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,

Bambang J. Priatmadi
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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 NH_4^+-N, NO_3^--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 NH_4^+-N, NO_3^--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

^{o}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 NH_4^+-N and NO_3^--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 (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259%, 425% and

189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces 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 $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

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 ± 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 (Mg/m^3)	0.38 ± 0.07	0.63 ± 0.09	1.17 ± 0.12	1.17 ± 0.08
Particle density (Mg/m^3)	1.34 ± 0.12	1.98 ± 0.11	1.45 ± 0.08	2.34 ± 0.08
pH (H_2O)	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 ($cmol_+/kg$)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

Figures

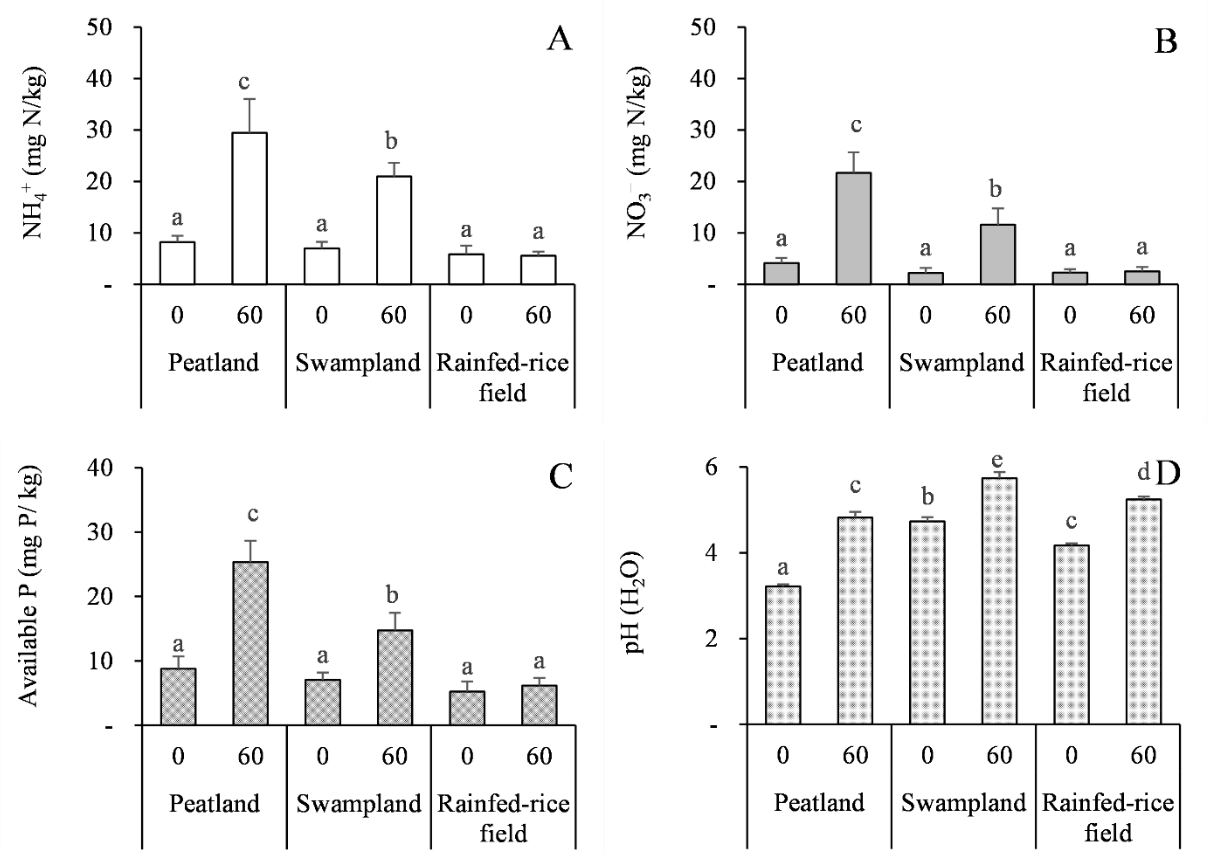

Figure 1. Changes in the amounts of NH_4^+ (A), NO_3^- (B), available P (C), and soil pH (D) of three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The letters above the lines indicate no statistical difference between treatments based on the least significant difference (LSD) test at P <0.05.

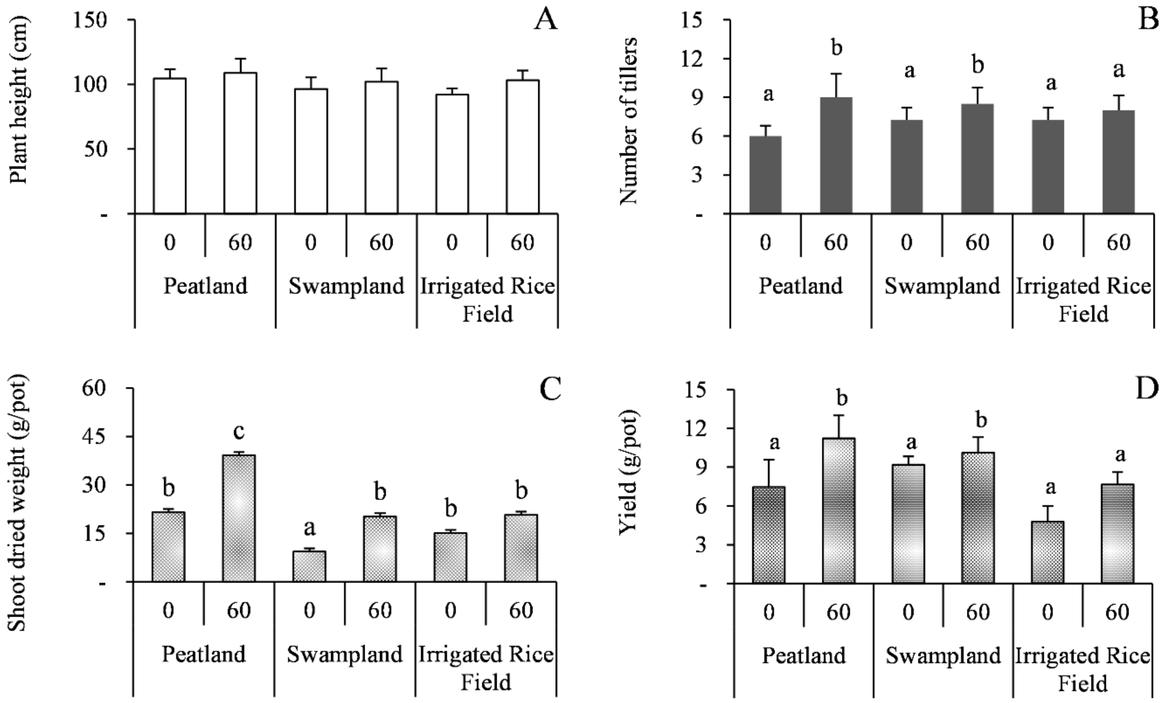

Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), and yield (D) of rice grown in three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4).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

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

1 message

PSE@cazv.cz <PSE@cazv.cz> Mon, Jun 27, 2022 at 9:54 PM
Reply-To: PSE@cazv.cz
To: bj_priatmadi@ulm.ac.id

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

2 messages

pse@cazv.cz <pse@cazv.cz> Tue, Jun 28, 2022 at 4:49 PM
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To: bj_priatmadi@ulm.ac.id

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.

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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 tittle 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 NH_4^+-N, NO_3^--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 NH_4^+-N, NO_3^--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

^{o}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 NH_4^+-N and NO_3^--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 (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259%, 425% and

189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces 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 $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

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 ± 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 (Mg/m^3)	0.38 ± 0.07	0.63 ± 0.09	1.17 ± 0.12	1.17 ± 0.08
Particle density (Mg/m^3)	1.34 ± 0.12	1.98 ± 0.11	1.45 ± 0.08	2.34 ± 0.08
pH (H_2O)	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 $_+$/kg)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

Figures

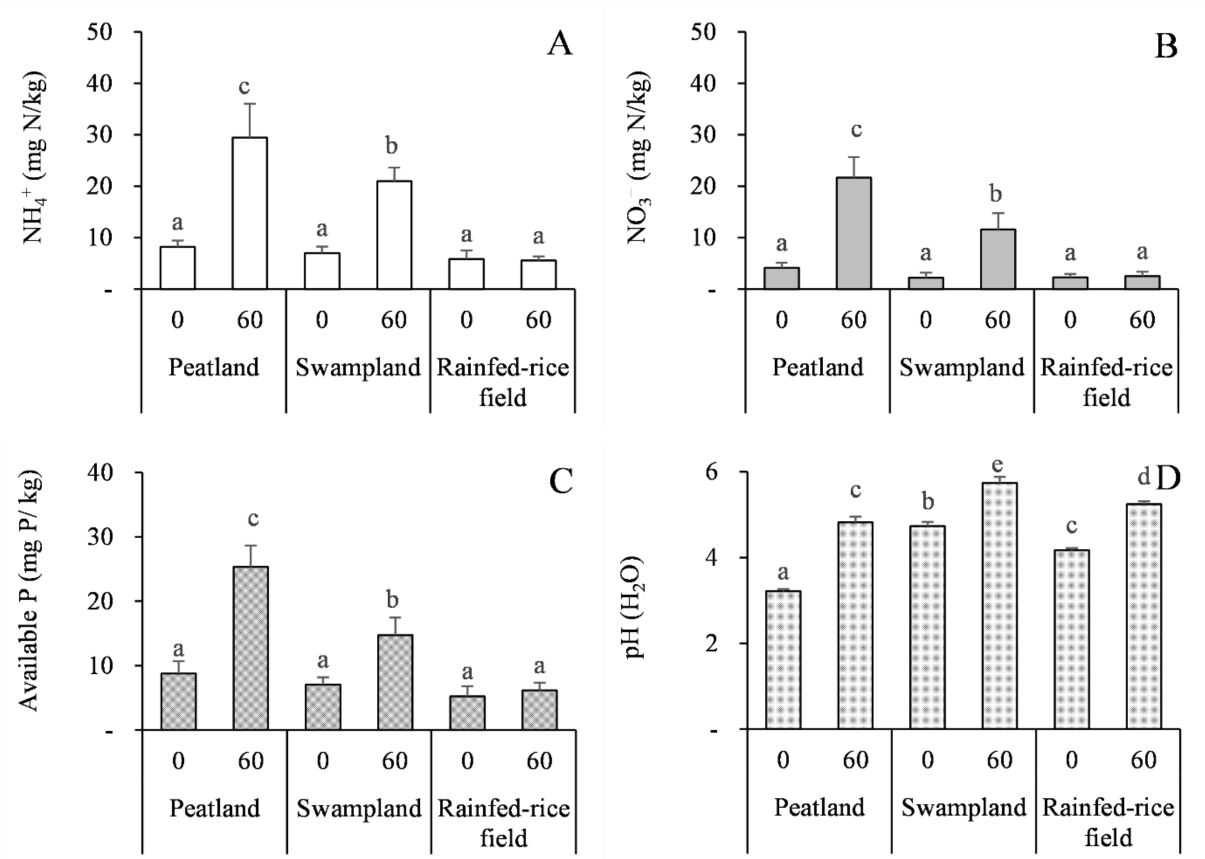

Figure 1. Changes in the amounts of NH_4^+ (A), NO_3^- (B), available P (C), and soil pH (D) of three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The letters above the lines indicate no statistical difference between treatments based on the least significant difference (LSD) test at $P < 0.05$.

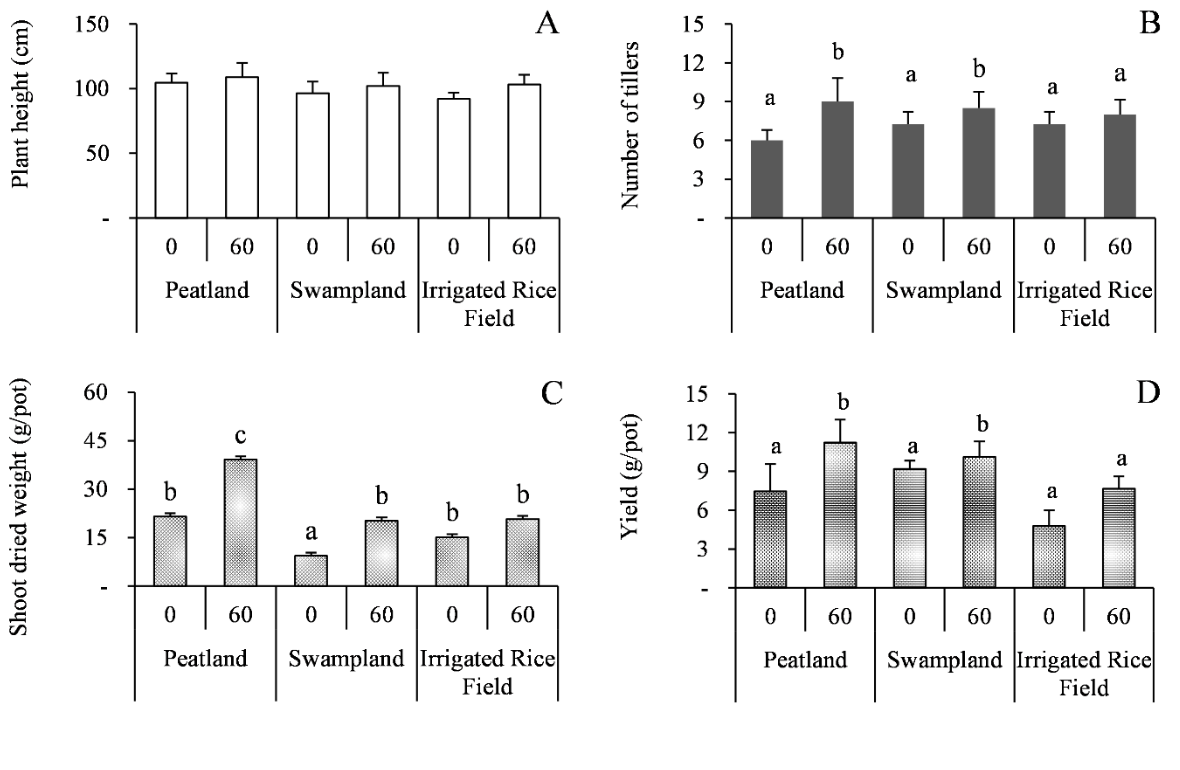

Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), and yield (D) of rice grown in three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). 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)

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Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id>

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

3 messages

pse@cazv.cz <pse@cazv.cz> Mon, Nov 7, 2022 at 6:39 PM
Reply-To: pse@cazv.cz
To: bj_priatmadi@ulm.ac.id

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).

Growth performance and yield of rice grown in three different types of soil collected from the 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 effectively improve the soil properties of wetlands. In this study, an amount of CFA (326-632 g CFA/pot) was applied to three different soils collected from the rice fields: peatland, swampland, and rainfed field, in a 15-liter pot to obtain an equivalent to a field application of 60 tonnes CFA/ha, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in the soil were quantified following the completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in peatland and swampland, the rice fields that 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: available nutrients; mineralisation; soil fertility; toxic element; wetlands

INTRODUCTION

Coal fly ash (CFA) is a byproduct using coal as an energy source in power plants. The long term storage of this industrial waste in open, indiscriminate disposal sites without further consumption poses environmental issues. Khan and Umar (2019) showed an increase in the concentration of several heavy metals in groundwater near CFA disposal sites, which exceeded the World Health Organization‘s (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 (Haris et al. 2021; 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 highly advantageous for using 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 soil collected from rice fields. In this study, rice fields with varying levels of organic carbon were utilised so that the influence of the CFA on nutrient availability from the mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

MATERIALS AND METHODS

Sampling and Characterization of Soil and Coal Fly Ash

Based on the soil formation process and organic carbon content, the samples used in this study consist of three distinct rice fields: peatland, swampland, and rainfed. Peatland samples 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.

Coal fly ash (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 ^{o}C until used for the experiment. The characteristics of CFA used for this study are showed in Table 1.

Green House Experiment

This greenhouse experiment used the same amount of soil for each soil type collected from the rice field, in which the amount of CFA added to each experimental pot was adjusted using the bulk density of each soil type. Therefore, the rate of CFA application for each experimental pot appears to be different for each soil type. Twelve kilograms of soil samples from each type of rice field were placed in a 15 liter (25 cm in diameter) pot, to which 632 grams CFA/pot (peatland), 381 CFA grams/pot (swampland), 326 grams CFA/pot (rainfed) was added and mixed homogenously. 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 NH_4^+-N and NO_3^--N in soil (Bundy and Meisinger 1994), and available phosphorus in Bray extract (Jackson 1967). Rice seedlings (30 days old) previously prepared at the nursery were planted as many as three seedlings in each experimental pot. The rice variety used for this research was Ciherang. Finally, the rice growth (height, number of tillers, and shoot dry 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 t/m^3 and 1.17 t/m^3, respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows that these soil characteristics were higher in peatland and swampland 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 calcium (Ca), magnesium (Mg), and iron (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 (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259%, 425% and 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces 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 (Manoharan et al. 2010; Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in the CFA (Ram and Masto 2014), which may be considered physiologically equivalent to approximately 20% reagent grade $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

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).

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

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 carbon content did not allow for an increase in nutrient availability through the mineralisation process. This was in line with the results of Parab et al. (2015), which reported a significant correlation between crop yield and soil pH, available P and Ca. Lee et al. (2019) stated that CFA application to soils containing low organic C (15 g kg^{-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 carbon contents.

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

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

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Tables

Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after ± 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_2O)	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 ($cmol_{+}$/kg)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

Figures

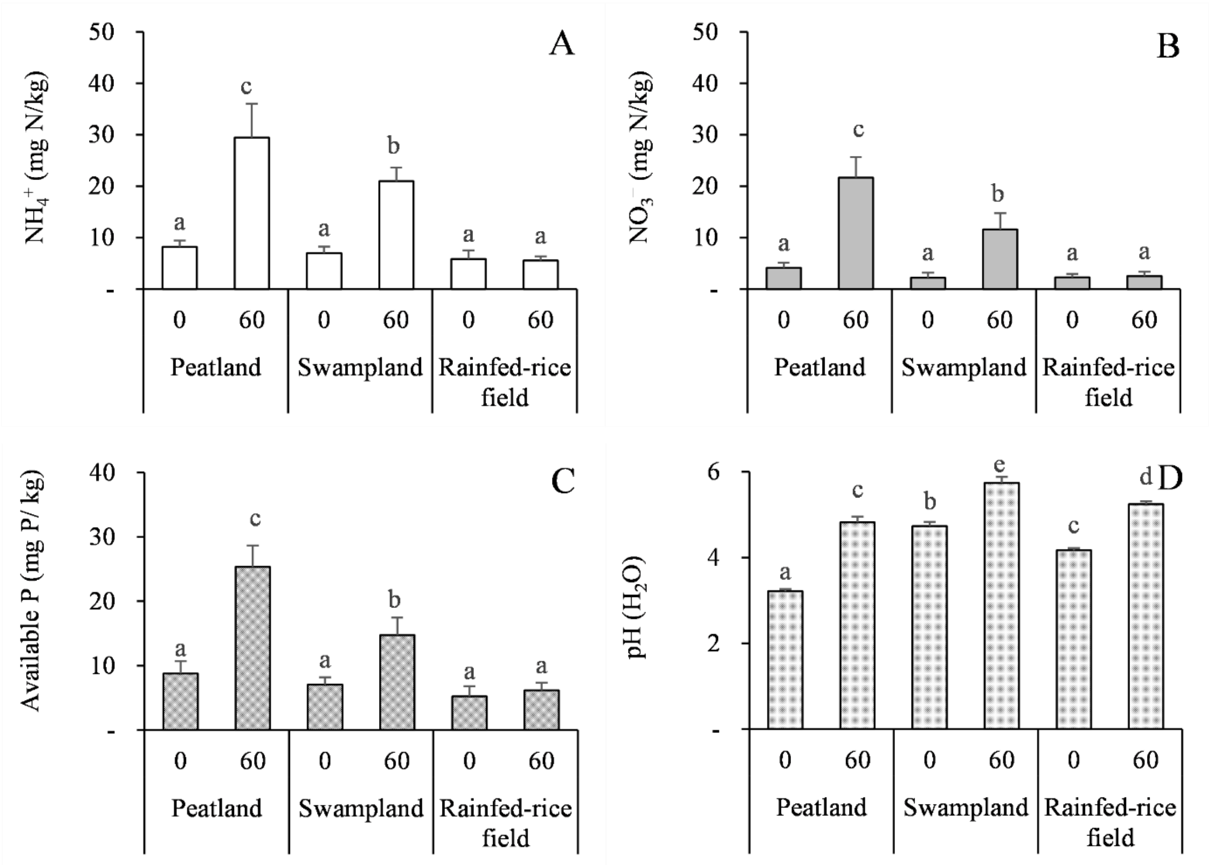

Figure 1. Changes in the amounts of NH_4^+ (A), NO_3^- (B), available P (C), and soil pH (D) of three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). The letters above the lines indicate no statistical difference between treatments based on the least significant difference (LSD) test at *P* <0.05.

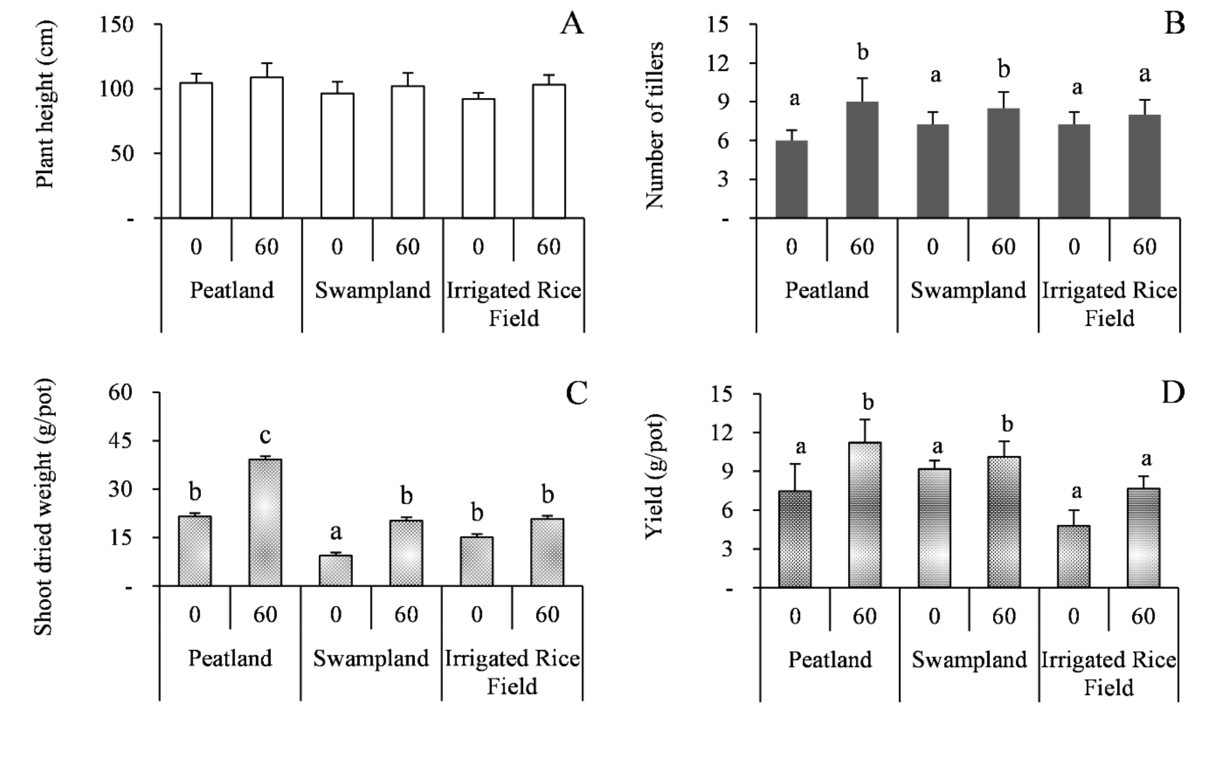

Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), and yield (D) of rice grown in three different types of rice fields as influenced by the application of coal-fly ash. The lines above bars represent the standard deviation of the mean (n=4). 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 4 (Revision 3)

UNIVERSITAS LAMBUNG MANGKURAT

Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id>

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

3 messages

pse@cazv.cz <pse@cazv.cz> Mon, Dec 5, 2022 at 3:40 PM
Reply-To: pse@cazv.cz
To: bj_priatmadi@ulm.ac.id

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 rewievers comments in required accompaning 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 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.

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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Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id> Mon, Dec 5, 2022 at 10:09 PM
To: asaidy@ulm.ac.id

[Quoted text hidden]

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Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id> Sun, Dec 11, 2022 at 9:08 PM
To: pse@cazv.cz

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 rewievers comments in required accompaning 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 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.
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 recaltulated 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).

Growth performance and yield of rice grown in three different types of soil collected from the 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 effectively improve the soil properties of wetlands. In this study, an amount of CFA equivalent to a field application of 60 tonnes CFA/ha ~~(326-632 g CFA/pot)~~ was added~~applied~~ to three different soils collected from the rice fields~~:~~(~~-~~peatland, swampland, and rainfed field)~~,~~ in a 15-liter pot, ~~to obtain an equivalent to a field application of 60 tonnes CFA/ha~~, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in the soil were quantified following the completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in peatland and swampland, the rice fields that 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. Results of this study demonsrate~~Therefore,~~ the soil organic C content in the rice fields plays ~~controls~~ an important role in determining the effect of CFA on nutrient availability, ~~as well as rice~~ growth and yield of rice.

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

INTRODUCTION

Coal fly ash (CFA) is a byproduct using coal as an energy source in power plants. The long term storage of this industrial waste in open, indiscriminate disposal sites without further consumption poses environmental issues. Khan and Umar (2019) showed an increase in the concentration of several heavy metals in groundwater near CFA disposal sites, which exceeded the World Health Organization's (Dowhower et al.) 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 (Haris et al. 2021; 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 highly advantageous for using CFA as a soil ameliorant (Jambhulkar et al. 2018). Dwivedi et al. (2007) discovered that the application of CFA~~this industrial waste~~ at high concentration of 50% (weight of soil:weight of CFA) reduces rice growth, but promotes rice growth at low concentrations of 10-25%. Furthermore, other studies have demonstrated the beneficial effect of CFA treatment on rice growth (Munda et al. 2016; Padhy et al. 2016).

However, Lee et al. (2019) observed that CFA application does not enhance rice growth due to lowering nitrogen 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 soil collected from rice fields. In this study, rice fields with varying levels of organic carbon were utilised so that the influence of the CFA on nutrient availability from the mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

MATERIALS AND METHODS

Sampling and Characterization of Soil and Coal Fly Ash

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

Coal fly ash (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

This greenhouse experiment used the same amount of soil for each soil type collected from the rice field, in which the amounts of CFA added to each experimental pot were equivalent to a field application of 60 t CFA/ha. Therefore, the determination of CFA amount applied to each experimental pot was calculated adjusted using the bulk density of each soil type. As bulk density of each soil is quite different (peatland = 379.60 g/L; swampland = 629.50 g/L; rainfed rice field = 735.90 g/L); thusTherefore, the rate of CFA application for each experimental pot appears to be different for each soil type. Twelve kilograms of soil samples from each type of rice field were placed in a 15 liter (25 cm in diameter) pot, to which 632 grams CFA/pot (peatland), 381 CFA grams/pot (swampland), 326 grams CFA/pot (rainfed) was added and mixed homogenously. 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 NH_4^+-N and NO_3^--N in soil (Bundy and Meisinger 1994), and available phosphorus in Bray extract (Jackson 1967). Rice seedlings (30 days old) previously prepared at the nursery were planted as many as three seedlings in each experimental pot. The rice variety used for this research was Ciherang. Finally, the rice growth (height, number of tillers, and shoot dry 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 t/m^3 and 1.17 t/m^3, respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows that these soil characteristics were higher in peatland and swampland 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 calcium (Ca), magnesium (Mg), and iron (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 (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259%, 425% and 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces available N ~~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 (Manoharan et al. 2010; Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in the CFA (Ram and Masto 2014), which may be considered physiologically equivalent to approximately 20% reagent grade $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

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).

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

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 carbon content did not allow for an increase in nutrient availability through the mineralisation process. This was in line with the results of Parab et al. (2015), which reported a significant correlation between crop yield and soil pH, available P and Ca. Lee et al. (2019) stated that CFA application to soils containing low organic C (15 g kg^{-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 carbon contents.

Besides the presence of macronutrients (Ca and Mg) and micronutrients (Fe, Mn, Cu and B), CFA also contains a number of metal element such as Cd, Pb and Cr. Therefore, CFA application to soils may enhance the concentrations of heavy metals in soils, that may subsequently be taken up by plants and then transferred along the food chain. The total concentrations of heavy metals present in soils are not readily available for plant uptake. Thus, the metals must be mobilized to bioavailable form in soil solution to be taken by roots (Thakur et al. 2016). Uptake of heavy metals by plants varies and depend largely on several factors such as soil pH and organic matter contents (Olowoyo et al. 2012). Heavy metals in soils adsorbed by the carbonates, organic matter, and secondary minerals may not be available for plant uptake. However, plant-producing chelating agent and plant-inducing pH changes and redox reaction assist plant root to dissolve and adsorb heavy metals in the soils, even those which are in the form of insoluble minerals (Zakaria et al. 2021). Passive diffusion through the cell membrane and active transport mediated by carriers are common mechanisms for transfer of heavy metals from soils into plant roots (Thakur et al. 2016). Although heavy metals are present in soils, their bioaccumulation in plants is determined by chemical processes of soil-plant interactions.

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

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Tables

Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after ± 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 (g~~t~~/~~m^3~~L)	~~0.~~3798.60 ± ~~0.0~~70.21	~~0.~~6~~3~~29.50 ± ~~0.0~~90.23	~~1.17~~735.90 ± ~~0.91~~2.34	1~~.~~170.30 ± ~~0.0~~80.45
Particle density (g~~t~~/L~~m^3~~)	1~~.~~340.23 ± ~~0.~~120.34	1~~.~~980.65 ± ~~0.~~110.78	1~~.~~450.45 ± ~~0.0~~80.76	2~~.~~340.45 ± ~~0.0~~80.23
pH (H_2O)	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 $_+$/kg)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

Figures

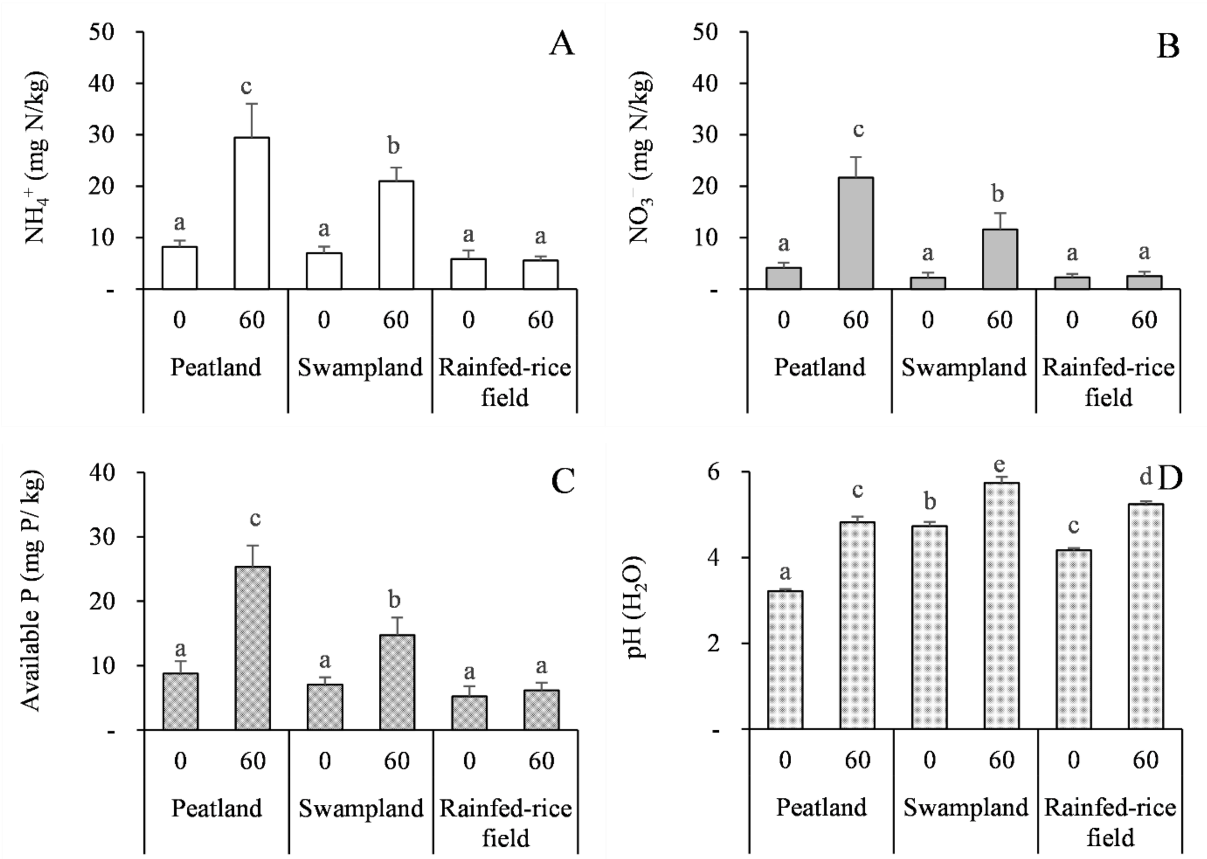

Figure 1. Changes in the amounts of NH_4^+ (A), NO_3^- (B), available P (C), and soil pH (D) of three different types of rice fields without CFA application (0 t /ha) and with CFA application (60 t/ha)~~as influenced by the application of coal-fly ash~~. The lines above bars represent the standard deviation 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.

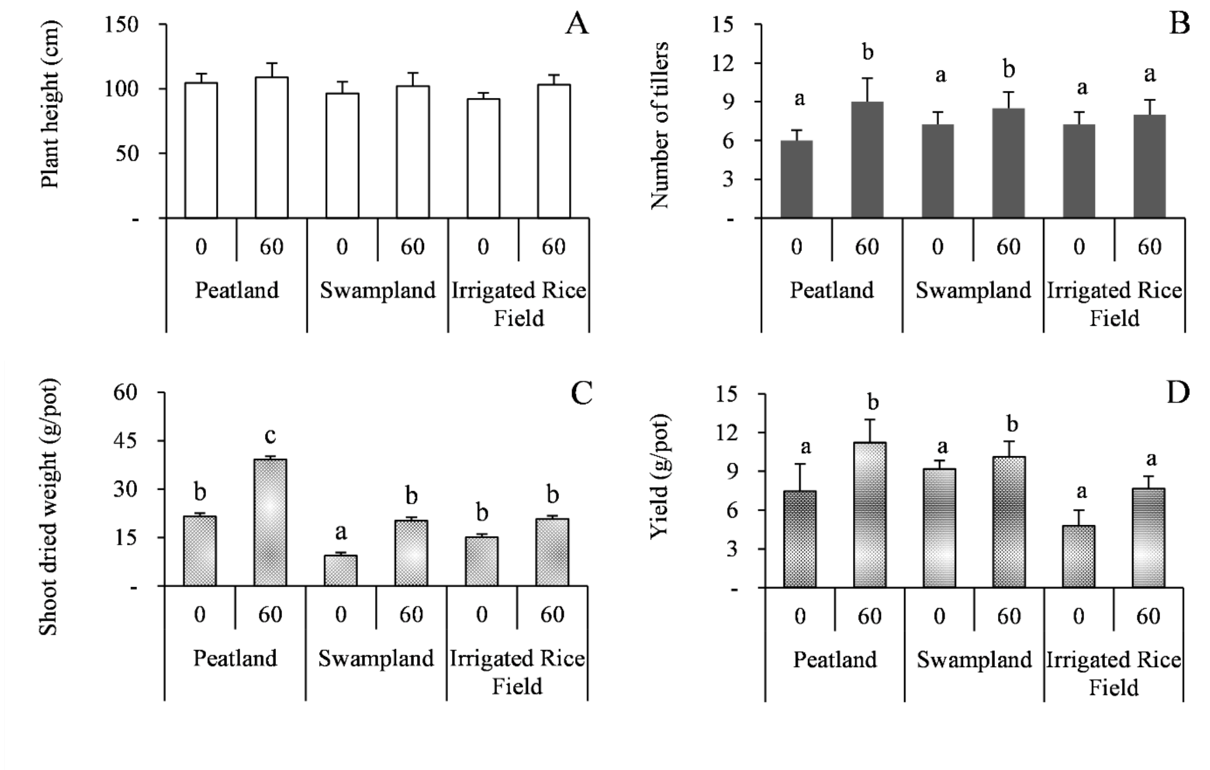

Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), and yield (D) of rice grown in three different types of rice fields without CFA application (0 t /ha) and with CFA application (60 t/ha)~~as influenced by the application of coal-fly ash~~. 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 5 (Revision 4)

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Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id>

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

2 messages

pse@cazv.cz <pse@cazv.cz> Tue, Jan 10, 2023 at 1:03 PM
Reply-To: pse@cazv.cz
To: bj_priatmadi@ulm.ac.id

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 improprict 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.

Please, login to the editorial system at: https://www.old-aj.cz/login2
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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Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id> Mon, Jan 23, 2023 at 8:09 AM
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[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 improprieт 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.

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 approriately. 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).

Growth performance and yield of rice grown in three different types of soil collected from the 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 effectively improve the soil properties of wetlands. In this study, CFA with an amount of 2% (weight/volume) or 240 grams were added to 12 litres of three different soils collected from the rice fields (peatland, swampland, and rainfed field) in a 15-litre pot, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in the soil were quantified following the completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in peatland and swampland, the rice fields that 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. Results of this study indicate an important role of soil organic C content in the rice fields in controlling the effect of CFA on nutrient availability, growth and yield of rice.

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

INTRODUCTION

Coal fly ash (CFA) is a byproduct using coal as an energy source in power plants. The long term storage of this industrial waste in open, indiscriminate disposal sites without further consumption poses environmental issues. Khan and Umar (2019) showed an increase in the concentration of several heavy metals in groundwater near CFA disposal sites, which exceeded the World Health Organization's (Dowhower et al.) 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 (Haris et al. 2021; Saidy et al. 2020; Ukwattage et al. 2021).

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

(2019) observed that CFA application does not enhance rice growth due to lowering nitrogen 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 soil collected from rice fields. In this study, rice fields with varying levels of organic carbon were utilised so that the influence of the CFA on nutrient availability from the mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

MATERIALS AND METHODS

Sampling and Characterization of Soil and Coal Fly Ash

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

Coal fly ash (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 ^{o}C until used for the experiment. The characteristics of CFA used for this study are showed in Table 1.

Green House Experiment

A 240-gram of CFA was added to twelve litres of soil samples collected from each type of rice in a 15-litre (25 cm in diameter) pot, and mixed homogenously. The amounts of CFA added to the soils were equivalent to 2% (weight/volume) or 20 g/L. Control soil was prepared from each type of rice field without the CFA addition. There were 24 experimental units with three types of rice fields with and without CFA application and four replicates per treatment. Water was added to each pot to obtain a water level of 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.

A sub-sampling was performed by collecting 250 grams of soil from each experimental pot on the 15th day after the CFA application (after the completion of incubation period) for the characterisation of amended-soils. The characterisation includes soil pH measured using a glass electrode method (McLean 1982) and the concentration of NH_4^+-N and NO_3^--N in soil (Bundy and Meisinger 1994), available phosphorus in Bray extract (Jackson 1967), and exchangeable Ca and Mg (Lanyon and Heald 1982). Rice seedlings (30 days old) previously prepared at the nursery were planted as many as three seedlings in each experimental pot. The rice variety used for this research was Ciherang. Finally, the rice harvest was carried out 90 days after planting, and then the growth (height, number of tillers, and shoot dry weight) and yield of rice were determined. All the growth and yield attributing characters were studied after the harvesting period of 90 days. Plant height (cm) was measured by a metric scale and number of tillers/hill was counted manually. After this, plant parts were partitioned into roots, leaves, straw and grains and then were washed with double distilled water and blotted. Observations on plant height, number of panicles andpanicle weight per pot were recorded in each treatment at harvest. The harvested samples were sun-dried, weighed and recorded as total biomass.

The rice grains and rice shoot were separated from other rice parts, then oven-dried ~~Shoot rice was separated from other plant parts, oven-dried~~ at 70 °C to constant weight, and then~~-~~ grind to powder for the determiniation of N and P contents. Content of N in shoot rice was quantified using the micro Kjeldahl method (Hafez and Mikkelsen 1981), while content of P in shoot rice was determined using ascorbic acid-molybdate method after the digestion of rice shoot with 60% concentrated HNO_3 (Caradus and Snaydon 1987).

Data Analysis

The analysis of variance (ANOVA) was conducted to determine the effect of CFA application on changes in the properties of amended soils, and 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 t/m^3 and 1.17 t/m^3, respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows that values of investigated soil characteristics were higher at at peatland and swampland than at the rainfed rice field. Soil pH of the three types of rice fields was relatively not different and ranged from pH 3.23 to 4.72.

Coal fly ash (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 calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high, reaching 1454 mg Ca/kg, 1363 mg Mg/kg, and 1125 mg Fe/kg, respectively. 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 (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259%, 425% and 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces available N and available P with the application of CFA. Due to the relatively high OM content of peatland and swampland (Table 1), they have the potential to provide N and P nutrients through the transformation of organic N and P into N and P minerals, respectively. Previous studies have shown 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 (Manoharan et al. 2010; Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in the CFA (Ram and Masto 2014), which may be considered physiologically equivalent to approximately 20% reagent grade $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

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

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

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

The application of CFA to the three types of rice fields did not increase the height of the rice. Figure 2A shows that the rice height, with and without industrial waste application, ranged from 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers, rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively. Meanwhile, Figure 2B shows that the number of rice tillers in rainfed 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).

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

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 carbon content did not allow for an increase in nutrient availability through the mineralisation process. This was in line with the results of Parab et al. (2015), which reported a significant correlation between crop yield and soil pH, available P and Ca. Lee et al. (2019) stated that CFA application to soils containing low organic C (15 g kg^{-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 carbon contents.

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

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

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

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Tables

Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after ± represent 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 ± 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[b] (g/L)	379.60 ± 70.21	629.50 ± 90.23	735.90 ± 92.34	1170.30 ± 80.45
Particle density[c] (g/L)	1340.23 ±120.34	1980.65 ± 110.78	1450.45 ± 80.76	2340.45 ± 80.23
pH[d] (H_2O)	3.23 ± 0.09	4.72 ± 0.21	4.17 ± 0.08	7.43 ± 0.09
Organic[e] C (g C/kg)	214.54 ± 1.76	93.34 ± 1.32	4.60 ± 0.34	1.45 ± 0.08
Total N[f] (g N/kg)	22.60 ± 1.21	10.70 ± 0.96	5.70 ± 0.12	0.97 ± 0.05
P[g] (g P/kg)	12.90 ± 0.65	6.24 ± 0.34	3.13 ± 0.12	0.17 ± 0.08
Ca[h] (mg Ca/kg^{1})	3.21 ± 0.23	2.58 ± 0.23	1.67 ± 0.43	1453.67 ± 9.76
Mg[h] (mg Mg/kg)	4.56 ±0.13	3.23 ± 0.34	1.87 ± 0.12	1362.66 ± 8.54
Na[h] (mg Na/kg)	3.23 ± 0.08	2.34 ± 0.08	2.54 ± 0.09	365.87 ± 6.76
K[h] (mg K/kg)	3.23 ± 0.12	2.19 ± 0.08	1.44 ± 0.05	768.55 ± 8.87
Fe[h] (mg Fe/kg)	14.12 ± 0.07	22.55 ± 0.12	7.23 ± 0.60	1124.65 ± 7.88
Al[h] (mg Al/kg)	5.66 ± 0.12	17.56 ± 2.34	4.23 ± 0.09	865.54 ± 7.54
Cr[i] (mg Cr/kg)	-	-	-	121.32 ± 4.67
Pb[i] (mg Pb/kg)	-	-	-	98.78 ± 9.65
Ni[i] (mg Ni/kg)	-	-	-	176.78 ± 9.45
Cd[i] (mg Cd/kg)	-	-	-	4.02 ± 0.15
CEC[j] ($cmol_+$/kg)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

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

Figures

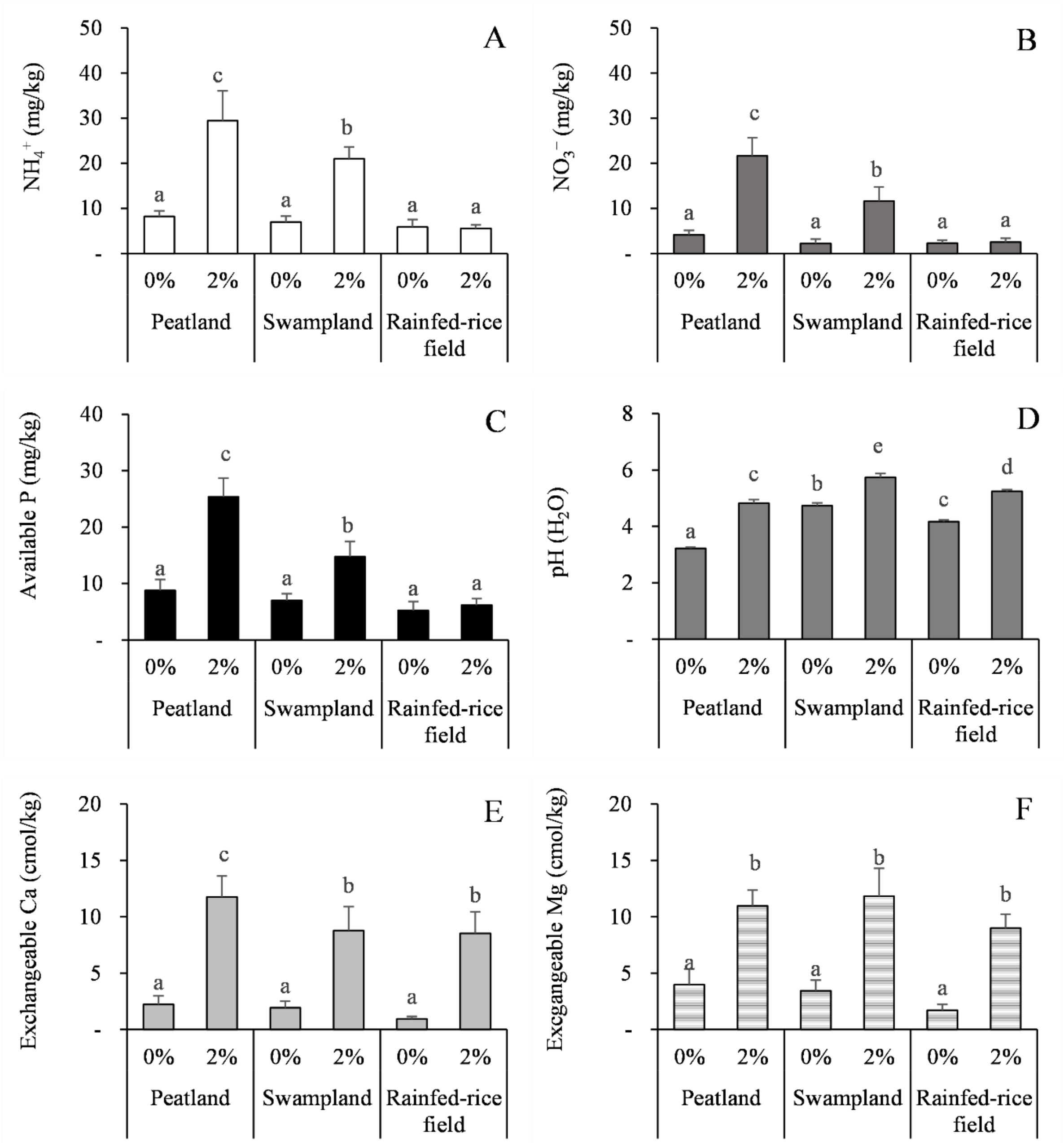

Figure 1. Changes in the amounts of NH_4^+ (A), NO_3^- (B), available P (C), soil pH (D), exchangeable Ca (E), and exchageable Mg (F) of three different types of rice fields without CFA application (0%) and with CFA application (2%) observed on 15th day after CFA application. The lines above bars represent 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 $P < 0.05$.

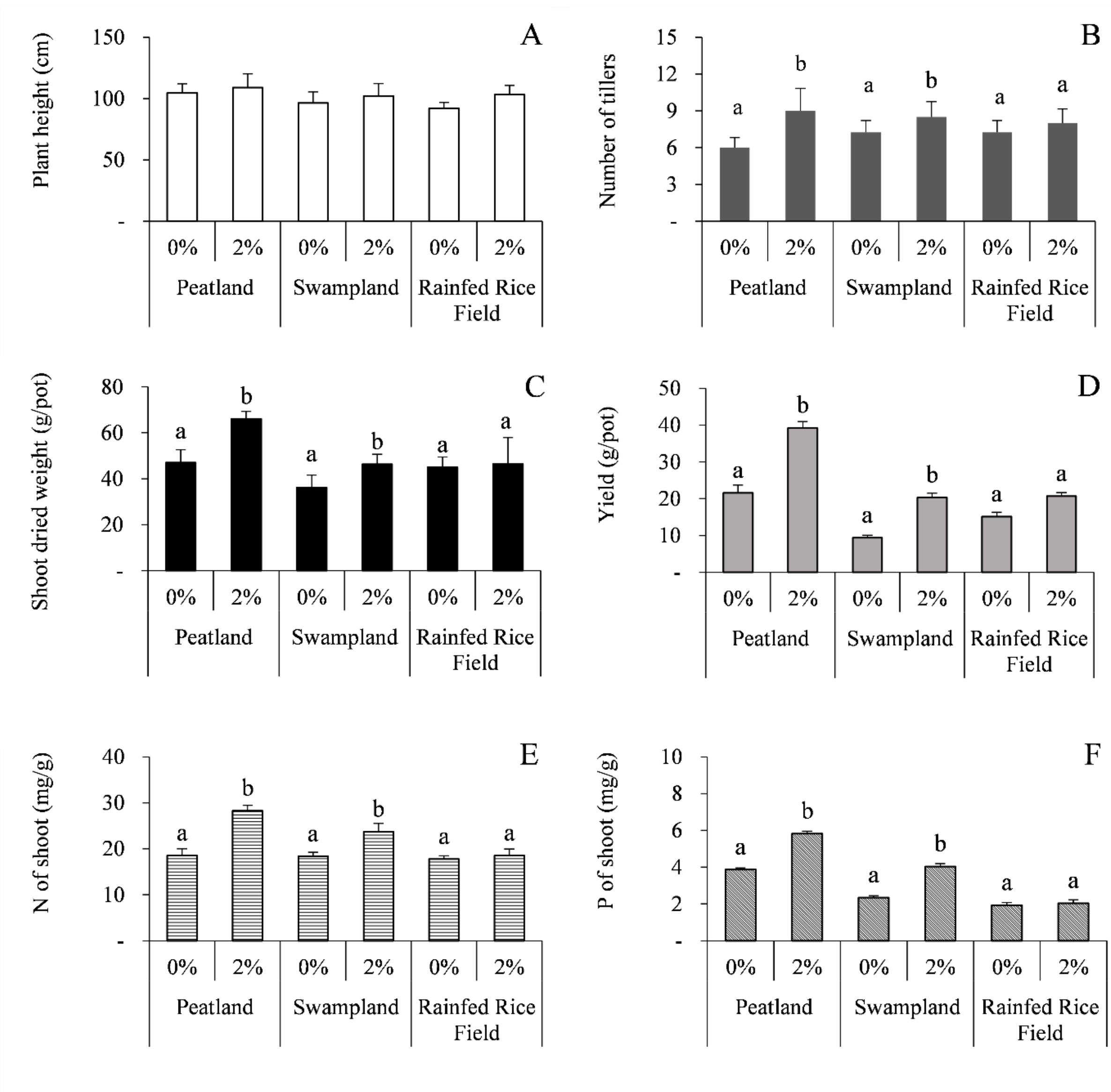

Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), yield (D), contents of nitrogen in shoot (E), and contents of phosphorous in shoot (F) of rice grown in three different types of rice fields without CFA application (0%) and with CFA application (2%) observed at 90 days after rice planting. 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 6 (Revision 5)

UNIVERSITAS LAMBUNG MANGKURAT

Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id>

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

2 messages

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pse@cazv.cz <pse@cazv.cz> Mon, Jun 5, 2023 at 1:46 PM
Reply-To: pse@cazv.cz
To: bj_priatmadi@ulm.ac.id

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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Yours sincerely,

Mgr. Kateřina Součková
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Bambang Joko priatmadi <bj_priatmadi@ulm.ac.id> Fri, Jun 9, 2023 at 10:43 AM
To: asaidy@ulm.ac.id

[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 acording to the journal style by adding the full names of journals to the list of references (lines 266-449).

Growth performance and yield of rice grown in three different types of soil collected from the 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 effectively improve the soil properties of wetlands. In this study, CFA with an amount of 2% (weight/volume) or 240 grams were added to 12 litres of three different soils collected from the rice fields (peatland, swampland, and rainfed field) in a 15-litre pot, and then incubated in the greenhouse for 15 days. The soil pH, concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in the soil were quantified following the completion of the incubation. Rice seedlings were planted in each pot, and after 90 days, the growth and yield variables were observed. The results showed that CFA application enhanced the concentrations of NH_4^+-N, NO_3^--N, and available phosphorus in peatland and swampland, the rice fields that 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. Results of this study indicate an important role of soil organic C content in the rice fields in controlling the effect of CFA on nutrient availability, growth and yield of rice.

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

INTRODUCTION

Coal fly ash (CFA) is a byproduct using coal as an energy source in power plants. The long term storage of this industrial waste in open, indiscriminate disposal sites without further consumption poses environmental issues. Khan and Umar (2019) showed an increase in the concentration of several heavy metals in groundwater near CFA disposal sites, which exceeded the World Health Organization‘s (Dowhower et al.) 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 (Haris et al. 2021; Saidy et al. 2020; Ukwattage et al. 2021).

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

(2019) observed that CFA application does not enhance rice growth due to lowering nitrogen 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 soil collected from rice fields. In this study, rice fields with varying levels of organic carbon were utilised so that the influence of the CFA on nutrient availability from the mineralisation process on crop growth in a variety of wetland ecosystems could be evaluated.

MATERIALS AND METHODS

Sampling and Characterization of Soil and Coal Fly Ash

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

Coal fly ash (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 ^{o}C until used for the experiment. The characteristics of CFA used for this study are showed in Table 1.

Green House Experiment

A 240-gram of CFA was added to twelve litres of soil samples collected from each type of rice in a 15-litre (25 cm in diameter) pot, and mixed homogenously. The amounts of CFA added to the soils were equivalent to 2% (weight/volume) or 20 g/L. Control soil was prepared from each type of rice field without the CFA addition. There were 24 experimental units with three types of rice fields with and without CFA application and four replicates per treatment. Water was added to each pot to obtain a water level of 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.

A sub-sampling was performed by collecting 250 grams of soil from each experimental pot on the 15th day after the CFA application (after the completion of incubation period) for the characterisation of amended-soils. The characterisation includes soil pH measured using a glass electrode method (McLean 1982) and the concentration of NH_4^+-N and NO_3^--N in soil (Bundy and Meisinger 1994), available phosphorus in Bray extract (Jackson 1967), and exchangeable Ca and Mg (Lanyon and Heald 1982). Rice seedlings (30 days old) previously prepared at the nursery were planted as many as three seedlings in each experimental pot. The rice variety used for this research was Ciherang. Finally, the rice harvest was carried out 90 days after planting, and then the growth (plant height, number of tillers, and shoot dry weight) and yield of rice were determined. Measurement of plant height (cm) was carried out using a metric scale and the number of tillers was calculated manually. All parts of the rice plant above the ground from each pot were cut (2–3 cm above the ground), washed with aquades, then rice shoots and grains were separated from each other. Rice shoots and grains were oven-dried at 70 ^{o}C for 48 hours, weighed immediately, and they were expressed as grams per pot (g/pot). Rice shoots were ~~Shoot rice was separated from other plant parts, oven-dried at 70 ^{o}C to constant weight, and then~~ then grind to powder for the determiniation of N and P contents. Content of N in shoot rice was quantified using the micro Kjeldahl method (Hafez and Mikkelsen 1981), while content of P in shoot rice was determined using ascorbic acid-molybdate method after the digestion of rice shoot with 60% concentrated HNO_3 (Caradus and Snaydon 1987).

Data Analysis

The analysis of variance (ANOVA) was conducted to determine the effect of CFA application on changes in the properties of amended soils, and 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 t/m^3 and 1.17 t/m^3, respectively. Furthermore, other soil properties that differ were organic C content, cation exchangeable capacity (CEC), total nitrogen (N), and phosphorous (P) contents. Table 1 shows that values of investigated soil characteristics were higher at at peatland and swampland than at the rainfed rice field. Soil pH of the three types of rice fields was relatively not different and ranged from pH 3.23 to 4.72.

Coal fly ash (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 calcium (Ca), magnesium (Mg), and iron (Fe) contents in CFA were very high, reaching 1454 mg Ca/kg, 1363 mg Mg/kg, and 1125 mg Fe/kg, respectively. 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 (NH_4^+-N and NO_3^--N) and P of peatland and swampland. The contents of NH_4^+-N, NO_3^--N and available P increased by 259%, 425% and 189% in peatland and 202%, 421% and 110% in swampland, respectively (Figure 1). However, no changes were observed in the rainfed-rice field (Figure 1). The increasing availability of NH_4^+-N, NO_3^--N and P in peatland and swampland could be attributed to the increased mineralisation of organic matter (OM), which produces available N and available P with the application of CFA. Due to the relatively high OM content of peatland and swampland (Table 1), they have the potential to provide N and P nutrients through the transformation of organic N and P into N and P minerals, respectively. Previous studies have shown 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 (Manoharan et al. 2010; Parab et al. 2015). Increasing soil pH is linearly associated with the CaO or MgO contents in the CFA (Ram and Masto 2014), which may be considered physiologically equivalent to approximately 20% reagent grade $CaCO_3$ (Kumar et al. 2020). The results indicate that the CFA could be used as a lime substitution to reduce soil acidity to a level suitable for agricultural activities.

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

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

The application of CFA to the three types of rice fields did not increase the height of the rice. Figure 2A shows that the rice height, with and without industrial waste application, ranged from 92 cm to 108 cm. In contrast to rice height, the CFA application improved the number of tillers, rice shoot dry weight, and rice yield. The application of this industrial waste to peatland and swampland increased the number of rice tillers from 6 to 9 and 7.25 to 8.5, respectively. Meanwhile, Figure 2B shows that the number of rice tillers in rainfed 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).

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

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 carbon content did not allow for an increase in nutrient availability through the mineralisation process. This was in line with the results of Parab et al. (2015), which reported a significant correlation between crop yield and soil pH, available P and Ca. Lee et al. (2019) stated that CFA application to soils containing low organic C (15 g kg^{-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 carbon contents.

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

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

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

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Tables

Table 1. Characteristics of the soil and coal-fly ash used for the study. Numbers after ± represent 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 ± 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[b] (g/L)	379.60 ± 70.21	629.50 ± 90.23	735.90 ± 92.34	1170.30 ± 80.45
Particle density[c] (g/L)	1340.23 ±120.34	1980.65 ± 110.78	1450.45 ± 80.76	2340.45 ± 80.23
pH[d] (H_2O)	3.23 ± 0.09	4.72 ± 0.21	4.17 ± 0.08	7.43 ± 0.09
Organic[e] C (g C/kg)	214.54 ± 1.76	93.34 ± 1.32	4.60 ± 0.34	1.45 ± 0.08
Total N[f] (g N/kg)	22.60 ± 1.21	10.70 ± 0.96	5.70 ± 0.12	0.97 ± 0.05
P[g] (g P/kg)	12.90 ± 0.65	6.24 ± 0.34	3.13 ± 0.12	0.17 ± 0.08
Ca[h] (mg Ca/kg^{1})	3.21 ± 0.23	2.58 ± 0.23	1.67 ± 0.43	1453.67 ± 9.76
Mg[h] (mg Mg/kg)	4.56 ±0.13	3.23 ± 0.34	1.87 ± 0.12	1362.66 ± 8.54
Na[h] (mg Na/kg)	3.23 ± 0.08	2.34 ± 0.08	2.54 ± 0.09	365.87 ± 6.76
K[h] (mg K/kg)	3.23 ± 0.12	2.19 ± 0.08	1.44 ± 0.05	768.55 ± 8.87
Fe[h] (mg Fe/kg)	14.12 ± 0.07	22.55 ± 0.12	7.23 ± 0.60	1124.65 ± 7.88
Al[h] (mg Al/kg)	5.66 ± 0.12	17.56 ± 2.34	4.23 ± 0.09	865.54 ± 7.54
Cr[i] (mg Cr/kg)	-	-	-	121.32 ± 4.67
Pb[i] (mg Pb/kg)	-	-	-	98.78 ± 9.65
Ni[i] (mg Ni/kg)	-	-	-	176.78 ± 9.45
Cd[i] (mg Cd/kg)	-	-	-	4.02 ± 0.15
CEC[j] ($cmol_+$/kg)	39.76 ± 3.23	23.76 ± 2.34	18.33 ± 1.23	-

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

Figures

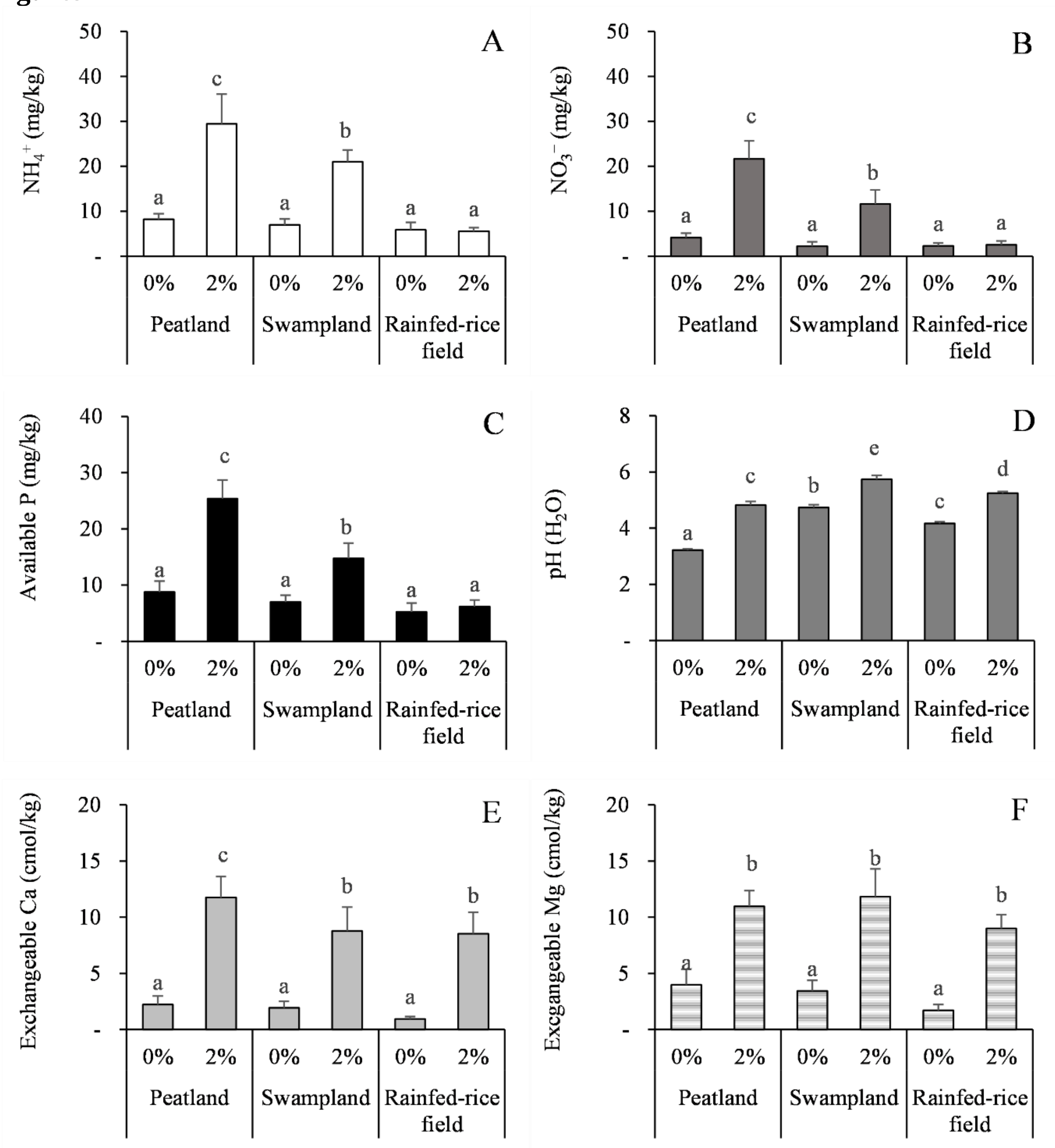

Figure 1. Changes in the amounts of NH_4^+ (A), NO_3^- (B), available P (C), soil pH (D), exchangeable Ca (E), and exchageable Mg (F) of three different types of rice fields without CFA application (0%) and with CFA application (2%) observed on 15th day after CFA application. The lines above bars represent 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.

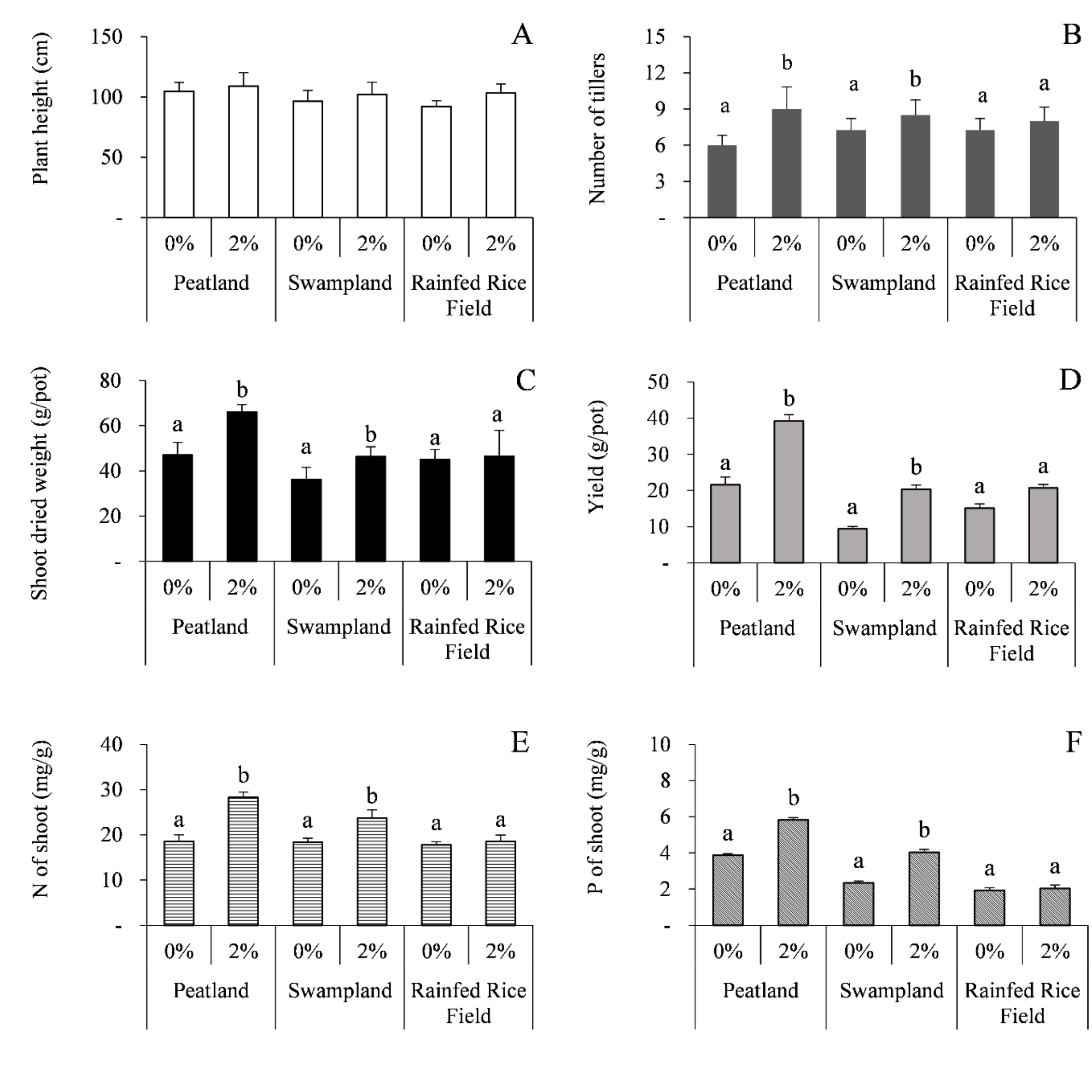

Figure 2. Influence of coal-fly ash application on plant height (A), number of tillers (B), shoot dried weight (C), yield (D), contents of nitrogen in shoot (E), and contents of phosphorous in shoot (F) of rice grown in three different types of rice fields without CFA application (0%) and with CFA application (2%) observed at 90 days after rice planting. 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.

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