Changes in Soil Chemical Properties and Growth Performance of Corn (*Zea mays* L.) Grown in an Acidic-tropical Soil Amended with Fly-ash

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Abstract: Fly-ash, by product in coal power-plant production, has many essential nutrients for plant growth along with toxic metals. Therefore, fly-ash is frequently applied for improving soil fertility. In this experiment, we applied four different amounts of fly-ash, viz. 0 (100% soil), 25, 50 and 75 Mg ha^{-1} to an acidic-tropical soil and determined the changes in soil chemical properties and corn production in a green-house experiment. Results of study showed that fly-ash application improved soil pH, exchangeable cations (Na, K, Ca and Mg), cation exchangeable capacity (CEC), concentrations of aluminium and iron. The experiment also showed that fly-ash application to soils also improved corn growth (plant height and dried-weight shoot) and production. Fly-ash 50 Mg ha^{-1} lead to higher corn production than the fly-ash application of 25 Mg ha^{-1}, and increasing the amounts of added fly-ash did not significantly increase the corn production. Results of this study demonstrate that medium-level of fly-ash application resulted in the improvements of soil chemical properties and corn production.

1 INTRODUCTION

One of the problems corn cultivation in dry-land is high soil-acidity (low pH of the soil). Low soil pH results in low availability of soil phosphorus, calcium, magnesium, potassium and sodium (Bohn *et al*., 2001), and this condition eventually results in unhealthy plant growth. The soil acidity problem can be reduced by the application of soil ameliorant. Soil amelioration materials such as lime and organic matter have been generally applied to soils for soil characteristic improvement (Ma *et al*., 2018; Soong *et al*., 2018). Soil amelioration increases soil pH (dos Santos *et al*., 2018; Jayalath *et al*., 2016; Li & Johnson, 2016; Soong *et al*., 2018) and improves the content of nutrients such as N, P, K, Ca and Mg (Holland *et al*., 2018; Rheinheimer *et al*., 2018; Soong *et al*., 2018).

Fly-ash is the result of the combustion process that contains elements such as Si, K, Ca, Mg and Na (Swain *et al*., 2007), which is generally existed in oxide form so that is able to increase the soil pH and cation exchange capacity (Clark *et al*., 2001). Fly-ash generally contains 4.9 to 25.2% CaO, 1.3 to 5.1% MgO, 1.0 to 1.7% Na_2O, 0.6 to 1.3% K_2O and from 36.9 to 52.5 % SiO_2 (Kishor *et al*., 2010); therefore, fly-ash is potential to be applied for soil amelioration. However, the use of fly-ash as a soil ameliorant is currently not done broadly because of the high concentration heavy metals in the fly-ash.

The use of fly-ash for improvement of soil properties is already done in some countries. Previous research showed that application of fly-ash to soils as a source of Si is able to increase the uptake of Si, P and K, and thereby increasing rice production (Lee *et al*., 2006). The research also showed that no accumulation of heavy metals in in rice plant was observed after fly-ash application. In this study, we applied different amounts of fly-ash to soils and then determined changes in chemical soil characteristics and the growth performance of corn grown at that amended soils.

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2 MATERIALS AND METHODS

2.1 Sampling of Soil and Fly-ash

Soil samples for this experiment was collected from the Experimental Plot for Up-land Crops, Lambung Mangkurat University, Pelaihari, South Kalimantan, Indonesia. The soil was sampled at a depth of 0-30 cm at several different points, and then the samples were homogenized. Plant debris was carefully removed from the collected samples and then stored in polyethylene vessels at 5 ºC. Fly-ash used for this study was sampled from the Asam-asam Steam Power Plant, South Kalimantan Province, Indonesia.

2.2 Greenhouse Experiment

Seven kilograms of soil was placed in a 10-L pot, then fly-ash in equal amount to 0, 25, 50 and 75 Mg ha^{-1} was added to the pots, swirled gently until the fly-ash evenly distributed to the soils. Water was applied to the pots to acquire 70% of water field capacity, then the pots were incubated for 15 days. Each treatment of soil and fly-ash had five replicates. Water was added periodically to each pot during the incubation period to compensate for evaporative losses and ensure constant water content in each pot. At the end of incubation, a 250 g of soil sub-sample was taken from the pot for determination of soil pH, exchangeable cations (Na, K, Ca and Mg), cation exchangeable capacity, exchangeable aluminium and iron, mineral nitrogen and available phosphor.

Seeds of corn (2-3 seeds) grown in the pots and only one corn plant was allowed to be grown in the pots after three weeks. Nitrogen, phosphorous and potassium fertilizers were applied to each pot at the rates of 150 kg, 100 kg and 100 kg per hectare, respectively. Plant maintenance was carried out by daily watering, weeding as well as pest and disease control by using pesticides if necessary. Measuring of corn growth and production were conducted after 90 days of planting.

2.3 Statistical Analysis

Influence of fly-ash application on changes in the soil properties and the growth of corn was quantified through analysis of variance (Anova) followed by the Least Significant Difference (LSD) test at level of $P<0.05$. Prior to the analysis of variance, Shapiro-Wilk's and Bartlett's tests were carried out to ensure data to be analyzed have a normal distribution and equal variances, respectively. All statistical tests were conducted using the package of GenStat 12^{th} Edition (Payne, 2008).

3 RESULTS AND DISCUSSION

3.1 Changes in Soil Characteristics with Fly-ash Application

Results of study showed that fly-ash application increased soil CEC, soil pH, exchangeable Al, Fe, inorganic nitrogen and available P (Figure 1). Increased soil pH occurs because fly-ash containing CaO and MgO, which reacted with H^+ ions to neutralize soil acidity. The greater the amount of fly-ash application, the greater the amount of CaO and MgO are given into the soils, thus the greater the change in soil pH. It was reported in the previous study that the neutralization capacity of fly-ash ranged from 0.01 to 3.74 meq per gram H_3O^+(Kishor et al., 2010). Increasing the pH of the soil treated with fly-ash was also reported in several other studies (Clark et al., 2001; Lee et al., 2006; Sajwan et al., 2007; Swain et al., 2007).

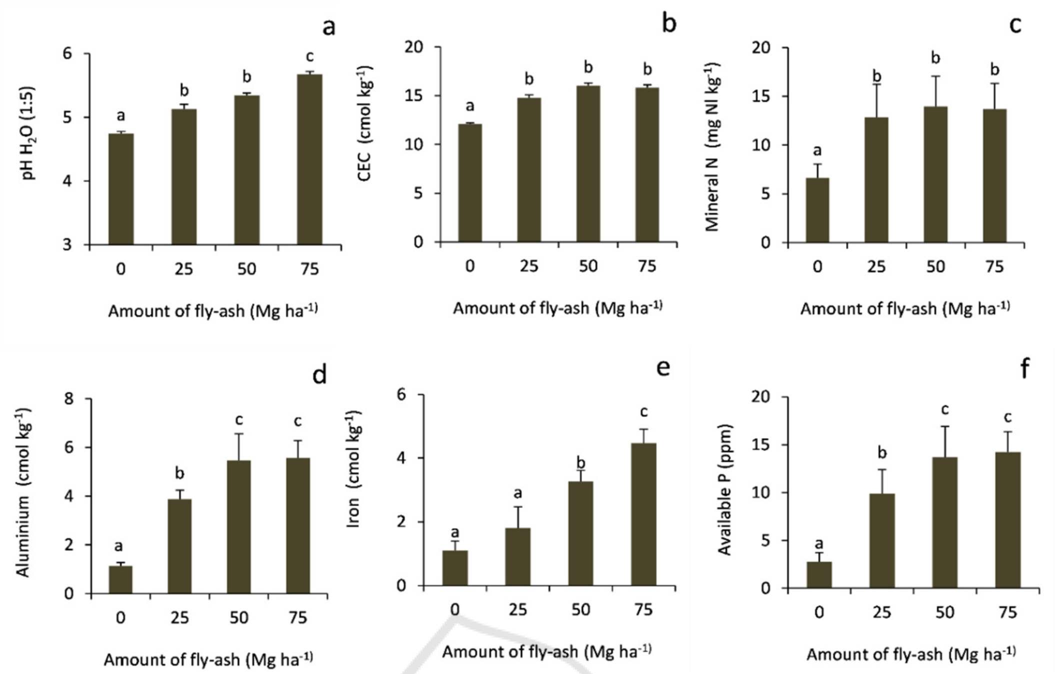

Figure 1. Changes in soil pH (a), cation exchangeable capacity – CEC (b), mineral/inorganic nitrogen (c), exchangeable aluminium (d), exchangeable iron (e), and available P (f) as influenced by the different amount of fly-ash application.

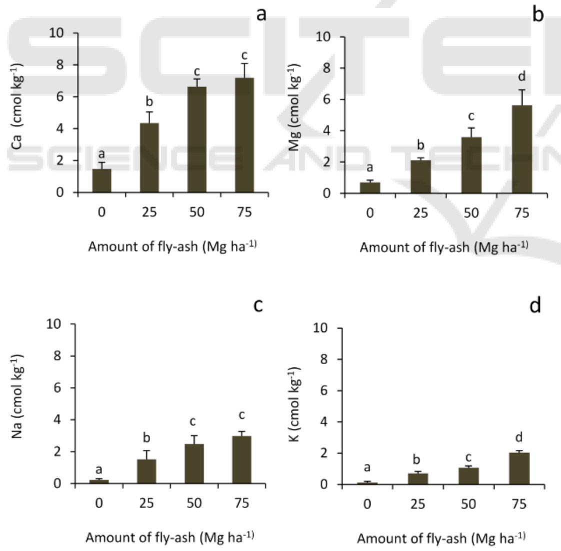

Figure 2: Changes in exchangeable calcium (a), magnesium (b), sodium (c) and potassium as influenced by fly-ash application.

Concentrations of exchangeable aluminium and iron in soil also increased with fly-ash application. The activity and solubility of certain metals may change with changes in pH. For example, aluminium is relatively insoluble as $Al(OH)_3$ at neutral pH, but it exists predominantly as highly soluble at pH range of 3.4 and 6.3 (Bohn et al., 2001; Sposito, 2004). Iron is also observed in insoluble phase at neutral pH, and the solubility of iron increase considerably when pH drops to a range of 3.7 and 5.9 (Sposito, 2004). When fly-ash was added to soils with a range of acidic pH, the aluminium and iron contained in the fly-ash dissolved and increased the amount of exchangeable aluminium and iron in soils.

Available phosphor and inorganic nitrogen (NH_4^+ and NO_3^-) of the soils increased significantly with fly-ash application (Figure 1). Low concentration of phosphor is often reported for acidic soils due to strong retention of phosphorus ion by mineral soils (Vitousek et al., 2010). Soil pH is believed to be one of the most significant soil characteristics since it affects nutrient availability in soil systems (Kemmitt et al., 2006; Lauber et al., 2009). Fly-ash application increased soil pH and eventually improved available phosphor (Figure 1). Another possible explanation for increasing available phosphor with fly-ash application is that fly-ash contains essential nutrients such K, Mg, P and S (Knapp & Insam, 2011). Consequently, fly-ash application to soils may provide soils with an abundant range of essential nutrients, among them phosphor. Previous study showed that significant increase in available phosphor for plants in soil systems following the incorporation of fly-ash to the soils (Schönegger *et al.*, 2018).

Plant-available nitrogen (NH_4^+ and NO_3^-) also improved significantly after application of fly-ash to the soils. It is well documented that soil pH plays an important role in controlling the rate of nitrogen mineralization, which increasing soil pH enhance organic nitrogen mineralization (Kemmitt *et al*., 2006; Ste-Marie & Paré, 1999; Thompson *et al*., 1954). Fly-ash incorporation in this study was able to improve soil pH from 4.7 to 5.1-5.7, depending the amounts of added fly-ash (Figure 1). Increasing soil pH subsequently leads to increase in the concentration of plant-available nitrogen, consistent with previous study reported that application of 50 Mg ha^{-1} fly-ash enhance plant-available inorganic nitrogen in paddy field (Singh *et al*., 2011).

Results of the study showed that the fly-ash application affected the concentration of exchangeable Na, Ca, and Mg in soil. Fig. 2 showed that the concentration of exchangeable Ca and Mg was higher than other cations (Na, K, and Mg) in all soils applied with fly-ash. This is due to the higher Ca and Mg contents than other cations (Na and K) of fly-ash, so that the availability of Ca and Mg increased significantly when the fly-ash is added to the soils. This result is consistent with the previous study that reported that Ca is the most dominant cation of soils applied with fly-ash (Sharma & Kalra, 2006).

3.2 Growth Performance of Corn with Fly-ash Application

Growth performance of corn (plant height, dry shoot matter weight and yield) was also improved by fly-ash application (Figure 3). Increasing growth performance of corn is attributed to increase in nutrient uptake by corn with fly-ash application. This was supported by significant correlations between nitrogen, phosphor and potassium uptake and the parameters of corn growth performance (plant height, dry shoot matter weight and yield) (data not shown).

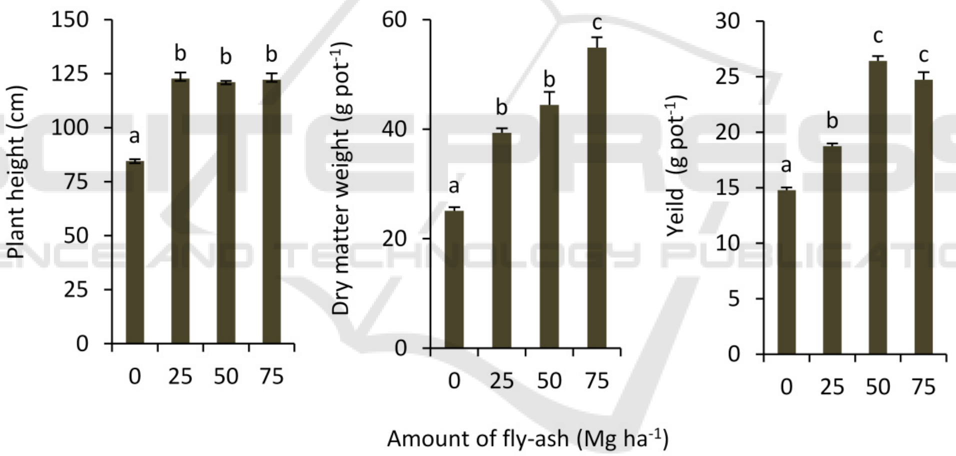

Figure 3: Influence of fly-ash application on corn growth and production

4 CONCLUSIONS

Observations on the chemical characteristics of soil showed that soil pH, exchangeable bases (Ca, Mg, Na and K), cation exchangeable capacity (CEC), mineral nitrogen, available P, exchangeable aluminium and iron improved with fly-ash application. The growth and production of corn also improve with fly-ash addition to soils. Increases in maize growth and production may relate to increasing the nutrient uptake by corn with fly- ash application. It could be concluded that fly-ash application to soils is able to improve the fertility of acidic soils and the growth of plant.

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