the rainfed rice field. Soil pH of the three types of rice fields was relatively not different and ranged from pH 3.23 to 4.72.

Coal fly ash used in this study had an alkaline pH of 7.43, with a very low organic C content of 1.45 g C/kg. Table 1 shows that the nutrients N and P of coal ash were also deficient. However, the calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high, reaching 1 454 mg Ca/kg, 1 363 mg Mg/kg, and 1 125 mg Fe/kg, respectively. The characteristics of CFA used in this experiment had the typical properties of those used in other studies (Schönegger et al. 2018, Saidy et al. 2020).

Changes in soil characteristics influenced by the application of coal fly ash. The addition of CFA increased the available N (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259, 425 and 189% in peatland and 202, 421 and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces available N and available P with the application of CFA. Due to the relatively high OM content of peatland and swampland (Table 1), they have the potential to provide N and P nutrients through the transformation of organic N and P into N and P minerals, respectively. Previous studies have shown

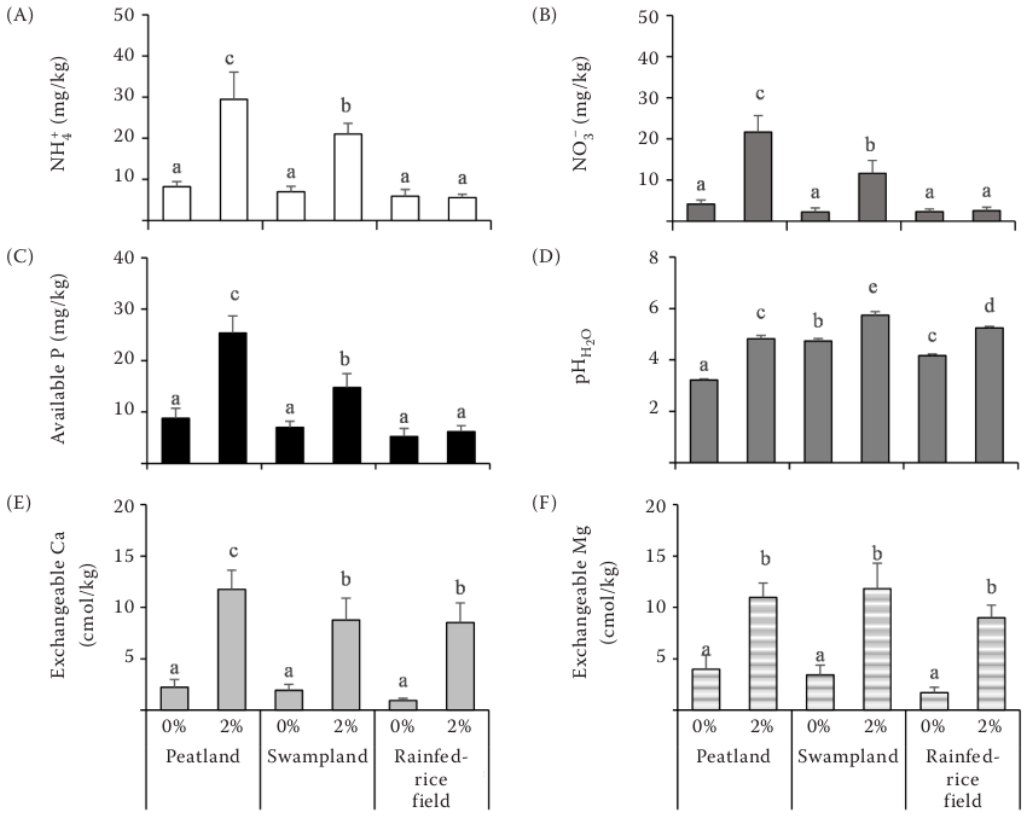

Figure 1. Changes in the amounts of (A) NH_4^+; (B) NO_3^-; (C) available phosphorus (P); (D) soil pH; (E) exchangeable calcium (Ca), and (F) exchangeable magnesium (Mg) of three different types of rice fields without coal fly ash (CFA) application (0%) and with CFA application (2%) observed on 15th day after CFA application. The lines above the bars represent the standard deviation of the mean (n = 4). The letters above the lines indicate no statistical difference between treatments based on the least significant difference (*LSD*) test at $P < 0.05$

https://doi.org/10.17221/245/2022-PSE

that the CFA addition enhances the mineralisation of OM, which in turn increase the availability of N and P. Singh et al. (2011) studied the availability of nitrogen on dry-land paddy agriculture field and found that the mineralisation of this element was higher in plot applied by coal fly ash and farmyard manure than that of farmyard manure application only. The CFA application at a low level enhances microbial activity (Nayak et al. 2015), which ultimately increases the availability of N and P.

Hu et al. (2021) studied the effect of modified CFA and OM application on soils and found that the increase in soil phosphorus was attributed to the increasing alkaline phosphatase activities after the application of these ameliorants, which stimulated the mineralisation of organic P. Furthermore, other studies have also shown that applying relatively high amounts of CFA enhances the availability of soil P (Parab et al. 2015, Ukwattage et al. 2020). The higher concentration of available P is primarily attributed to the change in pH value and the direct diffusion of P (Hong et al. 2018).

Soil pH in rice fields increased by 1.0–1.6 pH units after applying CFA (Figure 1D). The increase in soil pH is attributed to the liming characteristics of this industrial waste. The CFA used in this study has a relatively high pH as well as CaO and MgO contents (Table 1); hence, liming materials are expected to neutralise soil acidity to induce soil pH. Several studies have shown that applying industrial waste to acidic soil increases soil pH (Manoharan et al. 2010, Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in the CFA (Ram and Masto 2014), which may be considered physiologically equivalent to approximately 20% reagent grade $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

The results of the study indicate that the application of CFA has led to a significant increase in the concentrations of exchangeable Ca and Mg in the soil, which were 341–431% and 176–245% higher than those in soils without CFA application (Figure 1E, F). This increase in Ca and Mg could be attributed to the high contents of Ca and Mg present in the CFA used for the study (Table 1). Several previous studies have shown that the application of CFA to the soil supplies Mg (He et al. 2017) and exchangeable Ca (Parab et al. 2015). Overall, the study highlights the potential of CFA as a high source of Ca and Mg for improving soil fertility and crop productivity.

Effect of coal fly ash application on the growth and yield of rice. The application of CFA to the three types of rice fields did not increase the height of the rice. Figure 2A shows that the rice height, with and without industrial waste application, ranged from 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers, rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively. Meanwhile, Figure 2B shows that the number of rice tillers in rainfed fields did not change after the CFA application. The shoot-dried rice weight in peatland and swampland also rises in amended soils. Figure 2C shows that the application of CFA in peatlands and swamplands increased the shoot-dried weight of rice by 40% and 15%, respectively.

The application of CFA also enhanced rice yield in peatland and swampland. The rice yield of peatland and swampland increased from 22 g/pot to 39 g/pot and from 9 g/pot to 20 g/pot, respectively (Figure 2D). On the other hand, a similar amount of CFA applied to rainfed fields did not improve rice yield (Figure 2D). The increasing growth and yield of rice in this study are consistent with several previous studies which showed that CFA application enhances growth performance and production of crops. Tsadilas et al. (2018) observed that the treatments of inorganic fertilisation and CFA application increase wheat grain production by 71%. In contrast, inorganic fertilisation alone increased wheat grain yield by just 23%. The shoot and dry root mass of different crops grown in soils amended with CFA are always higher compared to those without CFA application (Harper and Mbakwe 2020, Ou et al. 2020).

The increasing growth and yield of rice in this study may also be related to the presence of silicon (Si) elements contained in CFA. Coal fly ash also contains SiO_2, which could be a source of soil silicon elements (Bhatt et al. 2019, Laxmidhar and Subhakanta 2020). Peatland (organic soils) and swampy land (high OC) contain no or low amounts of Si. Therefore, the addition of CFA to these soils increases the availability of Si, which in turn increases the growth and yield of rice. However, the addition of CFA to rainfed rice fields (mineral soils which generally contain Si) did not increase the availability of Si at a higher level and thereby did not cause an increase in the growth and yield of rice. Several studies have also reported that increases in the Si contents in soils increase rice growth and yield (Ning et al. 2014, Cuong et al. 2017).

https://doi.org/10.17221/245/2022-PSE

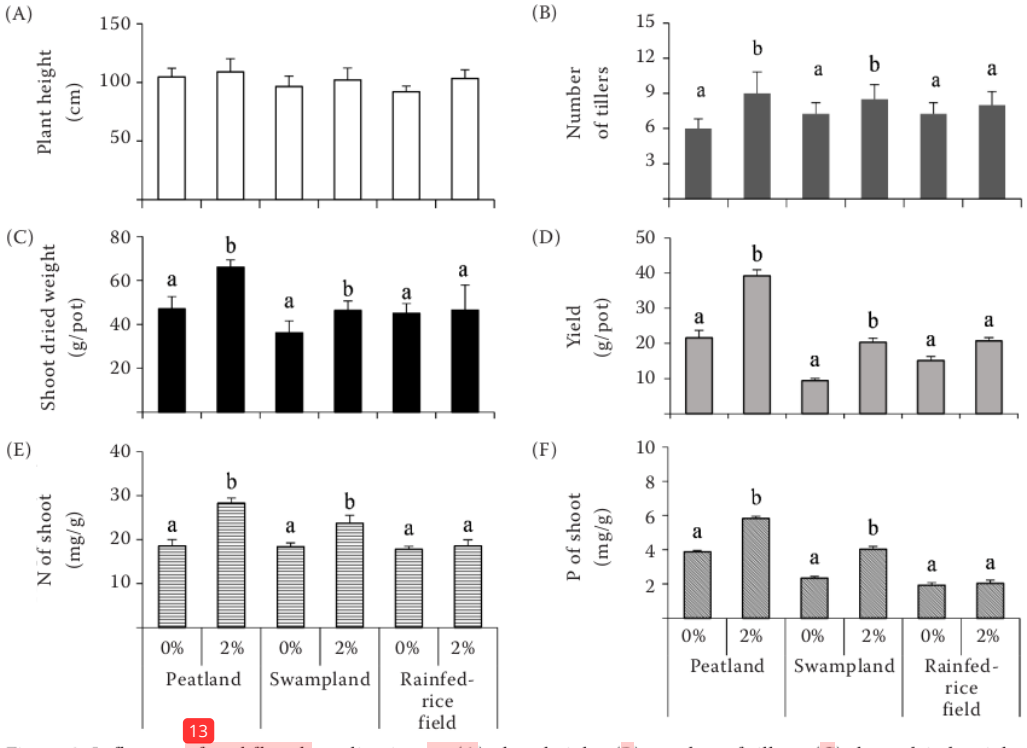

Figure 2. Influence of coal fly ash application on (A) plant height; (B) number of tillers; (C) shoot dried weight; (D) yield; (E) contents of nitrogen (N) in the shoot, and (F) contents of phosphorous (P) in the shoot of rice grown in three different types of rice fields without coal fly ash (CFA) application (0%) and with CFA application (2%) observed at 90 days after rice planting. The lines above the bars represent the standard deviation of the mean (n = 4). The same letter above the lines indicates no statistical difference between treatments based on the least significant difference (*LSD*) test at $P < 0.05$

The increase in growth performance and production of rice through the application of CFA in peatland and swampland is attributed to the improvement of available nutrients in these rice fields. The organic carbon content of peatland and swampland was relatively high (Table 1); hence, the application of CFA to raise the pH of these rice fields could promote the mineralisation of nitrogen and phosphorus. As a result, the plant availability of nitrogen and phosphorus increased, improving rice growth performance and yield. Meanwhile, the organic carbon content of the rainfed field was relatively low, as shown in Table 1, which meant that while the soil pH increased, the low organic carbon content did not allow for an increase in nutrient availability through the mineralisation process. This was in line with the results of Parab et al. (2015), which reported a significant correlation between crop yield and soil pH, available P and Ca. Lee et al. (2019) stated that CFA application to soils containing low organic C (15 g/kg) did not enhance rice growth. Additionally, the impacts of CFA on plant growth on plant growth are enhanced when other organic amendments, such as farmyard manure, are added, owing to the support of carbon and nitrogen (Kumar et al. 2020). The results of this study imply that the effect of coal fly ash on improving nutrient availability, rice growth, and yield is dependent on the soil's organic carbon contents.

Nutrients in soil-plant systems exhibit different behaviours to determine their availability and uptake by plants. The application of CFA to rice fields results in an increase in available nutrients in soils (Figure 1). Available nutrients are transported, absorbed and utilised by plants; a small portion of

https://doi.org/10.17221/245/2022-PSE

nutrients may become precipitated in soils as long-term fertilisers for plants; and a very small portion of nutrients may become immobilised by the cell wall of microorganisms (Liu et al. 2019). Behaviours of nutrients in soils are controlled by numerous factors, including the type of nutrient, soil properties, root architecture, environmental conditions, and microbial activity. Passive diffusion through the cell membrane and active transport are common mechanisms for the transfer of nutrients from soils into plant roots (Thakur et al. 2016, Yadav et al. 2021). Increasing the availability of nutrients with the application of CFA (Figure 1) led to increases in the growth and production of rice (Figure 2). Increasing the amount of available nutrients and then absorbed by plants with the application of CFA in this study is supported by the data of N and P contents in rice shoots. Peatland and swampland, which had increased growth and yield of rice with CFA application, showed increasing N and P contents in shoot rice (Figure 2E, F). On the other hand, the absence of differences in N and P contents in rainfed rice fields with and without CFA application (Figures 2E, F) is associated with no increase in growth and yield of rice with CFA application (Figure 2B–D). Understanding the behaviours of nutrients in soil-plant systems is crucial for optimising agricultural production, reducing environmental impact, and sustaining ecosystem services.

Besides the presence of macronutrients (Ca and Mg) and micronutrients (Fe, Mn, Cu and B), CFA also contains a number of metal elements such as Cd, Pb and Cr. Therefore, CFA application to soils may enhance the concentrations of heavy metals in soils, plants may subsequently take that up and then transfer to the plant tissue. The total concentrations of heavy metals in soils are not readily available for plant uptake. Thus, the metals must be mobilised to bioavailable form in the soil solution to be taken by roots (Thakur et al. 2016). The uptake of heavy metals by plants varies and depends largely on several factors, such as soil pH and organic matter contents (Olowoyo et al. 2012). Heavy metals in soils adsorbed by carbonates, organic matter, and secondary minerals may not be available for plant uptake. However, plant-producing chelating agents and plant-inducing pH changes and redox reactions assist plant roots to dissolve and adsorb heavy metals in the soils, even those which are in the form of insoluble minerals (Zakaria et al. 2021). Although heavy metals are present in soils, their bioaccumulation in plants is determined by chemical processes of soil-plant interactions.

The presence of heavy metals in CFA is a great concern in the use of CFA as a soil ameliorant, in which the application of CFA to soils could lead to the accumulation of heavy metals in plants. Previous studies have shown that a high amount of CFA application results in an increase in the accumulation of heavy metals in plants. Research by Singh et al. (2016) showed that the accumulation of Cd, Cr, Pb and As in rice grains was 4–20 fold higher in soils applied with 50% of CFA than in soils without CFA application. On the other hand, Nayak et al. (2015) reported that the accumulation of heavy metals in rice grains in soils applied with 40% CFA in greenhouses was not significantly different from soils without CFA application. Moreover, the application of CFA at 200 t/ha did not result in the accumulation of Pb, Cd, As and Cr in rice samples, which were different from rice samples without CFA application (Bhaskarachary et al. 2012). These results imply that the application of a relatively low amount of CFA did not lead to heavy metal accumulation in plants. This is in accordance with Yu et al. (2019), who compiled a database from 85 articles on plant biomass with and without CFA applications, and they suggest that CFA should be applied at less than 25% to increase plant biomass and yield but avoid high accumulations of Al, As, Cd, Cr, Pb, and Se in plants. The amount of CFA applied to soils in this study was 3–5% of soil mass, depending on the soil types; therefore, the high accumulation of metals in plant tissue is highly unlikely to occur in this study. However, further research on metal accumulation in plant tissue in response to the application of different amounts of CFA to different types of soil collected from rice fields is required to ensure the safety and health of the rice produced from rice fields with CFA application.

REFERENCES

Baker D.E., Amacher M.C. (1982): Nickel, copper, zinc, and cadmium. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 323–336.

Barnhisel R., Bertsch P.M. (1982): Aliminium. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 275–300.

https://doi.org/10.17221/245/2022-PSE

Bhaskarachary K., Ramulu P., Udayasekhararao P., Bapurao S., Kamala K., Syed Q., Udaykumar P., Sesikeran B. (2012): Chemical composition, nutritional and toxicological evaluation of rice (*Oryza sativa* L.) grown in fly ash amended soils. Journal of the Science of Food and Agriculture, 92: 2721–2726.

Bhatt A., Priyadarshini S., Acharath Mohanakrishnan A., Abri A., Sattler M., Techapaphawit S. (2019): Physical, chemical, and geotechnical properties of coal fly ash: a global review. Case Studies in Construction Materials, 11: e00263.

Blake G.R., Hartge K.H. (1986a): Bulk density. In: Klute A. (ed.): Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods. Madison, American Society of Agronomy, Soil Science Society of America, 363–375.

Blake G.R., Hartge K.H. (1986b): Particle density. In: Klute A. (ed.): Methods of Soil Analysis. Part 1: Physical and Mineralogical Methods. Madison, American Society of Agronomy, Soil Science Society of America, 377–381.

Bremer J.M., Mulvaney C.S. (1982): Nitrogen-total. In: Page A.L., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Biological Methods. Madison, American Society of Agronomy, Soil Science Society of America, 595–709.

Bundy L.G., Meisinger J.J. (1994): Nitrogen availability indices. In: Weaver R.W., Angle J.S., Bottomley P.S. (eds.): Methods of Soil Analysis. Part 2: Chemical and Biological Methods. Madison, American Society of Agronomy, Soil Science Society of America, 951–984.

Burau R.G. (1982): Lead. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 347–366.

Caradus J.R., Snaydon R.W. (1987): Aspects of the phosphorus nutrition of white clover populations I. Inorganic phosphorus content of leaf tissue. Journal of Plant Nutrition, 10: 273–285.

Cuong T.X., Ullah H., Datta A., Hanh T.C. (2017): Effects of silicon-based fertilizer on growth, yield and nutrient uptake of rice in tropical zone of Vietnam. Rice Science, 24: 283–290.

Dowhower S.L., Teague W.R., Casey K.D., Daniel R. (2020): Soil greenhouse gas emissions as impacted by soil moisture and temperature under continuous and holistic planned grazing in native tallgrass prairie. Agriculture, Ecosystems and Environment, 287: 106647.

Dwivedi S., Tripathi R.D., Srivastava S., Mishra S., Shukla M.K., Tiwari K.K., Singh R., Rai U.N. (2007): Growth performance and biochemical responses of three rice (*Oryza sativa* L.) cultivars grown in fly-ash amended soil. Chemosphere, 67: 140–151.

Gee G.W., Bander J.W. (1986): Particle size analysis. In: Klute A. (ed.): Method of Soil Analysis. Part 1. Physical and Mineralogical Methods. 2nd Edition. Madison, American Society of Agronomy, Soil Science Society of America, 234–289.

Hafez A.A., Mikkelsen D.S. (1981): Colorimetric determination of nitrogen for evaluating the nutritional status of rice. Communications in Soil Science and Plant Analysis, 12: 61–69.

Haris M., Ansari M.S., Khan A.A. (2021): Supplementation of fly ash improves growth, yield, biochemical, and enzymatic antioxidant response of chickpea (*Cicer arietinum* L.). Horticulture, Environment, and Biotechnology, 62: 715–724.

Harper J., Mbakwe I. (2020): The effectiveness of coal fly ash in the amelioration of acid soils of the South African highveld: a comparison with conventional liming materials. South African Journal of Plant and Soil, 37: 101–107.

He H., Dong Z., Peng Q., Wang X., Fan C., Zhang X. (2017): Impacts of coal fly ash on plant growth and accumulation of essential nutrients and trace elements by alfalfa (*Medicago sativa*) grown in a loessial soil. Journal of Environmental Management, 197: 428–439.

Hong C., Su Y., Lu S. (2018): Phosphorus availability changes in acidic soils amended with biochar, fly ash, and lime determined by diffusive gradients in thin films (DGT) technique. Environmental Science and Pollution Research, 25: 30547–30556.

Hu X., Huang X., Zhao H., Liu F., Wang L., Zhao X., Gao P., Li X., Ji P. (2021): Possibility of using modified fly ash and organic fertilizers for remediation of heavy-metal-contaminated soils. Journal of Cleaner Production, 284: 124713.

Jackson M.L. (1967): Phosphorous determination for soils. In: Jackson M.L. (ed.): Soil Chemical Analysis. London, Constables, 134–182.

Jambhulkar H.P., Shaikh S.M.S., Kumar M.S. (2018): Fly ash toxicity, emerging issues and possible implications for its exploitation in agriculture; Indian scenario: a review. Chemosphere, 213: 333–344.

Khan I., Umar R. (2019): Environmental risk assessment of coal fly ash on soil and groundwater quality, Aligarh, India. Groundwater for Sustainable Development, 8: 346–357.

Kicińska A. (2019): Chemical and mineral composition of fly ashes from home furnaces, and health and environmental risk related to their presence in the environment. Chemosphere, 215: 574–585.

Knudsen D., Peterson G.A. (1982): Lithium, sodium and potassium. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Biological Properties. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 225–246.

Kumar S.S., Kumar A., Singh S., Malyan S.K., Baram S., Sharma J., Singh R., Pugazhendhi A. (2020): Industrial wastes: fly ash, steel slag and phosphogypsum – potential candidates to mitigate greenhouse gas emissions from paddy fields. Chemosphere, 241: 124824.

Lanyon L.E., Heald W.R. (1982): Magnesium, calcium, strintium and barium. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Biological Properties. 2nd Edition. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 247–274.

Laxmidhar P., Subhakanta D. (2020): Characterization and utilization of coal fly ash: a review. Emerging Materials Research, 9: 921–934.

https://doi.org/10.17221/245/2022-PSE

Lee D.S., Lim S.S., Park H.J., Yang H.I., Park S.I., Kwak J.H., Choi W.J. (2019): Fly ash and zeolite decrease metal uptake but do not improve rice growth in paddy soils contaminated with Cu and Zn. Environment International, 129: 551–564.

Lim S.S., Choi W.J., Chang S.X., Arshad M.A., Yoon K.S., Kim H.Y. (2017): Soil carbon changes in paddy fields amended with fly ash. Agriculture, Ecosystems and Environment, 245: 11–21.

Liu L., Tan Z., Gong H., Huang Q. (2019): Migration and transformation mechanisms of nutrient elements (N, P, K) within biochar in straw-biochar-soil-plant systems: a review. ACS Sustainable Chemistry and Engineering, 7: 22–32.

Luo Y., Wu Y., Ma S., Zheng S., Zhang Y., Chu P.K. (2021): Utilization of coal fly ash in China: a mini-review on challenges and future directions. Environmental Science and Pollution Research, 28: 18727–18740.

Manoharan V., Yunusa I.A.M., Loganathan P., Lawrie R., Skilbeck C.G., Burchett M.D., Murray B.R., Eamus D. (2010): Assessments of class F fly ashes for amelioration of soil acidity and their influence on growth and uptake of Mo and Se by canola. Fuel, 89: 3498–3504.

McLean E.O. (1982): Soil pH and lime requirement. In: Page A.L., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Biological Properties. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 199–224.

Munda S., Nayak A., Mishra P., Bhattacharyya P., Mohanty S., Kumar A., Kumar U., Baig M., Tripathi R., Shahid M. (2016): Combined application of rice husk biochar and fly ash improved the yield of lowland rice. Soil Research, 54: 451–459.

Mushtaq F., Zahid M., Bhatti I.A., Nasir S., Hussain T. (2019): Possible applications of coal fly ash in wastewater treatment. Journal of Environmental Management, 240: 27–46.

Nayak A., Raja R., Rao K., Shukla A., Mohanty S., Shahid M., Tripathi R., Panda B., Bhattacharyya P., Kumar A. (2015): Effect of fly ash application on soil microbial response and heavy metal accumulation in soil and rice plant. Ecotoxicology and Environmental Safety, 114: 257–262.

Nelson D.W., Sommers L.E. (1996): Total carbon, organic carbon and organic matter. In: Sparks D.L. (ed.): Methods of Soil Analysis. Part 3: Chemical Methods. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 961–1011.

Ning D., Song A., Fan F., Li Z., Liang Y. (2014): Effects of slag-based silicon fertilizer on rice growth and brown-spot resistance. Plos One, 9: e102681.

Olowoyo J.O., Okedeyi O.O., Mkolo N.M., Lion G.N., Mdakane S.T.R. (2012): Uptake and translocation of heavy metals by medicinal plants growing around a waste dump site in Pretoria, South Africa. South African Journal of Botany, 78: 116–121.

Olsen S.R., Sommers L.E. (1982): Phosphorus. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Edition. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 403–430.

Olson R.V., Ellis R. (1982): Iron. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 301–312.

Ou Y., Ma S., Zhou X., Wang X., Shi J., Zhang Y. (2020): The effect of a fly ash-based soil conditioner on corn and wheat yield and risk analysis of heavy metal contamination. Sustainability, 12: 7281.

Padhy R.N., Nayak N., Dash-Mohini R.R., Rath S., Sahu R.K. (2016): Growth, metabolism and yield of rice cultivated in soils amended with fly ash and cyanobacteria and metal loads in plant parts. Rice Science, 23: 22–32.

Parab N., Sinha S., Mishra S. (2015): Coal fly ash amendment in acidic field: effect on soil microbial activity and onion yield. Applied Soil Ecology, 96: 211–216.

Premkumar S., Piratheepan J., Rajeev P. (2017): Effect of brown coal fly ash on dispersive clayey soils. Proceedings of the Institution of Civil Engineers – Ground Improvement, 170: 231–244.

Ram L.C., Masto R.E. (2014): Fly ash for soil amelioration: a review on the influence of ash blending with inorganic and organic amendments. Earth Science Reviews, 128: 52–74.

Reisenauser H.M. (1982): Chromium. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Edition. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 337–346.

Rhoades J.D. (1982): Cation exchange capacity. In: Page A.L., Miller R.H., Keeney D.R. (eds.): Methods of Soil Analysis. Part 2: Chemical and Microbiological Properties. 2nd Edition. Madison, American Society of Agronomy, Soil Science Society of America, Inc., 149–158.

Saidy A.R., Hayati A., Septiana M. (2020): Different effects of ash application on the carbon mineralization and microbial biomass carbon of reclaimed mining soils. Journal of Soil Science and Plant Nutrition, 10: 1001–1012.

Schönegger D., Gómez-Brandón M., Mazzier T., Insam H., Hermanns R., Leijenhorst E., Bardelli T., Fernández-Delgado J.M. (2018): Phosphorus fertilising potential of fly ash and effects on soil microbiota and crop. Resources, Conservation and Recycling, 134: 262–270.

Seki T., Nakamura K., Ogawa Y., Inoue C. (2021): Leaching of As and Se from coal fly ash: fundamental study for coal fly ash recycling. Environmental Monitoring and Assessment, 193: 225.

Singh J.S., Pandey V.C., Singh D.P. (2011): Coal fly ash and farmyard manure amendments in dry-land paddy agriculture field: effect on N-dynamics and paddy productivity. Applied Soil Ecology, 47: 133–140.

Singh P.K., Tripathi P., Dwivedi S., Awasthi S., Shri M., Chakrabarty D., Tripathi R.D. (2016): Fly-ash augmented soil enhances heavy metal accumulation and phytotoxicity in rice (*Oryza sativa* L.); a concern for fly-ash amendments in agriculture sector. Plant Growth Regulation, 78: 21–30.

https://doi.org/10.17221/245/2022-PSE

Thakur S., Singh L., Wahid Z.A., Siddiqui M.F., Atnaw S.M., Din M.F.M. (2016): Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives. Environmental Monitoring and Assessment, 188: 206.

Tsadilas C.D., Hu Z., Bi Y., Nikoli T. (2018): Utilization of coal fly ash and municipal sewage sludge in agriculture and for reconstruction of soils in disturbed lands: results of case studies from Greece and China. International Journal of Coal Science and Technology, 5: 64–69.

Ukwattage N.L., Lakmalie U.V., Gamage R.P. (2021): Soil and plant growth response and trace elements accumulation in sweet corn and snow pea grown under fresh and carbonated coal fly ash amendment. Agronomy Journal, 113: 3147–3158.

Ukwattage N.L., Li Y., Gan Y., Li T., Gamage R.P. (2020): Effect of biochar and coal fly ash soil amendments on the leaching loss of phosphorus in subtropical sandy Ultisols. Water, Air, and Soil Pollution, 231: 56.

Yadav B., Jogawat A., Lal S.K., Lakra N., Mehta S., Shabek N., Narayan O.P. (2021): Plant mineral transport systems and the potential for crop improvement. Planta, 253: 45.

Yu H.L., Deng Q., Jian S., Li J., Dzantor E.K., Hui D. (2019): Effects of fly ash application on plant biomass and element accumulations: a meta-analysis. Environmental Pollution, 250: 137–142.

Zakaria Z., Zulkafflee N.S., Mohd Redzuan N.A., Selamat J., Ismail M.R., Praveena S.M., Tóth G., Abdull Razis A.F. (2021): Understanding potential heavy metal contamination, absorption, translocation and accumulation in rice and human health risks. Plants (Basel), 10: 1070.

Received: June 26, 2022
Accepted: June 14, 2023
Published online: July 24, 2023

Growth performance and yield of rice grown in three different types of soil collected from rice fields with coal fly ash application

ORIGINALITY REPORT

11%	9%	13%	4%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Lenka Plavcová, Radek Jupa, Martin Mészáros, Klára Scháňková, Zuzana Kovalíková, Jan Náměstek. "Stem water potential, stomatal conductance and yield in irrigated apple trees", Plant, Soil and Environment, 2023 Publication	2%
2	Seyed Gholam Reza Hosseini, Behzad Sani, Hamid Mozafari, Hamidreza Zabihi, Faezeh Rajabzadeh. "Effect of silicon dioxide application and potassium levelson morphophysiological properties and storable seed yieldof hybrid super sweet maize (Zea mays L. 'Elika')under drought stress", Plant, Soil and Environment, 2023 Publication	1%
3	eprints.ulm.ac.id Internet Source	1%
4	A R Saidy, B J Priatmadi, M Septiana. "Reduction in carbon dioxide and methane	1%

production of tropical peatlands due to coal fly-ash application", IOP Conference Series: Earth and Environmental Science, 2022
Publication

5	engineersedge.weebly.com Internet Source	1 %
6	link.springer.com Internet Source	1 %
7	jwli.weebly.com Internet Source	1 %
8	B J Priatmadi, F Razie, M Septiana, A R Saidy. "The Influence of Fly Ash Application on the Sorption-Desorption of Phosphate on Raised-Bed Soil of Tidal Swamplands", IOP Conference Series: Earth and Environmental Science, 2020 Publication	1 %
9	www.biorxiv.org Internet Source	1 %
10	"Field Crops: Sustainable Management by PGPR", Springer Science and Business Media LLC, 2019 Publication	1 %
11	Smita S. Kumar, Amit Kumar, Swati Singh, Sandeep K. Malyan, Shahar Baram, Jyoti Sharma, Rajesh Singh, Arivalagan Pugazhendhi. "Industrial wastes: Fly ash, steel	1 %

slag and phosphogypsum- potential candidates to mitigate greenhouse gas emissions from paddy fields", Chemosphere, 2020
Publication

12	www.mdpi.com Internet Source	1 %
13	docksci.com Internet Source	1 %

Exclude quotes	On	Exclude matches	< 1%
Exclude bibliography	On		