



## Abstract

A study was conducted to alleviate Al toxicity of an acid sulphate soils collected from paddy cultivation area in Kedah, Peninsular Malaysia. For this purpose, the collected acid sulphate soils were treated with calcium silicate. The treated soils were incubated for 120 days in submerged condition in a glasshouse. Subsamples were collected every 30 days throughout the incubation period. Soil pH and exchangeable Al showed positive effect; soil pH increased from 2.9 to 3.5, meanwhile exchangeable Al was reduced from 4.26 to 0.82 cmol<sub>c</sub> kg<sup>-1</sup>, which was well below the critical Al toxicity level for rice growth of 2 cmol<sub>c</sub> kg<sup>-1</sup>. It was noted that the dissolution of calcium silicate (CaSiO<sub>3</sub>) supplied substantial amount of Ca<sup>2+</sup> and H<sub>4</sub>SiO<sub>4</sub><sup>2-</sup> ions into the soil, noted with increment in Si (silicate) content from 21.21 to 40 mg kg<sup>-1</sup> at day 30 and reduction of exchangeable Al at day 90 from 4.26 to below 2 cmol<sub>c</sub> kg<sup>-1</sup>. During the first 60 days of incubation, Si content was positively correlated with soil pH, while the exchangeable Al was negatively correlated with Si content. It is believed that the silicate anions released by calcium silicate were active in neutralizing H<sup>+</sup> ions that governs the high acidity (pH 2.90) of the acid sulphate soils. This scenario shows positive effect of calcium silicate to reduce soil acidity, therefore creates a favourable soil condition for good rice growth during its vegetative phase (30 days). Thus, application of calcium silicate to alleviate Al toxicity of acid sulphate soils for rice cultivation is a good soil amendment.

## 1 Introduction

Acid sulphate soils are widespread in Malaysia, occurring almost exclusively along its coastal plain (Shamshuddin and Auxtero, 1991; Shamshuddin et al., 1995; Muhrizal et al., 2006; Enio et al., 2011). In these areas, the alluvial sediments are intermittently inundated by seawater during low and high tide. These soil are dominated by pyrite (FeS<sub>2</sub>) with high acidity (soil pH < 3.5). These soils are produced when the pyrite-laden soils in the coastal plains are opened up for crop production and/or development. These

## Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



**Alleviating aluminium toxicity on an acid sulphate soils**

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



scenario leads to release of high amounts of Al into the soil environment (Shamshuddin et al., 2004) and affects crop growth. As an example, it affects oil palm growth (Auxtero and Shamshuddin, 1991) and cocoa production (Shamshuddin et al., 2004). In Peninsular Malaysia, acid sulphate soils are used for rice cultivation with mixed success. At times, rice cultivation in these soils are successful, but most often, the rice yield for every season is very low ( $< 2 \text{ t ha}^{-1}$ ). Some amelioration practice with ground magnesium lime (GML) and/or basalt shown improvement in rice yield to  $3.5 \text{ t ha}^{-1}$  (average per season).

Application of soil amendment onto the acid sulphate soils is a common approach to improve its fertility. Study by Suswanto et al. (2007), Shazana et al. (2013), Elisa et al. (2014) and Rosilawati et al. (2014) noted that acid sulphate soils infertility can be ameliorated by application of lime, basalt, organic fertilizer and/or their combinations at the appropriate rate. Application of these ameliorants increased the soil pH and reduced Al toxicity that resulted in better rice growth. Besides that, these ameliorants also supply calcium (Ca) and magnesium (Mg) which are needed for crop growth and development.

Besides Ca and Mg, silicon (Si) is another element important for rice growth. It has a positive effect on crop growth such as tomato (Peaslee and Frink, 1969), barley and soybean (Hodson and Evans, 1995) and many others crop (Liang et al., 2007). Si application able to reduce the severity of fungal disease, such as blast and sheath blight of rice (Farnaz Abed-Ashtiani et al., 2012), powdery mildew of barley, wheat, cucumber, muskmelon and grape leaves, and vermin damage of rice by plant hopper (Crock and Prentice, 2012; Ma et al., 2001; Menzies et al., 1992; Bowen et al., 1992; Datnoff et al., 2001). The beneficial effects of Si are mainly associated with high deposition in plant tissues, enhancing their strength and rigidity. In addition, Si would be able to reduce Al toxicity effectively (Barcelo et al., 1993). The source of Si could be obtained from calcium silicate application. This material is available in Peninsular Malaysia. Therefore, this study is relevant as, (i) the calcium silicate is able to alleviate the Al toxicity of soil

and at the same time it could, (ii) provide sufficient amount of Si to improve strength and rigidity, as needed for rice plant.

Merbok granary area is located at northern state of Kedah, Peninsular Malaysia. Part of the rice cultivation areas are classified as acid sulphate soils. The average rice yield in these areas is less than  $2 \text{ t ha}^{-1} \text{ season}^{-1}$ . This is due to high soil acidity, Al toxicity and/or rice blast disease (*M. grisea*). It is the duty of the Malaysian government to help improve the livelihood of the farming community in the area by increasing yield via employing innovative agronomic method of rice production. Therefore, the purpose of this study was to determine the ameliorative effects of applying calcium silicate on acid sulphate soils.

## 2 Materials and methods

### 2.1 Soil type, treatments and experimental design

The experiment was conducted at the Field 2 Glasshouse in Universiti Putra Malaysia, Serdang, Malaysia. The soil used in this study was Merbok Series, classified as *Typic Sulfaquepts* (Soil Survey Staff, 2010) from Merbok, Kedah, Peninsular Malaysia. The site of soil sampling was planted with rice, and soil samples were collected at the depth of 0–15 cm.

Five hundred gram of soil was filled in plastic pot and incubated for 120 days. The treatments applied were control (without calcium silicate), 1, 2 and  $3 \text{ t ha}^{-1}$  of calcium silicate, with three replications, arranged in completely randomized design (CRD). These treatments were, henceforth, referred to as CS0, CS1, CS2 and CS3, respectively. The soils were mixed thoroughly with treatments prior to addition of water. Tap water was added regularly and the water levels were maintained approximately 5 cm (height) from the soil surface. The soils were sampled every 30 days throughout the incubation period.

## Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



## 2.2 Calcium silicate

Calcium silicate ( $\text{CaSiO}_3$ ) used in this experiment was obtained from Kaolin (Malaysia) Sdn. Bhd., Malaysia. This calcium silicate had the following composition:  $\text{SiO}_2 = 40\text{--}55\%$ ; calcium (as  $\text{CaO}$ ) =  $40\text{--}50\%$ ;  $\text{Al}_2\text{O}_3 =$  below  $1.5\%$ ;  $\text{MgO} =$  below  $3\%$ ; iron (as  $\text{Fe}_2\text{O}_3$ ) = below  $1\%$ ; and  $\text{pH} = 8.54$ .

## 2.3 Soil analyses

Subsamples were taken every 30 days throughout the incubation period, and were air-dried, ground and passed through 2 mm sieve for chemical analysis. Soil pH was determined in water at the ratio of 1 : 2.5 (soil/distilled water) using a glass electrode pH meter. Total C, N and S were determined using Leco CNS analyser. Cation exchange capacity (CEC) was determined by 1 M  $\text{NH}_4\text{OAc}$  method at pH 7 (Chapman, 1965). Exchangeable Ca, Mg, K, and Na were determined by 1 M  $\text{NH}_4\text{Cl}$  method (Ross and Ketterings, 1995; Shamshuddin, 2006). Two gram of air-dried sample was put in 50 mL centrifuge tube and 20 mL 1 N  $\text{NH}_4\text{Cl}$  were added. The sample was shaken for 2 h on an end-to-end shaker at 150 rpm, followed by centrifugation at 2500 rpm for 15 min. The extract was filtered with filter paper into 50 mL plastic vial. The exchangeable Ca, Mg, K, and Na in the extract were determined by inductively couple plasma-optical emission spectroscopy (ICP-OES). Determination of exchangeable Al was done by extracting 5 g of soil with 50 mL of 1 M KCl. The mixture was shaken for 30 min the Al extracted was analysed with ICP-OES. Extractable Fe, Cu, Zn and Mn were extracted using extracting agent (0.05 N HCl and 0.025 N  $\text{H}_2\text{SO}_4$ ). Five gram of air-dried sample was shaken with 25 mL of extracting agent for 15 min. The extract was filtered with filter paper and used to determine Fe, Cu, Zn and Mn by Atomic Adsorption Spectrometer (AAS). Meanwhile, 0.01 M  $\text{CaCl}_2$  was used to extract plant-available Si from the soil. Two gram of soil was shaken for 16 h with 20 mL extractant in 50 mL centrifuge tube using an end-to-end shaker. The sample was centrifuged at 2000 rpm for 10 min and the supernatant were filtered and analysed for Si (Datnoff et al., 2001) using ICP-OES.

### Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion





## 3.2 Effect of calcium silicate on soil pH

Figure 1 shows the effects of calcium silicate application on soil pH under submerged condition. It showed that the soil pH increased directly with increment in the rate of calcium silicate applied. The highest soil pH increase was from 2.90 to 3.95 due to application of  $3 \text{ t ha}^{-1}$  of calcium silicate. After 30 days of incubation (D30), soil pH for CS2 was significantly higher compared to that of CS1, with value of 3.77 and 3.62, respectively. Treatment CS3 was significantly higher in soil pH compared to that of CS0, CS1 and CS2, CS0 and CS1, and CS0, CS1 and CS2 at D60, D90 and D120 days with value of 3.90, 3.84, and 3.95, respectively.

## 3.3 Effect of calcium silicate on exchangeable Al

Figure 2 shows the effects of calcium silicate application on exchangeable Al. It showed that as the calcium silicate rate increased, the exchangeable Al decreased. The exchangeable Al decreased from 4.26 to  $0.82 \text{ cmolckg}^{-1}$ . This is a 74% decrease in exchangeable Al in the acid sulphate soil with application of calcium silicate. After 30 and 120 days of incubation, exchangeable Al in the soil treated with 2 and  $3 \text{ t ha}^{-1}$  of calcium silicate had significantly decreased compared to that of the untreated soil. There was no significant effect observed on the exchangeable Al after 60 and 90 days of incubation among the calcium silicate applied.

## 3.4 Effect of calcium silicate on exchangeable calcium

Figure 3 show that application of calcium silicate increased the exchangeable Ca. There was a significant effect among the treatments after 30 days of incubation. Soil treated with 2 and  $3 \text{ t ha}^{-1}$  of calcium silicate were significantly increased compared than untreated and soil treated with  $1 \text{ t ha}^{-1}$  of calcium silicate after 60, 90 and 120 days of incubation.

SED

7, 2903–2926, 2015

## Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



### 3.5 Effect of calcium silicate on silicon content

Application of calcium silicate increased the silicon content in the soil as shown in Fig. 4. Silicon content in the soil had increased from 14 to 74 %. Soil treated with 2 and 3 t ha<sup>-1</sup> of calcium silicate were significantly increased compare to the untreated and soil treated with 1 t ha<sup>-1</sup> of calcium silicate after 30 days of incubation. After 60 days of incubation, silicon content was increased significantly for soil treated with 2 and 3 t ha<sup>-1</sup> of calcium silicate compared to the soil treated with 1 t ha<sup>-1</sup> of calcium silicate. Silicon content in the soil kept increasing after 90 days of incubation and soil treated with 1 t ha<sup>-1</sup> was significantly increased compare to 2 t ha<sup>-1</sup> of calcium silicate. However, no significant effect was observed among the treatments after 120 days of incubation. The reduction in exchangeable Al corresponded directly to the amount of Si in the soil; the former showed reduction, meanwhile the latter showed availability in soil. This means as more Si released from calcium silicate and becomes available in acid sulphate soil, reduction of exchangeable Al with the same value (%) occurs in the studied acid sulphate soil.

## 4 Discussions

From this study it was found that calcium silicate was able to neutralize H<sup>+</sup> ions as noted with pH increase in acid sulphate soils upon calcium silicate application (Fig. 1). Similar finding had been found by Smyth and Sanchez (1980) and Fiantis et al. (2002). These authors attributed their results to the OH<sup>-</sup> released from colloidal surfaces during the adsorption of the silicate ions. Soil pH increased significantly from pH 2.90 to pH 3.41–3.95 in the studied soil to the application of calcium silicate.

From this study, there was a strong relationship between calcium silicate with soil pH at D30 ( $R^2 = 0.77$ ), D60 ( $R^2 = 0.77$ ), D90 ( $R^2 = 0.84$ ) and at D120 ( $R^2 = 0.92$ ) of incubation period. The lower coefficient at D30 compared to higher coefficient at D120

## SED

7, 2903–2926, 2015

### Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

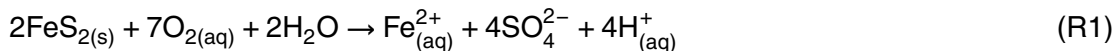
Interactive Discussion



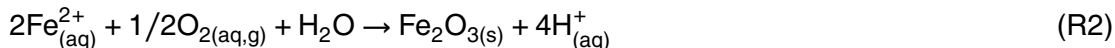


of the incubation period was related to the capacity of soil to adsorb silicate anion with increment in time.

It was observed that the soil pH was slightly lower for CS0, CS1 and CS2 at D60 and D90 compared to that at D30 and D120. The decrease in soil pH was believed to be due to the release of protons when pyrite in the soil was oxidized during the incubation period. Shamshuddin et al. (2004) reported that after 12 weeks of incubation, soil pH in the Cg horizon of acid sulphate soils was lowered by 1 unit. The results from the current study are consistent with the findings of other studies on acid sulphate soils (Shamshuddin and Auxtero, 1991; Shamshuddin et al., 1995, 2014). The oxidation of pyrite which produced acidity could have taken place according to the following reactions as outlined by van Breemen (1976):



Further oxidation of  $\text{Fe}^{2+}$  to  $\text{Fe}^{3+}$  oxide could again promote acidity:



As the soil pH increased due to application of calcium silicate, the exchangeable Al decreased to below the critical level of  $2 \text{ cmol}_c \text{ kg}^{-1}$  for rice growth. This was consistent with the findings of Hiradate et al. (2007). Figure 2 shows the effects of treatments on the exchangeable Al. It showed that exchangeable Al decreased significantly among the treatments. After 30 days of incubation, treatments CS2 and CS3 were significantly reduced compared to that of CS0 and CS1, which was near to the critical level of  $2 \text{ cmol}_c \text{ kg}^{-1}$ . It is also showed that the exchangeable Al was decreased further as the incubation period was extended longer. Figure 5 shows the relationship between exchangeable Al and soil pH where the line for D60, D90 and D120 shifted to below D30. This implies that prolonged incubation period would reduce the exchangeable Al. The decrease in Al could also be due to the precipitation of Al in the form of inert Al-hydroxides. The exchangeable Al was reduced to below the critical level of  $2 \text{ cmol}_c \text{ kg}^{-1}$  at D90 and D120.

**Alleviating aluminium toxicity on an acid sulphate soils**

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion





treatments CS0 and CS1. At D60, treatment CS3 increased the Si content significantly compared to that of CS0 and CS1, with value of  $40.81 \text{ mg kg}^{-1}$  Si. Si content in the soil surpassed the deficiency level for all treatments at D90 and D120. At D90, Si in treatment CS1 was significantly higher compared to that of CS2 with value Si of  $83.53 \text{ mg kg}^{-1}$ . Si content in the soil was affected by the days of incubation as the Si content increased further after 120 days of incubation for all treatments.

When the soil pH increased, Si content in the soil increased (Fig. 6). The Si content was positively correlated with soil pH at D30 and D60, plausibly due to the dissolution of calcium silicate. The ability of soil to adsorbed Si was higher at D30 and D60 compared to that at D90 and D120. There was no correlation observed at D90 and D120 even though Si content was higher probably because the soil exchangeable sites had been fully occupied by Si through adsorption processes. This proves that the application of calcium silicate to the soil accompanied by soil pH increment enhances the soil ability to adsorb Si.

The positive effect of the presence of Si at D30 and D60 corresponded to the early growth stage of rice, which is the active tillering stage. It means that rice plant can uptake Si actively during the tillering stage; hence, improves rice growth. Figure 7 shows the relationship between exchangeable Al and Si content in the soil throughout the incubation period upon application of calcium silicate. As the exchangeable Al decreased, Si content in the soil increased. Exchangeable Al was negatively correlated with Si content in the soil at D30 ( $R = 0.77$ ) and D60 ( $R = 0.92$ ), while no correlation were observed at D90 and D120. In Fig. 7, D60 line shifted below D30, this means that as the incubation period increased, Al and Si content showed antagonist pattern; Al decreased, while Si increased. This phenomenon indicated that when the Al content was low in the soil its toxicity was not the dominant factor that may inhibit rice plant growth. On the other hand, Si becomes more readily available for plant uptake. Therefore, the suitable time to start planting the rice is 30 days after applying calcium silicate as the exchangeable aluminum decreased almost below the critical value of  $2 \text{ cmol}_c \text{ kg}^{-1}$ .

## SED

7, 2903–2926, 2015

### Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



During active tillering, the rice plant could actively uptake the Si for its growth as the Si content increased with incubation time.

Silicon was released from calcium silicate into the soil's bulk solution and absorbed by plants as  $\text{Si}(\text{OH})_4$  where it was involved in the diverse structural and dynamic aspects of plant life and the performance of crops. Although not considered as an essential element for plant growth and development, silicon is considered as a beneficial element and is reported as being very useful when plants are under abiotic or biotic stress (Datnoff et al., 2001). An alleviative effect of Si on Al toxicity has been reported in many crops including soybean (Baylis et al., 1994) teosinte (Barcelo et al., 1993), sorghum (Hodson and Sangster, 1993), wheat, maize, cotton, rice (Cocker et al., 1998).

Prolonged incubation period without soil treated with calcium silicate might have also influenced the changes in soil chemical characteristics. As such, CS0 (untreated soil) recorded increment in soil pH from 2.90 (prior incubation) to 3.63 at D30. Decrease in soil pH values was noted for D60 and D90, likely due to the oxidation of pyrite in the soil system, and no significant effect was observed among the days of incubation. Meanwhile, exchangeable Al decreased significantly with days of incubation. For the first 2 months, exchangeable Al was above the critical level of  $2 \text{ cmol}_c \text{ kg}^{-1}$  and no significant effect between D30 and D60 was observed. Exchangeable Al was significantly reduced to  $1.89 \text{ cmol}_c \text{ kg}^{-1}$  at D90 and no significant effect was observed thereafter, which was between D90 and D120. Application of calcium silicate significantly increased Si content in the soil. However, no significant effect was observed for Si content between D30 and D60 as well as between D90 and D120. The Si content in soil increased significantly after 90 days of incubation to  $59.81 \text{ mg kg}^{-1}$ . The significant increment of Si in the soil was due to the hydrolysis of silicate minerals present in the acid sulphate soils. For instance, the hydrolysis of silicate is generalized in the reaction:



## SED

7, 2903–2926, 2015

### Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion





## Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



- Bowen, P., Menzies, J., and Ehret, D.: Soluble silicon sprays inhibit powdery mildew development on grape leaves, *J. Am. Soc. Hortic. Sci.*, 117, 906–912, 1992.
- Chapman, H. D.: Determination of cation exchange capacity, in: *Methods of Soil Analysis*, edited by: Black, C. A., Agronomy Monogr., 9. ASA, Madison, WI, 2, 891–900, 1965.
- 5 Cocker, K. M., Evans, D. E., and Hodson, M. J.: The amelioration of aluminium toxicity by silicon in higher plants: solution chemistry or an in planta mechanism?, *Physiol. Plantarum*, 104, 608–614, doi:10.1034/j.1399-3054.1998.1040413.x, 1998.
- Crooks, R. and Prentice, P.: The importance of silicon weathered soils, in: 8th International Symposium on Plant Soil Interactions at Low pH, 18–22 October 2012, Bengaluru, India, 10 412–413, 2012.
- Datnoff, L. E., Snyder, G. H., and Korndörfer, G. H.: *Silicon in Agriculture*, Elsevier Science, the Netherlands, Vol. 8, pp. 1–403, ISBN: 978-0-444-50262-9, 2001.
- Dobermann, A. and Fairhurst, T.: *Rice: Nutrient Disorders and Nutrient Management*, IRRI, Los Banos, 2000.
- 15 Elisa Azura, A., Shamshuddin, J., and Fauziah, C. I.: Root elongation, root surface area and organic acid exudation by rice seedling under Al<sup>3+</sup> and/or H<sup>+</sup> stress, *American Journal of Agricultural and Biological Sciences*, 6, 324–331, 2011.
- Elisa Azura, A., Shamshuddin, J., Fauziah, C. I., and Roslan, I.: Increasing rice production using different lime sources on an acid sulphate soil in Merbok, Malaysia, *Pertanika Journal of Tropical Agricultural Sciences*, 37, 223–247, 2014.
- 20 Enio, M. S. K., Shamshuddin, J., Fauziah, C. I., and Husni, M. H. A.: Pyritization of the coastal sediments in Kelantan plains in the Malay Peninsula during the Holocene, *American Journal of Agricultural and Biological Sciences*, 6, 393–402, 2011.
- Essington, M. E.: *Soil and water chemistry: an integrative approach*, CRC Press, Washington, DC, 104, 101–127, ISBN: 0-203-49614-0, 2005.
- 25 Farnaz, A. A., Jugah, K., Abbaz, N., Seyed, R. H. R., and Hailmi, S.: Effect of silicon on rice blast disease, *Pertanika Journal of Tropical Agricultural Sciences*, 35, 1–12, 2012.
- Fiantis, D., Van Ranst, E., Shamshuddin, J., Fauziah, I., and Zauyah, S.: Effect of calcium silicate and superphosphate application on surface charge properties of volcanic soils from West Sumatra, Indonesia, *Communication in Soil Science and Plant Analysis*, 33, 1887–30 1900, 2002.
- Hiradate, S., Ma, J. F., and Matsumoto, H.: Strategies of plants to adapt to mineral stresses in problem soils, *Adv. Agron.*, 96, 66–132, doi:10.1016/S0065-2113(07)96004-6, 2007.

## Alleviating aluminium toxicity on an acid sulphate soils

A. A. Elisa et al.

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion



Hodson, M. J. and Sangster, A. G.: The interaction between silicon and aluminium in *Sorghum bicolor* (L.) Moench: growth analysis and X-ray microanalysis, *Ann. Bot.-London*, 72, 389–400, doi:10.1006/anbo.1993.1124, 1993.

Hodson, M. J. and Evans, D. E.: Aluminum/silicon interaction in higher plants, *J. Exp. Bot.*, 46, 161–171, doi:10.1093/jxb/46.2.161, 1995.

Liang, Y. C., Sun, W. C., Zhu, Y. G., and Christie, P.: Mechanisms of silicon-mediated alleviation of abiotic stresses in higher plant: a review, *Environ. Pollut.*, 147, 422–428, doi:10.1016/j.envpol.2006.06.008, 2007.

Lindsay, W. L.: *Chemical Equilibria in Soil*, John Wiley & Sons, New York, 1979.

Lumsdon, D. G. and Farmer, V. C.: Solubility characteristics of proto-imogolite soils: how silicic acid can de-toxify aluminium solutions, *Eur. J. Soil Sci.*, 46, 179–186, doi:10.1111/j.1365-2389.1995.tb01825.x, 1995.

Ma, J. F., Miyake, Y., and Takahashi, E.: Silicon as a beneficial element for crop plants, in: *Silicon in Agriculture*, edited by: Datnoff, L. E., Snyder, G. H., and Korndorfer, G. H., Elsevier, Netherlands, 17–40, 2001.

Menzies, J., Bowen, P., and Ehret, D.: Foliar application of potassium silicate reduce severity of powdery mildew on cucumber, muskmelon and zucchini squash, *J. Am. Soc. Hort. Sci.*, 117, 902–905, 1992.

Miranda, S. R.: Calcium and magnesium Silicate, an alternative choice for liming acid soil, in: *8th International Symposium on Plant Soil Interactions at Low pH*, 18–22 October, 2012, Bengaluru, India, 414–415, 2012.

Muhrizal, S., Shamshuddin, J., Fauziah, I., and Husni, M, H, A.: Changes in an iron-poor acid sulfate soil upon submergence, *Geoderma*, 131, 110–122, 2006.

Palhares de Melo, L. A. M., Bertoli, D. J., Cajueiro, E. V. M., and Bastos, R. C.: Recommendation for fertilizer application for soils via qualitative reasoning, *Agricultural System*, 67, 21–30, 2001.

Panov, N. P., Goncharova, N. A., and Rodionova, L. P.: The role of amorphous silicic acid in solonetz soil processes, *Vestnik Agr. Sci.*, 11, 18–32, 1982.

Peaslee, D. E. and Frink, C. R.: Influence of silicic acid on uptake of Mn, Al, Zn and Cu by tomatoes (*Lycopersicon esculentum*) L grown on acid soil, *Soil Sci. Soc. Am. Pro.*, 33, 569–571, 1969.

Rahman, M. T., Kawamura, K., Koyama, H., and Hara, T.: Varietal differences in the growth of rice plants in response to aluminium and silicon, *Soil Sci. Plant Nutr.*, 44, 423–431, 1998.









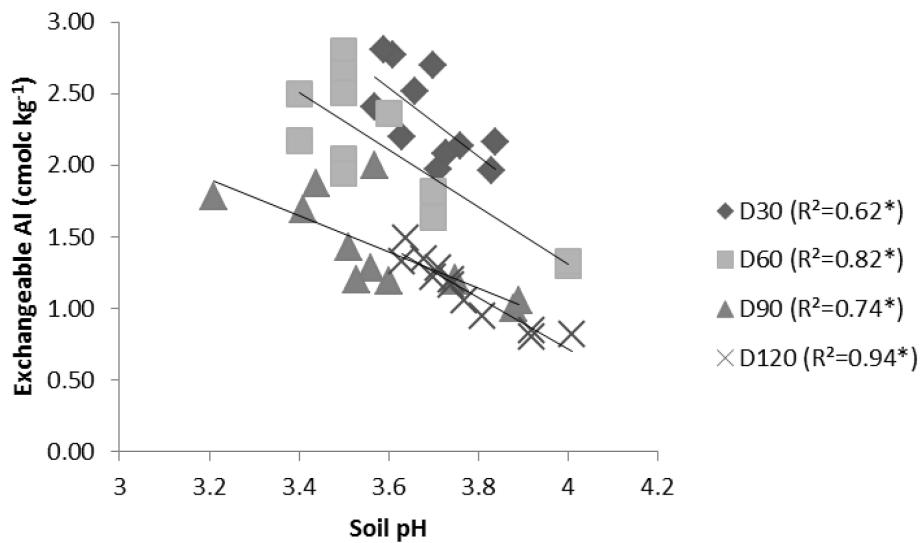






**Alleviating aluminium toxicity on an acid sulphate soils**

A. A. Elisa et al.

**Figure 5.** Relationship between exchangeable Al and soil pH ( $*p < 0.05$ ).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures



Back

Close

Full Screen / Esc

Printer-friendly Version

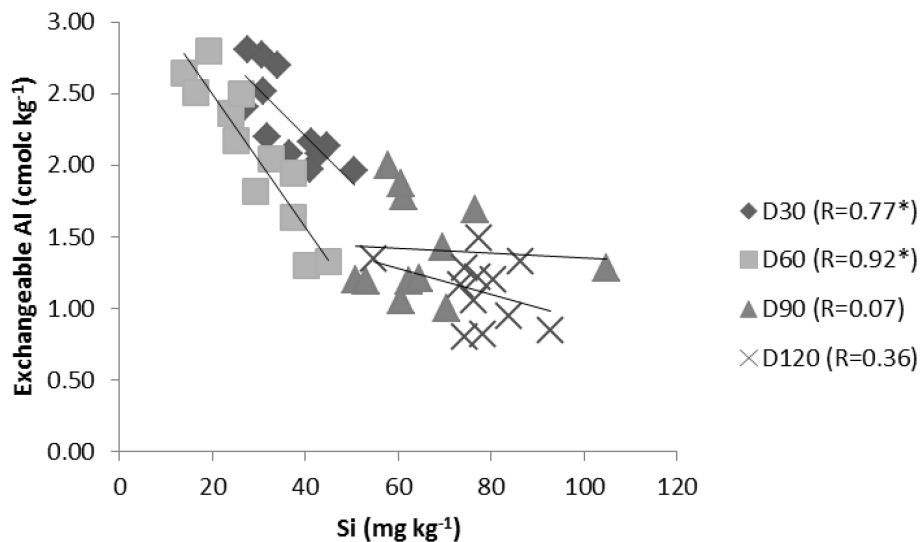
Interactive Discussion





**Alleviating aluminium toxicity on an acid sulphate soils**

A. A. Elisa et al.



**Figure 7.** Relationship between exchangeable Al and Si content in the soil throughout incubation period ( $*p < 0.05$ ).

Title Page

Abstract

Introduction

Conclusions

References

Tables

Figures

◀

▶

◀

▶

Back

Close

Full Screen / Esc

Printer-friendly Version

Interactive Discussion

