Use of Plant Derived Ash as Potassium Fertilizer and Its Effects on Soil Nutrient Status and Cocoa Growth

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ABSTRACT

Use of Plant Derived Ash as Potassium Fertilizer and Its Effects on Soil Nutrient Status and Cocoa (J. B. Baon): An alternative to replacing the expensive potassium (K) fertilizers, such as KCl, should be investigated by Indonesia as the third largest cocoa (*Theobroma cacao* L.) producing country. The objective of this study is to investigate the effect of plant derived ash (PDAsh) application on soil nutrient status and growth of cocoa. This research was conducted in ICCRI, Jember, using a soil from Balung subdistrict, Jember, East Java. Two series of experiments with and without cocoa plants consisted of six treatments replicated four times were laid in randomized completely block design. The six treatments of K_2O applied were 0, 300, 600, 900, 1200 and 1.500 mg 2.5 kg^{-1} soil. Results of this study showed that application of PDAsh as K fertilizer increased the availability of K and Mg in soil and K content in plant tissue. In case of Mn, the concentration in soil decreased in the experiment with cocoa plants, on the other hand the concentration increased where no cocoa plants and the relation followed quadratic curve. The results also indicated that application of PDAsh up to 1500 mg K_2O 2.5 kg^{-1} soil resulted in soil pH of 7.4 in two months after application and reached 6.8 in 6 months compared with the pH of ash was 13. Application of PDAsh 700 mg 2.5 kg^{-1} soil resulted in optimum cocoa seedling growth compared to other dosages tested, in term of plant height, plant diameter, leaf number, fresh and dry shoot weight.

Keywords: Cocoa, nutrient status, plant ash, potassium, soil chemical characteristics

INTRODUCTION

Potassium fertilizers as sources of one of macro essential nutrients for cocoa (*Theobroma cacao* L.) have been observed recently tend to be more expensive, due to the facts that these fertilizers have to be imported from other countries, and depend on the unrenewable energy source in their manufacturing. On the other hand, cocoa plants also need large amount of this nutrient in field application, which is mostly in form of KCl fertilizer. Deposits of K are dominated by three countries (Canada, Russian, and Germany). Therefore, there is a need for other alternative K fertilizers to fulfil the K need for cocoa plants.

One of the possibilities to replace KCl fertilizer which is commonly used in cocoa farms is the use of plant derived ash (PDAsh). Recently, in many cocoa plantations which are intercropped with coconut trees and equipped with coconut sugar processing, it is commonly found huge piles of PDAsh which is not known yet by the planters how to make use of it. Beside the waste of coconut sugar processing in form of PDAsh, many other sources of PDAsh that can be easily obtained, such as those from burning waste of rice straw and husk, waste of cane sugar processing, wood, tobacco shoot biomass, and others. Meanwhile, composition of the PDAsh depends on the kind of materials with variation content of K, Mg, Ca, P and micronutrients. However, in general the content of K in PDAsh is higher than other nutrients. Fly ash is another form of ash which is a finely divided residue resulting from the combustion of bituminous coal of thermal power plant. Although the chemical characteristics of fly ash are commonly similar to PDAsh, the object of this study will be PDAsh because this material is quietly easy found in around agricultural farms.

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Application of PDAsh on agricultural land is an acceptable alternative compared to overland waste disposal only. Although the PDAsh contains nutrient elements naturally present in soil, nonetheless its relationship with the application on agricultural land and plant nutrition can not be established, because there are still contradictive results among published data. Plant derived ash can supply essential nutrient elements to plants grown on nutrient deficient soils, beside its capacity as liming materials which is due to the very alkaline characteristic in pH. General characteristic of the PDAsh is its very high pH around 12. Application of fly ash has been reported to improve plant growth grown in deficient nutrient soils (Levula *et al.*, 2000, Jakobson, 2003).

Beside the reported benefits, PDAsh application on agricultural lands has also been reported to result in negative effect due to the presence of phytotoxicity due to high accumulation of B in soil. Accumulation of As, Mo and Se in tissues of plants treated with PDAsh, which are potentially to be toxic to animals which consume grasses (Aronsson *et al.*, 2004). Application of fly ash is also reported to reduce the plant uptake of heavy metal and micronutrients (Levula *et al.*, 2000; Chirenje *et al.*, 2002). Concentration of P in leaf tissues was frequently low after the application of fly ash (Codling *et al.*, 2002). This effect was due to the high soil pH as result of ash application, beside the formation of insoluble complex. Availability of K element from PDAsh for plants was reported to be lower compared than its total content (Demeyer *et al*., 2001). The contrary reported research results can be understood, considering that the chemical composition variation of the PDAsh is very huge.

The objective of this study is to investigate the influence of PDAsh application on soil nutrient status, K nutrient status in plant tissue, and on the growth of cocoa seedlings. It is expected that results of this study will supply information on the role of PDAsh as nutrient source and its impact on nutrient availability.

MATERIALS AND METHODS

Experimental Sites

This glasshouse research was carried out in Kaliwining Experimental Station, Indonesian Coffee and Cocoa Research Institute (ICCRI), Jember, East Java. Chemical analysis was done in Soil and Plant Analysis Laboratory, ICCRI, Jember.

Materials used in this study consisted of (1) PDAsh was taken from a coconut sugar processing unit located in a cocoa garden of ICCRI where cocoa and coconut were intercropped. PDAsh actually is the waste of wood burning process for supplying energy to coconut sugar processing unit. PDAsh contained K_2O 40%, MgO 13%, S 7%, CaO 7%, pH 13 and various micronutrient elements, such as Fe, Mn, Zn, B, Mo, Co; (2) planting materials as seeds of open pollinated cocoa clones of TSH 858;(3) sample of an Inceptisols taken from Balung Tutul village, Balung, Jember, East Java, which contained exchangeable K in moderate amount (0.64 cmol kg^{-1}); N (0.11%); Ca (13.54 cmol kg^{-1}); Mg (7.24 cmol kg^{-1}); pH (6.7); Fe (5 mg kg^{-1}); Cu (14 mg kg^{-1}); Zn (4 mg kg^{-1}); and Mn (171 mg kg^{-1}); and also (4) other chemical materials for soil chemical analysis. The soil sample was air dried for about one week followed by sieving before being put into polybags each with 2.5 kg.

To answer proposed research hypothesis, this study consisted of two experiments, namely those with and without cocoa seedlings as experimental plants. Seedlings of cocoa plants were grown for six months. The aim of establishing two experiments was to compare the availability of soil nutrients of the two as the result of PDAsh application to replace KCl fertilizer.

Experiment I

In this Experiment, randomized completely block design (RCBD) and cocoa plants as observed objects were used. This experiment consisted of 6 treatments replicated 4 times. The amount of air dried soil used was 2.5 kg per pot applied with treated with PDAsh in amount as treatment equivalent to K_2O (mg 2.5 kg^{-1}) as follow: Control (no K added), 300, 600, 900, 1,200 and 1,500 mg K_2O 2,5 kg^{-1} soil.

Experiment II

This experiment also used randomized completely block design (RCBD) but without cocoa plants. Number and kind of treatments and replication applied was the same with Experiment I, the difference was only in absence of cocoa plants in pots in this experiment.

The amount of PDAsh equivalent to K_2O applied was based on the content of K in soil sample raised to normal concentration of K_2O in soil (300 mg 2.5 kg^{-1} soil).

Plant Growth Parameters Measured

Leaf number, plant height and stem girth were observed every two weeks until the age of cocoa plants 6 months, while measurement of leaf area, fresh and dry weight of shoot and roots were carried at the end of experiment (6 months after application). Dry weight of shoots and roots were measured after oven drying at 70°C after 4 days. Leaf area was measured based on calculation of 0.68 x maximum leaf width (Sudarsono, 1990).

Soil Fertility Parameters Measured

Preliminary analysis was carried for nutrients content of N, P, K, Ca, Mg and soil pH. At the end of this experiment, the content of micronutrients (Fe, Cu, Zn and Mn) was also done.

In experiment II where cocoa plants were not involved, soil fertility parameter observation was carried out once in two months, consisting of N, P, K, Ca, Mg and soil pH analysis. Determination of K, Ca, and Mg elements used ammonium acetate extraction 1 *N* pH 7.0; N element used Kjeldahl method; P element used Bray and Olsen extraction; Fe element used ammonium acetate extraction 1 *N* pH 4.8; Zn and Cu elements used HCl 0.01 *N* extraction; Mn element used destruction using mixture of H_2SO_4, $HClO_4$, dan HNO_3; soil pH was measured using ratio soil and water 1 : 2.5 (Sudjadi *et al.*, 1971).

Nursery was carried out for 3 weeks in a nursery bed using mixture of sand and cow-dung as medium. Homogenous seedlings were chosen for being transplanted into polybags. However, before the transplanting of seedlings, mixture of soil and PDAsh (according to the treatments applied) in polybags were incubated for one week.

Experiment maintenance was carried out by watering the pots and plants every day to field capacity. Besides, weeding inside the pots was done when it was needed.

RESULTS AND DISCUSSION

Soil Nutrient

Based on nutrient content of the present experiment without cocoa plants, application of PDAsh did not affect most of soil nutrients, except for K, Mg and Mn. However, in experiment with cocoa plants, application of PDAsh affected the content of soil K and Mn, including content of K in cocoa tissue.

Response of soil K content as affected by application PDAsh dosages both in with and without plants was linearly positive (Figure 1). The present results indicated that higher dosages of PDAsh applied resulted in higher soil K content. The amount of K^+ ion in soil solution increased with higher application of K source treated. Similar result was obtained by Purba *et al.* (1992) on oil palm in which higher dosage of K fertilizer increased availability of K soil. From the same observation, it was also found that soil available K was higher in experiment with cocoa plants compared with one without cocoa plants. That difference may be due to acidity condition of the two experiments, where in experiment without cocoa plants the soil pH lower than those with cocoa plants which caused the soil available K in experiment with plants was higher that those without cocoa plants. In contrast, K was shown to be mostly plant unavailable in previous studies (Schumann and Sumner, 2000) because of its inclusion in the glassy matrix of fly ash particles.

Concentration of soil Mn showed a difference between the experiment with plants and that without (Figure 2). In the experiment with cocoa plants, there was an antagonistic reaction between K dosage applied with soil Mn content. Application of PDAsh dosage improved K^+ ion amount in soil solution which then repulse position of Mn^{+2} ions from soil adsorption complex. This situation was confirmed by concentration of Mn^{+2} ions on soil adsorption complex was reduced which was due to that nutrient uptake by plants and resulted in less concentration of soil Mn. In contrast, in experiment without cocoa plants Mn nutrient status in that experiment was in adequate level which was related with the unsignificantly change of Mn^{+2} ion concentration although there was and addition of K^+ ion to soil solution. The relatively stable concentration of Mn was due to lack of Mn nutrient uptake by plants. Increased content of soil Mn in experiment without plants was caused by soil pH at the end of experiment without plants was low than that of with plants, therefore concentration of soil Mn in experiment without plants was higher than that those with plants. Trend of Mn concentration in the experiment without plants followed quadratic curve which showed that least concentration of Mn was found in treatment of 625 mg K_2O applied as PDAsh per 2.5 kg soil, the concentration of Mn was

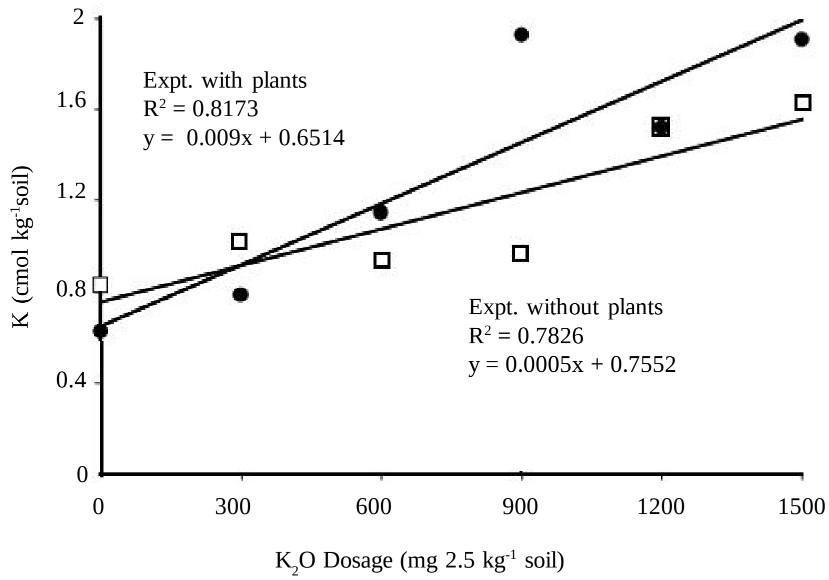

Figure 1. Relationships between dosages of PDAsh applied (as expressed in K_2O) and soil K content both in with and without cocoa plants.

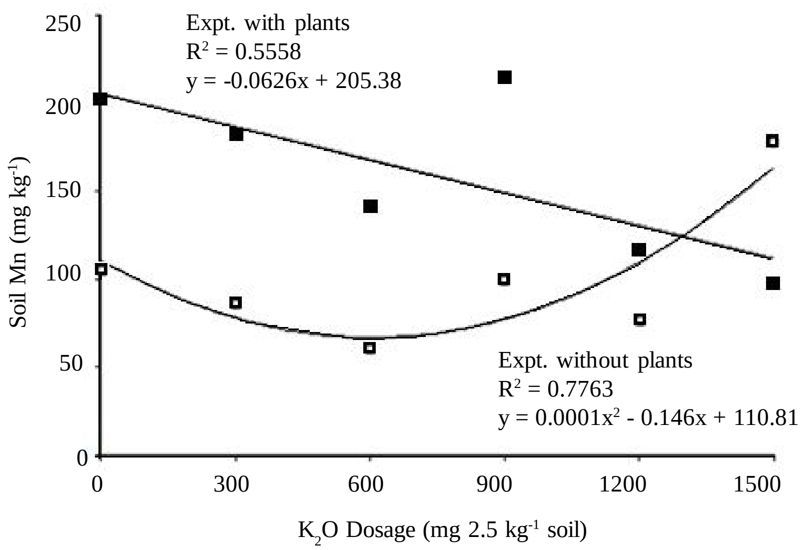

Figure 2. Relationships between dosages of PDAsh applied (as expressed in K_2O) and soil Mn content both in with and without cocoa plants.

higher at the treatment of PDAsh larger than this value.

There was a positive response of soil Mg concentration in experiment without cocoa plants to the dosage of K_2O applied as PDAsh (Figure 3). It is commonly found that there is an antagonistic reaction between K and Mg. Increased concentration of soil K usually followed by reduction of soil Mg content. Sparks and Huang (1985) stated that increased concentration of soil K caused domination of K ion on exchangeable complex which may repel position of Ca and Mg. According to Dibb and Thompson (1985), ratio of exchangeable Mg/K is a good indicator to predict a need for Mg nutrient considering the antagonism effect between K and Mg. Critical value of exchangeable K/Ca/Mg ratio for cocoa is 8:68:24

for mature cocoa trees to produce high yield (Wessel, 1985). Meanwhile, the good Mg/K ratio for cocoa is 3. Ratio of Mg/K at the end of experiment was in the range of 3.6 – 11.3 meaning that soil Mg content was in adequate level which will not result in Mg deficiency.

Considering plant tissue K, in experiment with cocoa plants there was a positive correlation between dosages of K_2O applied with the content of K in plant tissue (Figure 4). This finding indicates that high available K in soil causes high K uptake due to the fact that K nutrient can be luxury consumed by plants (Marschner, 1990). Nonetheless, from all of the K taken up only a part of it will be utilized by plants. Marschner (1990) also indicated that K content in plant tissue is linearly correlated with that available in soil. Therefore, application of PDAsh into soil will improve K concentration in plant tissue.

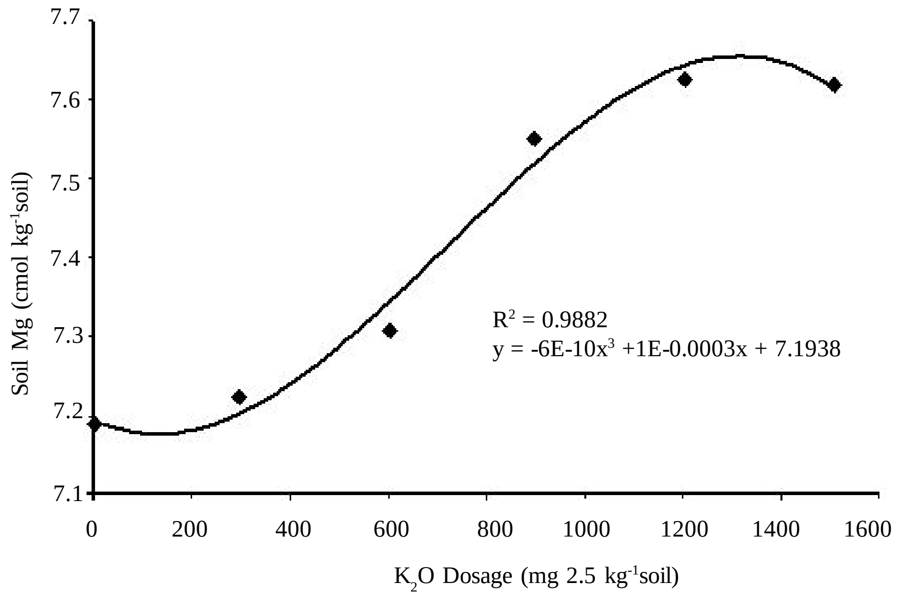

Figure 3. Relationship between dosages of PDAsh applied (as expressed in K_2O) and soil Mg content in experiment without cocoa plants.

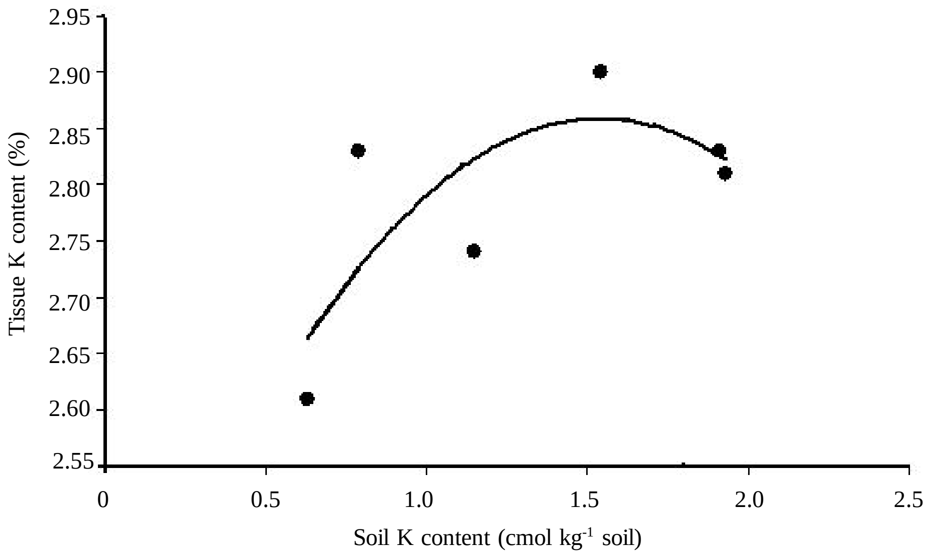

Figure 4. Relationship between K content in soil and cocoa tissue after application with several dosages of PDAsh.

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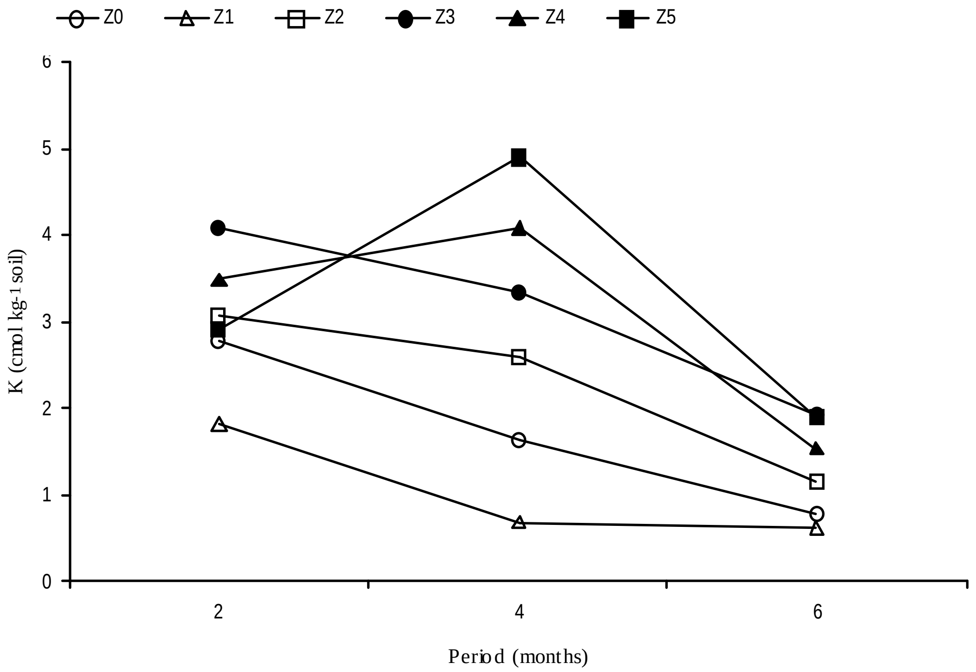

Figure 5. Relationship between dosage of PDAsh expressed in K_2O and concentration of K in soil and its development during the first 6 months. Notes: Dosage (mg 2.5 kg^{-1} soil): Z0 (0), Z1 (300), Z2 (600), Z3 (900), Z4 (1200), Z5 (1500).

From the two monthly measurement, in the experiment without plants it revealed that concentration of K in all dosages of K_2O applied as PDAsh had a tendency of decreasing in soil K content, except that of treatment with 300 mg K_2O applied as PDAsh which tended to be constant (Figure 5). Meanwhile, at the PDAsh dosage of 900 and 1.500 mg K_2O applied per 2.5 kg soil resulted in highest concentration of K element at the final of the experiment. The tendency of decreased K content in soil in nearly all treatments of dosages was possibly caused by process of overleaching through polybag which resulted in continuously reduction of K element content in soil. Besides, the presence of K in soil is very mobile, as stated by Sparks and Huang (1985) that K status in soil is very dynamic due to its characteristic of easily being leached. Based on polarizability, leaching level of K is higher than Ca and Mg.

Concentration of soil N tended to decrease in second month after application, however, measurement of N concentration at the end of experiment seemed to increase again while that of control (no PDAsh applied) was the highest at the end of experiment. Addition of water more than field capacity resulted in both decreased K soil concentration and N content at 2 and 4 months after application.

Application of all dosages of PDAsh caused reduction in soil P content. In soil applied with dosage of 900 mg K_2O applied as PDAsh per 2.5 kg soil had the highest content of P at the final of experiment, whereas in soil treated with 300 mg PDAsh the concentration of P was the lowest at the same period. The tendency of decreased soil P content was probably due to leaching process occurred in soil which according to Jiao *et al.* (2004) the leaching was more influenced by type of fertilizer than tillage or cropping practices. Therefore, lower the concentration of K, lower the concentration of P in soil.

Concentration of Ca in soil increased by application of PDAsh, except that of with dosage of 600 mg K_2O 2.5 kg^{-1} soil. The increased soil Ca concentration might be due the increased amount of Ca added to the soil, considering that PDAsh contained considerable amount of Ca. Comparing with K, Ca in soil is not easily leached. Sparks and Huang (1985) stated that on soil adsorption complex, Ca is adsorbed more strongly compared to K.

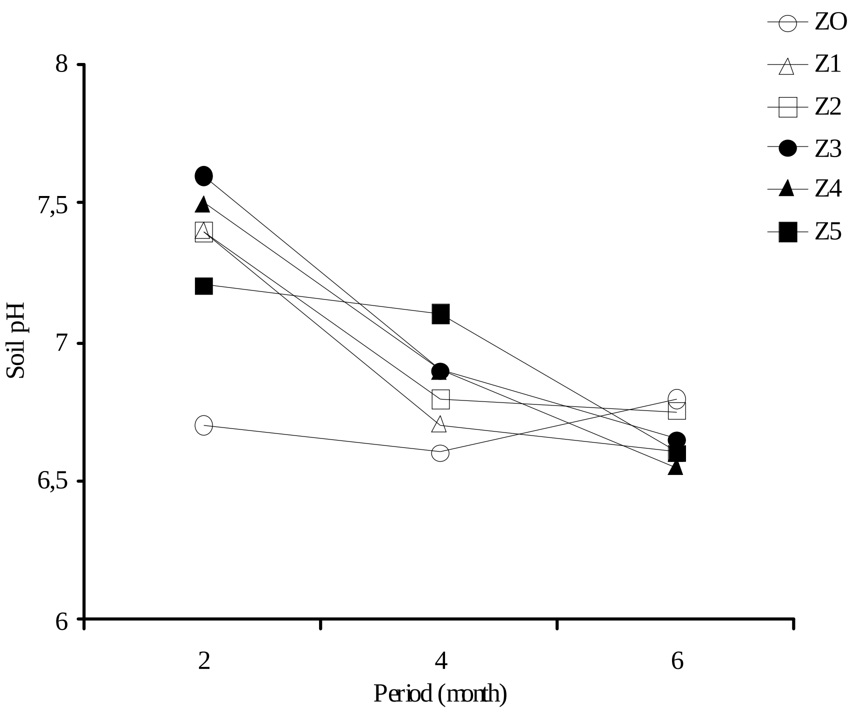

Figure 6. Relationship between dosage of PDAsh expressed in K_2O and soil pH and its development during the first 6 months. Notes: Dosage (mg 2.5 kg^{-1} tanah): Z0 (0), Z1 (300), Z2 (600), Z3 (900), Z4 (1200), Z5 (1500).

There was a tendency of increasing of Mg concentration at nearly all treatments, except that of dosage of 300 mg 2.5 mg^{-1} soil at the end of experiment. However, there was a tendency that concentration of Mg in soil decreased when dosage of PDAsh was higher than 1.200 mg 2.5^{-1} kg soil. Most probably that the decreased Mg concentration in soil was related with soil pH which reached the value of 6.4-7.0. According to Mengel and Kirkby (1982), availability of Mg nutrient in soil at that range of pH was reduced where it was strongly adsorbed on adsorption complex.

Results of this experiment showed that addition of PDAsh will not significantly increase pH of soil compared with the original pH of the PDAsh (pH = 13) which was shown by all treatments since 2 months until 6 months after application whereas for control the pH tended to increase at the end of experiment (Figure 6). This finding is line with the statement of Mengel and Kirkby (1982) that application of K nutrient into soil will cause the replacement of H^+ ion move to soil solution which eventually increased concentration of H^+ ion in soil solution and resulted in decreased soil pH. This study results was similar with that of Mozaffari *et al.* (2002) who found that application of a PDAsh from waste of sugar cane on peanut plants resulted in a reduction in soil pH (from 8 to 6.87). Whereas, results of Budianta *et al.* (1995) showed that application of a PDAsh from rice straw ash on soybean plants in high dosage improve plant height, number of pods and seeds. Meanwhile, the effect on soil N and P only found in the PDAsh combined with *Rhizobium*.

Plant Growth

This study has demonstrated that application of PDAsh significantly improve leaf number, plant height, stem diameter and leaf area (Table 1). The results were supported by the work of Sitepu *et al.* (1994) and Sholeh and Machfudz (1994) who found that addition of PDAsh from rice husks which contained high amount of K had resulted in positively response of tobacco plants in terms of leaf number, plant height and diameter of plant stem. Similarly, Hartatik *et al.* (1999) also found that addition of PDash from sawdust to peat soil had significantly increased leaf number and plant height of soybean plants.

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Table 1. Effect of several dosages of PDAsh expressed in K_2O on several parameters of cocoa plant growth.

K_2O Dosage (mg 2.5 kg^{-1} soil)	Leaf number	Plant height (cm)	Stem Diameter (mm)	Leaf area (cm^2)	Shoot freash weight (g $plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)
Kontrol	17.70 ab	34.55 ab	8.41 ab	1535 b	28.51 a	10.39 b
300	17.70 ab	35.68 ab	8.73 b	1268 a	28.33 a	9.70 ab
600	17.50 a	38.48 b	9.18 b	1476 ab	30.39 ab	11.27 bc
900	19.50 c	43.81 c	9.34 b	1861 c	36.33 b	13.29 d
1200	18.70 bc	38.39 a	8.87 b	1641 bc	35.63 b	12.51 cd
1500	18.00 ab	33.35 a	7.74 a	1264 a	24.35 a	8.57 a

Notes: Figures in the same column when followed by the same letter are not significantly different according to Duncan test at 5%.

From the dosages tested, cocoa plants applied with 900 mg K_2O applied as PDAsh per 2.5 kg soil had the highest plant growth, based on leaf number, plant height, stem diameter and leaf area which had started since 8 weeks after treatment. Specifically, the relationship between the dosage and the plant growth parameters followed a quadratic line with the optimum dosage around 700 mg 2.5 kg^{-1} soil. The improved growth may be due to the optimum balance condition among nutrients in soil which eventually resulted in better growth. According to Hartatik *et al.* (1999) leaf number and leaf area were improved by the better uptake by Mn nutrient, whereas the status of this nutrient in soil was moderate. Marschner (1986) indicated that Mn has a big role in the formation of chlorophyll and as catalyst for several metabolism processes and protein formation. Meanwhile, plant height and stem diameter were influenced by K nutrient uptake (Hartatik *et al.*, 1999). K nutrient play a role in accelerating growth of meristem tissues (Marschner, 1986).

Beside that plant growth parameters, shoot fresh and dry weights of cocoa seedlings were improved by the application of PDAsh. However, root fresh and dry weights were not affected by PDAsh addition. Hartatik *et al.* (1999) also found that application of PDAsh from sawdust produced higher shoot fresh and dry weights. There was no effect of PDAsh on root parameters which were usually controlled by genetic characteristics of the plants and by soil water condition. Houba and Keltjens (1990) stated that K nutrient was able indirectly to influence water uptake and also to improve plant fresh weight. Magnesium and P nutrients dominantly affect leaf weight, whereas other essential nutrients affected stem weight were K and Cu. Those elements essentially function in metabolism processes, such as in protein formation and oxidation-reduction reaction process.

Considering several limitations in the use of PDAsh in the field, such as potential phytotoxicity, shortages of essential major nutrients, unfavourable pH of PDAsh, and induced nutrient deficiencies, several researchers (Schumann and Sumner, 2000; Mittra *et al.*, 2003) had tried to over come these problems by exploiting the complementary nature of fly ash, sewage sludge, and poultry manure, and additional nutritional benefits (especially N–P–K balancing) should be possible by mixing these three waste materials together. Mittra *et al.* (2003) found that there was a reduction in the use chemical fertilizers by utilizing ash-organicsolid mixture.

CONCLUSION

Use of PDAsh as K fertilizer in general did not affect availability of other nutrients except Mn element, and increased concentration of Mg and K in soil and of K in cocoa plants. Addition of PDAsh as K fertilizer with a pH of 13 to soil up to the dosage of 1500 mg K_2O 2.5 kg^{-1} did not increase soil pH. Application of PDAsh as K fertilizer with appropriate dosage will improve growth of cocoa plants and will not result in negative affect. Relationship between dosage and plant growth followed quadratic curve line. Dosage of 900 mg K_2O applied as PDAsh per 2.5 kg soil produced the highest cocoa plant growth parameters, namely leaf number, stem diameter, plant height, leaf area and shoot fresh and dry weights. However, the optimum dosage was about 700 mg 2.5 kg^{-1} soil.

REFERENCES

Aronsson, K.A. and N.G.A. Ekelund. 2004. Biological Effects of Wood Ash Application to Forest and Aquatic Ecosystems J. Environ. Qual. 33: 1595-1605.

Budianta, D., D.S. Probowati and Sukrilani. 1997. Pengaruh abu jerami padi terhadap pertumbuhan kedelai pada tanah podsolik. *In*: L.I. Nasution *et al*. (Eds.). Prosiding Kongres Nasional VI Himpunan Ilmu Tanah Indonesia, Vol. I., Jakarta, 12-15 Desember 1995, pp. 671-680.

Codling, E.E., R.L. Chaney, and J. Sherwell. 2002. Poultry Litter Ash as a Potential Phosphorus Source for Agricultural Crops. J. Environ. Qual. 31: 954-961.

Chirenje, T., C. Rivero, and L.Q. Ma. 2002. Leachability of Cu and Ni in wood ash-amended soil as impacted by humic and fulvic acid. Geoderma 108: 31-47.

Demeyer, A., J.C.V. Nkana, and M.G. Verloo. 2001. Characteristics of wood ash and influence on soil properties and nutrient uptake: An overview. Bioresour. Technol. 77: 287-295.

Hartatik, W., I.G.M. Subiksa, D. Ardi and M. Farmadi. 1999. Emeliorasi tanah gambut dengan abu gergaji dan terak baja pada tanaman kedelai. Prosiding Kongres Nasional VII Himpunan Ilmu Tanah Indonesia. HITI, Bandung, 2-4 November 1999.

Houba, V.C.G. and W.G. Keltjens. 1990. Interpretation of Plant Analysis. International Potato Course. International Agricultural Centre. Wageningen, The Netherlands.

Jacobson, S. 2003. Addition of stabilized wood ashes to Swedish coniferous stands on mineral soil--Effects on stem growth and needle nutrient composition. Silva Fenn. 37: 437-450.

Levula, T., A. Saarsalmi, and A. Rantavaara. 2000. Effects of ash fertilization and prescribed burning on macronutrient, heavy metal, sulphur and Cs-137 concentrations in lingonberries (*Vaccinium vitis-idaea*). For. Ecol. Manage. 126: 269-279.

Marschner, H. 1990. Mineral nutrition of higher plants. Academic Press, London. pp. 674.

Mengel, K. and E.A. Kirkby. 1982. Principles of Plant Nutrition. International Potash Institute, Bern, Switzerland, p 655.

Mittra, B.N., S. Karmakar, D.K. Swain and B.C. Ghosh. 2003. Fly ash – a potential source of soil amendment and a component of integrated plant nutrient supply system. Presented at International Ash Utilization Symposium. Centre for Applied Energy Research, University of Kentucky, 20-22 October, 2003, 7 p.

Mozaffari, M., M.P. Russelle, C.J. Rosen, and E.A. Nater. 2002. Nutrient Supply and Neutralizing Value of Alfalfa Stem Gasification Ash. Soil Sci. Soc. Am. J. 66: 171-178.

Purba, P., T.L. Tobing, K. Martoyo, and Suwandi. 1992. Percobaan pemupukan kalium pada tanaman kelapa sawit di Sulawesi Utara. Buletin Puslitbun Marihat 12: 1-7.

Schumann, A.W. and M.E. Sumner. 2000. Chemical Evaluation of Nutrient Supply From Fly Ash–Biosolids Mixtures. Soil Sci. Soc. Am. J. 64: 419-426.

Sholeh, M. and Machfudz. 1994. Penggunaan abu limbah alcohol (Alia) sebagai sumber pupuk K pada tembakau Madura. Buletin Tembakau dan Tanaman Serat 9: 105-109.

Simoen, S., Windiharto, and A. Yogasara. 1998. Pemanfaatan limbah pabrik alkohol sebagai sumber hara K bagi tebu. In: Sudaryono *et al*. (Eds.). Prosiding Seminar Nasional dan Pertemuan Tahunan Komisariat Daerah Himpunan Ilmu Tanah Indonesia Tahun 1998. Malang, 16-17 Desember 1998, pp. 118-124.

Sitepu, R., D. Lubis and Erwin. 1994. Pengaruh komposisi media dengan pemakaian abu sekam sebagai bahan organik pada tanama tembakau. Buletin Perkebunan 8: 60-64.

Sparks, D.L. and P.M. Huang. 1985. Physical chemistry of soil potassium. In*:* R.D. Munson (Ed). Potassium in Agriculture. ASA-CSSA-SSSA, Madison, WI, pp. 201-276

Sudarsono, 1990. Pengaruh umur buah kakao terhadap daya tumbuh benih dan pertumbuhan semaian yang dihasilkan di Kaliwining. Pelita Perkebunan 5: 106-112.

Sudjadi, M., I.M. Widjik and M. Sholeh. 1971. Penuntun analisa tanah. Lembaga Penelitian Tanah. Direktorat Jenderal Pertanian, Bogor.