



Does coal fly ash influence the growth of mangroves?

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ABSTRACT

A 1320-Megawatt capacity coal-fired power plant is establishing near the Ecologically Critical Area of the Sundarbans, Bangladesh. This power plant will generate 0.71 million tons of coal fly ash annually. Most of the previous studies concentrated on the soil amelioration and growth and yield of agricultural crops. However, this study investigated the effects of coal fly ash on the seedling growth (collar diameter, height, and biomass) of the major tree species (*Bruguiera sexangula*, *Excoecaria agallocha*, *Heritiera fomes*, and *Xylocarpus mekongensis*) of the Sundarbans, as well as to assess the nutrient (N, P, and K) partitioning in their parts (leaf, stem, and roots). Mangrove soil and coal fly ash were mixed to get seven treatments say T0, T1, T2, T3, T4, T5, and T7, which contained 0%, 5%, 10%, 20%, 30%, 40% and 50% of fly ash (w/w) respectively. A significant ($p < 0.05$) variation was observed among the species and treatments. Irrespective of species, almost similar growth for collar diameter, height, and biomass was observed for the treatments up to 10% of fly ash mixture. Collectively, a common decreasing trend for growth parameters was observed for the treatments of the higher proportion of fly ash. Similar to the growth pattern, nitrogen and potassium concentration in seedling parts showed a decreasing pattern at the higher proportion of fly ash. In conclusion, coal fly ash did not influence the growth of these studied mangrove species in a positive way but can tolerate up to 10% of fly ash mixture.

Introduction

Coal is one of the cheapest energy sources that is used for producing electricity. Coal-fired power plants generate about 37% of the global electricity (IEA, 2017). Bangladesh generates about 5% of its' total electricity using coal (Taheruzzaman and Janik, 2016). Fly ash accounts 15–30% of total coal waste produced in thermal power stations (Gupta et al., 2002). Essentially, coal combustion produces two forms of ash, i.e., Pulverized Fuel Ash (PFA) or Fly Ash (FA) and Bottom Ash (BA). The physicochemical characteristics of fly ash vary with the sources of coal, pollution control devices, transportation system, usage, oxidation frequency, etc. (Adriano et al., 1980). Fly ash contains insoluble oxides, like SiO_2 , Al_2O_3 , CaO , Fe_2O_3 , SO_3 , and a low amount (<1%) of heavy metals. It can leach heavy metals into underground waters, contributing to groundwater pollution (Fernandez-Turiel et al., 1994; Querol et al., 1999). It also contains a lower amount of nitrogen compared to conventional soils and has been found rich in other macro and micro-nutrients (El-Mogazi et al., 1988; Chu, 2008; Magiera et al., 2013).

Fly ash has diverse implications (positive and negative) on the growth parameters of both forest trees and agricultural crops (Rautaray et al., 2003; Sarita et al., 2012; Katiyar et al., 2012;

Kishor et al., 2010; Ram and Masto, 2014; Rath et al., 2019;). The positive influence of fly ash on plant growth depends on the right ratio of fly ash and soil mixture, and the species (Singh et al., 1997; Lee et al., 2006; Ahmaruzzaman, 2010; Yunusa et al., 2012; Katiyar et al., 2012; Gupta et al., 2012; Pandey and Kumar, 2013;). The right composition or ratio of fly ash and soil improves the nutrient composition and physical properties of the mixture (Wong and Wong, 1990; Singh et al., 1997; Katiyar et al., 2012), which enables to stimulate the growth and yield of some agriculture crops, e.g., *Hordeum vulgare* (Taylor et al., 1988), *Brassica parachinensis* and *Brassica chinensis* (Wong and Wong, 1990), *Solanum melongena* (Gond et al., 2013), *Oryza sativa* (Singh et al., 2016; Fahim et al., 2017), etc. Conversely, the adverse impact of fly ash on plants is mainly attributable to changes in soil chemical balance (Pandey and Singh, 2010). Changes in soil physicochemical properties (i.e., water-holding capacity, bulk density, and hydraulic conductivity) caused by fly ash may cause a reduction in the root lengths of plants (Chang et al., 1977). However, a higher amount of fly ash in soil may significantly influence the soil salinity, which can cause saline stress to plant growth (Matsi and Keramidas, 1999; Ram et al., 2007; Fahim et al., 2017) and can lead to metal toxicity (Rodriguez et al., 2011; Singh et al., 2016).

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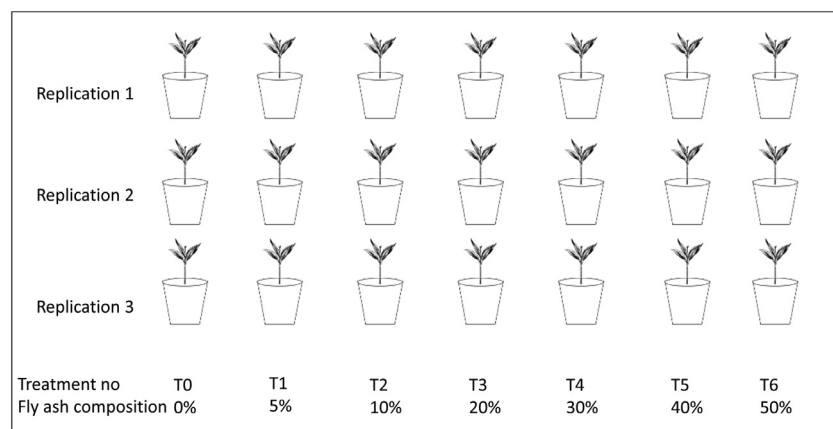


Fig. 1. Layout of the experiment with treatment detail.

There are several studies that dealt with the effects of fly ash on plant growth. For instance, *Anacardium occidentale* showed increased seedling growth, seed germination, and survival percentage in 30% fly ash with garden soil (Rath et al., 2019). While, 20% (W/W) fly ash and soil mixture was optimum for higher biomass growth of *Populus deltoids* (Jala and Goyal, 2010), and higher growth of *Simarouba glauca* seedlings was observed at a 1:3:1 ratio of fly ash, compost, and soil (Rajashekhar, 2017). However, there is not a single study on fly ash and the growth implication of mangrove tree species. The Sundarbans is a pristine mangrove ecosystem that shares both Bangladesh and Indian territories. This forest is rich in biodiversity and dominated by *Heritiera fomes* and *Excoecaria agallocha* (Mahmood, 2015). Presently, a coal-fired power plant of 1320 Megawatt is going to establish close to the Ecologically Critical Area of the Sundarbans, Bangladesh (Aziz and Paul, 2015; Islam and Al-Amin, 2019). This coal-fired power plant may cause regular and accidental release of both toxic effluents and fly ash into the surrounding environment, which may contaminant the Sundarbans mangrove ecosystem as a whole (Lemly, 2018; Chowdhury, 2017). It was forecasted that about 0.71 million ton of ash and 0.5 million ton of waste (both precipitated solid and liquid wastes) will be generated annually by the proposed power plant through the combustion of 4.75 million tons of coal (CEGIS, 2013). Considering this situation, the effect of fly ash on the growth of mangrove plant species is prime important for the sustainability of the Sundarbans mangrove forest of Bangladesh. The Sundarbans regenerate naturally and their sustainability depends on the dynamics of the natural regeneration (Mahmood et al., 1998; Biswas et al., 2007; Rahman et al., 2010). Therefore, this study aimed 1) to investigate the effects of fly ash on the seedling growth of major tree species (*Bruguiera sexangula*, *Excoecaria agallocha*, *Heritiera fomes*, and *Xylocarpus mekongensis*) of the Sundarbans and 2) to assess the nutrients (N, P, and K) partitioning in different parts (leaf, stem and root) of the seedlings.

Methodology

Treatments and experiment layout

The coal fly ash for this experiment was collected from the Barapukuria coal-based power plant located in the northern part of Bangladesh and established in 2006. This fly ash contained 54.4%, 35.6%, 3.2%, 2.9%, 0.56%, 0.46%, 0.18%, 0.66%, 0.13%, 0.11%, and 0.06% of SiO_2 , Al_2O_3 , TiO_2 , Fe_2O_3 , CaO , P_2O_5 , MgO , K_2O , SO_3 , Mn_3O_4 , and Na_2O respectively (Howladar and Islam, 2016). Topsoil (0–30 cm) of the Sundarbans was also collected for this study. The mangrove soil was air-dried and crushed. Soil and fly ash were mixed to get seven treatments say T0, T1, T2, T3, T4, T5, and T7, which contained 0%, 5%, 10%, 20%, 30%, 40% and 50% of fly ash w/w. Each treatment was replicated three times for individual species. Five (5) liter plastic

containers were filled with 2 kg of the soil and fly ash mixture of the respective treatments (Fig. 1).

Experiment setup

The seedling of *Bruguiera sexangula*, *Excoecaria agallocha*, *Heritiera fomes*, and *Xylocarpus mekongensis* were raised for six months in the Forest Nursery of Khulna University in 2019. Six (6) month-old seedlings of these species were used for this experiment. One seedling was planted in the plastic container with assigned treatment (Fig. 1). Thus 21 seedlings of an individual species were required for this experiment. The planted seedlings were irrigated four (4) times a week with tap water. This experiment was initiated during 2020 for six months in a glass house of Forest Nursery of Khulna University.

Measurements for seedlings

The collar diameter, height, and fresh weight of the seedlings that were used in this experiment were recorded before planting as initial measurements. Additionally, the fresh weight of a set of 10 seedlings of each species was recorded and oven-dried at 80 °C until constant weight to get fresh to oven-dry weight conversion ratio for the respective species. The conversion ratio of the respective species was used to estimate the initial oven-dry weight of the individual seedling that was used in this experiment.

At the end, the seedlings were uprooted carefully to minimize root loss. The collar diameter and height of the uprooted seedlings were recorded according to the treatments as the final measurement. The seedlings were then separated into parts (leaf, stem, and root), and oven-dried at 80 °C until constant weight. The oven-dried seedlings parts were weighted and summed to get the final oven-dry weight. Collar diameter, height, and biomass growth for the experiment period were estimated from the final and initial measurement. However, the oven-dried seedling parts (leaf, stem, and root) of respective species according to treatments were crushed, sieved (2 mm mesh), and stored according to Allen (1989) for further analysis.

Chemical properties of treatments (soil and fly ash mixture) and seedling parts

Micro Kjeldahl digestion for Nitrogen (N) and tri-acid (H_2SO_4 , HClO_4 and HNO_3) digestion for Phosphorus (P) and Potassium (K) were adopted for soil and seedling parts according to Allen (1989). The method of (Beathgen and Alley, 1989) Baethgen and Alley (1989) and Timothy et al. (1984) was followed to measure Nitrogen and Phosphorus in the sample extract using Spectrophotometer (HITACHI, U-2910, Japan) and Flame Photometer (PFP7, Jenway LTD, England) was also used to determine Potassium concentration in the extracts.

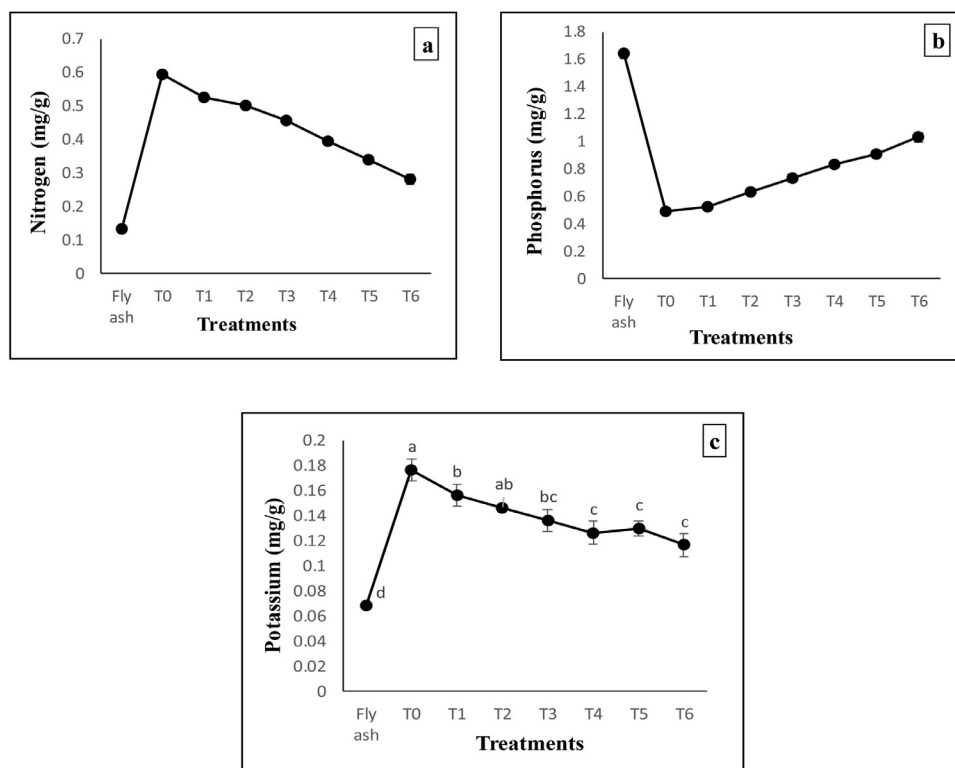


Fig. 2. Concentration of a) Nitrogen b) Phosphorus and c) Potassium in different treatments (Treatment means with similar alphabet indicates no significant (ANOVA, $p > 0.05$, DMRT) difference).

Statistical analysis

A two-way ANOVA analysis followed by DMRT (Duncan Multiple Range Test) were conducted to compare the collar diameter, height, and biomass growth for the studied species according to treatments and species. A one-way ANOVA analysis along with DMRT were conducted to compare the N, P, and K concentration in the fly ash (100%), and soil and fly ash mixture treatments. While, a two-way ANOVA analysis and DMRT were conducted to compare the N, P, and K concentration in seedling parts (leaf, stem, and root) according to treatments and species. All the statistical analysis was conducted by using SAS University Edition.

Results

Nutrients in treatments media and fly-ash

ANOVA analysis followed by DMRT indicated comparatively higher (0.59 mg/g) nitrogen concentration for T0 and lowest (0.28 mg/g, ANOVA, DMRT) for T6 treatment (Fig. 2a). Conversely, the highest (1.03 mg/g, ANOVA, DMRT) concentration of phosphorus was reported in T6 treatment and lowest (0.49 mg/g, ANOVA, DMRT) for the treatment T0 (Fig. 2b). In case of potassium, T0 contained the highest (0.18 mg/g, ANOVA, DMRT) and lowest (0.12 mg/g, ANOVA, DMRT) for T6 treatment (Fig. 2c). In comparison, 100% fly ash contained the highest concentration of phosphorus (1.64 mg/g, ANOVA, DMRT) and the lowest concentration of nitrogen (0.13 mg/g, ANOVA, DMRT) and potassium (0.07 mg/g, ANOVA, DMRT). However, a significant (ANOVA, $p < 0.05$) variation was observed for nutrients (N, P and K) concentration among the seven treatments (T0, T1, T2, T3, T4, T5, and T6) and 100% fly ash (Fig. 2a, b and c).

Seedling growth

Growth parameters (collar diameter, height, and biomass) were varied significantly (ANOVA, $p < 0.05$) with the treatments and species

(Table 1). Species-specific response to fly ash treatments was also noted. Comparatively (ANOVA, $p < 0.05$, DMRT) higher collar diameter and height growth were observed for *H. fomes* and *X. mekongensis* respectively up to treatment T5. While *Xylocarpus mekongensis* showed significant (ANOVA, $p < 0.05$, DMRT) highest biomass growth for the treatments containing up to 10% fly ash and *E. agallocha* secured the lowest biomass growth throughout the experiment. The collar diameter, height, and biomass growth of *X. mekongensis* found to decrease more sharply compared to other species at a higher proportion of fly ash (Fig. 3a, b, and c).

In case of individual species, the treatments of T0, T1, T2, and T3 showed no significant (ANOVA, $p > 0.05$, DMRT) difference among the collar diameter and height growth for *B. sexangula* and *X. mekongensis*, while of *H. fomes* showed no significant (ANOVA, $p > 0.05$, DMRT) difference for the treatments of T0, T1, T2, T3, and T4. *Excoecaria agallocha* showed almost similar (ANOVA, $p > 0.05$, DMRT) collar diameter, height, and biomass growth for treatments up to 10% fly ash (Fig. 2d).

Nutrients (N, p and K) in plant parts

Nitrogen in plant parts

Among the studied species, *E. agallocha* contained higher nitrogen. Irrespective of species, comparatively (ANOVA, $p < 0.05$, DMRT) higher nitrogen concentration was observed in leaves followed by roots and stems. Nitrogen in plant parts showed decreasing trend with the increasing proportion of fly ash (Fig. 4a, b, c and d). Collectively, a significant (ANOVA, $p < 0.05$) difference was observed in nitrogen concentration for species, treatments and plant parts (Table 2). However, the nitrogen concentration in leaves of *E. agallocha* showed significant (ANOVA, $p < 0.05$, DMRT) variation among the treatments. While nitrogen concentration in stems of *B. sexangula*, and roots of *E. agallocha* was not varied significantly (ANOVA, $p > 0.05$) (Table 2, Fig. 4d).

Phosphorus in plant parts

Excoecaria agallocha contained higher phosphorus followed by *H. fomes*. Comparatively (ANOVA, $p < 0.05$, DMRT) higher phosphorus

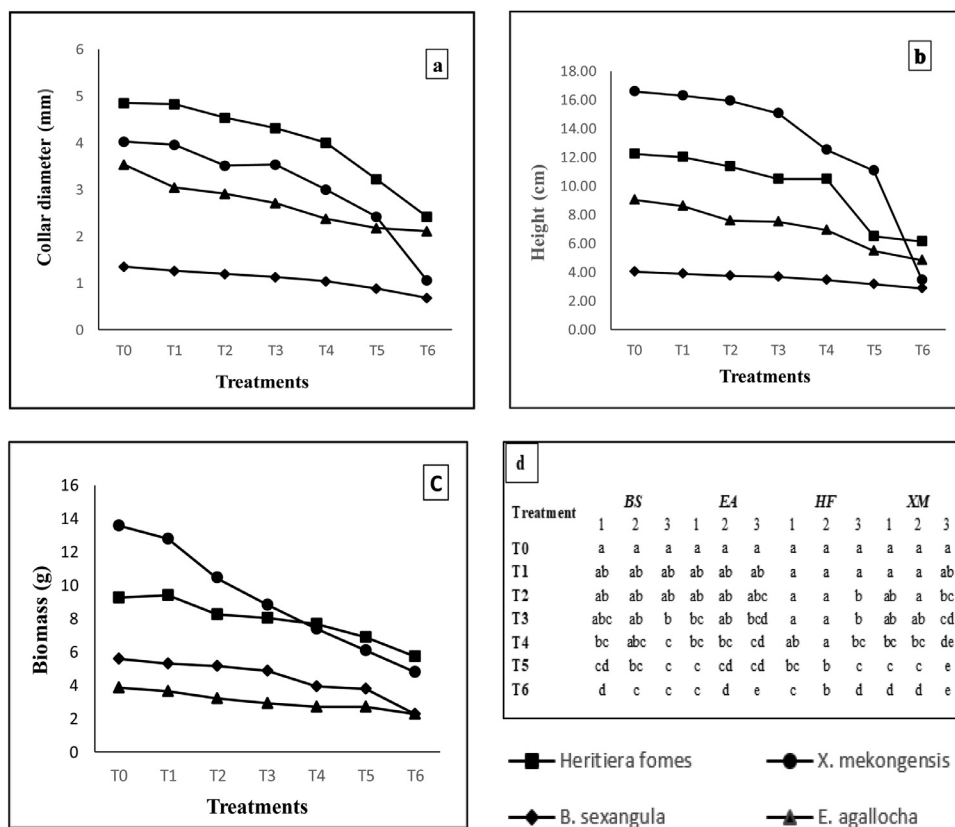


Fig. 3. (a) Collar diameter b) Height c) Biomass growth of BS, EA, HF and XM in different treatments and d) Duncan Multiple Range Test (DMRT) result for collar diameter, height and biomass growth of each species along the treatments, where 1 = collar diameter, 2 = height, 3 = biomass, BS = *Bruguiera sexangula*, EA = *Excoecaria agallocha*, HF = *Heritiera fomes*, XM = *Xylocarpus mekongensis*. Similar alphabet in the column according to treatment are not varied significantly ($p < 0.05$).

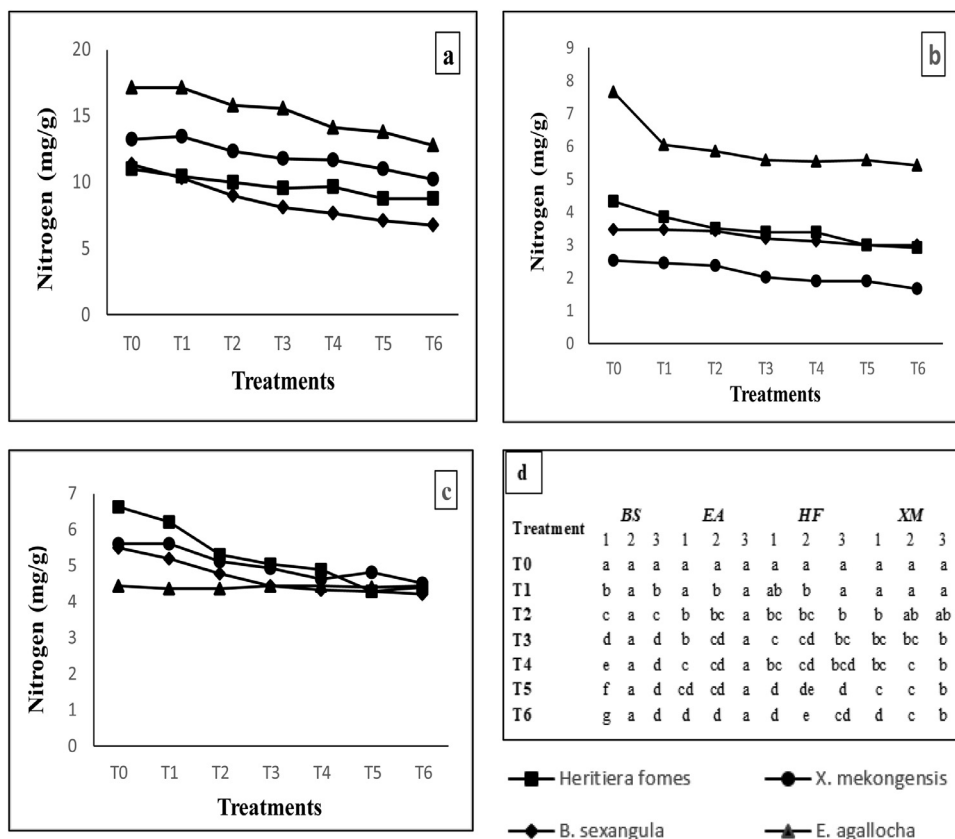


Fig. 4. Nitrogen concentration in a) Leaves, b) Stems c) Roots of BS, EA, HF and XM in different treatments and d) Duncan Multiple Range Test (DMRT) result for nitrogen concentration in leaves, stems and roots of each species along the treatments, where 1=leaves, 2= stems, 3 = roots, BS = *Bruguiera sexangula*, EA = *Excoecaria agallocha*, HF = *Heritiera fomes*, XM = *Xylocarpus mekongensis*. Similar alphabet in the column according to treatment are not varied significantly ($p < 0.05$).

Table 1

Analysis of Variance (ANOVA) for the growth parameters (collar diameter, height and biomass) among the treatments and species.

Parameter	Treatment	Species	<i>Bruguiera sexangula</i>	<i>Excoecaria agallocha</i>	<i>Heritiera fomes</i>	<i>Xylocarpus mekongensis</i>
Collar diameter	Df = 6, SS = 31.31, MS = 0.26, <i>F</i> = 20.13,	Df = 3, SS = 95.32, MS = 31.77, <i>F</i> = 122.58	Df = 6, SS = 0.94, MS = 0.16, <i>F</i> = 6.88	Df = 6, SS = 4.73, MS = 0.79, <i>F</i> = 5.52	Df = 6, SS = 14.70, MS = 2.45, <i>F</i> = 7.89	Df = 6, SS = 19.95, MS = 3.32, <i>F</i> = 13.27
Height	Df = 6, SS = 359.67, MS = 59.96, <i>F</i> = 15.41	Df = 3, SS = 1025.20, MS = 341.73, <i>F</i> = 87.84	Df = 6, SS = 3.10, MS = 0.52, <i>F</i> = 3.27	Df = 6, SS = 42.92, MS = 7.15, <i>F</i> = 6.02	Df = 6, SS = 116.60, MS = 19.43, <i>F</i> = 7.51	Df = 6, SS = 396.82, MS = 66.14, <i>F</i> = 28.01
Biomass	Df = 6, SS = 176.11, MS = 29.35, <i>F</i> = 18.04	Df = 3, SS = 519.23, MS = 173.23, <i>F</i> = 106.45	Df = 6, SS = 24.67, MS = 4.11, <i>F</i> = 30.82	Df = 6, SS = 5.91, MS = 0.98, <i>F</i> = 4.99	Df = 6, SS = 30.12, MS = 5.02, <i>F</i> = 20.43	Df = 6, SS = 198.66, MS = 33.11, <i>F</i> = 15.92

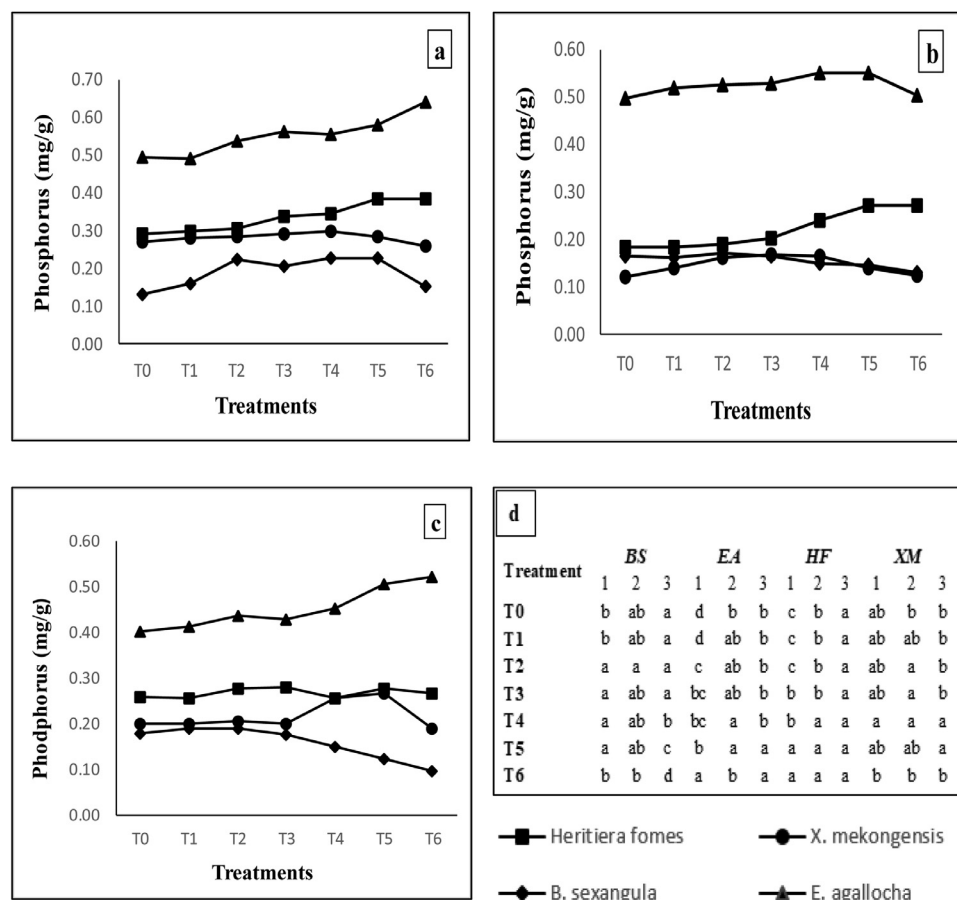
Where, Df= Degree of freedom, SS = Sums of Square, MS = Mean Squares, *F*= Calculated 'F' Value.**Table 2**

Analysis of Variance (ANOVA) for nitrogen concentration in plant parts among the treatments and species.

Parameter	<i>Bruguiera sexangula</i>	<i>Excoecaria agallocha</i>	<i>Heritiera fomes</i>	<i>Xylocarpus mekongensis</i>
Leaf	Df = 6, SS = 51.29, MS = 8.55, <i>F</i> = 227.48	Df = 6, SS = 50.29, MS = 8.38, <i>F</i> = 22.64	Df = 6, SS = 12.65, MS = 2.11, <i>F</i> = 10.35	Df = 6, SS = 24.28, MS = 4.05, <i>F</i> = 21.20
Stem	Df = 6, SS = 0.85, MS = 0.14, <i>F</i> = 1.77*	Df = 6, SS = 11.08, MS = 1.85, <i>F</i> = 71.97	Df = 6, SS = 4.33, MS = 0.72, <i>F</i> = 15.28	Df = 6, SS = 1.94, MS = 0.32, <i>F</i> = 7.38
Root	Df = 6, SS = 4.59, MS = 0.77, <i>F</i> = 45.23	Df = 6, SS = 0.03, MS = 0.004, <i>F</i> = 0.06*	Df = 6, SS = 14.14, MS = 2.36, <i>F</i> = 16.81	Df = 6, SS = 3.48, MS = 0.58, <i>F</i> = 4.78

Where, Df= Degree of freedom, SS = Sums of Square, MS = Mean Squares, *F*= Calculated 'F' Value.

** Indicates no significant difference at 95% level.

**Fig. 5.** Phosphorus concentration in a) Leaves, b) Stems c) Roots of BS, EA, HF and XM in different treatments and d) Duncan Multiple Range Test (DMRT) result for phosphorus concentration in leaves, stems and roots of each species along the treatments, where 1=leaves, 2= stems, 3 = roots, BS = *Bruguiera sexangula*, EA= *Excoecaria agallocha*, HF= *Heritiera fomes*, XM = *Xylocarpus mekongensis*. Similar alphabet in the column according to treatment are not varied significantly ($p < 0.05$).

concentration was detected in leaves followed by roots and stems. Phosphorus in leaves of all the studied species showed an increasing trend with the increasing proportion of fly ash in the treatments (Fig. 5a, b, c and d). Collectively, a significant (ANOVA, $p < 0.05$) variation was observed in phosphorus concentration for species, treatments, and plant parts (Table 2). However, no significant (ANOVA, $p < 0.05$) difference in phosphorus concentration

was observed for leaves of *X. mekongensis*, stem of *B. sexangula* and *E. agallocha*, and roots of *H. fomes* among the treatments (Table 3, Fig. 5d).

Phosphorus in plant parts

Excoecaria agallocha contained higher potassium followed by *H. fomes* and the lowest potassium concentration was observed for *B. sexan-*

Table 3

Analysis of Variance (ANOVA) for phosphorus concentration in plant parts among the treatments and species.

Parameter	Bruguiera sexangula	Excoecaria agallocha	Heritiera fomes	Xylocarpus mekongensis
Leaf	Df = 6, SS = 0.03, MS = 0.004, $F = 7.44$	Df = 6, SS = 0.05, MS = 0.01, $F = 27.88$	Df = 6, SS = 0.03, MS = 0.01, $F = 26.36$	Df = 6, SS = 0.003, MS = 0.0004, $F = 1.85^*$
Stem	Df = 6, SS = 0.003, MS = 0.0005, $F = 1.34^*$	Df = 6, SS = 0.01, MS = 0.001, $F = 2.57^*$	Df = 6, SS = 0.03, MS = 0.005, $F = 14.74$	Df = 6, SS = 0.01, MS = 0.001, $F = 5.07$
Root	Df = 6, SS = 0.02, MS = 0.004, $F = 19.77$	Df = 6, SS = 0.04, MS = 0.01, $F = 9.23$	Df = 6, SS = 0.002, MS = 0.0003, $F = 0.87^*$	Df = 6, SS = 0.02, MS = 0.003, $F = 5.15$

Where, Df= Degree of freedom, SS = Sums of Square, MS = Mean Squares, F = Calculated 'F' Value.

** Indicates no significant difference at 95% level.

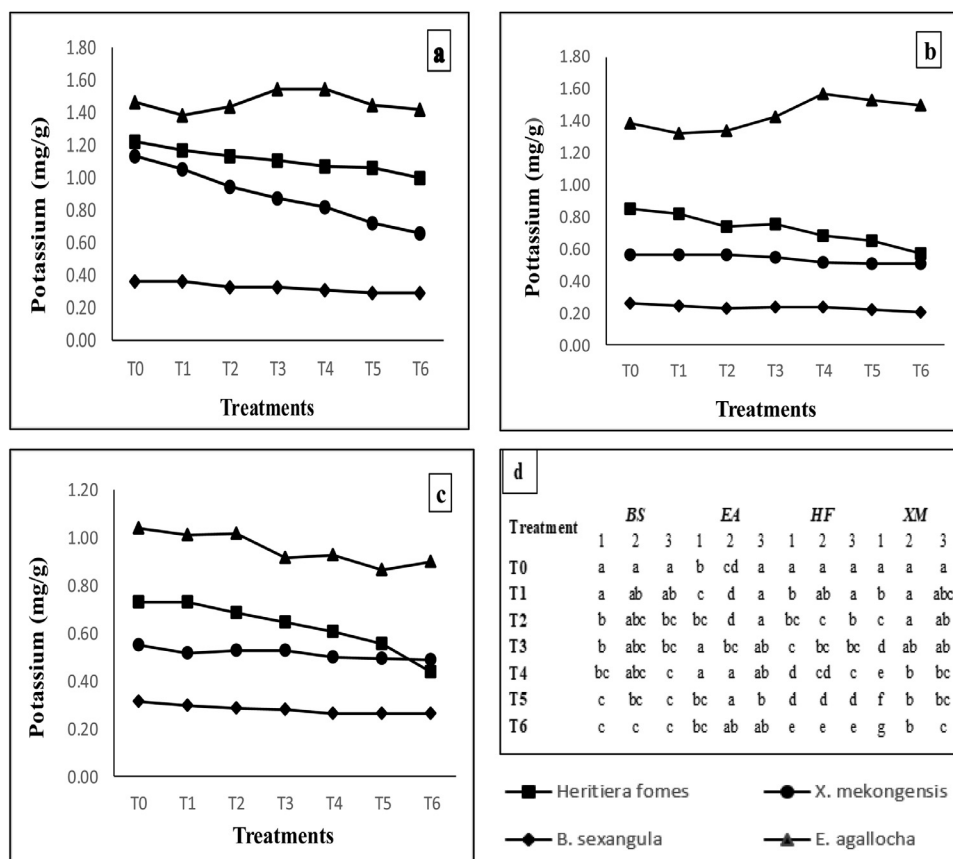


Fig. 6. Potassium concentration in a) Leaves, b) Stems c) Roots of BS, EA, HF and XM in different treatments and d) Duncan Multiple Range Test (DMRT) result for potassium concentration in leaves, stems and roots of each species along the treatments, where 1=leaves, 2= stems, 3 = roots, BS = Bruguiera sexangula, EA= Excoecaria agallocha, HF= Heritiera fomes, XM = Xylocarpus mekongensis. Similar alphabet in the column according to treatment are not varied significantly ($p < 0.05$).

Table 4

Analysis of Variance (ANOVA) for potassium concentration in plant parts among the treatments and species.

Parameter	Bruguiera sexangula	Excoecaria agallocha	Heritiera fomes	Xylocarpus mekongensis
Leaf	Df = 6, SS = 0.02, MS = 0.003, $F = 10.91$	Df = 6, SS = 0.06, MS = 0.01, $F = 11.99$	Df = 6, SS = 0.10, MS = 0.02, $F = 44.27$	Df = 6, SS = 0.53, MS = 0.09, $F = 143.93$
Stem	Df = 6, SS = 0.006, MS = 0.001, $F = 3.04$	Df = 6, SS = 0.17, MS = 0.03, $F = 12.30$	Df = 6, SS = 0.18, MS = 0.03, $F = 16.88$	Df = 6, SS = 0.01, MS = 0.002, $F = 4.34$
Root	Df = 6, SS = 0.01, MS = 0.001, $F = 6.98$	Df = 6, SS = 0.08, MS = 0.01, $F = 2.47^*$	Df = 6, SS = 0.20, MS = 0.03, $F = 59.99$	Df = 6, SS = 0.009, MS = 0.001, $F = 3.93$

Where, Df= Degree of freedom, SS = Sums of Square, MS = Mean Squares, F = Calculated 'F' Value.

** Indicates no significant difference at 95% level.

gula. Irrespective of species, comparatively (ANOVA, $p < 0.05$, DMRT) higher potassium concentration was observed in leaves followed by stem and roots. However, potassium in plant parts showed decreasing trend with the increasing proportion of fly ash (Fig. 6a, b, c, and d). Collectively, a significant (ANOVA, $p < 0.05$) difference was observed in potassium concentration for species, treatments, and plant parts (Table 2). However, no significant (ANOVA, $p < 0.05$) difference in potassium con-

centration was detected for roots of *E. agallocha* among the treatments (Table 4, Fig. 6d).

Discussion

The chemical properties of fly ash found to vary with the origin and types (Howladar and Islam, 2016). Comparatively higher con-

centration of SiO_2 (~50%) and Al_2O_3 (~35.6%) was observed in fly ash, while nitrogen, phosphorus, and potassium contain less than 1% (Wardell, 1991; Howladar and Islam, 2016). Generally, the concentration of Carbon (C) and Nitrogen (N) in the fly ash is reduced due to oxidation of C and N during the coal combustion process (Hodgson, 1966). In this study, N and K contents in treatments (soil and fly ash mixture) decreased with the increasing proportion of fly ash (w/w). Conversely, phosphorus concentration found to increase with the increasing proportion of fly ash in the treatments. This phenomenon is directly related to the nutrient concentration of soil and fly ash used in the experiment, which has influenced the nutrient composition of the different treatments (mixture of soil and fly ash). A similar observation was also reported by Jala and Goyal (2010) and Kishor et al. (2010).

The growth of mangrove species found to vary with species, stages (seedlings, saplings and trees), and site conditions (Tomlinson, 1986). The growth parameters (collar diameter, height and biomass) of the studied species responded differently with the treatments. The species-specific inherent growth performance may be responsible for the variations in growth parameters among the species in a particular treatment. In particular, *X. mekongensis* was more sensitive considering the sharp decline of the growth parameters at the treatments with a higher proportion of fly ash. However, a common decreasing trend for growth parameters was observed for all the studied species with a higher proportion of fly ash. The growth of seedlings is linked with the nutrient availability and toxicity of certain elements (Binkley, 1986; Tam et al., 1995; Jones 1998; Mahmood et al., 2001; Sandilyan and Kathiresan, 2014). The present study showed almost similar growth for diameter, height and biomass up to 10% of fly ash mixture. This indicated that the fly ash was not able to influence the better growth of these studied mangrove plant species. The nutrient (N, P and K) composition of the treatments indicated that the concentration of nitrogen and potassium reduced significantly (ANOVA, $p < 0.05$, DMRT) with the increasing proportion of fly ash in the treatments (Fig. 2). Nitrogen and potassium are the most important nutrients that significantly controls the growth and development of plants (Jones, 1998). Conversely, *Populus deltoids* (Jala and Goyal, 2010) and *Anacardium occidentale* (Rath et al., 2019) showed higher biomass growth performance at 10 and 30% of fly ash respectively. The fly ash of the study of Jala and Goyal (2010) and Rath et al. (2019) contained 0.04 to 0.41%, 0.11 to 0.224% and 0.0043 to 0.05% of nitrogen, phosphorus and potassium respectively, which was much higher than the fly ash composition of the present study. Plant growth and biomass productivity are greatly influenced by nitrogen, phosphorus and potassium (Ågren et al., 2012; Wieder et al., 2015). In another way, fly ash can improve the physical properties of the soil especially the water holding capacity (Khan et al., 2013) for the coarse-textured soil. Conversely, it may have little or no influence on the fine-textured (silty clay) mangrove soil that was used in this study. Therefore, lower nutrients (nitrogen and potassium) content in the treatments, species-specific responses (stress-sensitive and adaptive) metal toxicity can be responsible for the slower growth of the studied species at the treatments of a higher proportion of fly ash. This statement has also been proven during the detection of a lower concentration of nitrogen and potassium in the leaves and roots of the studied species. In other ways, fly ash that was used in this study contained higher aluminium (Howladar and Islam, 2016). aluminium is not essential for plant growth, but may negatively influence the growth and nutrient distribution in plant part at higher concentration (Zhao and Shen, 2018). A high level of aluminium lowers the uptake of nitrogen and its efficiency that result in lower root growth (Zhao et al., 2014). aluminium also showed interact with other nutrients within soils and plants (Zhao et al., 2014), especially phosphorus and potassium in leaves showed a negative relationship (Shafaqat et al., 2011). The interruption in nutrient availability and toxicity of aluminium may also be responsible for the lower growth of the studied mangrove species at a higher proportion of fly ash in this experiment.

Conclusion

Fly ash has no positive influence on the growth of the studied mangrove species and a negative trend of growth was observed for all the species at the higher proportion of fly ash. The negative growth trend believed to relate to the poor nutrient composition of the fly ash, which has been reflected in the nutrient (N, P, and K) concentration in the treatments and plant parts. Finally, the findings of this study demonstrated that the studied mangrove species can tolerate up to 10% fly ash mixture without any significant negative influence on their growth.

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.envc.2021.100201.

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