

Correspondence 1 (Article Submission)

27 June 2022

Prof. Ing. Václav Vaněk, CSc.
Editor in Chief
Plant, Soil and Environment

Dear Prof. Ing. Václav Vaněk, CSc.,

I wish to submit a research article for publication in *Plant, Soil and Environment*, titled “Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application”. The paper was coauthored by Meldia Septiana and Akhmad R. Saidy. All authors contributed to the study and the writing of the manuscript and have read and approved of the manuscript as it is being submitted.

Storage of coal-fly ash, industrial waste generated in the power plant industry, in open and indiscriminate disposal sites causes environmental problems through the contamination of soil and water around disposal sites with toxic elements originating from leached coal-fly ash. The utilization of coal-fly ash as soil ameliorant may improve soil characteristics and plant growth, while simultaneously reducing environmental problems caused by coal-fly ash. However, the effect of this industrial waste on soil and plant varies from one study to others. We believe that our study makes a significant contribution to the literature because our findings indicated that the application of coal-fly ash improved selected soil properties and plant growth and yield of soils with high organic carbon content. On the other hand, the application of coal-fly ash to soils with low organic carbon content did not increase soil properties and growth and yield of plant. Thus, the effect of CFA on nutrient availability and plant growth and yield is controlled by the soil organic carbon content of the soils.

This manuscript has not been published or presented elsewhere in part or in entirety and is not under consideration by another journal. We have read and understood your journal’s policies, and we believe that neither the manuscript nor the study violates any of these. There are no conflicts of interest to declare.

Thank you for your consideration. I look forward to hearing from you.

Sincerely,

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

Abstract: The improvement of rice production to meet food needs for increasing population is a general problem faced in wetland development for agriculture. The use of industrial waste such as coal fly-ash (CFA) could be effective for improving soil properties of wetlands. In this study, an amount of CFA (326-632 g CFA/pot) was applied to three different rice fields: peatland, swampland, and rainfed field, in a 15-L pot to obtain an equivalent to a field application of 60 t CFA/ha, and then incubated in the greenhouse for 15 days. Furthermore, the soil pH, concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus were quantified following the completion of the incubation. Rice seedlings were then planted in the pots, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in peatland and swampland, the rice fields that containing high organic carbon (C), which ultimately leads to increasing rice growth and yield. The application of CFA to rice field containing low organic carbon did not improve available nitrogen and phosphorus nor enhance the growth and yield of rice. Therefore, the soil organic C content in the rice fields controls the effect of CFA on nutrient availability as well as rice growth and yield.

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

INTRODUCTION

Coal fly ash (CFA) is a byproduct of the use of 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 Organization (WHO) 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, Fenton process, photocatalysis, and coagulation (Mushtaq et al. 2019). Premkumar et al. (2017) reported that CFA is an effective stabilizer 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. 2021; Ukwattage et al. 2021).

The presence of oxides, which neutralize acidic soils, and trace elements, that provide nutrients for plant growth, is extremely advantageous for the use of CFA as a soil ameliorant (Jambhulkar et al., 2018). Dwivedi et al. (2007) discovered that this industrial waste 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 and phosphorus 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 rice fields. In this study, rice fields with varying levels of organic matter 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 Characterization of Soil and Coal Fly-Ash

Based on the soil formation process and organic matter content, the samples used in this study consist of three distinct types of rice fields: peatland, swampland, and rainfed. Peatland samples were collected from Pangkoh Hilir Village, Pandih Batu Sub-district, Palang Pisau Regency, Central Kalimantan Province, Indonesia. Swampland soils were obtained from Desa Tinggiran II Luar, Tamban Subdistrict, Barito Kuala Regency, South Kalimantan Province, Indonesia. Meanwhile, rainfed rice fields were sampled from Desa Timbaan, Tapin Selatan Sub-district, Tapin Regency, South Province, Indonesia. 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 experiment. Characteristics of the soils used for this study are described in Table 1.

CFA 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 showed in Table 1.

Green House Experiment

Twelve kilograms of soil samples from each type of rice field were placed in a 15 L (25 cm in diameter) pot, to which 632 g CFA/pot (peatland), 381 CFA g/pot (swampland), 326 g CFA/pot (rainfed) was added. These amounts of CFA added to soils were equivalent to a field application of 60 t CFA/ha. 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 one 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.

After completion of the incubation period, a sub-sampling was performed by collecting 250 g of soil from each experimental pot for amended-soil characterisation. The characterisation includes soil pH measured using a glass electrode method (McLean 1982) and the concentration of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in soil (Bundy and Meisinger 1994), and available P in Bray I extract (Jackson 1967). Rice seedlings (30 days old) prepared at the nursery were planted in each experimental pot. The rice variety used for this research was Ciherang. Finally, the rice growth (height, number of tillers, and shoot dried weight) and yield were observed 90 days after planting.

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 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.

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 Mg/m^3 and 1.17 Mg/m^3 , respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen (N), and phosphorous contents. Table 1 shows that these soil characteristics were higher in peatland than in 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 (CFA) 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 Ca, Mg, and Fe contents in CFA were very high, reaching 1454 mg Ca/kg , 1363 mg Mg/kg , and 1125 mg Fe/kg , respectively (Table 1). The characteristics of CFA used in this experiment had the typical properties of those used in other studies (Saidy et al. 2020; Schönegger et al. 2018).

Changes in soil characteristics influenced by the application of coal-fly ash

The addition of CFA increased the available N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) and P of peatland and swampland. The contents of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ 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 N minerals 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 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 enhance 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, it is expected that liming materials neutralize soil acidity to induce soil pH. Several studies have

shown that applying industrial waste to acidic soil increases soil pH (Parab et al. 2015; Sajid-Ansari et al. 2022). 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 CaCO₃ (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.

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 field did not change after CFA application. The shoot dried weight of rice in peatland and swampland also rise 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 field 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 fertilization and CFA application increase wheat grain production by 71 percent. In contrast, inorganic fertilization alone increased wheat grain yield by just 23 percent. The shoot

and dry root mass of different crops grown in soils amended with CFA is always higher compared to those without CFA application (Harper and Mbakwe 2020; Ou et al. 2020).

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 phosphorous 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 matter 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^{-1}) 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). 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 organic matter contents.

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Tables

Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after \pm represent the standard deviation of the mean (n=3).

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal-fly ash
Texture				
- Sand (%)	-	18.23 \pm 1.23	21.36 \pm 2.34	-
- Silt (%)	-	34.56 \pm 3.45	34.23 \pm 2.45	-
- Clay (%)	-	47.21 \pm 4.32	44.41 \pm 3.56	-
Bulk density (Mg/m ³)	0.38 \pm 0.07	0.63 \pm 0.09	1.17 \pm 0.12	1.17 \pm 0.08
Particle density (Mg/m ³)	1.34 \pm 0.12	1.98 \pm 0.11	1.45 \pm 0.08	2.34 \pm 0.08
pH (H ₂ O)	3.23 \pm 0.09	4.72 \pm 0.21	4.17 \pm 0.08	7.43 \pm 0.09
Organic C (g C/kg)	214.54 \pm 1.76	93.34 \pm 1.32	4.60 \pm 0.34	1.45 \pm 0.08
Total N (g N/kg)	22.60 \pm 1.21	10.70 \pm 0.96	5.70 \pm 0.12	0.97 \pm 0.05
P (g P/kg)	12.90 \pm 0.65	6.24 \pm 0.34	3.13 \pm 0.12	0.17 \pm 0.08
Ca (mg Ca/kg ¹)	3.21 \pm 0.23	2.58 \pm 0.23	1.67 \pm 0.43	1453.67 \pm 9.76
Mg (mg Mg/kg)	4.56 \pm 0.13	3.23 \pm 0.34	1.87 \pm 0.12	1362.66 \pm 8.54
Na (mg Na/kg)	3.23 \pm 0.08	2.34 \pm 0.08	2.54 \pm 0.09	365.87 \pm 6.76
K (mg K/kg)	3.23 \pm 0.12	2.19 \pm 0.08	1.44 \pm 0.05	768.55 \pm 8.87
Fe (mg Fe/kg)	14.12 \pm 0.07	22.55 \pm 0.12	7.23 \pm 0.60	1124.65 \pm 7.88
Al (mg Al/kg)	5.66 \pm 0.12	17.56 \pm 2.34	4.23 \pm 0.09	865.54 \pm 7.54
Cr (mg Cr/kg)	-	-	-	121.32 \pm 4.67
Pb (mg Pb/kg)	-	-	-	98.78 \pm 9.65
Ni (mg Ni/kg)	-	-	-	176.78 \pm 9.45
CEC (cmol _c /kg)	39.76 \pm 3.23	23.76 \pm 2.34	18.33 \pm 1.23	-

Figures

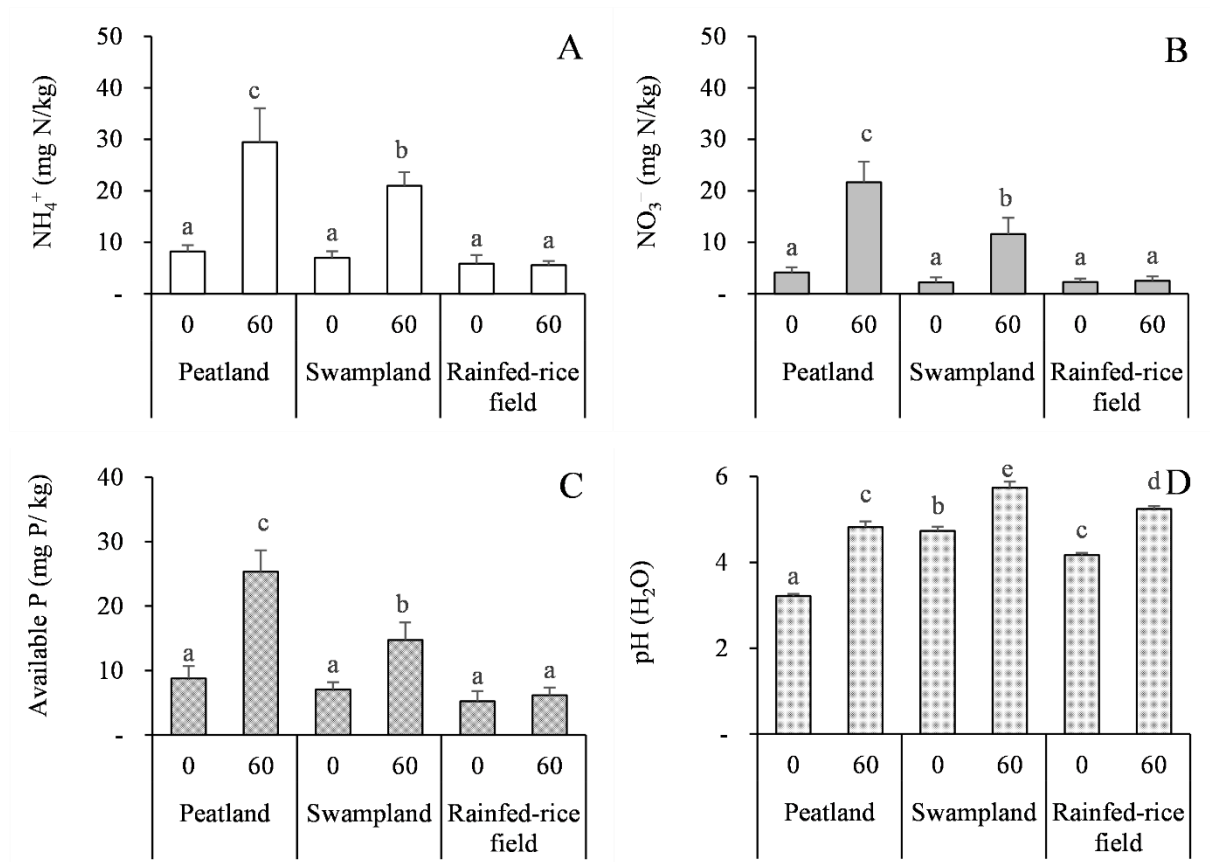


Figure 1. Changes in the amounts of NH₄⁺ (A), NO₃⁻ (B), available P (C), and soil pH (D) of three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The letters above the lines indicate no statistical difference between treatments based on the least significant difference (LSD) test at $P < 0.05$.

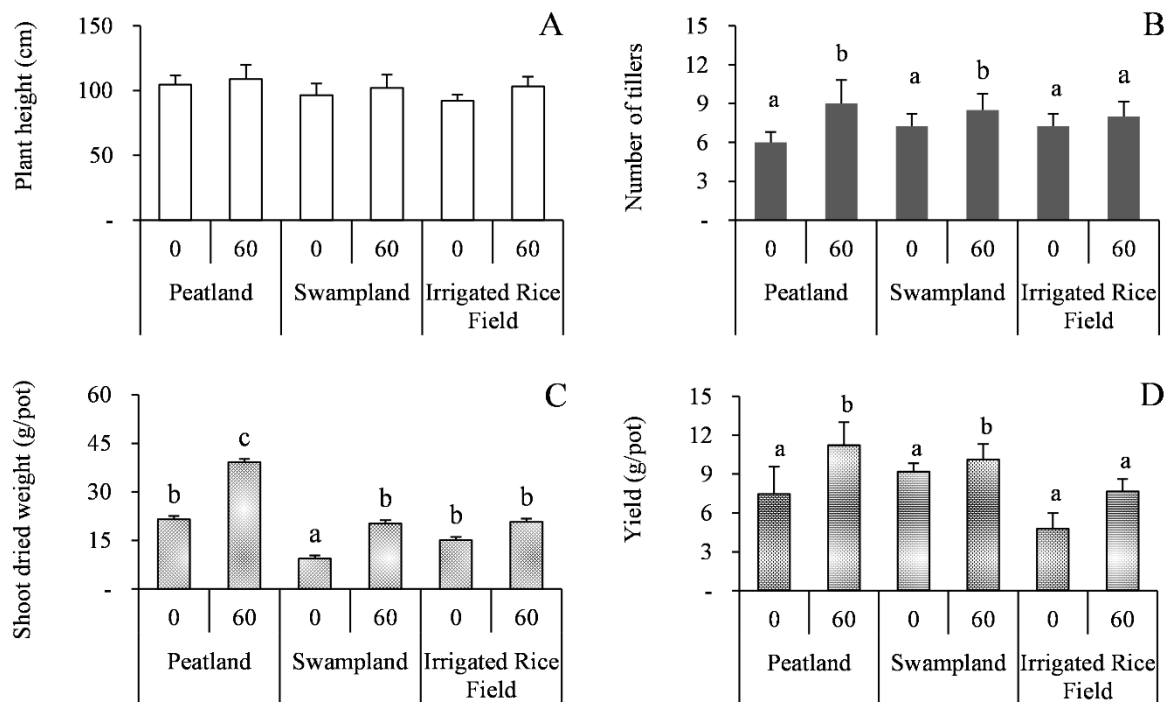


Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), and yield (D) of rice grown in three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The same letter above the lines indicates no statistical difference between treatments based on the least significant difference (LSD) test at $P < 0.05$.

[CAAS Agricultural Journals] 245/2022-PSE Article submission

1 message

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Mon, Jun 27, 2022 at 9:54 PM

Reply-To: PSE@cazv.cz

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Dear Bambang Priatmadi,

Thank you for your interest to publish your manuscript in Plant, Soil and Environment. Your manuscript **Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application** written by Priatmadi Bambang (bj_priatmadi@ulm.ac.id) has been registered as 245/2022-PSE.

You will be duly informed about the assessment procedure. The "corresponding author" (the one who has submitted the manuscript) can view the status of the manuscript at any time by checking the Author's account after logging to the editorial system.

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Yours sincerely,

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[CAAS Agricultural Journals] 245/2022-PSE Article for correction

2 messages

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Tue, Jun 28, 2022 at 4:49 PM

Dear Bambang Priatmadi,

We would like to inform you that your manuscript **Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application** (submitted as 245/2022-PSE) should be corrected according to the executive editors' comments.

Dear authors,

Your manuscript cannot be reviewed till you have it shortened, for example, reduce the number of references. I am sending you also the instructions for the authors and asking you to correct your manuscript according to them.

- I recommend changing the keywords without overlapping with the manuscript title and the abstract.
- Please, use the units according to the journal style, for example, t instead of Mg etc.
- Please, write the units according to the journal style, for example, t/ha or kg/ha etc.
- The doses of nutrients must be in pure chemical elements per pot, not per ha.
- Table 1 – add the content of toxic elements in ash.
- In the editorial system, there are missing the co-authors of this manuscript. Please, add all co-authors of this manuscript to the editorial system.

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Dear Mgr. Kateřina Součková,

I am very sorry for the late reply of your email.

I have corrected the submission of our article in your editorial system.

Best regards,
Bambang J. Priatmadi

[Quoted text hidden]

Accompanying letter

We have done revision of our article accordingly, these including:

- Changed the keywords that overlapping with the manuscript title and abstract,
- Used the units according to journal style,
- Amended the nutrients added to soil to pure chemical per pot,
- Toxic elements (Ni, Pb and Cr) have been added to Table 1,
- Added the co-authors of the manuscript in the editorial system,
- Shortened the length of article, this including the reduction of reference number.

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

Abstract: The improvement of rice production to meet food needs for increasing population is a general problem faced in wetland development for agriculture. The use of industrial waste such as coal fly-ash (CFA) could be effective for improving soil properties of wetlands. In this study, an amount of CFA (326-632 g CFA/pot) was applied to three different rice fields: peatland, swampland, and rainfed field, in a 15-L pot to obtain an equivalent to a field application of 60 t CFA/ha, and then incubated in the greenhouse for 15 days. Furthermore, the soil pH, concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus were quantified following the completion of the incubation. Rice seedlings were then planted in the pots, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in peatland and swampland, the rice fields that containing high organic carbon (C), which ultimately leads to increasing rice growth and yield. The application of CFA to rice field containing low organic carbon did not improve available nitrogen and phosphorus nor enhance the growth and yield of rice. Therefore, the soil organic C content in the rice fields controls the effect of CFA on nutrient availability as well as rice growth and yield.

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

INTRODUCTION

Coal fly ash (CFA) is a byproduct of the use of 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 Organization (WHO) 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, Fenton process, photocatalysis, and coagulation (Mushtaq et al. 2019). Premkumar et al. (2017) reported that CFA is an effective stabilizer 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. 2021; Ukwattage et al. 2021).

The presence of oxides, which neutralize acidic soils, and trace elements, that provide nutrients for plant growth, is extremely advantageous for the use of CFA as a soil ameliorant (Jambhulkar et al., 2018). Dwivedi et al. (2007) discovered that this industrial waste 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 and phosphorus 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 rice fields. In this study, rice fields with varying levels of organic matter 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 Characterization of Soil and Coal Fly-Ash

Based on the soil formation process and organic matter content, the samples used in this study consist of three distinct types of rice fields: peatland, swampland, and rainfed. Peatland samples were collected from Pangkoh Hilir Village, Pandih Batu Sub-district, Palang Pisau Regency, Central Kalimantan Province, Indonesia. Swampland soils were obtained from Desa Tinggiran II Luar, Tamban Subdistrict, Barito Kuala Regency, South Kalimantan Province, Indonesia. Meanwhile, rainfed rice fields were sampled from Desa Timbaan, Tapin Selatan Sub-district, Tapin Regency, South Province, Indonesia. 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 experiment. Characteristics of the soils used for this study are described in Table 1.

CFA 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 showed in Table 1.

Green House Experiment

Twelve kilograms of soil samples from each type of rice field were placed in a 15 L (25 cm in diameter) pot, to which 632 g CFA/pot (peatland), 381 CFA g/pot (swampland), 326 g CFA/pot (rainfed) was added. These amounts of CFA added to soils were equivalent to a field application of 60 t CFA/ha. 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 one 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.

After completion of the incubation period, a sub-sampling was performed by collecting 250 g of soil from each experimental pot for amended-soil characterisation. The characterisation includes soil pH measured using a glass electrode method (McLean 1982) and the concentration of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in soil (Bundy and Meisinger 1994), and available P in Bray I extract (Jackson 1967). Rice seedlings (30 days old) prepared at the nursery were planted in each experimental pot. The rice variety used for this research was Ciherang. Finally, the rice growth (height, number of tillers, and shoot dried weight) and yield were observed 90 days after planting.

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 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.

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 Mg/m^3 and 1.17 Mg/m^3 , respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen (N), and phosphorous contents. Table 1 shows that these soil characteristics were higher in peatland than in 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 (CFA) 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 Ca, Mg, and Fe contents in CFA were very high, reaching 1454 mg Ca/kg , 1363 mg Mg/kg , and 1125 mg Fe/kg , respectively (Table 1). The characteristics of CFA used in this experiment had the typical properties of those used in other studies (Saidy et al. 2020; Schönegger et al. 2018).

Changes in soil characteristics influenced by the application of coal-fly ash

The addition of CFA increased the available N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) and P of peatland and swampland. The contents of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ 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 N minerals 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 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 enhance 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, it is expected that liming materials neutralize soil acidity to induce soil pH. Several studies have

shown that applying industrial waste to acidic soil increases soil pH (Parab et al. 2015; Sajid-Ansari et al. 2022). 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 CaCO₃ (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.

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 field did not change after CFA application. The shoot dried weight of rice in peatland and swampland also rise 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 field 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 fertilization and CFA application increase wheat grain production by 71 percent. In contrast, inorganic fertilization alone increased wheat grain yield by just 23 percent. The shoot

and dry root mass of different crops grown in soils amended with CFA is always higher compared to those without CFA application (Harper and Mbakwe 2020; Ou et al. 2020).

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 phosphorous 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 matter 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^{-1}) 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). 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 organic matter contents.

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Tables

Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after \pm represent the standard deviation of the mean (n=3).

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal-fly ash
Texture				
- Sand (%)	-	18.23 \pm 1.23	21.36 \pm 2.34	-
- Silt (%)	-	34.56 \pm 3.45	34.23 \pm 2.45	-
- Clay (%)	-	47.21 \pm 4.32	44.41 \pm 3.56	-
Bulk density (Mg/m ³)	0.38 \pm 0.07	0.63 \pm 0.09	1.17 \pm 0.12	1.17 \pm 0.08
Particle density (Mg/m ³)	1.34 \pm 0.12	1.98 \pm 0.11	1.45 \pm 0.08	2.34 \pm 0.08
pH (H ₂ O)	3.23 \pm 0.09	4.72 \pm 0.21	4.17 \pm 0.08	7.43 \pm 0.09
Organic C (g C/kg)	214.54 \pm 1.76	93.34 \pm 1.32	4.60 \pm 0.34	1.45 \pm 0.08
Total N (g N/kg)	22.60 \pm 1.21	10.70 \pm 0.96	5.70 \pm 0.12	0.97 \pm 0.05
P (g P/kg)	12.90 \pm 0.65	6.24 \pm 0.34	3.13 \pm 0.12	0.17 \pm 0.08
Ca (mg Ca/kg ¹)	3.21 \pm 0.23	2.58 \pm 0.23	1.67 \pm 0.43	1453.67 \pm 9.76
Mg (mg Mg/kg)	4.56 \pm 0.13	3.23 \pm 0.34	1.87 \pm 0.12	1362.66 \pm 8.54
Na (mg Na/kg)	3.23 \pm 0.08	2.34 \pm 0.08	2.54 \pm 0.09	365.87 \pm 6.76
K (mg K/kg)	3.23 \pm 0.12	2.19 \pm 0.08	1.44 \pm 0.05	768.55 \pm 8.87
Fe (mg Fe/kg)	14.12 \pm 0.07	22.55 \pm 0.12	7.23 \pm 0.60	1124.65 \pm 7.88
Al (mg Al/kg)	5.66 \pm 0.12	17.56 \pm 2.34	4.23 \pm 0.09	865.54 \pm 7.54
Cr (mg Cr/kg)	-	-	-	121.32 \pm 4.67
Pb (mg Pb/kg)	-	-	-	98.78 \pm 9.65
Ni (mg Ni/kg)	-	-	-	176.78 \pm 9.45
CEC (cmol _c /kg)	39.76 \pm 3.23	23.76 \pm 2.34	18.33 \pm 1.23	-

Figures

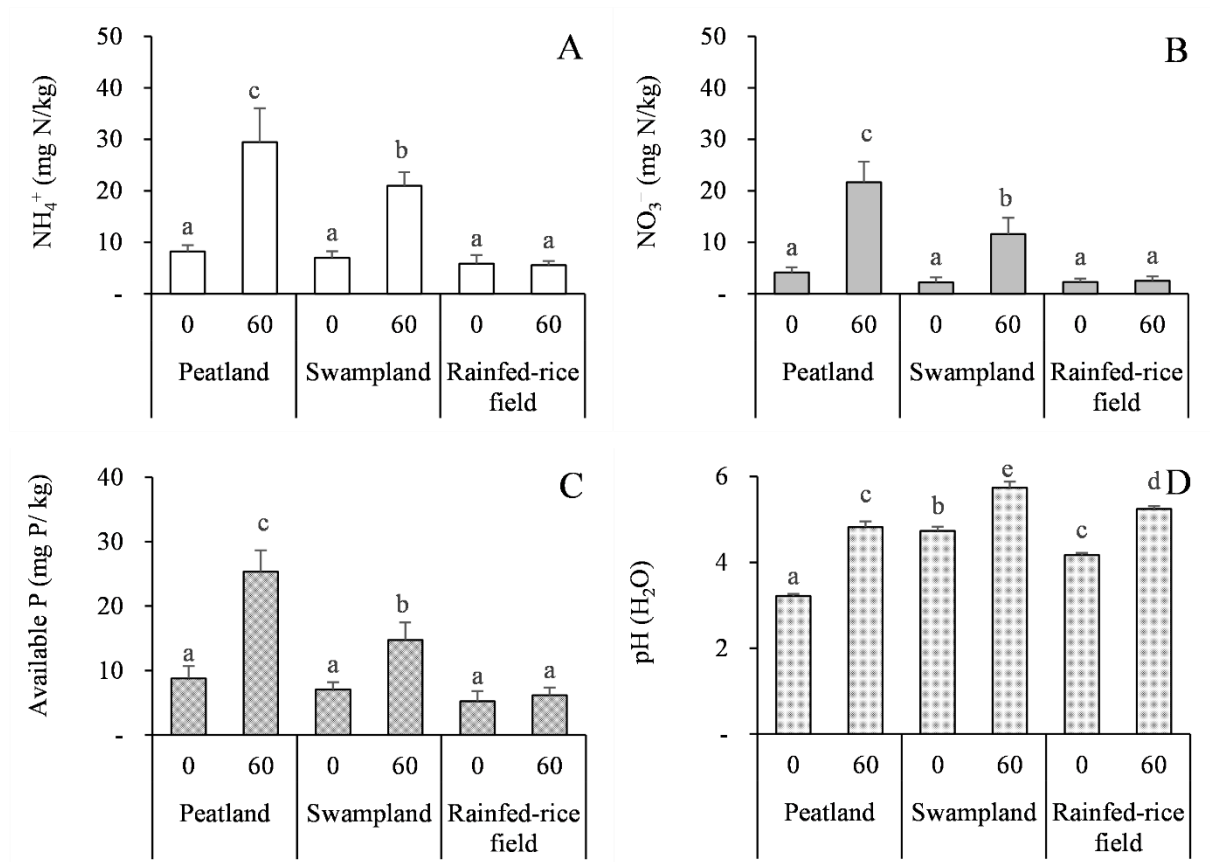


Figure 1. Changes in the amounts of NH₄⁺ (A), NO₃⁻ (B), available P (C), and soil pH (D) of three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The letters above the lines indicate no statistical difference between treatments based on the least significant difference (LSD) test at *P* < 0.05.

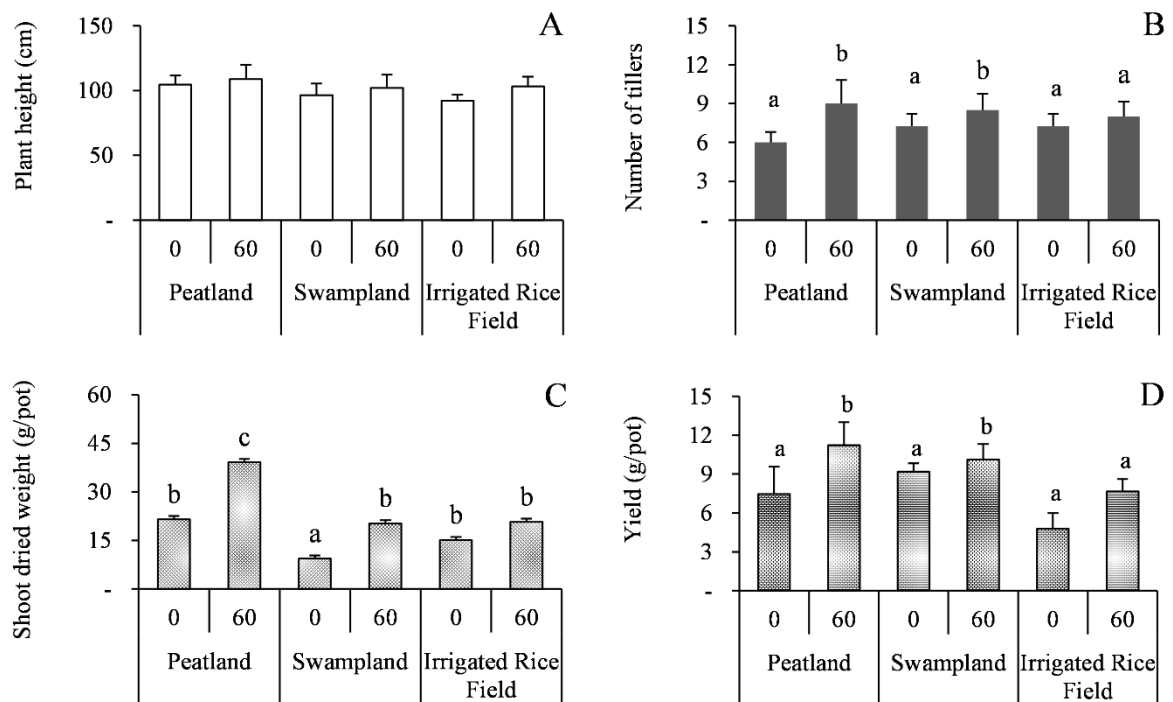


Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), and yield (D) of rice grown in three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The same letter above the lines indicates no statistical difference between treatments based on the least significant difference (LSD) test at $P < 0.05$.

Correspondence 3 (Revision 2)

[CAAS Agricultural Journals] 245/2022-PSE Article for correction

3 messages

pse@cazv.cz <pse@cazv.cz>
Reply-To: pse@cazv.cz
To: bj_priatmadi@ulm.ac.id

Mon, Nov 7, 2022 at 6:39 PM

Dear Bambang Priatmadi,

We would like to inform you that your manuscript **Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application** (submitted as 245/2022-PSE) should be corrected according to the reviewers' comments.

Reviewer 1:

Please see the file attached for the reviewers' comments.

Reviewer 2:

In this manuscript, the heavy metals in coal ash should be considered, for example, the related standard for coal ash application should be quoted. In most cases, the soil contains silicon element, which can influence rice grown, but the author didn't find it in soil, I think that should be determined again.

Reviewer 3:

Summary: The authors investigated the use of coal fly ash, an industrial waste product, as a soil amendment for rice production. The effectiveness of CFA as a soil amendment was tested in three different rice field soil types in a greenhouse experiment. The authors found that CFA increased nutrient availability and rice yield in soils with high organic carbon, but not in the low organic carbon soil. Generally, the study used a sound methodology and the writing of the paper is mostly clear.

Recommended improvements:

Discuss the risk of heavy metal contamination of rice fields from CFA application. The authors mention that heavy metal contamination has been documented in groundwater near CFA disposal sites (Line 26). The authors do not note that rice grain can accumulate heavy metals, especially Hg (methylmercury in particular) and As. This is a serious concern for human health concern as well as water quality in areas with heavy metal contamination. The anaerobic soil environment of rice flooded rice fields can lead the production of methylmercury which is much more bioavailable and toxic than inorganic Hg. Will the use of CFA in rice fields result in widespread heavy metal contamination? The authors should acknowledge this question and make an attempt to address it. What is the concentration of heavy metals in CFA? What amount of heavy metals are added to rice fields amended with CFA at 60 t/ha, and how does this amount compare to the concentrations of heavy metals in soils that lead to heavy metal contaminated rice? Clearly explain how the number of g of CFA added to each pot of each soil type was calculated. The authors state that the amounts were equivalent to a field applied rate of 60 t/ha (line 77), but do not explain how the values were calculated. My initial reaction was that the CFA rates were different, which would be a flaw in the experimental design. I am guessing the authors adjusted the rate of CFA to account for differences in bulk density. One way the authors could address this is by explaining how the rates were determined before stating the rates. An alternative approach to the experimental design would be to have each pot represent the same area and volume of field soil. The pot would have a different mass of soil depending on soil type, but would receive the same amount of CFA. By using a consistent mass of soil, the plants in the peatland pots would have proportionally more soil than plants in the swampland and rainfed pots.

Line by line comments:

51 – The term "rice fields" is used here and elsewhere in a way that suggests this study was conducted in a field setting. You should make it clear that you were testing three soils that came from rice fields, you were not testing the rice fields. You could change this line to "production of rice grown in soils from three distinct rice fields. In this study rice field soils with varying..."

77 – Was the CFA mixed with the soil or spread on the top of the pot?

84 – If the CFA was not mixed into the soil, how was the 250 g soil sample collected so that the sample was representative?

88 – How many rice seedlings per pot?

Executive editor comments:

- Please write the units according to the journal style; for example, use t instead of Mg etc.
- Please use organic carbon instead of the soil organic matter.

For correction use the MS Word Track Changes function. Please submit the corrected manuscript and also the Accompanying letter in anonymized form. See the Instructions to Authors.

We kindly ask you to resubmit the corrected manuscript under the same identification number. To do so, login to the system, click on the manuscript and fill in the "Corrected Text File and Attachments" input field.

Please attach an **Accompanying letter (Cover letter)** where you will respond to all suggestions of reviewers and where you will inform us whether you accepted their suggestions or not and what revisions you made in the original text of the paper according to these suggestions. In a cover letter, answer each question or comment presented in the text with the line number according to the latest version.

Please revise the paper within 21 days.

Please, confirm the acceptance of this e-mail until one week, because the e-mail servers are sometimes out of order.

Yours sincerely,

Dear Mgr. Kateřina Součková,

We have submitted a revised version of this manuscript in which all of the points raised by the reviewers and editors have been addressed. We thank the reviewers and editors for their comments and suggestions. We sincerely believe that in this case in particular they are responsible for substantial improvements to our manuscript. Our responses to each individual comment are detailed below. The line numbers referred to are those of the revised manuscript.

Yours sincerely,

Bambang J. Priatmadi

Executive editor comments:

- Please write the units according to the journal style; for example, use t instead of Mg etc.

We have changed “Mg” to “t” throughout the manuscript (lines 109-110).

- Please use organic carbon instead of the soil organic matter.

“Organic matter” has been changed to “organic carbon” (line 55, 60, 191, 199).

Reviewer 1:

Line 1: Change the title of this research article. You did not use the three different types of rice fields. You used the three different types of soil collected from the rice fields. So, it would be best if you changed the title.

We have amended the title of manuscript according to the reviewer (now lines 1-2).

Lines 5-6: The use of industrial waste, such as coal fly ash (CFA), could effectively improve the soil properties of wetlands.

We have revised the sentence according to the review (lines 5-6).

Line 7: Is this gram? Different soil collected from rice fields.

Yes, it is “gram”. We also have added “soils collected from the” to the sentence (lines 7-8).

Line 8: What is L? you must write in complete form.

We have changed “L” to “liter” according to suggestion of reviewer (line 8).

Line 9: Write full form of t.

“t” have been changed to “tonnes” according to suggestion of reviewer (line 9).

Line 9: delete “and then incubated in the greenhouse for 15 days”.

We retain the phrase of “and incubated in the greenhouse for 15 days” in the sentence (lines 9-10) to indicate the period of incubation before several chemical characteristics of soils have been measured. Information on the incubation period is important in this study because it provides information on the time for the admixture of soil and added coal-fly ash to react with each other to produce the soil property improvement.

Line 10: phosphorus in the soil were quantified.

We have added “in the soil” to the sentence (line 11).

Line 11: delete “following the completion of the incubation”. Pots --- should be in each pot.

The phrase “following the completion of the incubation” was retained in the sentences (line 11) to show that the measurements were carried out after the completion of incubation period.

We have changed “pots” to “each pot” according to suggestion of reviewer (line 12).

Line 20: Alphabetically arrange the keywords.

We have amended the arrangement of keywords so that they are arranged alphabetically (lines 21-22).

Line 23: Change the use of to using.

We have changed “the use of” to “using” according to the suggestion of reviewer (line 26).

Lines 38-39: Another citation also adds- (Saidy et al. 2021; Ukwattage et al. 2021; Haris et al. 2021).

Add in reference list-Haris, M., Ansari, M.S. & Khan, A.A. Supplementation of fly ash improves growth, yield, biochemical, and enzymatic antioxidant response of chickpea (*Cicer arietinum* L.).

Hortic. Environ. Biotechnol. 62, 715–724 (2021). <https://doi.org/10.1007/s13580-021-00351-0>.

Reference of Haris et al. (2021) have been added to the manuscript (line 41 and lines 237-239).

Line 41: Change “extremely” to highly and “the use of” to “using”

We have changed “extremely” to “highly” and “the use of” to “using” according to the suggestion of reviewer (line 44).

Line 42: Not present in the reference list.

Reference of “Jambhulkar et al. (2018)” have been added to the reference list (lines 251-253).

We have added the reference of “Dwivedi et al. (2007)” to the reference list (line 234-236).

Line 44: Not present in the reference list.

We have added to the reference list this three references of Munda et al. (2016) (lines 280-282);

Padhy et al. (2016) (lines 294-296); Lee et al. (2019) (lines 264-266).

Line 47: Not present in the reference list.

We have added the reference of “Lim et al. (2017)” to the reference list (lines 267-268).

Line 51: Distinct soil collected from rice fields.

We have amended the phrase of “distinct rice soils” to “distinct soil collected from rice fields” (line 54).

Line 68: Why write it two times?

Asam Asam (not a repeated word) is the name of a village in Jorong Sub-district, Tanah Laut Regency, South Kalimantan Province, Indonesia, where a power plant that used coal as a source of electricity is located. This power plant has been named according to the name of the village where the power plant is located.

Line 88: What is it and why you write this?

We have amended “Bray I extract” to “Bray extract” (line 88) to clearly indicate that the measurement of available phosphorus in soil was carried out using acid ammonium fluoride extraction (0.03 M NH_4F + 0.025 M HCl) because the soils used in this study had acidic pH. Several methods are frequently used in the determination of soil P, namely Bray, Mehlich-1, and Olsen. The bicarbonate method using NaHCO_3 solution buffered at pH 8.5 (P Olsen) has been used successfully in alkaline soils, while the acid ammonium fluoride extraction (P Bray) has been widely used on acid and neutral soils. Therefore, stating the extraction method in the manuscript is very important to ensure that the extraction method used in P measurement is appropriate to the soil pH used in the study.

Lines 104-105: Is this milligram? Then write like this mg.

Mg in this sentence is not milligram. Bulk density = dry soil weight (g)/soil volume (cm^3).

International unit for bulk density is megagrams per cubic metre, and is abbreviated as Mg/m^3 .

Therefore, Mg in this sentence is megagrams. However, we have changed “ Mg/m^3 ” to “ t/m^3 ” to address the comment of the editor (lines 109-110).

Line 107: But the soil characteristics of swampland are higher than rainfed rice field. Check it and correct the result.

Table 1 shows that contents of organic C, total nitrogen, phosphorous, and cation exchangeable capacity (CEC) in peatland and swampland were higher than those in rainfed rice field. Therefore, we have change the sentence of “shows that these soil characteristics were higher in peatland than in the rainfed rice field” to “.... shows that these soil characteristics were higher in peatland and swampland than in the rainfed rice field” (lines 111-113).

Line 136: Check it. Is this a relevant or irrelevant citation?

Research results by Parab et al. (2015) showed that the availability of P, K and Ca increased with the application of 50 Mg/ha of CFA. Increases in these nutrients availability are related to significant stimulation in soil microbial activity due to better soil physico-chemical environment with CFA application. Therefore, this citation is relevant, and we would like to retain this reference (line 141).

Line 144: Irrelevant; use another citation in place of this.

We have changed the citation of “Sajid-Ansari et al. 2022” to “Manoharan et al. (2010)” (line 148 and lines 273-276).

Line 164: Not present in the reference list.

Reference of “Tsadilas et al. (2018)” have been added to the reference list” (lines 324-327).

Reviewer 2:

In this manuscript, the heavy metals in coal ash should be considered, for example, the related standard for coal ash application should be quoted. In most cases, the soil contains silicon element, which can influence rice grown, but the author didn't find it in soil, I think that should be determined again.

We agree to consider the heavy metals in coal fly ash when used this waste material as soil ameliorant materials. A paragraph to explain that the rate of CFA application in our study was lower than the rate applied in other studies that led to the accumulation of heavy metals in plants has been added to the manuscript to address this issue (lines 200-220). Please also see the comment of Reviewer 3.

We agree that we cannot rule out the possibility that the presence of silicon in soils could affect the rice growth. Testing this possibility is outside the scope of this study, as it would not only require a great deal of additional work but would also substantially lengthen a paper already pushing the word limit. However, in acknowledgement of this point, we have added a paragraph in the discussion that raises this issue (lines 174-183).

Reviewer 3:

Summary: The authors investigated the use of coal fly ash, an industrial waste product, as a soil amendment for rice production. The effectiveness of CFA as a soil amendment was tested in three different rice field soil types in a greenhouse experiment. The authors found that CFA increased nutrient availability and rice yield in soils with high organic carbon, but not in the low organic carbon soil. Generally, the study used a sound methodology and the writing of the paper is mostly clear.

Recommended improvements:

Discuss the risk of heavy metal contamination of rice fields from CFA application. The authors mention that heavy metal contamination has been documented in groundwater near CFA disposal sites (Line 26). The authors do not note that rice grain can accumulate heavy metals, especially Hg (methylmercury in particular) and As. This is a serious concern for human health concern as well as water quality in areas with heavy metal contamination. The anaerobic soil environment of rice flooded rice fields can lead the production of methylmercury which is much more bioavailable and toxic than inorganic Hg. Will the use of CFA in rice fields result in widespread heavy metal contamination? The authors should acknowledge this question and make an attempt to address it. What is the concentration of heavy metals in CFA? What amount of heavy metals are added to rice fields amended with CFA at 60 t/ha, and how does this amount compare to the concentrations of heavy metals in soils that lead to heavy metal contaminated rice?

Widespread heavy metals contamination in soils and water due to CFA application to soils is interesting, but it is beyond the scope of this study to carry out the extra analyses and experiments required to test these points. In the paper we develop what we believe is a sound explanation for excessive heavy metals accumulation in rice is highly unlikely to occur in our study. The rate of CFA application in our study is relatively low (3-5% of soil mass, depending on soil types collected from the rice field) compared to other studies that revealed highly accumulation in plant tissue with CFA application (> 25% of soil mass). We have added a paragraph to the manuscript in acknowledgement of this point (lines 200-220).

Clearly explain how the number of g of CFA added to each pot of each soil type was calculated. The authors state that the amounts were equivalent to a field applied rate of 60 t/ha (line 77), but do not explain how the values were calculated. My initial reaction was that the CFA rates were different, which would be a flaw in the experimental design. I am guessing the authors adjusted the rate of CFA to account for differences in bulk density. One way the authors could address this is by explaining how the rates were determined before stating the rates. An alternative approach to the experimental design would be to have each pot represent the same area and volume of field soil. The pot would have a different mass of soil depending on soil type, but would receive the same amount of CFA. By using a consistent mass of soil, the plants in the peatland pots would have proportionally more soil than plants in the swampland and rainfed pots.

We have substantially reworked this section. It now begins (lines 78-90) with an explanation of the experiment employed the same amount of soils for each soil type collected from the rice fields, and the amount of added CFA was corrected using the bulk density of each soil type. Therefore, each soil type was applied with different amounts of CFA (i.e. peatland would receive the highest amount of CFA). We believe this provides a clear explanation on how the amount of added CFA for experimental pot was calculated.

Line by line comments:

51 – The term “rice fields” is used here and elsewhere in a way that suggests this study was conducted in a field setting. You should make it clear that you were testing three soils that came from rice fields, you were not testing the rice fields. You could change this line to “production of rice grown in soils from three distinct rice fields. In this study rice field soils with varying...”

Reviewer 1 also commented this phrase. We have amended this to “...rice grown in three distinct soil collected from rice fields distinct rice fields. In this study, rice fields with...” (lines 53-54).

77 – Was the CFA mixed with the soil or spread on the top of the pot?

We have amended the sentence by adding “... and mixed homogenously” (lines 83-84) to indicate that the soils and CFA was mixed thoroughly to obtain homogenous the admixture of soils-CFA.

84 – If the CFA was not mixed into the soil, how was the 250 g soil sample collected so that the sample was representative?

Soils and CFA have been mixed homogenously; therefore, we are confident that a 250 gram of soil sub-sampling is representative the whole mixture of soil-CFA in the experimental pot.

88 – How many rice seedlings per pot?

We have reworked the sentence to indicate that three rice seedlings were planted in each experimental pot (lines 95-96).

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

3
4 **Abstract:** The improvement of rice production to meet food needs for increasing population is
5 a general problem faced in wetland development for agriculture. The use of industrial waste,
6 such as coal fly ash (CFA), could effectively improve the soil properties of wetlands. In this
7 study, an amount of CFA (326-632 g CFA/pot) was applied to three different soils collected
8 from the rice fields: peatland, swampland, and rainfed field, in a 15-liter pot to obtain an
9 equivalent to a field application of 60 tonnes CFA/ha, and then incubated in the greenhouse for
10 15 days. The soil pH, concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in the soil
11 were quantified following the completion of the incubation. Rice seedlings were planted in each
12 pot, and after 90 days, the growth and yield variables were observed. The results showed that
13 CFA application enhanced the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in
14 peatland and swampland, the rice fields that containing high organic carbon (C), which
15 ultimately leads to increasing rice growth and yield. The application of CFA to rice field
16 containing low organic carbon did not improve available nitrogen and phosphorus nor enhance
17 the growth and yield of rice. Therefore, the soil organic C content in the rice fields controls the
18 effect of CFA on nutrient availability as well as rice growth and yield.

19
20 **Keywords:** available nutrients; mineralisation; soil fertility; toxic element; wetlands

21

22

23 INTRODUCTION

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

33 The mineral and chemical properties of CFA allow the reuse of CFA to have a better economic
34 value while simultaneously reducing environmental risks. CFA is used in manufacturing
35 ceramic tiles and producing high-volume concretes (Luo et al. 2021). It also treats wastewater
36 through adsorption, filtration, Fenton process, photocatalysis, and coagulation (Mushtaq et al.
37 2019). Premkumar et al. (2017) reported that CFA is an effective stabilizer in enhancing the
38 erosion resistance of dispersive soils. This industrial waste is also used in agriculture to improve
39 soil properties and increase the yield of crops (Haris et al. 2021; Saidy et al. 2021; Ukwattage
40 et al. 2021).

41 The presence of oxides, which neutralize acidic soils, and trace elements, that provide nutrients
42 for plant growth, is highly advantageous for using CFA as a soil ameliorant (Jambhulkar et al.
43 2018). Dwivedi et al. (2007) discovered that this industrial waste promotes rice growth at low
44 concentrations of 10-25%. Furthermore, other studies have demonstrated the beneficial effect
45 of CFA treatment on rice growth (Munda et al. 2016; Padhy et al. 2016). However, Lee et al.
46 (2019) observed that CFA application does not enhance rice growth due to lowering nitrogen

47 and phosphorus uptakes. Although the application of CFA does not diminish grain yield, it
 48 inhibits the tillering process and reduces rice plant biomass (Lim et al. 2017). The results of
 49 these studies indicate that the effect of CFA application on the growth and yield of rice may
 50 vary depending on the soil conditions employed in the studies. Therefore, this study aimed to
 51 investigate the effect of CFA treatment on the growth and production of rice grown in three
 52 distinct soil collected from rice fields. In this study, rice fields with varying levels of organic
 53 carbon were utilised so that the influence of the CFA on nutrient availability from the
 54 mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

55 **MATERIALS AND METHODS**

56 **Sampling and Characterization of Soil and Coal Fly Ash**

57 Based on the soil formation process and organic carbon content, the samples used in this study
 58 consist of three distinct rice fields: peatland, swampland, and rainfed. Peatland samples were
 59 collected from Pangkoh Hilir Village, Pandih Batu Sub-district, Palang Pisau Regency, Central
 60 Kalimantan Province, Indonesia. Swampland soils were obtained from Desa Tinggiran II Luar,
 61 Tamban Subdistrict, Barito Kuala Regency, South Kalimantan Province, Indonesia.
 62 Meanwhile, rainfed rice fields were sampled from Desa Timbaan, Tapin Selatan Sub-district,
 63 Tapin Regency, South Province, Indonesia. In each type of rice field, soil samples were
 64 collected using a PVC pipe (12.5 cm in diameter) squeezed to a depth of 30 cm. Following the
 65 removal of plant debris, soil samples were homogenised, sealed in plastic bags, and transferred
 66 to the laboratory for soil characterisation and greenhouse experiment. Characteristics of the
 67 soils used for this study are described in Table 1.

68 Coal fly ash (CFA) was collected from the disposal site of the Asam Asam Power Plant located
 69 in the Asam Asam Village, Jorong Sub-district, Tanah Laut Regency, South Kalimantan
 70 Province, Indonesia. After being transported to the laboratory, the CFA was air-dried, sieved

71 through a 2.00 mm sieve, and a portion was used for the characterisation, while another was
 72 stored at 4 °C until used for the experiment. The characteristics of CFA used for this study are
 73 showed in Table 1.

74 **Green House Experiment**

75 This greenhouse experiment used the same amount of soil for each soil type collected from the
 76 rice field, in which the amount of CFA added to each experimental pot was adjusted using the
 77 bulk density of each soil type. Therefore, the rate of CFA application for each experimental
 78 pot appears to be different for each soil type. Twelve kilograms of soil samples from each type
 79 of rice field were placed in a 15 liter (25 cm in diameter) pot, to which 632 grams CFA/pot
 80 (peatland), 381 CFA grams/pot (swampland), 326 grams CFA/pot (rainfed) was added and
 81 mixed homogenously. These amounts of CFA added to soils were equivalent to a field
 82 application of 60 t CFA/ha. Control soil was prepared from each type of rice field without the
 83 CFA addition. There were 24 experimental units with three types of rice fields with and without
 84 CFA application and four replicates per treatment. Water was added to each pot to obtain a
 85 water level of one cm above the soil surface in the pot, and then the soil and CFA combination
 86 was incubated for 15 days in the greenhouse. The water level in the pot during the incubation
 87 period was maintained by watering daily.

88 After completion of the incubation period, a sub-sampling was performed by collecting 250 g
 89 of soil from each experimental pot for amended-soil characterisation. The characterisation
 90 includes soil pH measured using a glass electrode method (McLean 1982) and the concentration
 91 of NH_4^+ -N and NO_3^- -N in soil (Bundy and Meisinger 1994), and available phosphorus in Bray
 92 extract (Jackson 1967). Rice seedlings (30 days old) previously prepared at the nursery were
 93 planted as many as three seedlings in each experimental pot. The rice variety used for this

94 research was Ciherang. Finally, the rice growth (height, number of tillers, and shoot dry weight)
95 and yield were observed 90 days after planting.

96 **Data Analysis**

97 The analysis of variance (ANOVA) was conducted to determine the effect of CFA application
98 on changes in the properties of amended soils, and growth and yield of rice. Previously, data
99 normality and variance homogeneity were verified using the Shapiro-Wilk and Bartlett tests,
100 respectively. The ANOVA results were significant; hence, the analysis was continued with the
101 mean difference test using the procedure of least significant difference multiple comparisons at
102 $P < 0.05$. All the analyses were performed using the GenStat 11th Edition package.

103 **RESULTS AND DISCUSSION**

104 **Characteristics of soils and coal fly ash**

105 The three rice fields used in this study have different bulk densities (BD). The highest and
106 lowest values were observed in peatlands and rainfed rice fields at 0.38 t/m^3 and 1.17 t/m^3 ,
107 respectively. Furthermore, other soil properties that differ were organic C content, cation
108 exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows
109 that these soil characteristics were higher in peatland and swampland than in the rainfed rice
110 field. Soil pH of the three types of rice fields was relatively not different and ranged from pH
111 3.23 to 4.72.

112 Coal fly ash (CFA) used in this study had an alkaline pH of 7.43, with a very low organic C
113 content of 1.45 g C/kg. Table 1 shows that the nutrients N and P of coal ash were also deficient.
114 However, the calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high,
115 reaching 1454 mg Ca/kg, 1363 mg Mg/kg, and 1125 mg Fe/kg, respectively (Table 1). The

116 characteristics of CFA used in this experiment had the typical properties of those used in other
117 studies (Saidy et al. 2020; Schönegger et al. 2018).

118 **Changes in soil characteristics influenced by the application of coal fly ash**

119 The addition of CFA increased the available N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) and P of peatland and
120 swampland. The contents of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and available P increased by 259%, 425% and
121 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However,
122 no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of
123 $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and P in peatland and swampland could be attributed to the increased
124 mineralisation of organic matter (OM), which produces N minerals and available P with the
125 application of CFA. Due to the relatively high OM content of peatland and swampland (Table
126 1), they have the potential to provide N and P nutrients through the transformation of organic
127 N and P into N and P minerals, respectively. Previous studies have shown that the CFA addition
128 enhances the mineralisation of OM, which in turn increase the availability of N and P. Singh et
129 al. (2011) studied the availability of nitrogen on dry-land paddy agriculture field and found that
130 the mineralisation of this element was higher in plot applied by coal fly-ash and farmyard
131 manure than that of farmyard manure application only. The CFA application at a low level
132 enhances microbial activity (Nayak et al. 2015), which ultimately increases the availability of
133 N and P.

134 Hu et al. (2021) studied the effect of modified CFA and OM application on soils and found that
135 the increase in soil phosphorus was attributed to the increasing alkaline phosphatase activities
136 after the application of these ameliorants, which stimulated the mineralisation of organic P.
137 Furthermore, other studies have also shown that applying relatively high amounts of CFA
138 enhance the availability of soil P (Parab et al. 2015; Ukwattage et al. 2020). The higher

139 concentration of available P is primarily attributed to the change in pH value and the direct
140 diffusion of P (Hong et al. 2018).

141 Soil pH in rice fields increased by 1.0–1.6 pH units after applying CFA (Figure 1D). The
142 increase in soil pH is attributed to the liming characteristics of this industrial waste. The CFA
143 used in this study has a relatively high pH as well as CaO and MgO contents (Table 1); hence,
144 it is expected that liming materials neutralize soil acidity to induce soil pH. Several studies have
145 shown that applying industrial waste to acidic soil increases soil pH (Manoharan et al. 2010;
146 Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in
147 the CFA (Ram and Masto 2014), which may be considered physiologically equivalent to
148 approximately 20% reagent grade CaCO₃ (Kumar et al. 2020). The results indicate that the CFA
149 could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural
150 activities.

151 **Effect of Coal Fly Ash Application on the Growth and Yield of Rice**

152 The application of CFA to the three types of rice fields did not increase the height of the rice.
153 Figure 2A shows that the rice height, with and without industrial waste application, ranged from
154 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers,
155 rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and
156 swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively.
157 Meanwhile, Figure 2B shows that the number of rice tillers in rainfed field did not change after
158 CFA application. The shoot dried weight of rice in peatland and swampland also rise in
159 amended soils. Figure 2C shows that the application of CFA in peatlands and swamplands
160 increased the shoot dried weight of rice by 40% and 15%, respectively.

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

171 Increasing growth and yield of rice in this study may also related to the presence of silicon (Si)
 172 element containing in CFA. Coal fly ash also contains SiO_2 which could be a source of silicon
 173 elements in soils (Bhatt et al. 2019; Laxmidhar and Subhakanta 2020). Peatland (organic soils)
 174 and swampyland (contain high OC) contain no or low amounts of Si, respectively. Therefore,
 175 the addition of CFA to these soils increases the availability of Si which in turn increases the
 176 growth and yield of rice. However, the addition of CFA to rainfed rice fields (mineral soils
 177 which generally contain Si) did not increase the availability of Si at a higher level, and thereby
 178 do not cause an increase in the growth and yield of rice. Several studies have also reported that
 179 increases in the Si contents in soils result in increasing the growth and yield of rice (Cuong et
 180 al. 2017; Ning et al. 2014).

181 The increase in growth performance and production of rice through the application of CFA in
 182 peatland and swampland is attributed to the improvement of available nutrients in these rice
 183 fields. The organic carbon content of peatland and swampland was relatively high (Table 1);
 184 hence, the application of CFA to raise the pH of these rice fields could promote the

185 mineralisation of nitrogen and phosphorus. As a result, the plant availability of nitrogen and
 186 phosphorous increased, improving rice growth performance and yield. Meanwhile, the organic
 187 carbon content of the rainfed field was relatively low, as shown in Table 1, which meant that
 188 while the soil pH increased, the low organic carbon content did not allow for an increase in
 189 nutrient availability through the mineralisation process. This was in line with the results of
 190 Parab et al. (2015), which reported a significant correlation between crop yield and soil pH,
 191 available P and Ca. Lee et al. (2019) stated that CFA application to soils containing low organic
 192 C (15 g kg^{-1}) did not enhance rice growth. Additionally, the impacts of CFA on plant growth
 193 on plant growth are enhanced when other organic amendments, such as farmyard manure, are
 194 added, owing to the support of carbon and nitrogen (Kumar et al. 2020). Results of this study
 195 imply that the effect of coal fly ash on improving nutrient availability, rice growth, and yield is
 196 dependent on the soil organic carbon contents.

197 The presence of heavy metals in CFA is a great concern in the use of CFA as a soil ameliorant,
 198 in which the application of CFA to soils could lead to the accumulation of heavy metals in
 199 plants. Previous studies shown that a high amount of CFA application results in an increase in
 200 the accumulation of heavy metals in plants. Research by Singh et al. (2016) showed that the
 201 accumulation of Cd, Cr, Pb and As in rice grains was 4–20 fold higher in soils applied with
 202 50% of CFA than soils without CFA application. On the other hand, Nayak et al. (2015)
 203 reported that the accumulation of heavy metals in rice grains in soils applied with 40% CFA in
 204 greenhouses was not significantly different from soils without CFA application. Moreover, the
 205 application of CFA at an amount of 200 t/ha did not result in the accumulation of Pb, Cd, As
 206 and Cr in rice samples which were different from rice samples without CFA application
 207 (Bhaskarachary et al. 2012). These results imply that the application of a relatively low amount
 208 of CFA did not lead to heavy metal accumulation in plants. This is in accordance with Yu et al.

209 (2019) who compiled a database from 85 articles on plant biomass with and without CFA
 210 applications, and they suggest that CFA should be applied at less than 25% in order to increase
 211 plant biomass and yield but avoid high accumulations of Al, As, Cd, Cr, Pb, and Se in plants.
 212 The amount of CFA applied to soils in this study were 3-5% of soil mass, depending on the soil
 213 types; therefore, the high accumulation of metals in plant tissue is highly unlikely to occur in
 214 this study. However, further research on metal accumulation in plant tissue in response to the
 215 application of different amounts of CFA to different types of soil collected from rice fields is
 216 required to ensure the safety and health of the rice produced from rice fields with CFA
 217 application.

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332 plant biomass and element accumulations: a meta-analysis. *Environmental Pollution*,
333 250: 137-142.
- 334
- 335

336 **Tables**

337 Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after ±
 338 represent the standard deviation of the mean (n=3).

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal-fly ash
Texture				
- 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 (t/m ³)	0.38 ± 0.07	0.63 ± 0.09	1.17 ± 0.12	1.17 ± 0.08
Particle density (t/m ³)	1.34 ± 0.12	1.98 ± 0.11	1.45 ± 0.08	2.34 ± 0.08
pH (H ₂ O)	3.23 ± 0.09	4.72 ± 0.21	4.17 ± 0.08	7.43 ± 0.09
Organic C (g C/kg)	214.54 ± 1.76	93.34 ± 1.32	4.60 ± 0.34	1.45 ± 0.08
Total N (g N/kg)	22.60 ± 1.21	10.70 ± 0.96	5.70 ± 0.12	0.97 ± 0.05
P (g P/kg)	12.90 ± 0.65	6.24 ± 0.34	3.13 ± 0.12	0.17 ± 0.08
Ca (mg Ca/kg ¹)	3.21 ± 0.23	2.58 ± 0.23	1.67 ± 0.43	1453.67 ± 9.76
Mg (mg Mg/kg)	4.56 ± 0.13	3.23 ± 0.34	1.87 ± 0.12	1362.66 ± 8.54
Na (mg Na/kg)	3.23 ± 0.08	2.34 ± 0.08	2.54 ± 0.09	365.87 ± 6.76
K (mg K/kg)	3.23 ± 0.12	2.19 ± 0.08	1.44 ± 0.05	768.55 ± 8.87
Fe (mg Fe/kg)	14.12 ± 0.07	22.55 ± 0.12	7.23 ± 0.60	1124.65 ± 7.88
Al (mg Al/kg)	5.66 ± 0.12	17.56 ± 2.34	4.23 ± 0.09	865.54 ± 7.54
Cr (mg Cr/kg)	-	-	-	121.32 ± 4.67
Pb (mg Pb/kg)	-	-	-	98.78 ± 9.65
Ni (mg Ni/kg)	-	-	-	176.78 ± 9.45
CEC (cmol _c /kg)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

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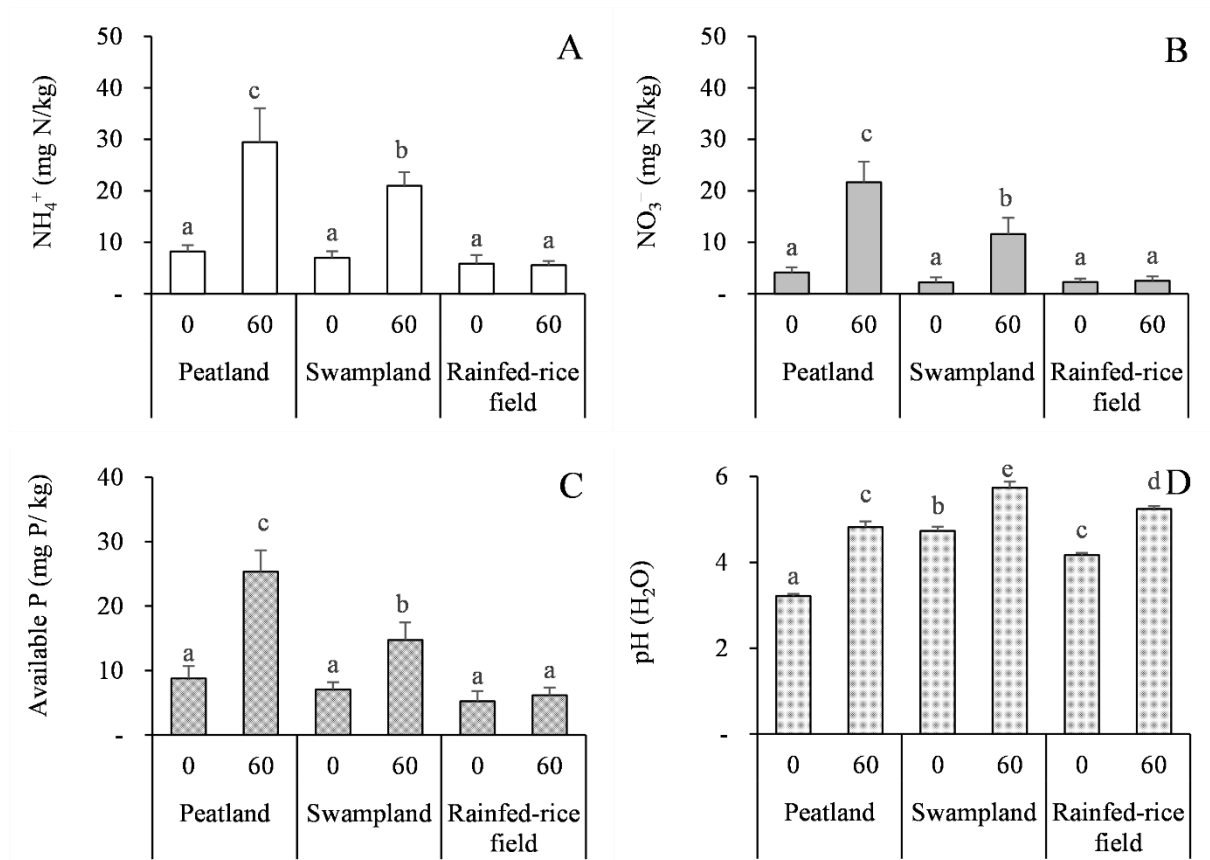
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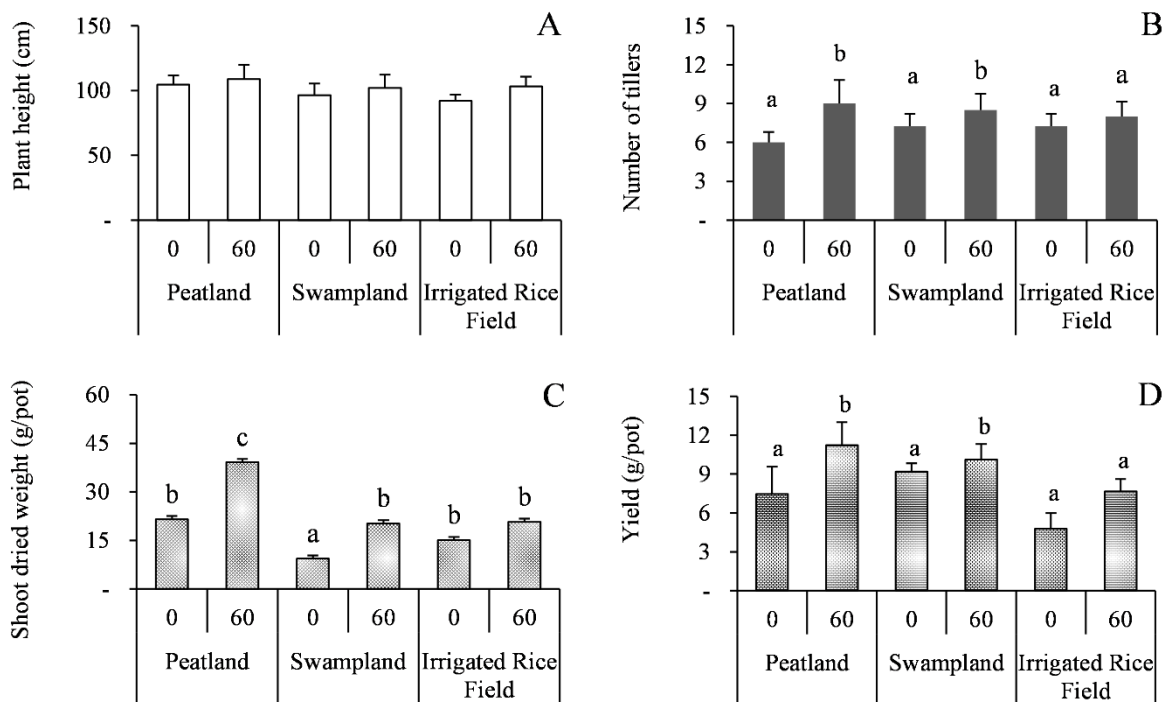
345 **Figures**



346

347 Figure 1. Changes in the amounts of NH₄⁺ (A), NO₃⁻ (B), available P (C), and soil pH (D) of
 348 three different types of rice fields as influenced by the application of coal-fly ash. The lines
 349 above bars represent the standard deviation of the mean (n=4). The letters above the lines
 350 indicate no statistical difference between treatments based on the least significant difference
 351 (LSD) test at *P* < 0.05.

352



353 Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot
 354 dried weight (C), and yield (D) of rice grown in three different types of rice fields as
 355 influenced by the application of coal-fly ash. The lines above bars represent the standard
 356 deviation of the mean (n=4). The same letter above the lines indicates no statistical difference
 357 between treatments based on the least significant difference (LSD) test at $P < 0.05$.
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Correspondence 4 (Revision 3)

[CAAS Agricultural Journals] 245/2022-PSE Article for correction

3 messages

pse@cazv.cz <pse@cazv.cz>
Reply-To: pse@cazv.cz
To: bj_priatmadi@ulm.ac.id

Mon, Dec 5, 2022 at 3:40 PM

Dear Bambang Priatmadi,

We would like to inform you that your manuscript **Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application** (submitted as 245/2022-PSE) should be corrected according to the reviewers' comments.

Reviewer:

Dear authors,

you have not made proper answers for previous reviewers comments in required accompanying letter to show all them with added rows numbers from last review version. You have to do it, and you have to fix also comments expressed in text, see as attachment. You commented results of heavy metals and nutrients, but their transfer to plants is missing, please add them into text, and explained their behaviour, and the effect of ash on it.

Please see the file attached for the reviewers' comments.

For correction use the MS Word Track Changes function. Please submit the corrected manuscript and also the Accompanying letter in anonymized form. See the Instructions to Authors.

We kindly ask you to resubmit the corrected manuscript under the same identification number. To do so, login to the system, click on the manuscript and fill in the "Corrected Text File and Attachments" input field.


Please attach **an Accompanying letter (Cover letter)** where you will respond to all suggestions of reviewers and where you will inform us whether you accepted their suggestions or not and what revisions you made in the original text of the paper according to these suggestions.

Please revise the paper within 14 days.

Please, confirm the acceptance of this e-mail until one week, because the e-mail servers are sometimes out of order.

Yours sincerely,


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 **Corrected manuscript 245-2022 PSE_FINAL-3.pdf**
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Mon, Dec 5, 2022 at 10:09 PM

[Quoted text hidden]

 **Corrected manuscript 245-2022 PSE_FINAL-3.pdf**
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Sun, Dec 11, 2022 at 9:08 PM

Dear Executive Editor,

Thank you for your email.

Yes, we are going to correct the manuscript shortly.

Regards,
Bambang J. Priatmadi
[Quoted text hidden]

Accompanying letter

Dear Mgr. Kateřina Součková,

We have submitted second revised version of this manuscript in which all of the points raised by the reviewers and editors have been addressed. We thank the reviewers and editors for their comments and suggestions. Our responses to each individual comment are detailed below. The line numbers referred to are those of the revised manuscript.

Yours sincerely,

Bambang J. Priatmadi

You have not made proper answers for previous reviewers comments in required accompanying letter to show all them with added rows numbers from last review version. You have to do it, and you have to fixed also comments expressed in text, see as attachment.

You commented results of heavy metals and nutrients, but their transfer to plants is missing, please add them into text, and explained their behaviour, and the effect of ash on it.

We have added a paragraph to explain the effect of coal fly ash on increasing heavy metals concentrations in soils, changes in heavy metals from insoluble forms to available forms for taking up by plant roots, and transfer of heavy metals from soils into roots (lines 205-219).

Line 7: this expression does not make sense, express as g/kg of soil it is confusing to express the application of CFA per ha in the pot experiment.

The application of CFA in this greenhouse experiment was carried out with the same amount of CFA for field experiment. Determination of the amount of CFA application to each soil in the greenhouse experiment was carried out using data of bulk density for each soil, so that the amount of CFA applied to soils in the greenhouse experiment for each soil type was different. The details of experiment that produce different amounts of applied CFA to 12 kg of each soil type have been described in the method section (lines 80-90).

We have revised the sentence to state that the amount of CFA application in this study was equivalent to a field application of 60 t CFA/ha (lines 6-10).

Lines 17-19: be carefull with this, only soil organic C can control the yield, it is not probably true, also other factors can effect this!!

We agree that other factors than soil organic C contents may control the growth and yield of rice. We have softened the sentence to address this issue (lines 18-20).

Line 45: what does is mean, please explain it.

We have referred the positive effect of CFA application on rice growth to the study of Dwivedi et al. (2007). In this study, CFA was applied in the amounts of 0%, 10%, 25%, 50%, 75%, and 100% (weight of CFA:weight of soil) to garden soils, and then rice was grown in the mixed CFA–garden soils. Results of this study showed that the toxicity of CFA was observed at higher concentration (> 50%) as reflected by the reduction in photosynthetic pigments, protein and growth parameters. However, at lower concentrations (10–25%), CFA application enhanced rice growth.

We have revised the sentence to indicated that at CFA application at high concentration leads to negative affect on rice growth but has positive effect on rice growth at low concentration (lines 45-47).

Line 61: it does not make any sence to show, only simple description site is required + GPS coordinates, please express for all sites. You have to show soil type of each soil according to FAO classification.

We have simplified the description of sampling location, have also added GPS coordinates and FAO soil classification system for each soil (lines 61-68).

Lines 81-82: You applied the same amount of soil, why different amount of CFA, if amount of ash was recalculated per the same amount of soil.

We use the amount of CFA applied in the field as a reference for the amount of CFA applied in greenhouse experiment, in this case the amount of CFA applied in greenhouse experiment are equivalent to a field application of 60 t CFA/ha. The use of CFA application amount in the field in the greenhouse experiment is based on the consideration that greenhouse experiment should be as similar as possible to the conditions in the field. Soil bulk density data are used to convert the amount of CFA applied in the field to the same amount of CFA applied in the greenhouse experiment. Because the soil bulk density of the three types of rice fields was different (peatland = 379.60 g/L; swampland = 629.50 g/L; and rainfed rice field = 735.90 g/L), the amount of CFA applied to 12 kg of soil from each type of rice fields are also different.

We have revised the sentences to describe that CFA application in greenhouse experiment with an equivalent amount to a field application of 60 t CFA/ha produces a different amount of CFA application for each soil type in greenhouse experiment (lines 80-90).

Line 118: why you mentioned it twice

We have deleted “Table 1” from the sentence (Line 123).

Line 127: produce mineral N available compounds not minerals!!!

We have changed “N minerals” to “available N” (line 132).

Table 1: Bulk density and particle density: Please express all in g/litre

We have amended the units of bulk density and particle density from t/m^3 to g/L (Table 1). We also corrected the bulk density of rainfed rice field from 1170.30 g/L or 1.17 t/m^3 (bulk density of CFA) to 735.90 g/L (Table 1).

Figure 1: what 0 and 60 means in the figure on x oxe.

We have revised the caption of Figure 1 and Figure 2 to indicate that “0” and “60” represent the soils without CFA application (0 t/ha) and soils with CFA application of 60 t/ha, respectively (lines 384-386 and lines 391-394).

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

3
4 **Abstract:** The improvement of rice production to meet food needs for increasing population is
5 a general problem faced in wetland development for agriculture. The use of industrial waste,
6 such as coal fly ash (CFA), could effectively improve the soil properties of wetlands. In this
7 study, an amount of CFA equivalent to a field application of 60 tonnes CFA/ha (~~326-632 g~~
8 ~~CFA/pot~~) was ~~added~~applied to three different soils collected from the rice fields: (~~peatland,~~
9 ~~swampland, and rainfed field~~), in a 15-liter pot, ~~to obtain an equivalent to a field application of~~
10 ~~60 tonnes CFA/ha~~, and then incubated in the greenhouse for 15 days. The soil pH,
11 concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in the soil were quantified
12 following the completion of the incubation. Rice seedlings were planted in each pot, and after
13 90 days, the growth and yield variables were observed. The results showed that CFA application
14 enhanced the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in peatland and
15 swampland, the rice fields that containing high organic carbon (C), which ultimately leads to
16 increasing rice growth and yield. The application of CFA to rice field containing low organic
17 carbon did not improve available nitrogen and phosphorus nor enhance the growth and yield of
18 rice. Results of this study demonstrate~~Therefore~~, the soil organic C content in the rice fields
19 plays ~~controls an important role in determining~~ the effect of CFA on nutrient availability, ~~as~~
20 ~~well as rice~~ growth and yield of rice.

21
22 **Keywords:** available nutrients; mineralisation; soil fertility; toxic element; wetlands

23

24

25 **INTRODUCTION**

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

35 The mineral and chemical properties of CFA allow the reuse of CFA to have a better economic
 36 value while simultaneously reducing environmental risks. CFA is used in manufacturing
 37 ceramic tiles and producing high-volume concretes (Luo et al. 2021). It also treats wastewater
 38 through adsorption, filtration, Fenton process, photocatalysis, and coagulation (Mushtaq et al.
 39 2019). Premkumar et al. (2017) reported that CFA is an effective stabilizer in enhancing the
 40 erosion resistance of dispersive soils. This industrial waste is also used in agriculture to improve
 41 soil properties and increase the yield of crops (Haris et al. 2021; Saidy et al. 2021; Ukwattage
 42 et al. 2021).

43 The presence of oxides, which neutralize acidic soils, and trace elements, that provide nutrients
 44 for plant growth, is highly advantageous for using CFA as a soil ameliorant (Jambhulkar et al.
 45 2018). Dwivedi et al. (2007) discovered that the application of CFA this industrial waste at high
 46 concentration of 50% (weight of soil:weight of CFA) reduces rice growth, but promotes rice
 47 growth at low concentrations of 10-25%. Furthermore, other studies have demonstrated the
 48 beneficial effect of CFA treatment on rice growth (Munda et al. 2016; Padhy et al. 2016).

49 However, Lee et al. (2019) observed that CFA application does not enhance rice growth due to
50 lowering nitrogen and phosphorus uptakes. Although the application of CFA does not diminish
51 grain yield, it inhibits the tillering process and reduces rice plant biomass (Lim et al. 2017). The
52 results of these studies indicate that the effect of CFA application on the growth and yield of
53 rice may vary depending on the soil conditions employed in the studies. Therefore, this study
54 aimed to investigate the effect of CFA treatment on the growth and production of rice grown in
55 three distinct soil collected from rice fields. In this study, rice fields with varying levels of
56 organic carbon were utilised so that the influence of the CFA on nutrient availability from the
57 mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

58 MATERIALS AND METHODS

59 Sampling and Characterization of Soil and Coal Fly Ash

60 Based on the soil formation process and organic carbon content, the samples used in this study
61 consist of three distinct rice fields: peatland, swampland, and rainfed. Peatland samples (Sapric
62 Histosols) were collected from Pangkoh Hilir Village, ~~Pandih Batu Sub-district, Palang Pisau~~
63 ~~Regency~~, Central Kalimantan Province, Indonesia (3°06'01.2"S, 114°08'40.5"E). Swampland
64 soils (Thionic Fluvisols) were obtained from Desa Tinggiran II Luar, ~~Tamban Subdistrict,~~
65 ~~Barito Kuala Regency~~, South Kalimantan Province, Indonesia (3°17'25.5"S, 114°32'23.3"E).
66 Meanwhile, rainfed rice fields (Argic Fluvisols) were sampled from Desa Timbaan, ~~Tapin~~
67 ~~Selatan Sub-district, Tapin Regency~~, South Kalimantan Province, Indonesia (2°58'37.9"S,
68 115°07'16.5"E). In each type of rice field, soil samples were collected using a PVC pipe (12.5
69 cm in diameter) squeezed to a depth of 30 cm. Following the removal of plant debris, soil
70 samples were homogenised, sealed in plastic bags, and transferred to the laboratory for soil
71 characterisation and greenhouse experiment. Characteristics of the soils used for this study are
72 described in Table 1.

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

79 **Green House Experiment**

80 This greenhouse experiment used the same amount of soil for each soil type collected from the
81 rice field, in which the amounts of CFA added to each experimental pot were equivalent to a
82 field application of 60 t CFA/ha. Therefore, the determination of CFA amount applied to each
83 experimental pot was calculated adjusted using the bulk density of each soil type. As bulk
84 density of each soil is quite different (peatland = 379.60 g/L; swampland = 629.50 g/L; rainfed
85 rice field = 735.90 g/L); thus~~Therefore~~, the rate of CFA application for each experimental pot
86 appears to be different for each soil type. Twelve kilograms of soil samples from each type of
87 rice field were placed in a 15 liter (25 cm in diameter) pot, to which 632 grams CFA/pot
88 (peatland), 381 CFA grams/pot (swampland), 326 grams CFA/pot (rainfed) was added and
89 mixed homogenously. ~~These amounts of CFA added to soils were equivalent to a field~~
90 ~~application of 60 t CFA/ha.~~ Control soil was prepared from each type of rice field without the
91 CFA addition. There were 24 experimental units with three types of rice fields with and without
92 CFA application and four replicates per treatment. Water was added to each pot to obtain a
93 water level of one cm above the soil surface in the pot, and then the soil and CFA combination
94 was incubated for 15 days in the greenhouse. The water level in the pot during the incubation
95 period was maintained by watering daily.

96 After completion of the incubation period, a sub-sampling was performed by collecting 250 g
 97 of soil from each experimental pot for amended-soil characterisation. The characterisation
 98 includes soil pH measured using a glass electrode method (McLean 1982) and the concentration
 99 of NH_4^+ -N and NO_3^- -N in soil (Bundy and Meisinger 1994), and available phosphorus in Bray
 100 extract (Jackson 1967). Rice seedlings (30 days old) previously prepared at the nursery were
 101 planted as many as three seedlings in each experimental pot. The rice variety used for this
 102 research was Ciherang. Finally, the rice growth (height, number of tillers, and shoot dry weight)
 103 and yield were observed 90 days after planting.

104 **Data Analysis**

105 The analysis of variance (ANOVA) was conducted to determine the effect of CFA application
 106 on changes in the properties of amended soils, and growth and yield of rice. Previously, data
 107 normality and variance homogeneity were verified using the Shapiro-Wilk and Bartlett tests,
 108 respectively. The ANOVA results were significant; hence, the analysis was continued with the
 109 mean difference test using the procedure of least significant difference multiple comparisons at
 110 $P < 0.05$. All the analyses were performed using the GenStat 11th Edition package.

111 **RESULTS AND DISCUSSION**

112 **Characteristics of soils and coal fly ash**

113 The three rice fields used in this study have different bulk densities (BD). The highest and
 114 lowest values were observed in peatlands and rainfed rice fields at 0.38 t/m^3 and 1.17 t/m^3 ,
 115 respectively. Furthermore, other soil properties that differ were organic C content, cation
 116 exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows
 117 that these soil characteristics were higher in peatland and swampland than in the rainfed rice
 118 field. Soil pH of the three types of rice fields was relatively not different and ranged from pH
 119 3.23 to 4.72.

120 Coal fly ash (CFA) used in this study had an alkaline pH of 7.43, with a very low organic C
 121 content of 1.45 g C/kg. Table 1 shows that the nutrients N and P of coal ash were also deficient.
 122 However, the calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high,
 123 reaching 1454 mg Ca/kg, 1363 mg Mg/kg, and 1125 mg Fe/kg, respectively ~~(Table 1)~~. The
 124 characteristics of CFA used in this experiment had the typical properties of those used in other
 125 studies (Saidy et al. 2020; Schönegger et al. 2018).

126 **Changes in soil characteristics influenced by the application of coal fly ash**

127 The addition of CFA increased the available N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) and P of peatland and
 128 swampland. The contents of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and available P increased by 259%, 425% and
 129 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However,
 130 no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of
 131 $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and P in peatland and swampland could be attributed to the increased
 132 mineralisation of organic matter (OM), which produces available N ~~minerals~~ and available P
 133 with the application of CFA. Due to the relatively high OM content of peatland and swampland
 134 (Table 1), they have the potential to provide N and P nutrients through the transformation of
 135 organic N and P into N and P minerals, respectively. Previous studies have shown that the CFA
 136 addition enhances the mineralisation of OM, which in turn increase the availability of N and P.
 137 Singh et al. (2011) studied the availability of nitrogen on dry-land paddy agriculture field and
 138 found that the mineralisation of this element was higher in plot applied by coal fly-ash and
 139 farmyard manure than that of farmyard manure application only. The CFA application at a low
 140 level enhances microbial activity (Nayak et al. 2015), which ultimately increases the availability
 141 of N and P.

142 Hu et al. (2021) studied the effect of modified CFA and OM application on soils and found that
 143 the increase in soil phosphorus was attributed to the increasing alkaline phosphatase activities

144 after the application of these ameliorants, which stimulated the mineralisation of organic P.
145 Furthermore, other studies have also shown that applying relatively high amounts of CFA
146 enhance the availability of soil P (Parab et al. 2015; Ukwattage et al. 2020). The higher
147 concentration of available P is primarily attributed to the change in pH value and the direct
148 diffusion of P (Hong et al. 2018).

149 Soil pH in rice fields increased by 1.0–1.6 pH units after applying CFA (Figure 1D). The
150 increase in soil pH is attributed to the liming characteristics of this industrial waste. The CFA
151 used in this study has a relatively high pH as well as CaO and MgO contents (Table 1); hence,
152 it is expected that liming materials neutralize soil acidity to induce soil pH. Several studies have
153 shown that applying industrial waste to acidic soil increases soil pH (Manoharan et al. 2010;
154 Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in
155 the CFA (Ram and Mastro 2014), which may be considered physiologically equivalent to
156 approximately 20% reagent grade CaCO₃ (Kumar et al. 2020). The results indicate that the CFA
157 could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural
158 activities.

159 **Effect of Coal Fly Ash Application on the Growth and Yield of Rice**

160 The application of CFA to the three types of rice fields did not increase the height of the rice.
161 Figure 2A shows that the rice height, with and without industrial waste application, ranged from
162 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers,
163 rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and
164 swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively.
165 Meanwhile, Figure 2B shows that the number of rice tillers in rainfed field did not change after
166 CFA application. The shoot dried weight of rice in peatland and swampland also rise in

167 amended soils. Figure 2C shows that the application of CFA in peatlands and swamplands
 168 increased the shoot dried weight of rice by 40% and 15%, respectively.

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

179 Increasing growth and yield of rice in this study may also related to the presence of silicon (Si)
 180 element containing in CFA. Coal fly ash also contains SiO_2 which could be a source of silicon
 181 elements in soils (Bhatt et al. 2019; Laxmidhar and Subhakanta 2020). Peatland (organic soils)
 182 and swampyland (contain high OC) contain no or low amounts of Si, respectively. Therefore,
 183 the addition of CFA to these soils increases the availability of Si which in turn increases the
 184 growth and yield of rice. However, the addition of CFA to rainfed rice fields (mineral soils
 185 which generally contain Si) did not increase the availability of Si at a higher level, and thereby
 186 do not cause an increase in the growth and yield of rice. Several studies have also reported that
 187 increases in the Si contents in soils result in increasing the growth and yield of rice (Cuong et
 188 al. 2017; Ning et al. 2014).

189 The increase in growth performance and production of rice through the application of CFA in
 190 peatland and swampland is attributed to the improvement of available nutrients in these rice

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

205 Besides the presence of macronutrients (Ca and Mg) and micronutrients (Fe, Mn, Cu and B),
 206 CFA also contains a number of metal element such as Cd, Pb and Cr. Therefore, CFA
 207 application to soils may enhance the concentrations of heavy metals in soils, that may
 208 subsequently be taken up by plants and then transferred along the food chain. The total
 209 concentrations of heavy metals present in soils are not readily available for plant uptake. Thus,
 210 the metals must be mobilized to bioavailable form in soil solution to be taken by roots (Thakur
 211 et al. 2016). Uptake of heavy metals by plants varies and depend largely on several factors such
 212 as soil pH and organic matter contents (Olowoyo et al. 2012). Heavy metals in soils adsorbed
 213 by the carbonates, organic matter, and secondary minerals may not be available for plant uptake.
 214 However, plant-producing chelating agent and plant-inducing pH changes and redox reaction
 215 assist plant root to dissolve and adsorb heavy metals in the soils, even those which are in the

216 form of insoluble minerals (Zakaria et al. 2021). Passive diffusion through the cell membrane
 217 and active transport mediated by carriers are common mechanisms for transfer of heavy metals
 218 from soils into plant roots (Thakur et al. 2016). Although heavy metals are present in soils,
 219 their bioaccumulation in plants is determined by chemical processes of soil-plant interactions.

220 The presence of heavy metals in CFA is a great concern in the use of CFA as a soil ameliorant,
 221 in which the application of CFA to soils could lead to the accumulation of heavy metals in
 222 plants. Previous studies shown that a high amount of CFA application results in an increase in
 223 the accumulation of heavy metals in plants. Research by Singh et al. (2016) showed that the
 224 accumulation of Cd, Cr, Pb and As in rice grains was 4–20 fold higher in soils applied with
 225 50% of CFA than soils without CFA application. On the other hand, Nayak et al. (2015)
 226 reported that the accumulation of heavy metals in rice grains in soils applied with 40% CFA in
 227 greenhouses was not significantly different from soils without CFA application. Moreover, the
 228 application of CFA at an amount of 200 t/ha did not result in the accumulation of Pb, Cd, As
 229 and Cr in rice samples which were different from rice samples without CFA application
 230 (Bhaskarachary et al. 2012). These results imply that the application of a relatively low amount
 231 of CFA did not lead to heavy metal accumulation in plants. This is in accordance with Yu et al.
 232 (2019) who compiled a database from 85 articles on plant biomass with and without CFA
 233 applications, and they suggest that CFA should be applied at less than 25% in order to increase
 234 plant biomass and yield but avoid high accumulations of Al, As, Cd, Cr, Pb, and Se in plants.
 235 The amount of CFA applied to soils in this study were 3-5% of soil mass, depending on the soil
 236 types; therefore, the high accumulation of metals in plant tissue is highly unlikely to occur in
 237 this study. However, further research on metal accumulation in plant tissue in response to the
 238 application of different amounts of CFA to different types of soil collected from rice fields is

239 required to ensure the safety and health of the rice produced from rice fields with CFA
240 application.

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370

371 **Tables**

372 Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after \pm
 373 represent the standard deviation of the mean (n=3).

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal-fly ash
Texture				
- Sand (%)	-	18.23 \pm 1.23	21.36 \pm 2.34	-
- Silt (%)	-	34.56 \pm 3.45	34.23 \pm 2.45	-
- Clay (%)	-	47.21 \pm 4.32	44.41 \pm 3.56	-
Bulk density (g/m^3)	0.37 <u>1.79</u> 8.60 \pm 0.07 <u>0.21</u>	0.63 <u>1.29</u> 5.50 \pm 0.09 <u>0.23</u>	1.17 <u>1.77</u> 35.90 \pm 0.94 <u>2.34</u>	1.17 <u>0.30</u> \pm 0.08 <u>0.45</u>
Particle density (g/L)	1.34 <u>0.23</u> \pm 0.12 <u>0.34</u>	1.98 <u>0.65</u> \pm 0.11 <u>0.78</u>	1.45 <u>0.45</u> \pm 0.08 <u>0.76</u>	2.34 <u>0.45</u> \pm 0.08 <u>0.23</u>
pH (H ₂ O)	3.23 \pm 0.09	4.72 \pm 0.21	4.17 \pm 0.08	7.43 \pm 0.09
Organic C (g C/kg)	214.54 \pm 1.76	93.34 \pm 1.32	4.60 \pm 0.34	1.45 \pm 0.08
Total N (g N/kg)	22.60 \pm 1.21	10.70 \pm 0.96	5.70 \pm 0.12	0.97 \pm 0.05
P (g P/kg)	12.90 \pm 0.65	6.24 \pm 0.34	3.13 \pm 0.12	0.17 \pm 0.08
Ca (mg Ca/kg ¹)	3.21 \pm 0.23	2.58 \pm 0.23	1.67 \pm 0.43	1453.67 \pm 9.76
Mg (mg Mg/kg)	4.56 \pm 0.13	3.23 \pm 0.34	1.87 \pm 0.12	1362.66 \pm 8.54
Na (mg Na/kg)	3.23 \pm 0.08	2.34 \pm 0.08	2.54 \pm 0.09	365.87 \pm 6.76
K (mg K/kg)	3.23 \pm 0.12	2.19 \pm 0.08	1.44 \pm 0.05	768.55 \pm 8.87
Fe (mg Fe/kg)	14.12 \pm 0.07	22.55 \pm 0.12	7.23 \pm 0.60	1124.65 \pm 7.88
Al (mg Al/kg)	5.66 \pm 0.12	17.56 \pm 2.34	4.23 \pm 0.09	865.54 \pm 7.54
Cr (mg Cr/kg)	-	-	-	121.32 \pm 4.67
Pb (mg Pb/kg)	-	-	-	98.78 \pm 9.65
Ni (mg Ni/kg)	-	-	-	176.78 \pm 9.45
CEC (cmol ⁺ /kg)	39.76 \pm 3.23	23.76 \pm 2.34	18.33 \pm 1.23	-

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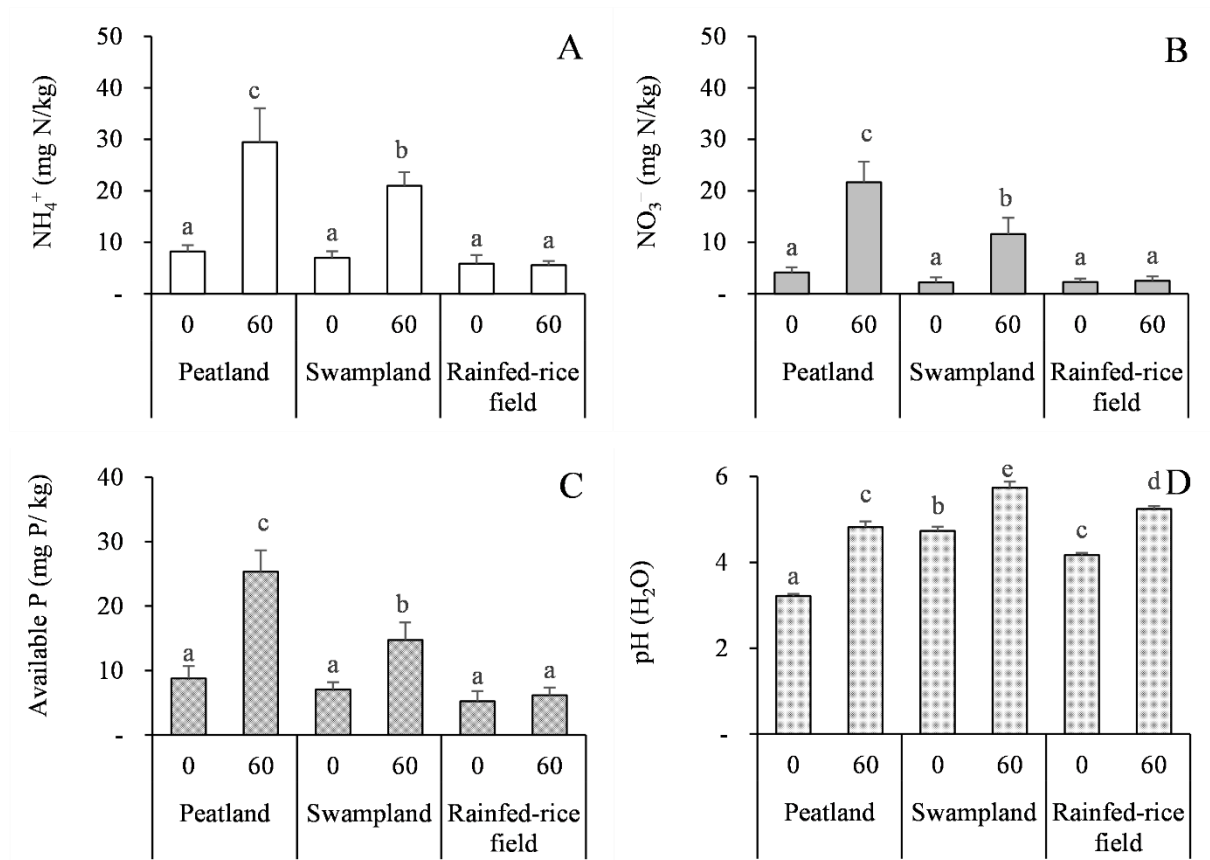
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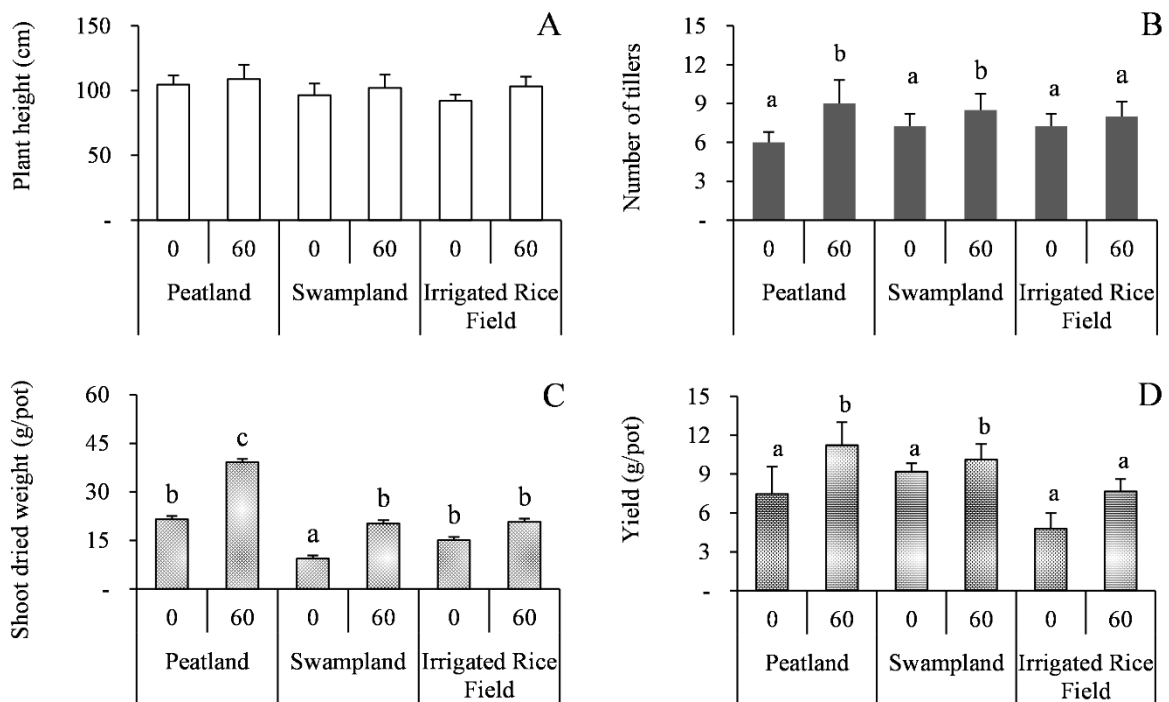
380 **Figures**



381

382 Figure 1. Changes in the amounts of NH₄⁺ (A), NO₃⁻ (B), available P (C), and soil pH (D) of
 383 three different types of rice fields without CFA application (0 t /ha) and with CFA application
 384 (60 t/ha) as influenced by the application of coal fly ash. The lines above bars represent the
 385 standard deviation of the mean (n=4). The letters above the lines indicate no statistical
 386 difference between treatments based on the least significant difference (LSD) test at *P* < 0.05.

387



388
 389 Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot
 390 dried weight (C), and yield (D) of rice grown in three different types of rice fields without
 391 CFA application (0 t/ha) and with CFA application (60 t/ha) as influenced by the application
 392 of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The
 393 same letter above the lines indicates no statistical difference between treatments based on the
 394 least significant difference (LSD) test at $P < 0.05$.
 395

Correspondence 5 (Revision 4)

[CAAS Agricultural Journals] 245/2022-PSE Article for correction

2 messages

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Tue, Jan 10, 2023 at 1:03 PM

Dear Bambang Priatmadi,

We would like to inform you that your manuscript **Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application** (submitted as 245/2022-PSE) should be corrected according to the reviewers' comments.

Reviewer:

Dear authors,

you have made majority of proper answers and improvement of manuscript in last review. Unfortunately, they are several weaknesses and impropriet expressions which have to be answered and corrected. In required accompanying letter you have to show all of them with added rows numbers in new review version. You have to do it, and you have to fixed also comments expressed in text, see as attachement.

You commented results of heavy metals and nutrients, but their transfer to plants is missing, please add them into text, and explained their behaviour, and the effect of ash on it.

Please see the file attached for the reviewers' comments.

For correction use the MS Word Track Changes function. Please submit the corrected manuscript and also the Accompanying letter in anonymized form. See the Instructions to Authors.

We kindly ask you to resubmit the corrected manuscript under the same identification number. To do so, login to the system, click on the manuscript and fill in the "Corrected Text File and Attachments" input field.

Please attach **an Accompanying letter (Cover letter)** where you will respond to all suggestions of reviewers and where you will inform us whether you accepted their suggestions or not and what revisions you made in the original text of the paper according to these suggestions.

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You can reset your password using your e-mail (registered in the system) or your username on this site.

Please revise the paper within 14 days.

Please, confirm the acceptance of this e-mail until one week, because the e-mail servers are sometimes out of order.

Yours sincerely,


Mgr. Kateřina Součková
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Mon, Jan 23, 2023 at 8:09 AM

[Quoted text hidden]

 **Corrected manuscript 245-2022 PSE_Reviewer.pdf**
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Accompanying letter

Dear Mgr. Kateřina Součková,

We have submitted third revised version of this manuscript in which all of the points raised by the reviewers and editors have been addressed. We thank the reviewers and editors for their comments and suggestions. Our responses to each individual comment are detailed below. The line numbers referred to are those of the revised manuscript.

Yours sincerely,

Bambang J. Priatmadi

you have made majority of proper answers and improvement of manuscript in last review. Unfortunately, they are several weaknesses and impropriet expressions which have to be answered and corrected. In required accompanying letter you have to show all of them with added rows numbers in new review version. You have to do it, and you have to fixed also comments expressed in text, see as attachment.

You commented results of heavy metals and nutrients, but their transfer to plants is missing, please add them into text, and explained their behaviour, and the effect of ash on it.

A description of the effect of CFA on increasing available nutrients (nitrogen, phosphorous, calcium, magnesium) has been added to the manuscript. We have also added an explanation of how the behaviors of nutrients in soils and the transfer of these nutrients to plants, which will ultimately increase plant growth and production (lines 219-237).

A statement of the possibility of increasing heavy metal concentrations in plant tissues with CFA applications has been also added to the manuscript. Several research results which show that the application of CFA with low amounts did not result in the accumulation of heavy metals in plant tissues has been also cited in the manuscript. Due to the relatively low amount of CFA application, we have added a statement that an increase in heavy metal content in this study is unlikely to occur. We also provide an explanation of how the behavior of heavy metals originating from CFA has changed from insoluble forms to available forms, their transfer from soils into roots for taking up by plant root (lines 238-272).

Line 7: See bellow, I already mentioned in previous review, it is not true you have to express more suitable.

We have revised the unit for CFA application from weight-based to volume-based because the three soils used for this experiment have different bulk densities. Therefore the unit of CFA application changes to 2% (weight/volume) or 240 grams per 12 litres of soil (lines 7-9).

Line 17: It was not just effect of organic carbon, and what about pH and CFA solubility?

We agree that under certain conditions the pH and solubility of CFA may influence the changes in soil characteristics, the growth and yield of rice. However, this study was not specifically designed to determine the effect of pH and solubility of CFA on the observed parameters. Thus, the effect of pH and solubility of CFA on the observed parameters could not be tested appropriately. It should also be noted that the pH of the soils used for this study is in a relatively narrow range, pH 3.23-4.72 before CFA application and pH 4.73-5.25 after CFA application, and the soil-CFA has relatively similar water contents during the experiment. Thus, the soil pH-CFA is unlikely to affect the results of the study.

Soils with different organic carbon content were used in this study, so that the effect of CFA application on the mineralization process of organic matter which may result in increases in available nutrients could be tested. This statement has been conveyed in the research objectives of this article (lines 55-57). We have made changes in the summary/implication of this study in the abstract (lines 17-20).

Line 70: Table is poor of information, you have to clearly mention for each element if it is total or available content and how was extracted and determined. Why is Cd content in CFA missing. where analyses of mentioned elements are described, if not you have to simply describe it with proper references.

We have added the methods and corresponding references of measurement for each soil and CFA characteristics in Table 1 (lines 460-470). Data of Cd in CFA have also been added to the Table 1.

Line 81: We already discussed this before, that you must clearly show the recalculation for pot experiment, because this value is not true, you have not showed recalculation so far. The rate shown is extremely high according to European limits for CFA application, if you express it per L, or per kg is OK for pot experiment with the explanation why rates differ.

We have recalculated the amount of CFA applied to each soil type. Because the soil used has a relatively different bulk density (BD), so the amount of each type of soil used for research is determined based on volume, which is 12 liters. With the fact that the amount of CFA applied remains equivalent to 60 Mg/ha and by using BD data for each type of soil, the amount of CFA applied for each type of soil collected from rice fields is 20 g/L or equivalent to 2% (weight/volume). We have changed the unit of CFA application to be volume-based so that the amount of CFA applied to each soil type is uniform. We have used units of 20 g/L or equivalent to 2% (weight/volume) in the manuscript for unit of CFA application (lines 77-88).

Lines 83-88: How you can fill 12 kg of peat soil to 15 liter pot, it is impossible. How you did it? How many replications were made for each treatment?

We have revised these sentences. Please see the comments for Line 81 above. Each treatment has four replication (please see lines 89-90).

Line 101: When soil samples for analyses were taken, after harvest? It is not mentioned here, as well in tables or figures.

We have revised the manuscript to indicate that soil sampling was conducted on the 15th day after the CFA application (lines 94-96). Information on when this soil sampling was carried out has also been added to Figure 1 (lines 475-478) and Figure 2 (lines 482-486).

Line 116: ...that these soil characteristics....

We have revised ...“ that these soil characteristics“ ... to ...“values of investigated soil characteristics were higher at“... as suggested by the reviewer/editor (lines 122-123).

Lines 385-387. When samples were taken?, why not analyses of other elements were made?

Information on when soil samples were taken and characterized was added to the Figure 1 and the manuscript. We have also added two graphs to the Figure 1 to show the effect of CFA application on the availability of other nutrients (exchangeable Ca and Mg) (Figure 1). Details on increasing exchangeable Ca and Mg due to CFA application have also been added to the manuscript (lines 164-171).

Line 392: Are you able to show content of nutrients at least N, and P in plant tissues, it would help a lot.

We totally agree with the comments from the reviewer/editor that the data of N and P contents in plant tissue is very helpful in explaining the effect of CFA application on increasing plant growth and production. Data of N and P contents in rice shoots as influenced by CFA application have been added

to the manuscript. We also added an explanation that the increase in plant growth and production with CFA application was due to an increase in the availability of N and P nutrients which was supported by data on increased N and P content in rice shoots (lines 228-237).

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

3
4 **Abstract:** The improvement of rice production to meet food needs for increasing population is
5 a general problem faced in wetland development for agriculture. The use of industrial waste,
6 such as coal fly ash (CFA), could effectively improve the soil properties of wetlands. In this
7 study, CFA with an amount of 2% (weight/volume) or 240 grams were added to 12 litres of
8 three different soils collected from the rice fields (peatland, swampland, and rainfed field) in a
9 15-litre pot, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of
10 $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in the soil were quantified following the
11 completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the
12 growth and yield variables were observed. The results showed that CFA application enhanced
13 the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in peatland and swampland,
14 the rice fields that containing high organic carbon (C), which ultimately leads to increasing rice
15 growth and yield. The application of CFA to rice field containing low organic carbon did not
16 improve available nitrogen and phosphorus nor enhance the growth and yield of rice. Results
17 of this study indicate an important role of soil organic C content in the rice fields in controlling
18 the effect of CFA on nutrient availability, growth and yield of rice.

19
20 **Keywords:** available nutrients; mineralisation; soil fertility; toxic element; wetlands

21

22

23 INTRODUCTION

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

33 The mineral and chemical properties of CFA allow the reuse of CFA to have a better economic
34 value while simultaneously reducing environmental risks. CFA is used in manufacturing
35 ceramic tiles and producing high-volume concretes (Luo et al. 2021). It also treats wastewater
36 through adsorption, filtration, Fenton process, photocatalysis, and coagulation (Mushtaq et al.
37 2019). Premkumar et al. (2017) reported that CFA is an effective stabilizer in enhancing the
38 erosion resistance of dispersive soils. This industrial waste is also used in agriculture to improve
39 soil properties and increase the yield of crops (Haris et al. 2021; Saidy et al. 2020; Ukwattage
40 et al. 2021).

41 The presence of oxides, which neutralize acidic soils, and trace elements, that provide nutrients
42 for plant growth, is highly advantageous for using CFA as a soil ameliorant (Jambhulkar et al.
43 2018). Dwivedi et al. (2007) discovered that the application of CFA at high concentration of
44 50% (weight of soil:weight of CFA) reduces rice growth, but promotes rice growth at low
45 concentrations of 10-25%. Furthermore, other studies have demonstrated the beneficial effect
46 of CFA treatment on rice growth (Munda et al. 2016; Padhy et al. 2016). However, Lee et al.

47 (2019) observed that CFA application does not enhance rice growth due to lowering nitrogen
 48 and phosphorus uptakes. Although the application of CFA does not diminish grain yield, it
 49 inhibits the tillering process and reduces rice plant biomass (Lim et al. 2017). The results of
 50 these studies indicate that the effect of CFA application on the growth and yield of rice may
 51 vary depending on the soil conditions employed in the studies. Therefore, this study aimed to
 52 investigate the effect of CFA treatment on the growth and production of rice grown in three
 53 distinct soil collected from rice fields. In this study, rice fields with varying levels of organic
 54 carbon were utilised so that the influence of the CFA on nutrient availability from the
 55 mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

56 **MATERIALS AND METHODS**

57 **Sampling and Characterization of Soil and Coal Fly Ash**

58 Based on the soil formation process and organic carbon content, the samples used in this study
 59 consist of three distinct rice fields: peatland, swampland, and rainfed. Peatland samples (Sapric
 60 Histosols) were collected from Pangkoh Hilir Village, Central Kalimantan Province, Indonesia
 61 (3°06'01.2"S, 114°08'40.5"E). Swampland soils (Thionic Fluvisols) were obtained from Desa
 62 Tinggiran II Luar, South Kalimantan Province, Indonesia (3°17'25.5"S, 114°32'23.3"E).
 63 Meanwhile, rainfed rice fields (Argic Fluvisols) were sampled from Desa Timbaan, South
 64 Kalimantan Province, Indonesia (2°58'37.9"S, 115°07'16.5"E). In each type of rice field, soil
 65 samples were collected using a PVC pipe (12.5 cm in diameter) squeezed to a depth of 30 cm.
 66 Following the removal of plant debris, soil samples were homogenised, sealed in plastic bags,
 67 and transferred to the laboratory for soil characterisation and greenhouse experiment.
 68 Characteristics of the soils used for this study are described in Table 1.

69 Coal fly ash (CFA) was collected from the disposal site of the Asam Asam Power Plant located
 70 in the Asam Asam Village, Jorong Sub-district, Tanah Laut Regency, South Kalimantan

71 Province, Indonesia. After being transported to the laboratory, the CFA was air-dried, sieved
72 through a 2.00 mm sieve, and a portion was used for the characterisation, while another was
73 stored at 4 °C until used for the experiment. The characteristics of CFA used for this study are
74 showed in Table 1.

75 **Green House Experiment**

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

84 A sub-sampling was performed by collecting 250 grams of soil from each experimental pot on
85 the 15th day after the CFA application (after the completion of incubation period) for the
86 characterisation of amended-soils. The characterisation includes soil pH measured using a glass
87 electrode method (McLean 1982) and the concentration of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in soil (Bundy
88 and Meisinger 1994), available phosphorus in Bray extract (Jackson 1967), and exchangeable
89 Ca and Mg (Lanyon and Heald 1982). Rice seedlings (30 days old) previously prepared at the
90 nursery were planted as many as three seedlings in each experimental pot. The rice variety used
91 for this research was Ciherang. Finally, the rice harvest was carried out 90 days after planting,
92 and then the growth (height, number of tillers, and shoot dry weight) and yield of rice were
93 determined. All the growth and yield attributing characters were studied after the harvesting
94 period of 90 days. Plant height (cm) was measured by a metric scale and number of tillers/hill

95 was counted manually. After this, plant parts were partitioned into roots, leaves, straw and
 96 grains and then were washed with double distilled water and blotted. Observations on plant
 97 height, number of panicles and panicle weight per pot were recorded in each treatment at
 98 harvest. The harvested samples were sun-dried, weighed and recorded as total biomass.
 99 The rice grains and rice shoot were separated from other rice parts, then oven-dried ~~Shoot rice~~
 100 ~~was separated from other plant parts, oven-dried~~ at 70 °C to constant weight, and then grind to
 101 powder for the determination of N and P contents. Content of N in shoot rice was quantified
 102 using the micro Kjeldahl method (Hafez and Mikkelsen 1981), while content of P in shoot rice
 103 was determined using ascorbic acid-molybdate method after the digestion of rice shoot with
 104 60% concentrated HNO₃ (Caradus and Snaydon 1987).

105 **Data Analysis**

106 The analysis of variance (ANOVA) was conducted to determine the effect of CFA application
 107 on changes in the properties of amended soils, and growth and yield of rice. Previously, data
 108 normality and variance homogeneity were verified using the Shapiro-Wilk and Bartlett tests,
 109 respectively. The ANOVA results were significant; hence, the analysis was continued with the
 110 mean difference test using the procedure of least significant difference multiple comparisons at
 111 $P < 0.05$. All the analyses were performed using the GenStat 11th Edition package.

112 **RESULTS AND DISCUSSION**

113 **Characteristics of soils and coal fly ash**

114 The three rice fields used in this study have different bulk densities (BD). The highest and
 115 lowest values were observed in peatlands and rainfed rice fields at 0.38 t/m³ and 1.17 t/m³,
 116 respectively. Furthermore, other soil properties that differ were organic C content, cation
 117 exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows

118 that values of investigated soil characteristics were higher at at peatland and swampland than
119 at the rainfed rice field. Soil pH of the three types of rice fields was relatively not different and
120 ranged from pH 3.23 to 4.72.

121 Coal fly ash (CFA) used in this study had an alkaline pH of 7.43, with a very low organic C
122 content of 1.45 g C/kg. Table 1 shows that the nutrients N and P of coal ash were also deficient.
123 However, the calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high,
124 reaching 1454 mg Ca/kg, 1363 mg Mg/kg, and 1125 mg Fe/kg, respectively. The characteristics
125 of CFA used in this experiment had the typical properties of those used in other studies (Saidy
126 et al. 2020; Schönegger et al. 2018).

127 **Changes in soil characteristics influenced by the application of coal fly ash**

128 The addition of CFA increased the available N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) and P of peatland and
129 swampland. The contents of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and available P increased by 259%, 425% and
130 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However,
131 no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of
132 $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and P in peatland and swampland could be attributed to the increased
133 mineralisation of organic matter (OM), which produces available N and available P with the
134 application of CFA. Due to the relatively high OM content of peatland and swampland (Table
135 1), they have the potential to provide N and P nutrients through the transformation of organic
136 N and P into N and P minerals, respectively. Previous studies have shown that the CFA addition
137 enhances the mineralisation of OM, which in turn increase the availability of N and P. Singh et
138 al. (2011) studied the availability of nitrogen on dry-land paddy agriculture field and found that
139 the mineralisation of this element was higher in plot applied by coal fly-ash and farmyard
140 manure than that of farmyard manure application only. The CFA application at a low level

141 enhances microbial activity (Nayak et al. 2015), which ultimately increases the availability of
142 N and P.

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

150 Soil pH in rice fields increased by 1.0–1.6 pH units after applying CFA (Figure 1D). The
151 increase in soil pH is attributed to the liming characteristics of this industrial waste. The CFA
152 used in this study has a relatively high pH as well as CaO and MgO contents (Table 1); hence,
153 it is expected that liming materials neutralize soil acidity to induce soil pH. Several studies have
154 shown that applying industrial waste to acidic soil increases soil pH (Manoharan et al. 2010;
155 Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in
156 the CFA (Ram and Mastro 2014), which may be considered physiologically equivalent to
157 approximately 20% reagent grade CaCO₃ (Kumar et al. 2020). The results indicate that the CFA
158 could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural
159 activities.

160 The results of the study indicate that the application CFA has led to a significant increase in the
161 concentrations of exchangeable Ca and Mg in the soil, which were 341-431% and 176-245%
162 higher than those in soils without CFA application (Figure 1E and 1F). This increase in Ca and
163 Mg could be attributed to the high contents of Ca and Mg present in the CFA used for the study
164 (Table 1). Several previous studies have shown that the application of CFA to the soil supplies

165 Mg (He et al. 2017) and exchangeable Ca (Parab et al. 2015). Overall, the study highlights the
166 potential of CFA as a high source of Ca and Mg for improving soil fertility and crop
167 productivity.

168 **Effect of Coal Fly Ash Application on the Growth and Yield of Rice**

169 The application of CFA to the three types of rice fields did not increase the height of the rice.
170 Figure 2A shows that the rice height, with and without industrial waste application, ranged from
171 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers,
172 rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and
173 swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively.
174 Meanwhile, Figure 2B shows that the number of rice tillers in rainfed field did not change after
175 CFA application. The shoot dried weight of rice in peatland and swampland also rise in
176 amended soils. Figure 2C shows that the application of CFA in peatlands and swamplands
177 increased the shoot dried weight of rice by 40% and 15%, respectively.

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

188 Increasing growth and yield of rice in this study may also related to the presence of silicon (Si)
 189 element containing in CFA. Coal fly ash also contains SiO₂ which could be a source of silicon
 190 elements in soils (Bhatt et al. 2019; Laxmidhar and Subhakanta 2020). Peatland (organic soils)
 191 and swampyland (contain high OC) contain no or low amounts of Si, respectively. Therefore,
 192 the addition of CFA to these soils increases the availability of Si which in turn increases the
 193 growth and yield of rice. However, the addition of CFA to rainfed rice fields (mineral soils
 194 which generally contain Si) did not increase the availability of Si at a higher level, and thereby
 195 do not cause an increase in the growth and yield of rice. Several studies have also reported that
 196 increases in the Si contents in soils result in increasing the growth and yield of rice (Cuong et
 197 al. 2017; Ning et al. 2014).

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

212 imply that the effect of coal fly ash on improving nutrient availability, rice growth, and yield is
213 dependent on the soil organic carbon contents.

214 Nutrients in soil-plant systems exhibit different behaviors to determine their availability and
215 uptake by plants. The application of CFA to rice fields results in an increase in available
216 nutrients in soils (Figure 1). Available nutrients are transported, absorbed and utilized by
217 plants; a small portion of nutrients may become precipitated in soils as long-term fertilizers for
218 plants; and a very small portion of nutrients may become immobilized by the cell wall of
219 microorganisms (Liu et al. 2019). Behaviours of nutrients in soils are controlled by numerous
220 factors, including the type of nutrient, soil properties, root architecture, environmental
221 conditions, and microbial activity. Passive diffusion through the cell membrane and active
222 transport are common mechanisms for transfer of nutrients from soils into plant roots (Thakur
223 et al. 2016; Yadav et al. 2021). Increasing the availability of nutrients with the application of
224 CFA (Figure 1) led to increases in the growth and production of rice (Figure 2). Increasing the
225 amount of available nutrients and then absorbed by plants with the application of CFA in this
226 study is supported by the data of N and P contents in rice shoots. Peatland and swampland
227 which had increased growth and yield of rice with CFA application showed increasing N and
228 P contents in shoot rice (Figure 2E and 2F). On the other hand, the absence of differences in N
229 and P contents in rainfed rice fields with and without CFA application (Figure 2E and 2F) is
230 associated with no increase in growth and yield of rice with CFA application (Figure 2B, 2C,
231 and 2D). Understanding the behaviors of nutrients in soil-plant systems is crucial for optimizing
232 agricultural production, reducing environmental impact, and sustaining ecosystem services.

233 Besides the presence of macronutrients (Ca and Mg) and micronutrients (Fe, Mn, Cu and B),
234 CFA also contains a number of metal element such as Cd, Pb and Cr. Therefore, CFA
235 application to soils may enhance the concentrations of heavy metals in soils, that may

236 subsequently be taken up by plants and then transferred to the plant tissue. The total
 237 concentrations of heavy metals present in soils are not readily available for plant uptake. Thus,
 238 the metals must be mobilized to bioavailable form in soil solution to be taken by roots (Thakur
 239 et al. 2016). Uptake of heavy metals by plants varies and depend largely on several factors such
 240 as soil pH and organic matter contents (Olowoyo et al. 2012). Heavy metals in soils adsorbed
 241 by the carbonates, organic matter, and secondary minerals may not be available for plant uptake.
 242 However, plant-producing chelating agent and plant-inducing pH changes and redox reaction
 243 assist plant root to dissolve and adsorb heavy metals in the soils, even those which are in the
 244 form of insoluble minerals (Zakaria et al. 2021). Although heavy metals are present in soils,
 245 their bioaccumulation in plants is determined by chemical processes of soil-plant interactions.

246 The presence of heavy metals in CFA is a great concern in the use of CFA as a soil ameliorant,
 247 in which the application of CFA to soils could lead to the accumulation of heavy metals in
 248 plants. Previous studies shown that a high amount of CFA application results in an increase in
 249 the accumulation of heavy metals in plants. Research by Singh et al. (2016) showed that the
 250 accumulation of Cd, Cr, Pb and As in rice grains was 4–20 fold higher in soils applied with
 251 50% of CFA than soils without CFA application. On the other hand, Nayak et al. (2015)
 252 reported that the accumulation of heavy metals in rice grains in soils applied with 40% CFA in
 253 greenhouses was not significantly different from soils without CFA application. Moreover, the
 254 application of CFA at an amount of 200 t/ha did not result in the accumulation of Pb, Cd, As
 255 and Cr in rice samples which were different from rice samples without CFA application
 256 (Bhaskarachary et al. 2012). These results imply that the application of a relatively low amount
 257 of CFA did not lead to heavy metal accumulation in plants. This is in accordance with (Yu et
 258 al. 2019) who compiled a database from 85 articles on plant biomass with and without CFA
 259 applications, and they suggest that CFA should be applied at less than 25% in order to increase

260 plant biomass and yield but avoid high accumulations of Al, As, Cd, Cr, Pb, and Se in plants.
 261 The amount of CFA applied to soils in this study were 3-5% of soil mass, depending on the soil
 262 types; therefore, the high accumulation of metals in plant tissue is highly unlikely to occur in
 263 this study. However, further research on metal accumulation in plant tissue in response to the
 264 application of different amounts of CFA to different types of soil collected from rice fields is
 265 required to ensure the safety and health of the rice produced from rice fields with CFA
 266 application.

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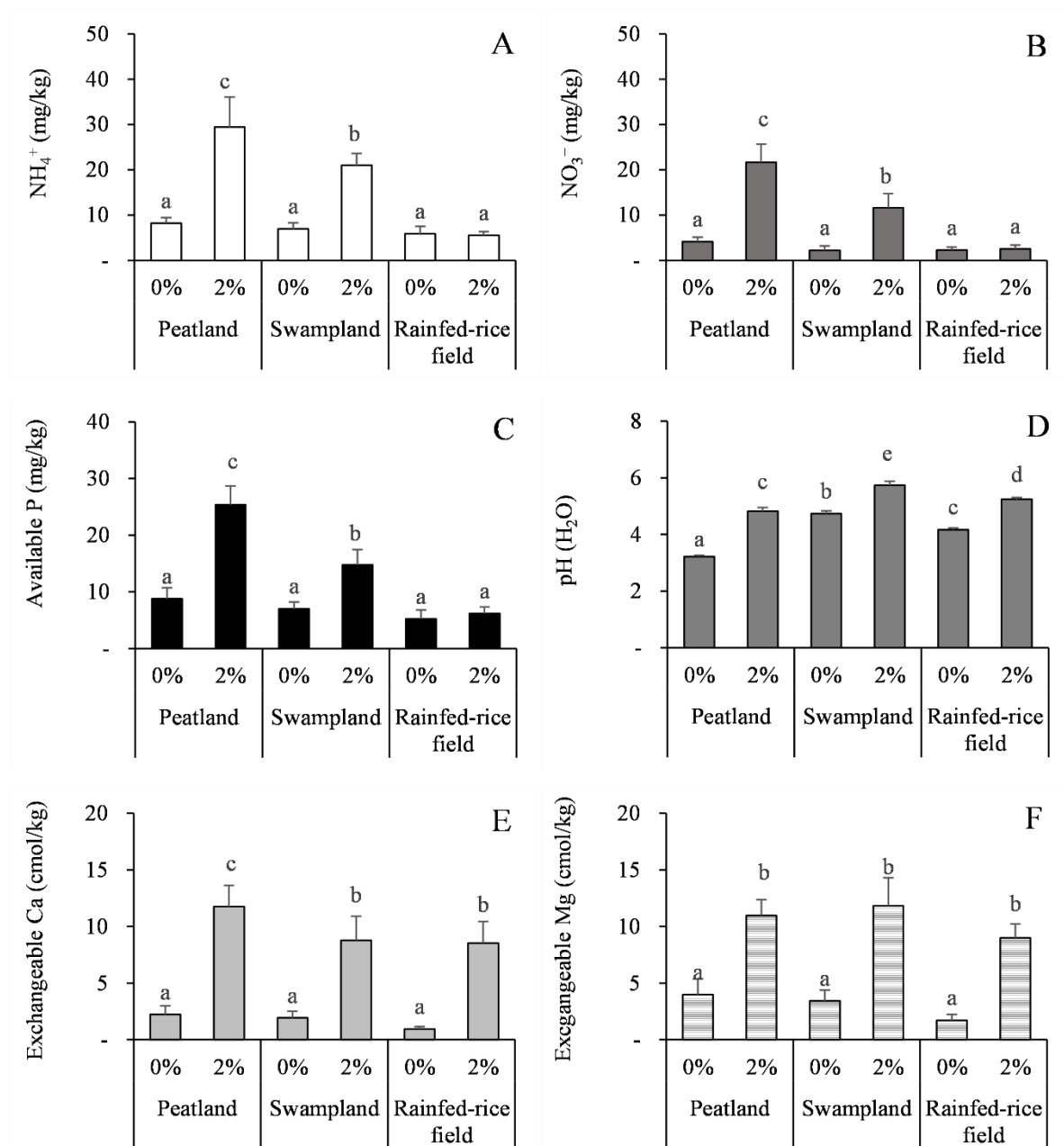
450 **Tables**

451 Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after \pm represent
452 the standard deviation of the mean (n=3).

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal-fly ash
Texture ^a				
- Sand (%)	-	18.23 \pm 1.23	21.36 \pm 2.34	-
- Silt (%)	-	34.56 \pm 3.45	34.23 \pm 2.45	-
- Clay (%)	-	47.21 \pm 4.32	44.41 \pm 3.56	-
Bulk density ^b (g/L)	379.60 \pm 70.21	629.50 \pm 90.23	735.90 \pm 92.34	1170.30 \pm 80.45
Particle density ^c (g/L)	1340.23 \pm 120.34	1980.65 \pm 110.78	1450.45 \pm 80.76	2340.45 \pm 80.23
pH ^d (H ₂ O)	3.23 \pm 0.09	4.72 \pm 0.21	4.17 \pm 0.08	7.43 \pm 0.09
Organic ^e C (g C/kg)	214.54 \pm 1.76	93.34 \pm 1.32	4.60 \pm 0.34	1.45 \pm 0.08
Total N ^f (g N/kg)	22.60 \pm 1.21	10.70 \pm 0.96	5.70 \pm 0.12	0.97 \pm 0.05
P ^g (g P/kg)	12.90 \pm 0.65	6.24 \pm 0.34	3.13 \pm 0.12	0.17 \pm 0.08
Ca ^h (mg Ca/kg ^l)	3.21 \pm 0.23	2.58 \pm 0.23	1.67 \pm 0.43	1453.67 \pm 9.76
Mg ^h (mg Mg/kg)	4.56 \pm 0.13	3.23 \pm 0.34	1.87 \pm 0.12	1362.66 \pm 8.54
Na ^h (mg Na/kg)	3.23 \pm 0.08	2.34 \pm 0.08	2.54 \pm 0.09	365.87 \pm 6.76
K ^h (mg K/kg)	3.23 \pm 0.12	2.19 \pm 0.08	1.44 \pm 0.05	768.55 \pm 8.87
Fe ^h (mg Fe/kg)	14.12 \pm 0.07	22.55 \pm 0.12	7.23 \pm 0.60	1124.65 \pm 7.88
Al ^h (mg Al/kg)	5.66 \pm 0.12	17.56 \pm 2.34	4.23 \pm 0.09	865.54 \pm 7.54
Cr ⁱ (mg Cr/kg)	-	-	-	121.32 \pm 4.67
Pb ⁱ (mg Pb/kg)	-	-	-	98.78 \pm 9.65
Ni ⁱ (mg Ni/kg)	-	-	-	176.78 \pm 9.45
Cd ⁱ (mg Cd/kg)	-	-	-	4.02 \pm 0.15
CEC ^j (cmol ₊ /kg)	39.76 \pm 3.23	23.76 \pm 2.34	18.33 \pm 1.23	-

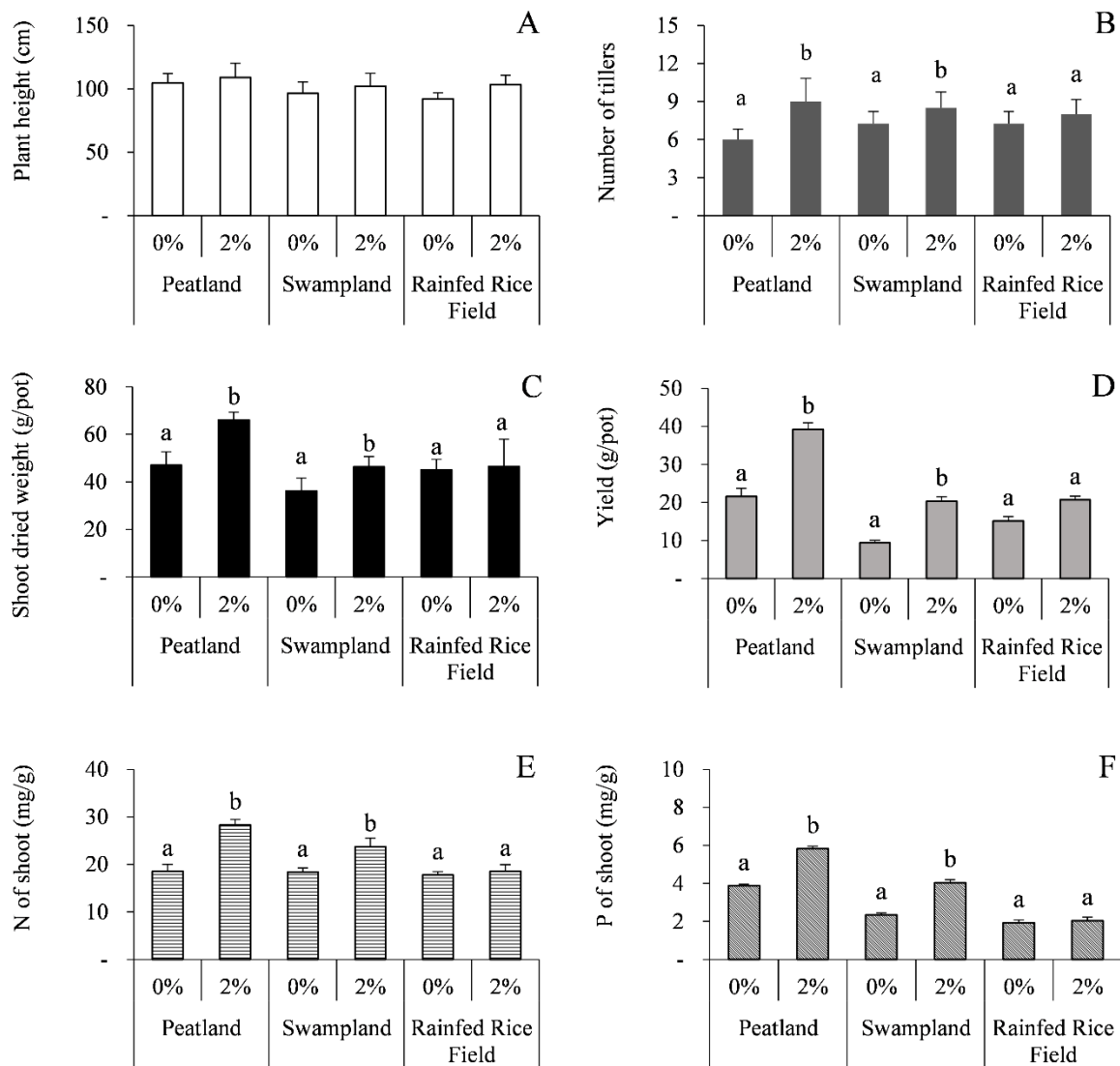
453
454 ^a Sieving and sedimentation methods (Gee and Bander 1986); ^b soil core sampling method
455 (Blake and Hartge 1986a); ^c volumetric flask method (Blake and Hartge 1986b); ^d electrode
456 glass method (1:5, mass: volume) (McLean 1982); ^e Walkley and Black method (Nelson and
457 Sommers 1996); ^f Kjeldahl method (Bremer and Mulvaney 1982); ^g digestion of soil and CFA
458 with 60% HClO₄ and measurement at 660 nm using a spectrophotometer (Olsen and
459 Sommers 1982); ^h digestion of soil and CFA using a mixture of HNO₃ and HClO₄ and
460 determination of digested solution using an atomic absorption spectrophotometer (Barnhisel
461 and Bertsch 1982; Knudsen and Peterson 1982; Lanyon and Heald 1982; Olson and Ellis
462 1982); ⁱ digestion of CFA in tri-acid mixture (10:1:4, HNO₃:H₂SO₄:HClO₄ acids) and
463 measurement using an atomic absorption spectrophotometer (Baker and Amacher 1982;
464 Bureau 1982; Reisenauer 1982); ^j ammonium acetate (pH 7.0) method (Rhoades 1982).

466 **Figures**



467

468 Figure 1. Changes in the amounts of NH₄⁺ (A), NO₃⁻ (B), available P (C), soil pH (D),
 469 exchangeable Ca (E), and exchangeable Mg (F) of three different types of rice fields without
 470 CFA application (0%) and with CFA application (2%) observed on 15th day after CFA
 471 application. The lines above bars represent the standard deviation of the mean (n=4). The
 472 letters above the lines indicate no statistical difference between treatments based on the least
 473 significant difference (LSD) test at $P < 0.05$.



474

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

482

Correspondence 6 (Revision 5)

[CAAS Agricultural Journals] 245/2022-PSE Article for correction

2 messages

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Reply-To: pse@cazv.cz
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Mon, Jun 5, 2023 at 1:46 PM

Dear Bambang Priatmadi,

We would like to inform you that your manuscript **Growth performance and yield of rice grown in three different types of rice fields with coal fly ash application** (submitted as 245/2022-PSE) should be corrected according to the reviewers' comments.

Reviewer 1:

- on row 91 a further there is not clearly described specific difference between shoot dry mass and yield of rice similarly in Figure 2 c and d.

Please describe properly postharvest operations and what these expressions means.

Executive editor's comments:

- please, correct the references according to the journal style. Please, add the full names of journals to the list of references.

For correction use the MS Word Track Changes function. Please submit the corrected manuscript and also the Accompanying letter in anonymized form. See the Instructions to Authors.

We kindly ask you to resubmit the corrected manuscript under the same identification number. To do so, login to the system, click on the manuscript and fill in the "Corrected Text File and Attachments" input field. Please attach an **Accompanying letter (Cover letter)** where you will respond to all suggestions of reviewers and where you will inform us whether you accepted their suggestions or not and what revisions you made in the original text of the paper according to these suggestions.

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Please, confirm the acceptance of this e-mail until two days, because the e-mail servers are sometimes out of order.

Yours sincerely,

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Fri, Jun 9, 2023 at 10:43 AM

[Quoted text hidden]

Accompanying letter

Dear Executive Editor of Plant, Soil and Environment,

We have submitted fourth revised version of this manuscript in which all of the points raised by the reviewer and editor have been addressed. We thank you very much for the comments and suggestions. The comments and suggestions are valuable and very helpful for revising and improving our manuscript. Our responses to each individual comment are detailed below. The line numbers referred to are those of the revised manuscript.

Yours sincerely,

Bambang J. Priatmadi

Reviewer 1:

- on row 91 a further there is not clearly described specific difference between shoot dry mass and yield of rice similarly in Figure 2 c and d. Please describe properly postharvest operations and what these expressions means.

We have added details on how rice growth and yield measurements (plant height, number of tillers, shoot dry weight, and rice yield) were carried out (please see lines 93-99).

Executive editor's comments:

- please, correct the references according to the journal style. Please, add the full names of journals to the list of references.

We have corrected the references according to the journal style by adding the full names of journals to the list of references (lines 266-449).

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

3
4 **Abstract:** The improvement of rice production to meet food needs for increasing population is
5 a general problem faced in wetland development for agriculture. The use of industrial waste,
6 such as coal fly ash (CFA), could effectively improve the soil properties of wetlands. In this
7 study, CFA with an amount of 2% (weight/volume) or 240 grams were added to 12 litres of
8 three different soils collected from the rice fields (peatland, swampland, and rainfed field) in a
9 15-litre pot, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of
10 $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in the soil were quantified following the
11 completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the
12 growth and yield variables were observed. The results showed that CFA application enhanced
13 the concentrations of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$, and available phosphorus in peatland and swampland,
14 the rice fields that containing high organic carbon (C), which ultimately leads to increasing rice
15 growth and yield. The application of CFA to rice field containing low organic carbon did not
16 improve available nitrogen and phosphorus nor enhance the growth and yield of rice. Results
17 of this study indicate an important role of soil organic C content in the rice fields in controlling
18 the effect of CFA on nutrient availability, growth and yield of rice.

19
20 **Keywords:** available nutrients; mineralisation; soil fertility; toxic element; wetlands

21

22

23 INTRODUCTION

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

33 The mineral and chemical properties of CFA allow the reuse of CFA to have a better economic
34 value while simultaneously reducing environmental risks. CFA is used in manufacturing
35 ceramic tiles and producing high-volume concretes (Luo et al. 2021). It also treats wastewater
36 through adsorption, filtration, Fenton process, photocatalysis, and coagulation (Mushtaq et al.
37 2019). Premkumar et al. (2017) reported that CFA is an effective stabilizer in enhancing the
38 erosion resistance of dispersive soils. This industrial waste is also used in agriculture to improve
39 soil properties and increase the yield of crops (Haris et al. 2021; Saidy et al. 2020; Ukwattage
40 et al. 2021).

41 The presence of oxides, which neutralize acidic soils, and trace elements, that provide nutrients
42 for plant growth, is highly advantageous for using CFA as a soil ameliorant (Jambhulkar et al.
43 2018). Dwivedi et al. (2007) discovered that the application of CFA at high concentration of
44 50% (weight of soil:weight of CFA) reduces rice growth, but promotes rice growth at low
45 concentrations of 10-25%. Furthermore, other studies have demonstrated the beneficial effect
46 of CFA treatment on rice growth (Munda et al. 2016; Padhy et al. 2016). However, Lee et al.

47 (2019) observed that CFA application does not enhance rice growth due to lowering nitrogen
48 and phosphorus uptakes. Although the application of CFA does not diminish grain yield, it
49 inhibits the tillering process and reduces rice plant biomass (Lim et al. 2017). The results of
50 these studies indicate that the effect of CFA application on the growth and yield of rice may
51 vary depending on the soil conditions employed in the studies. Therefore, this study aimed to
52 investigate the effect of CFA treatment on the growth and production of rice grown in three
53 distinct soil collected from rice fields. In this study, rice fields with varying levels of organic
54 carbon were utilised so that the influence of the CFA on nutrient availability from the
55 mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

56 **MATERIALS AND METHODS**

57 **Sampling and Characterization of Soil and Coal Fly Ash**

58 Based on the soil formation process and organic carbon content, the samples used in this study
59 consist of three distinct rice fields: peatland, swampland, and rainfed. Peatland samples (Sapric
60 Histosols) were collected from Pangkoh Hilir Village, Central Kalimantan Province, Indonesia
61 (3°06'01.2"S, 114°08'40.5"E). Swampland soils (Thionic Fluvisols) were obtained from Desa
62 Tinggiran II Luar, South Kalimantan Province, Indonesia (3°17'25.5"S, 114°32'23.3"E).
63 Meanwhile, rainfed rice fields (Argic Fluvisols) were sampled from Desa Timbaan, South
64 Kalimantan Province, Indonesia (2°58'37.9"S, 115°07'16.5"E). In each type of rice field, soil
65 samples were collected using a PVC pipe (12.5 cm in diameter) squeezed to a depth of 30 cm.
66 Following the removal of plant debris, soil samples were homogenised, sealed in plastic bags,
67 and transferred to the laboratory for soil characterisation and greenhouse experiment.
68 Characteristics of the soils used for this study are described in Table 1.

69 Coal fly ash (CFA) was collected from the disposal site of the Asam Asam Power Plant located
70 in the Asam Asam Village, Jorong Sub-district, Tanah Laut Regency, South Kalimantan

71 Province, Indonesia. After being transported to the laboratory, the CFA was air-dried, sieved
 72 through a 2.00 mm sieve, and a portion was used for the characterisation, while another was
 73 stored at 4 °C until used for the experiment. The characteristics of CFA used for this study are
 74 showed in Table 1.

75 **Green House Experiment**

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

84 A sub-sampling was performed by collecting 250 grams of soil from each experimental pot on
 85 the 15th day after the CFA application (after the completion of incubation period) for the
 86 characterisation of amended-soils. The characterisation includes soil pH measured using a glass
 87 electrode method (McLean 1982) and the concentration of $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$ in soil (Bundy
 88 and Meisinger 1994), available phosphorus in Bray extract (Jackson 1967), and exchangeable
 89 Ca and Mg (Lanyon and Heald 1982). Rice seedlings (30 days old) previously prepared at the
 90 nursery were planted as many as three seedlings in each experimental pot. The rice variety used
 91 for this research was Ciherang. Finally, the rice harvest was carried out 90 days after planting,
 92 and then the growth (plant height, number of tillers, and shoot dry weight) and yield of rice
 93 were determined. Measurement of plant height (cm) was carried out using a metric scale and
 94 the number of tillers was calculated manually. All parts of the rice plant above the ground from

95 each pot were cut (2–3 cm above the ground), washed with aquades, then rice shoots and grains
 96 were separated from each other. Rice shoots and grains were oven-dried at 70 °C for 48 hours,
 97 weighed immediately, and they were expressed as grams per pot (g/pot). Rice shoots were
 98 ~~Shoot rice was separated from other plant parts, oven-dried at 70 °C to constant weight, and~~
 99 ~~then-then~~ grind to powder for the determination of N and P contents. Content of N in shoot
 100 rice was quantified using the micro Kjeldahl method (Hafez and Mikkelsen 1981), while
 101 content of P in shoot rice was determined using ascorbic acid-molybdate method after the
 102 digestion of rice shoot with 60% concentrated HNO₃ (Caradus and Snaydon 1987).

103 **Data Analysis**

104 The analysis of variance (ANOVA) was conducted to determine the effect of CFA application
 105 on changes in the properties of amended soils, and growth and yield of rice. Previously, data
 106 normality and variance homogeneity were verified using the Shapiro-Wilk and Bartlett tests,
 107 respectively. The ANOVA results were significant; hence, the analysis was continued with the
 108 mean difference test using the procedure of least significant difference multiple comparisons at
 109 $P < 0.05$. All the analyses were performed using the GenStat 11th Edition package.

110 **RESULTS AND DISCUSSION**

111 **Characteristics of soils and coal fly ash**

112 The three rice fields used in this study have different bulk densities (BD). The highest and
 113 lowest values were observed in peatlands and rainfed rice fields at 0.38 t/m³ and 1.17 t/m³,
 114 respectively. Furthermore, other soil properties that differ were organic C content, cation
 115 exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows
 116 that values of investigated soil characteristics were higher at at peatland and swampland than
 117 at the rainfed rice field. Soil pH of the three types of rice fields was relatively not different and
 118 ranged from pH 3.23 to 4.72.

119 Coal fly ash (CFA) used in this study had an alkaline pH of 7.43, with a very low organic C
 120 content of 1.45 g C/kg. Table 1 shows that the nutrients N and P of coal ash were also deficient.
 121 However, the calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high,
 122 reaching 1454 mg Ca/kg, 1363 mg Mg/kg, and 1125 mg Fe/kg, respectively. The characteristics
 123 of CFA used in this experiment had the typical properties of those used in other studies (Saidy
 124 et al. 2020; Schönegger et al. 2018).

125 **Changes in soil characteristics influenced by the application of coal fly ash**

126 The addition of CFA increased the available N ($\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$) and P of peatland and
 127 swampland. The contents of $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and available P increased by 259%, 425% and
 128 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However,
 129 no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of
 130 $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$ and P in peatland and swampland could be attributed to the increased
 131 mineralisation of organic matter (OM), which produces available N and available P with the
 132 application of CFA. Due to the relatively high OM content of peatland and swampland (Table
 133 1), they have the potential to provide N and P nutrients through the transformation of organic
 134 N and P into N and P minerals, respectively. Previous studies have shown that the CFA addition
 135 enhances the mineralisation of OM, which in turn increase the availability of N and P. Singh et
 136 al. (2011) studied the availability of nitrogen on dry-land paddy agriculture field and found that
 137 the mineralisation of this element was higher in plot applied by coal fly-ash and farmyard
 138 manure than that of farmyard manure application only. The CFA application at a low level
 139 enhances microbial activity (Nayak et al. 2015), which ultimately increases the availability of
 140 N and P.

141 Hu et al. (2021) studied the effect of modified CFA and OM application on soils and found that
 142 the increase in soil phosphorus was attributed to the increasing alkaline phosphatase activities

143 after the application of these ameliorants, which stimulated the mineralisation of organic P.
144 Furthermore, other studies have also shown that applying relatively high amounts of CFA
145 enhance the availability of soil P (Parab et al. 2015; Ukwattage et al. 2020). The higher
146 concentration of available P is primarily attributed to the change in pH value and the direct
147 diffusion of P (Hong et al. 2018).

148 Soil pH in rice fields increased by 1.0–1.6 pH units after applying CFA (Figure 1D). The
149 increase in soil pH is attributed to the liming characteristics of this industrial waste. The CFA
150 used in this study has a relatively high pH as well as CaO and MgO contents (Table 1); hence,
151 it is expected that liming materials neutralize soil acidity to induce soil pH. Several studies have
152 shown that applying industrial waste to acidic soil increases soil pH (Manoharan et al. 2010;
153 Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in
154 the CFA (Ram and Mastro 2014), which may be considered physiologically equivalent to
155 approximately 20% reagent grade CaCO₃ (Kumar et al. 2020). The results indicate that the CFA
156 could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural
157 activities.

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

166 **Effect of Coal Fly Ash Application on the Growth and Yield of Rice**

167 The application of CFA to the three types of rice fields did not increase the height of the rice.
 168 Figure 2A shows that the rice height, with and without industrial waste application, ranged from
 169 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers,
 170 rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and
 171 swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively.
 172 Meanwhile, Figure 2B shows that the number of rice tillers in rainfed field did not change after
 173 CFA application. The shoot dried weight of rice in peatland and swampland also rise in
 174 amended soils. Figure 2C shows that the application of CFA in peatlands and swamplands
 175 increased the shoot dried weight of rice by 40% and 15%, respectively.

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

186 Increasing growth and yield of rice in this study may also related to the presence of silicon (Si)
 187 element containing in CFA. Coal fly ash also contains SiO₂ which could be a source of silicon
 188 elements in soils (Bhatt et al. 2019; Laxmidhar and Subhakanta 2020). Peatland (organic soils)
 189 and swampyland (contain high OC) contain no or low amounts of Si, respectively. Therefore,

190 the addition of CFA to these soils increases the availability of Si which in turn increases the
 191 growth and yield of rice. However, the addition of CFA to rainfed rice fields (mineral soils
 192 which generally contain Si) did not increase the availability of Si at a higher level, and thereby
 193 do not cause an increase in the growth and yield of rice. Several studies have also reported that
 194 increases in the Si contents in soils result in increasing the growth and yield of rice (Cuong et
 195 al. 2017; Ning et al. 2014).

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

212 Nutrients in soil-plant systems exhibit different behaviors to determine their availability and
 213 uptake by plants. The application of CFA to rice fields results in an increase in available

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

231 Besides the presence of macronutrients (Ca and Mg) and micronutrients (Fe, Mn, Cu and B),
 232 CFA also contains a number of metal element such as Cd, Pb and Cr. Therefore, CFA
 233 application to soils may enhance the concentrations of heavy metals in soils, that may
 234 subsequently be taken up by plants and then transferred to the plant tissue. The total
 235 concentrations of heavy metals present in soils are not readily available for plant uptake. Thus,
 236 the metals must be mobilized to bioavailable form in soil solution to be taken by roots (Thakur
 237 et al. 2016). Uptake of heavy metals by plants varies and depend largely on several factors such

238 as soil pH and organic matter contents (Olowoyo et al. 2012). Heavy metals in soils adsorbed
 239 by the carbonates, organic matter, and secondary minerals may not be available for plant uptake.
 240 However, plant-producing chelating agent and plant-inducing pH changes and redox reaction
 241 assist plant root to dissolve and adsorb heavy metals in the soils, even those which are in the
 242 form of insoluble minerals (Zakaria et al. 2021). Although heavy metals are present in soils,
 243 their bioaccumulation in plants is determined by chemical processes of soil-plant interactions.

244 The presence of heavy metals in CFA is a great concern in the use of CFA as a soil ameliorant,
 245 in which the application of CFA to soils could lead to the accumulation of heavy metals in
 246 plants. Previous studies shown that a high amount of CFA application results in an increase in
 247 the accumulation of heavy metals in plants. Research by Singh et al. (2016) showed that the
 248 accumulation of Cd, Cr, Pb and As in rice grains was 4–20 fold higher in soils applied with
 249 50% of CFA than soils without CFA application. On the other hand, Nayak et al. (2015)
 250 reported that the accumulation of heavy metals in rice grains in soils applied with 40% CFA in
 251 greenhouses was not significantly different from soils without CFA application. Moreover, the
 252 application of CFA at an amount of 200 t/ha did not result in the accumulation of Pb, Cd, As
 253 and Cr in rice samples which were different from rice samples without CFA application
 254 (Bhaskarachary et al. 2012). These results imply that the application of a relatively low amount
 255 of CFA did not lead to heavy metal accumulation in plants. This is in accordance with (Yu et
 256 al. 2019) who compiled a database from 85 articles on plant biomass with and without CFA
 257 applications, and they suggest that CFA should be applied at less than 25% in order to increase
 258 plant biomass and yield but avoid high accumulations of Al, As, Cd, Cr, Pb, and Se in plants.

259 The amount of CFA applied to soils in this study were 3-5% of soil mass, depending on the soil
 260 types; therefore, the high accumulation of metals in plant tissue is highly unlikely to occur in
 261 this study. However, further research on metal accumulation in plant tissue in response to the

262 application of different amounts of CFA to different types of soil collected from rice fields is
 263 required to ensure the safety and health of the rice produced from rice fields with CFA
 264 application.

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448 G., Abdull Razis A.F. (2021): Understanding potential heavy metal contamination,
449 absorption, translocation and accumulation in rice and human health risks. *Plants*, 10.
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451 **Tables**

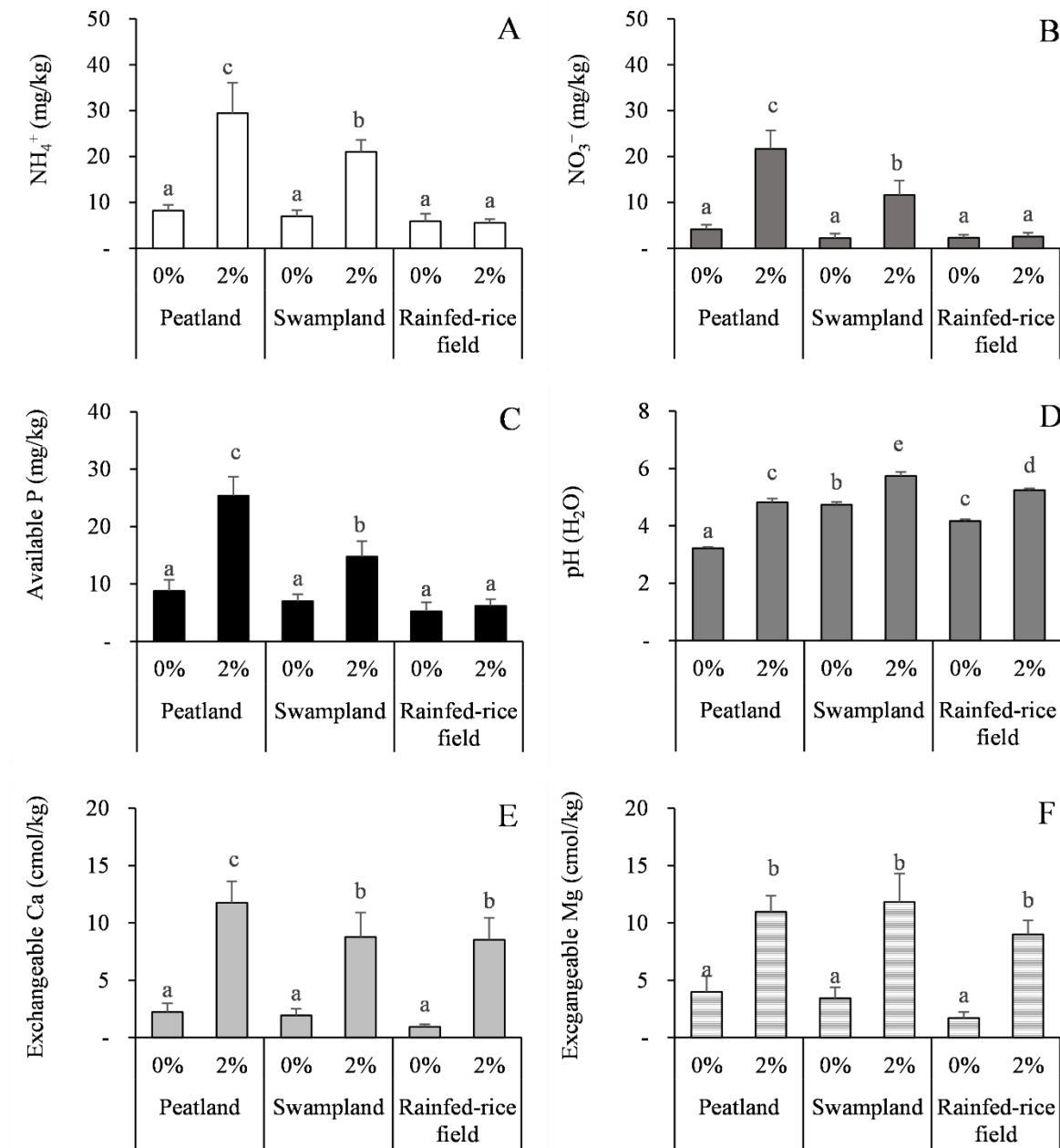
452 Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after \pm represent
453 the standard deviation of the mean (n=3).

Characteristics of soil/coal fly ash	Peatland	Swampland	Rainfed rice field	Coal-fly ash
Texture ^a				
- Sand (%)	-	18.23 \pm 1.23	21.36 \pm 2.34	-
- Silt (%)	-	34.56 \pm 3.45	34.23 \pm 2.45	-
- Clay (%)	-	47.21 \pm 4.32	44.41 \pm 3.56	-
Bulk density ^b (g/L)	379.60 \pm 70.21	629.50 \pm 90.23	735.90 \pm 92.34	1170.30 \pm 80.45
Particle density ^c (g/L)	1340.23 \pm 120.34	1980.65 \pm 110.78	1450.45 \pm 80.76	2340.45 \pm 80.23
pH ^d (H ₂ O)	3.23 \pm 0.09	4.72 \pm 0.21	4.17 \pm 0.08	7.43 \pm 0.09
Organic ^e C (g C/kg)	214.54 \pm 1.76	93.34 \pm 1.32	4.60 \pm 0.34	1.45 \pm 0.08
Total N ^f (g N/kg)	22.60 \pm 1.21	10.70 \pm 0.96	5.70 \pm 0.12	0.97 \pm 0.05
P ^g (g P/kg)	12.90 \pm 0.65	6.24 \pm 0.34	3.13 \pm 0.12	0.17 \pm 0.08
Ca ^h (mg Ca/kg ^l)	3.21 \pm 0.23	2.58 \pm 0.23	1.67 \pm 0.43	1453.67 \pm 9.76
Mg ^h (mg Mg/kg)	4.56 \pm 0.13	3.23 \pm 0.34	1.87 \pm 0.12	1362.66 \pm 8.54
Na ^h (mg Na/kg)	3.23 \pm 0.08	2.34 \pm 0.08	2.54 \pm 0.09	365.87 \pm 6.76
K ^h (mg K/kg)	3.23 \pm 0.12	2.19 \pm 0.08	1.44 \pm 0.05	768.55 \pm 8.87
Fe ^h (mg Fe/kg)	14.12 \pm 0.07	22.55 \pm 0.12	7.23 \pm 0.60	1124.65 \pm 7.88
Al ^h (mg Al/kg)	5.66 \pm 0.12	17.56 \pm 2.34	4.23 \pm 0.09	865.54 \pm 7.54
Cr ⁱ (mg Cr/kg)	-	-	-	121.32 \pm 4.67
Pb ⁱ (mg Pb/kg)	-	-	-	98.78 \pm 9.65
Ni ⁱ (mg Ni/kg)	-	-	-	176.78 \pm 9.45
Cd ⁱ (mg Cd/kg)	-	-	-	4.02 \pm 0.15
CEC ^j (cmol ₊ /kg)	39.76 \pm 3.23	23.76 \pm 2.34	18.33 \pm 1.23	-

454
455 ^a Sieving and sedimentation methods (Gee and Bander 1986); ^b soil core sampling method
456 (Blake and Hartge 1986a); ^c volumetric flask method (Blake and Hartge 1986b); ^d electrode
457 glass method (1:5, mass: volume) (McLean 1982); ^e Walkley and Black method (Nelson and
458 Sommers 1996); ^f Kjeldahl method (Bremer and Mulvaney 1982); ^g digestion of soil and CFA
459 with 60% HClO₄ and measurement at 660 nm using a spectrophotometer (Olsen and Sommers
460 1982); ^h digestion of soil and CFA using a mixture of HNO₃ and HClO₄ and determination of
461 digested solution using an atomic absorption spectrophotometer (Barnhisel and Bertsch 1982;
462 Knudsen and Peterson 1982; Lanyon and Heald 1982; Olson and Ellis 1982); ⁱ digestion of CFA
463 in tri-acid mixture (10:1:4, HNO₃:H₂SO₄:HClO₄ acids) and measurement using an atomic
464 absorption spectrophotometer (Baker and Amacher 1982; Bureau 1982; Reisenauer 1982); ^j
465 ammonium acetate (pH 7.0) method (Rhoades 1982).

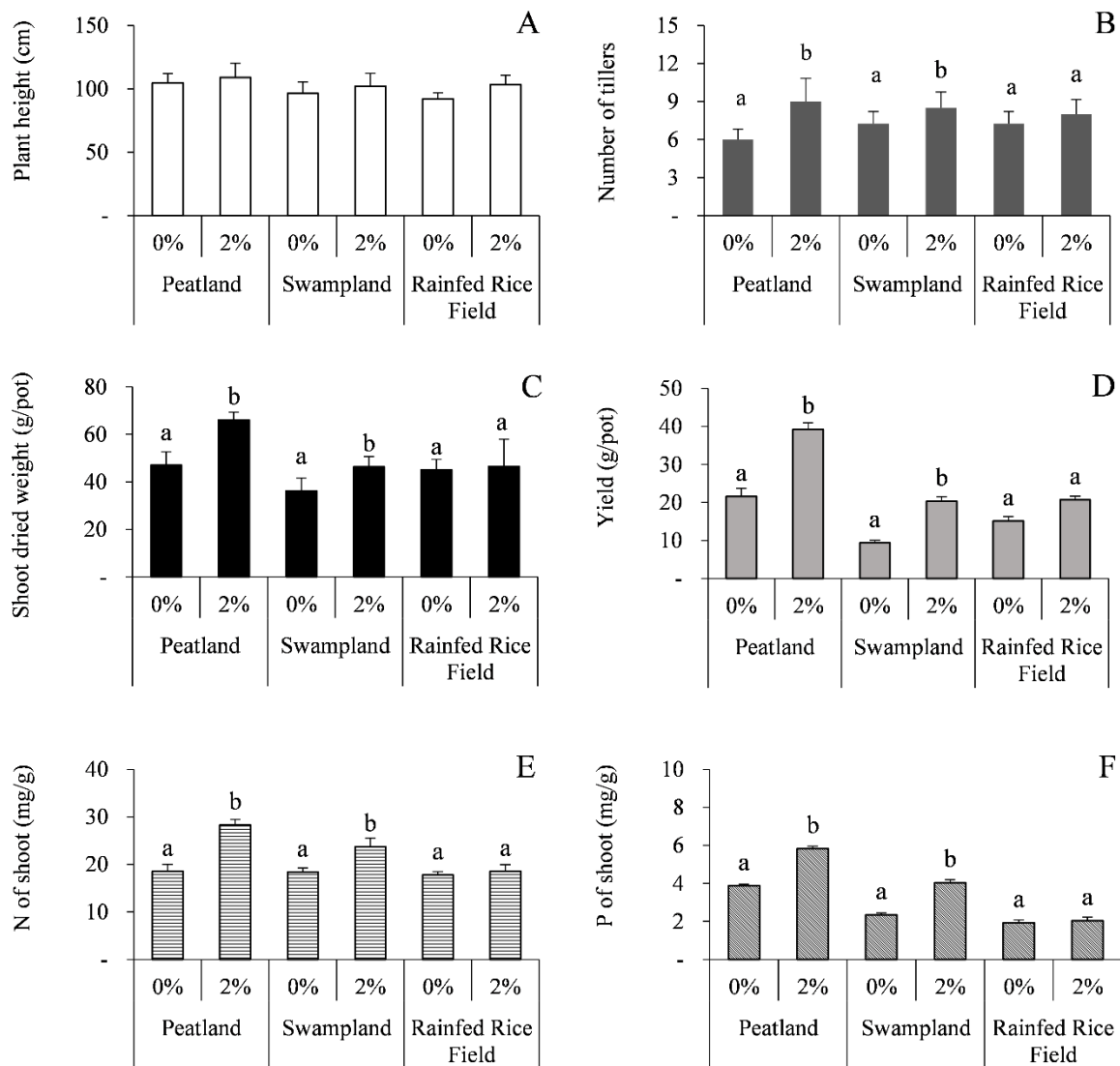
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467 **Figures**



468

469 Figure 1. Changes in the amounts of NH₄⁺ (A), NO₃⁻ (B), available P (C), soil pH (D),
 470 exchangeable Ca (E), and exchangeable Mg (F) of three different types of rice fields without
 471 CFA application (0%) and with CFA application (2%) observed on 15th day after CFA
 472 application. The lines above bars represent the standard deviation of the mean (n=4). The
 473 letters above the lines indicate no statistical difference between treatments based on the least
 474 significant difference (LSD) test at $P < 0.05$.



475

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

483

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