

1 **Alleviating aluminum toxicity in an acid sulfate soil from Peninsular Malaysia by**
2 **calcium silicate application**

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1 **Abstract**

2 In response to human population increase, the utilization of acid sulfate soils for rice
3 cultivation is one option for increasing production. The main problems associated with
4 such soils are their low pH values and their associated high content of exchangeable Al,
5 which could be detrimental to crop growth. The application of soil amendments is one
6 approach for mitigating this problem, and calcium silicate is an alternative soil
7 amendment that could be used. Therefore, the main objective of this study was to
8 ameliorate soil acidity in rice-cropped soil. The secondary objective was to study the
9 effects of calcium silicate amendment on soil acidity, exchangeable Al, exchangeable
10 Ca, and Si content. The soil was treated with 0, 1, 2, and 3 Mg ha⁻¹ of calcium silicate
11 under submerged conditions and the soil treatments were sampled every 30 days
12 throughout an incubation period of 120 days. Application of calcium silicate induced a
13 positive effect on soil pH and exchangeable Al; soil pH increased from 2.9 (initial) to
14 3.5, while exchangeable Al was reduced from 4.26 (initial) to 0.82 cmol_c kg⁻¹.
15 Furthermore, the exchangeable Ca and Si contents increased from 1.68 cmol_c kg⁻¹
16 (initial) to 4.94 cmol_c kg⁻¹ and from 21.21 mg kg⁻¹ (initial) to 81.71 mg kg⁻¹,
17 respectively. Therefore, it was noted that calcium silicate was effective at alleviating Al
18 toxicity in acid sulfate, rice-cropped soil, yielding values below the critical level of 2
19 cmol_c kg⁻¹. In addition, application of calcium silicate showed an ameliorative effect as
20 it increased soil pH and supplied substantial amounts of Ca and Si.

21

22 **1 Introduction**

23 Acid sulfate soils are widespread in Malaysia, occurring almost exclusively along its
24 coastal plain (Shamshuddin and Auxtero, 1991; Shamshuddin et al., 1995; Muhrizal et

1 al., 2006; Enio et al., 2011). In these areas, the alluvial sediments are intermittently
2 inundated by seawater during low and high tides. These soils are dominated by pyrite
3 with high acidity (soil pH < 3.5) (Shamshuddin, 2006) and are produced when the
4 pyrite-laden soils in the coastal plains are opened up for crop production and/or
5 development. This scenario leads to the release of large amounts of Al into the soil
6 environment (Shamshuddin et al., 2004), which affects crop growth. For example, it
7 affects oil palm growth (Auxtero and Shamshuddin, 1991) and cocoa production
8 (Shamshuddin et al., 2004). In Peninsular Malaysia, acid sulfate soils are used for rice
9 cultivation with mixed success. At times, rice cultivation in these soils is successful; but
10 most often, the rice yield each season is very low (< 2 t ha⁻¹). Amelioration practices
11 with ground magnesium lime (GML) and/or basalt have shown improvements of up to
12 3.5 t ha⁻¹ in rice yield (average per season).

13 The application of soil amendments to acid sulfate soil is a common approach for
14 improving fertility. Suswanto et al. (2007), Shazana et al. (2013), Elisa et al. (2014), and
15 Rosilawati et al. (2014) reported that the infertility of acid sulfate soils can be
16 ameliorated by application of lime, basalt, organic fertilizer, and/or their combination at
17 an appropriate rate. Application of these ameliorants increased soil pH and reduced Al
18 toxicity, resulting in improved rice growth. In addition to these improvements, these
19 ameliorants also supply calcium (Ca) and magnesium (Mg), which are needed for crop
20 growth and development.

21 Besides Ca and Mg, silicon (Si) is also important for rice growth. It has a positive effect
22 on the growth of crops such as tomato (Peaslee and Frink, 1969), barley and soybean
23 (Hodson and Evans, 1995), and many others (Liang et al., 2007). The application of Si
24 may reduce the severity of fungal diseases such as blast and sheath blight of rice

1 (Farnaz Abed-Ashtiani et al., 2012); powdery mildew of barley, wheat, cucumber,
2 muskmelon, and grape leaves; and vermin damage of rice by plant hopper (Crock and
3 Prentice, 2012; Ma et al., 2001; Menzies et al., 1992; Bowen et al., 1992; Datnoff et al.,
4 2001). In addition, Si can effectively reduce Al toxicity (Barcelo et al., 1993). Calcium
5 silicate application could be a source of Si for soils. This material is available in
6 Peninsular Malaysia. Therefore, this study is relevant because calcium silicate could be
7 used to alleviate Al toxicity of soil from the Merbok granary area located in the northern
8 state of Kedah, Peninsular Malaysia. Certain regions of the rice cultivation area are
9 classified as acid sulfate soils and the average rice yield in these areas is less than 2 t ha⁻¹
10 season⁻¹. This is due to high soil acidity, Al toxicity, and/or rice blast disease (*M.*
11 *grisea*). Therefore, the main objective of this study was to ameliorate soil acidity in the
12 rice-cropped soils of this area. The secondary objective was to study the effects of
13 calcium silicate amendment on soil acidity, exchangeable Al, exchangeable Ca, and Si
14 content.

15

16 **2 Materials and methods**

17 **2.1 Soil type, treatments, and experimental design**

18 The experiment was conducted at the Field 2 Glasshouse at Universiti Putra Malaysia,
19 Serdang, Malaysia. The soil used in this study was obtained from Merbok, Kedah,
20 Peninsular Malaysia. The soil sampling site was a rice-cropped area and the sampling
21 was performed 1 month prior to rice cultivation (dry conditions). A composite soil
22 sample of approximately 2500 g was taken from 0–15 cm depth using an auger. The
23 sample was taken within a 0.5 ha region of the rice-cropped area. Afterward, the soil
24 was crushed, passed through a 2 mm sieve, and mixed thoroughly prior to incubation.

1 Five hundred grams of soil was used to fill a plastic pot, which was then incubated for
2 120 days. The treatments included 0 (CS0), 1 (CS1), 2 (CS2), and 3 (CS3) Mg ha⁻¹ of
3 calcium silicate, with three replications. These were arranged in a completely
4 randomized design (CRD). The total number of samples was 48 (4 treatments × 3
5 replications × 4 sampling times). Twelve pots were sampled every 30 days throughout
6 the incubation period, i.e., the sampling times were at 30 days (30D), 60 days (60D), 90
7 days (90D), and 120 days (120D) of incubation and corresponded to the vegetative,
8 reproductive, flowering, and maturity phases of rice growth, respectively. The calcium
9 silicate (CaSiO₃) used in this experiment was obtained from Kaolin (Malaysia) Sdn.
10 Bhd., Malaysia. This calcium silicate had the following composition: SiO₂ = 40–55%,
11 calcium (as CaO) = 40–50%, Al₂O₃ = below 1.5%, MgO = below 3%, iron (as Fe₂O₃) =
12 below 1%, and pH = 8.54.

13 The soils were mixed thoroughly with the added calcium silicate prior to the addition of
14 water. Tap water was added regularly and the water levels were maintained at
15 approximately 5 cm (height) above the soil surface. The composition of the tap water in
16 relation to phosphorus (P), potassium (K), aluminum (Al), calcium (Ca), iron (Fe),
17 magnesium (Mg), and silicon (Si) was 0.74, 10.62, 0.14, 19.78, 0.03, 1.00, and 5.18 mg
18 L⁻¹, respectively. The pH of the tap water used was 7.37.

19

20 **2.2 Soil analyses**

21 Soil samples were air-dried, ground, and passed through a 2 mm sieve prior to chemical
22 analyses. Soil pH was determined in water at a ratio of 1:2.5 (soil/distilled water) using
23 a glass electrode pH meter. Total C, N, and S were determined using a Leco CNS
24 analyzer. Cation exchange capacity (CEC) was determined using 1M NH₄OA_c at pH 7

1 (Chapman, 1965). Exchangeable Ca, Mg, K, and Na were determined using 1N NH₄Cl
2 (Ross and Ketterings, 1995; Shamshuddin, 2006). To achieve this, 2 g of air-dried soil
3 was placed in a 50 mL centrifuge tube and 20 mL 1N NH₄Cl was added. The sample
4 was shaken for 2 h on an end-to-end shaker at 150 rpm, followed by centrifugation at
5 2500 rpm for 15 min. The extract was passed through a filter paper into a 50 mL plastic
6 vial. The exchangeable Ca, Mg, K, and Na in the extract were determined by
7 inductively coupled plasma-optical emission spectroscopy (ICP-OES). Exchangeable Al
8 was determined by extracting 5 g of soil with 50 mL of 1M KCl. The mixture was
9 shaken for 30 min and the extracted Al was analyzed by ICP-OES. Extractable Fe, Cu,
10 Zn, and Mn were extracted using extracting agent (0.05N HCl and 0.025N H₂SO₄). To
11 achieve this, 5 g of air-dried soil was shaken with 25 mL of extracting agent for 15 min.
12 The extract was passed through a filter paper and used to determine Fe, Cu, Zn, and Mn
13 by atomic absorption spectrometry (AAS). Additionally, 0.01M CaCl₂ was used to
14 extract plant-available Si from the soil. For this, 2 g of soil was shaken for 16 h with 20
15 mL CaCl₂ extractant in a 50 mL centrifuge tube on an end-to-end shaker. The sample
16 was centrifuged at 2000 rpm for 10 min before the supernatant was filtered and
17 analyzed for Si (Datnoff et al., 2001) using ICP-OES.

18

19 **2.3 Statistical analysis**

20 Statistical analysis for means comparison was performed using Tukey's test in SAS
21 version 9.2 (SAS, Institute, Inc., Cary, NC).

22

23 **3 Results**

24 **3.1 Initial soil chemical characteristics**

1 Initial soil pH and exchangeable Al were 2.90 and 4.26 $\text{cmol}_c \text{ kg}^{-1}$, respectively.
2 Exchangeable Ca, Mg, K, and Na were 1.68, 2.61, 0.55, and 2.61 $\text{cmol}_c \text{ kg}^{-1}$,
3 respectively. Total C, N, and S were 3%, 0.2%, and 0.13%, respectively. At the site
4 where the soil was sampled, rice is normally grown twice per year and the straw is often
5 left to rot on the paddy field. The decomposition of the rice straw, to some extent,
6 contributed to the increased C content and CEC of the soil. In this study, the CEC of the
7 soil was 18.12 $\text{cmol}_c \text{ kg}^{-1}$. The values for extractable Fe, Cu, Zn, Mn, and Si prior to
8 incubation were 1118.6, 0.23, 0.96, 1.60, and 21.21 mg kg^{-1} , respectively.

9

10 **3.2 Effect of calcium silicate on soil pH**

11 Figure 1 shows the effect of calcium silicate application on soil pH under the submerged
12 conditions. It shows that soil pH increased in line with the incremental increases in the
13 calcium silicate application rate. The highest soil pH increase was from 2.90 (initial) to
14 3.95 due to the application of 3 t ha^{-1} calcium silicate. After 30 days of incubation
15 (D30), soil pH of CS2 was significantly higher than that of CS1, with values of 3.77 and
16 3.62, respectively. Treatment CS3 was significantly higher in terms of soil pH compared
17 with CS0, CS1, and CS2 at D60; CS0 and CS1 at D90; and CS0, CS1, and CS2 at
18 D120, showing values of 3.90, 3.84, and 3.95, respectively.

19

20 **3.3 Effect of calcium silicate on exchangeable Al**

21 Figure 2 shows the effect of calcium silicate application on exchangeable Al. It shows
22 that as the calcium silicate rate increased, the exchangeable Al decreased from 4.26 to
23 0.82 $\text{cmol}_c \text{ kg}^{-1}$. This is a 74% decrease in exchangeable Al in the acid sulfate soil due
24 to the application of calcium silicate. At 30 and 120 days of incubation, exchangeable Al

1 content in the soil treated with 2 and 3 t ha⁻¹ of calcium silicate had significantly
2 decreased compared to that in the untreated soil. However, there was no significant
3 effect of calcium silicate on exchangeable Al after 60 and 90 days of incubation.

4 5 **3.4 Effect of calcium silicate on exchangeable calcium**

6 Figure 3 show that the application of calcium silicate increased exchangeable Ca. There
7 was a significant effect among the treatments after 30 days of incubation. At 60, 90, and
8 120 days of incubation, soil treated with 2 and 3 t ha⁻¹ of calcium silicate had
9 significantly increased soil-exchangeable Ca compared with both untreated soil and soil
10 treated with 1 t ha⁻¹ of calcium silicate.

11 12 **3.5 Effect of calcium silicate on silicon content**

13 Application of calcium silicate increased the Si content of the soil, as shown in Figure 4,
14 from 14% to 74%. At 30 days of incubation, soil treated with 2 and 3 t ha⁻¹ of calcium
15 silicate had a significantly increased Si content compared with both untreated soil and
16 soil treated with 1 t ha⁻¹ of calcium silicate. At 60 days of incubation, the Si content
17 increased significantly for soil treated with 2 and 3 t ha⁻¹ of calcium silicate compared
18 with the soil treated with 1 t ha⁻¹ of calcium silicate. The Si content of the soil continued
19 to increase at 90 days of incubation; in the soil treated with 1 t ha⁻¹ calcium silicate, it
20 was significantly increased compared to the 2 t ha⁻¹ treatment. However, no significant
21 effect was observed among the treatments after 120 days of incubation.

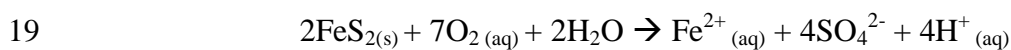
22 23 **4 Discussion**

24 From this study, it was found that calcium silicate can neutralize H⁺ ions in soil, as

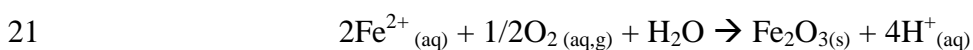
1 noted by the pH increase in acid sulfate soils upon calcium silicate application (Figure
2 1). Similar findings have been found by Smyth and Sanchez (1980) and Fiantis et al.
3 (2002). These authors attributed their results to the OH⁻ released from colloidal surfaces
4 during the adsorption of the silicate ions. Due to the application of calcium silicate, soil
5 pH increased significantly from 2.90 (initial) to 3.41–3.95.

6 During the incubation period, there was a strong relationship between calcium silicate
7 and soil pH at D30 (R² = 0.77), D60 (R² = 0.77), D90 (R² = 0.84), and D120 (R² = 0.92).
8 The increasing correlation coefficient over time was related to the increasing capacity of
9 the soil to adsorb silicate anions.

10 It was observed that the soil pH was slightly lower for CS0, CS1, and CS2 at D60 and
11 D90 compared to that at D30 and D120. The decrease in soil pH is believed to be due to
12 the release of protons as pyrite in the soil was oxidized during the incubation period.
13 Shamshuddin et al. (2004) reported that after 12 weeks of incubation, soil pH in the Cg
14 horizon of acid sulfate soil was lowered by 1 unit. The results from the current study are
15 consistent with those from other studies on acid sulfate soils (Shamshuddin and Auxtero,
16 1991; Shamshuddin et al., 1995; Shamshuddin et al., 2014). The oxidation of pyrite,
17 which produces acidity, may have taken place according to the following reactions
18 outlined by van Breemen (1976):



20 Further oxidation of Fe²⁺ to Fe³⁺ oxide could also promote acidity:



22

23 As the soil pH increased due to the application of calcium silicate, exchangeable Al
24 decreased to below the critical level for rice growth (2 cmol_c kg⁻¹). This is consistent

1 with the findings of Hiradate et al. (2007). Figure 2 shows the effect of the treatments
2 on exchangeable Al. It shows that exchangeable Al decreased significantly among the
3 treatments after 30D and 120D. After 30 days of incubation, the exchangeable Al
4 contents of treatments CS2 and CS3 were significantly reduced compared to CS0,
5 which was near the critical level of 2 cmol_c kg⁻¹. It is also shown that exchangeable Al
6 decreased further as the incubation period was further extended. Figure 5 shows the
7 relationship between exchangeable Al and soil pH, where the lines for D60, D90, and
8 D120 are below the line for D30. This implies that a prolonged incubation period would
9 further reduce the exchangeable Al content. The decrease in Al could also be due to the
10 precipitation of Al in the form of inert Al-hydroxides. The exchangeable Al content was
11 reduced to below the critical level of 2 cmol_c kg⁻¹ at D90 and D120.

12 The reduction in exchangeable Al is explained as follows. It is possible that soil Al can
13 be reduced by the reactions of Si-rich compounds. By such reactions, Datnoff et al.
14 (2001) postulated five mechanisms of Al reduction: 1) monosilicic acids increase soil
15 pH (Lindsay, 1979); 2) monosilicic acids are adsorbed on Al hydroxides, reducing their
16 mobility (Panov et al., 1982); 3) soluble monosilicic acid forms slightly soluble
17 substances with Al ions (Lumsdon and Farmer, 1995); 4) mobile Al is strongly adsorbed
18 on silica surfaces (Schulthess and Tokunaga, 1996); and 5) mobile silicon compounds
19 increase plant tolerance to Al (Rahman et al., 1998). All of these mechanisms may work
20 simultaneously, with one perhaps prevailing under certain soil conditions (Dantoff et al.,
21 2001).

22 The silicate anion can also neutralize H⁺ in the soil solution. As the silicate anion
23 captures H⁺ ions, it forms monosilicic acid (H₄SiO₄), as shown in the equation below:



1 Monosilicic acid could complex with Al^{3+} in the soil solution to form non-toxic
2 alumino-silicate and hydroxyl-alumino-silicate compounds, which precipitate in the root
3 zone. This reaction would reduce Al toxicity in rice grown on acid sulfate soils treated
4 with calcium silicate (Miranda, 2012).

5 Furthermore, the application of calcium silicate to the acid sulfate soil showed an
6 immediate ameliorative effect, i.e., the Ca content increased from 1.68 (initial) to above
7 the critical level of $2 \text{ cmol}_c \text{ kg}^{-1}$ (Palhares de Melo et al., 2001) at D30. Increasing the
8 rate of calcium silicate increased the Ca content of the soil significantly (Figure 3). For
9 treatment CS3, exchangeable Ca increased significantly compared to CS0 and CS1
10 throughout the incubation period, with increases of 42.48%, 47.78%, 60.65%, and
11 38.66% after 30D, 60D 90D and 120D, respectively. However, no significant difference
12 was observed between treatments CS2 and CS3 at D90 and D120.

13 In the current study, the Si content prior to the incubation was 21.21 mg kg^{-1} ; the critical
14 soil Si concentration for crop production is 40 mg kg^{-1} (Dobermann & Fairhurst, 2000).
15 Figure 4 shows the effect of calcium silicate application on Si content. At D30, the Si
16 content in treatments CS2 and CS3 was significantly higher than in treatments CS0 and
17 CS1. At D60, treatment CS3 increased the Si content significantly compared to that of
18 CS0 and CS1, with a value of 40.81 mg kg^{-1} Si. In all treatments at D90 and D120, the
19 Si content of the soil surpassed the deficiency level. At D90, the Si content of treatment
20 CS1 was significantly higher than that of CS2, with a value of 83.53 mg kg^{-1} . The Si
21 content of the soil was affected by the length of incubation, i.e., the Si content of all
22 treatments further increased at 120 days of incubation.

23 When the soil pH increased, the Si content of the soil also increased (Figure 6). The Si
24 content was positively correlated with soil pH at D30 and D60, likely due to the

1 dissolution of calcium silicate. The ability of the soil to adsorb Si was higher at D30 and
2 D60 than at D90 and D120. There was no correlation observed at D90 and D120, even
3 though the Si content was higher, probably because the soil-exchangeable sites became
4 fully occupied with Si through adsorption processes. This proves that the application of
5 calcium silicate to soil, accompanied by an increase in soil pH, enhances the ability of
6 soil to adsorb Si.

7 The positive effect of the presence of Si at D30 and D60 corresponds with the early
8 growth stage of rice, i.e., the active tillering stage. This means that a rice plant can
9 actively uptake Si during the tillering stage, hence improving rice growth. Figure 7
10 shows the relationship between the exchangeable Al and Si contents of the soil
11 throughout the incubation period after the application of calcium silicate. The reduction
12 in exchangeable Al corresponded directly with the availability of Si in the soil. This
13 means that as more Si is available in acid sulfate soil, a reduction in the exchangeable
14 Al content occurs. Exchangeable Al was negatively correlated with Si content in the soil
15 at D30 ($R = 0.77$) and D60 ($R = 0.92$), whereas no correlation was observed at D90 and
16 D120. In Figure 7, the D60 line is below the D30 line, indicating that as the incubation
17 period increased, the Al and Si contents showed an antagonistic pattern: Al decreased,
18 while Si increased. This phenomenon indicates that when the Al content of the soil is
19 low, its toxicity may not be the dominant factor inhibiting rice plant growth. On the
20 other hand, Si becomes more readily available for plant uptake. Therefore, the optimal
21 time to plant rice is 30 days after applying calcium silicate because the exchangeable Al
22 is almost reduced to below the critical value of $2 \text{ cmol}_c \text{ kg}^{-1}$. Because the Si content
23 increased with incubation time, the rice plant could actively uptake Si for growth during
24 active tillering.

1 Silicon is released from calcium silicate into the bulk soil solution and may become
2 absorbed by plants as $\text{Si}(\text{OH})_4$. It may thus be involved in the diverse structural and
3 dynamic aspects of plant life and crop performance. Although not considered an
4 essential element for plant growth and development, Si is considered a beneficial
5 element and is reported as being very useful to plants when they are under abiotic or
6 biotic stress (Datnoff et al., 2001). An alleviating effect of Si on Al toxicity has been
7 reported in many crops including soybean (Baylis et al., 1994), teosinte (Barcelo et al.,
8 1993), sorghum (Hodson and Sangster, 1993), wheat, maize, cotton, and rice (Cocker et
9 al., 1998).

10 A prolonged incubation of soil not treated with calcium silicate might have also
11 influenced the changes in soil chemical characteristics. As such, CS0 (untreated soil)
12 showed an increase in soil pH from 2.90 (prior to incubation) to 3.63 at D30. A decrease
13 in soil pH values was noted for D60 and D90, likely due to pyrite oxidation in the soil
14 system, and no significant effect was observed among the days of incubation.
15 Meanwhile, exchangeable Al decreased significantly with increasing incubation time.
16 For the first 2 months, exchangeable Al was above the critical level of $2 \text{ cmol}_c \text{ kg}^{-1}$ and
17 no significant difference between D30 and D60 was observed. Exchangeable Al was
18 significantly reduced to $1.89 \text{ cmol}_c \text{ kg}^{-1}$ at D90, but no significant effect was observed
19 thereafter, i.e., at D120. Application of calcium silicate significantly increased the Si
20 content of the soil. However, no significant effect on Si content was observed between
21 D30 and D60 or between D90 and D120. The Si content of the soil increased
22 significantly, to 59.81 mg kg^{-1} , after 90 days of incubation. The significant increase in Si
23 was due to the hydrolysis of silicate minerals present in the acid sulfate soils. For
24 instance, the hydrolysis of silicate is generalized in the following reaction:

1

2 Silicate + H₂O + H₂CO₃ → base cation + HCO₃⁻ + H₄SiO₄ + accessory mineral

3

4 In this reaction, the base cation would commonly be Mg²⁺ or Ca²⁺, H₂CO₃ is a proton
5 source, HCO₃⁻ is bicarbonate, H₄SiO₄ is silicic acid, and gibbsite [Al (OH)₃] is a
6 representative accessory mineral (Essington, 2005).

7

8 Farmers in the study area have applied GML to overcome soil fertility problems
9 associated with Al toxicity. As an alternative to GML application, this study suggests
10 that such farmers could benefit from the use calcium silicate as a soil amendment.
11 Therefore, the costs of the input (calcium silicate) and labor should be taken into
12 account to better understand the feasibility of such an approach for farmers in this
13 region. Table 1 shows the costs of applying calcium silicate to 1 ha area for rice
14 production. The costs for calcium silicate and labor were USD 407 t⁻¹ and USD 45 t⁻¹,
15 respectively. The total cost (calcium silicate and labor) ranged from USD 452 to USD
16 1354 ha⁻¹.

17

18 **5 Conclusions**

19 Application of calcium silicate showed an ameliorative effect on acid sulfate soil, i.e.,
20 an increase in soil pH, exchangeable Ca content, and Si content, and a reduction in
21 exchangeable Al. This suggests that calcium silicate amendment is effective in
22 alleviating Al toxicity in acid sulfate, rice-cropped soils. Furthermore, it is an affordable
23 soil amendment, with a cost ranging from USD 452 to USD 1354 ha⁻¹.

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3 Security: Enhancing sustainable rice production).

4

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1 Table 1. Cost of calcium silicate applied to a 1 ha area for rice production

Rate (t/ha)	0	1	2	3
Price	0	USD 407 t ⁻¹	USD 407 t ⁻¹	USD 407 t ⁻¹
(calcium silicate)		= USD 407	= USD 813	= USD 1219
Labor	0	USD 45 t ⁻¹	USD 45 t ⁻¹	USD 45 t ⁻¹
		= USD 45	= USD 90	= USD 135
Total	0	USD 452	USD 903	USD 1354

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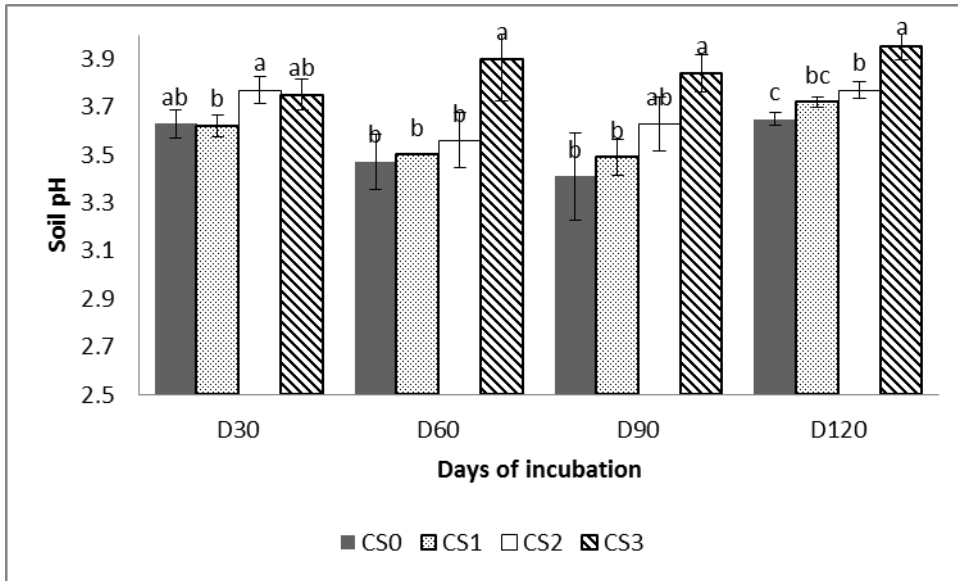
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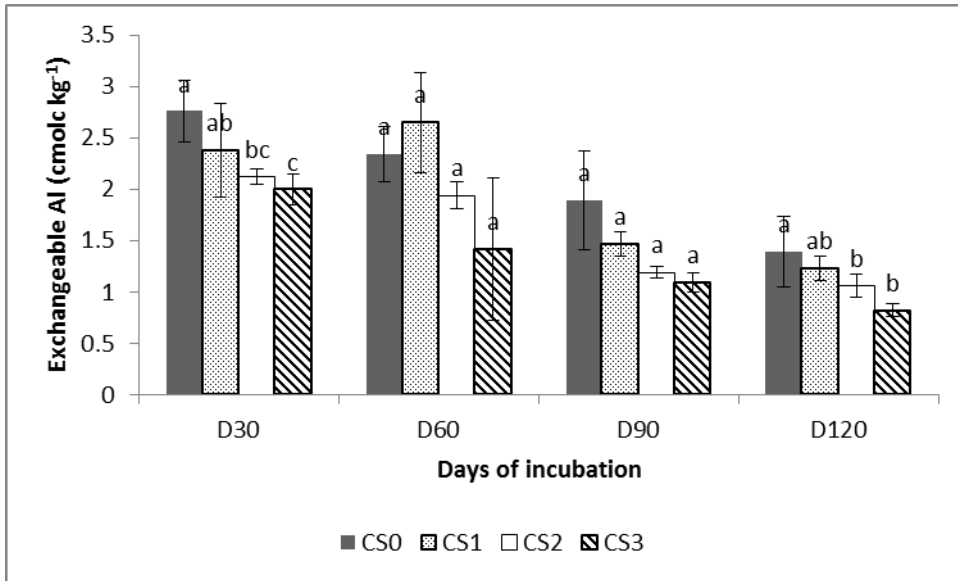
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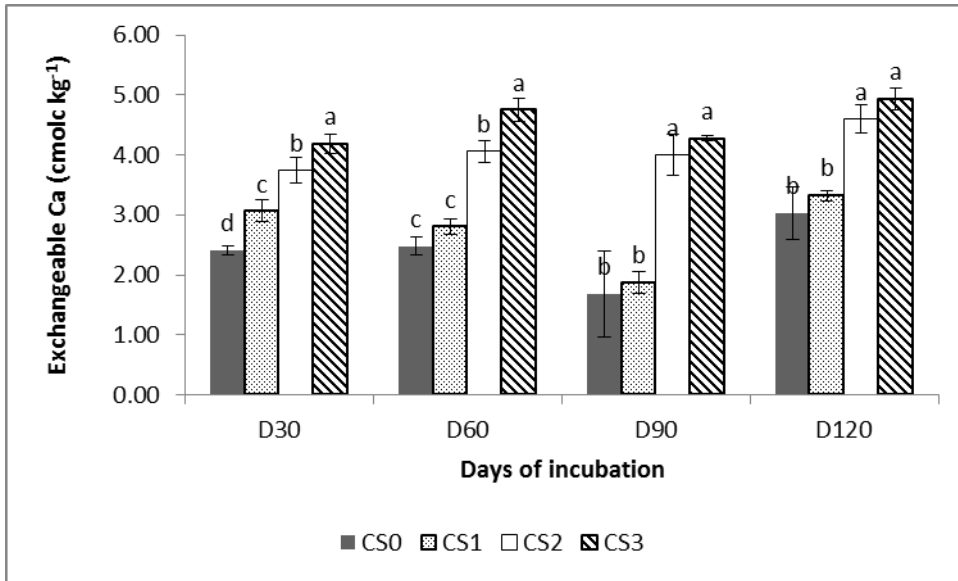
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Figure 1. Effects of calcium silicate application on soil pH under submerged conditions. Means marked with the same letter for each incubation day are not significantly different at $p < 0.05$ (Tukey`s Test).



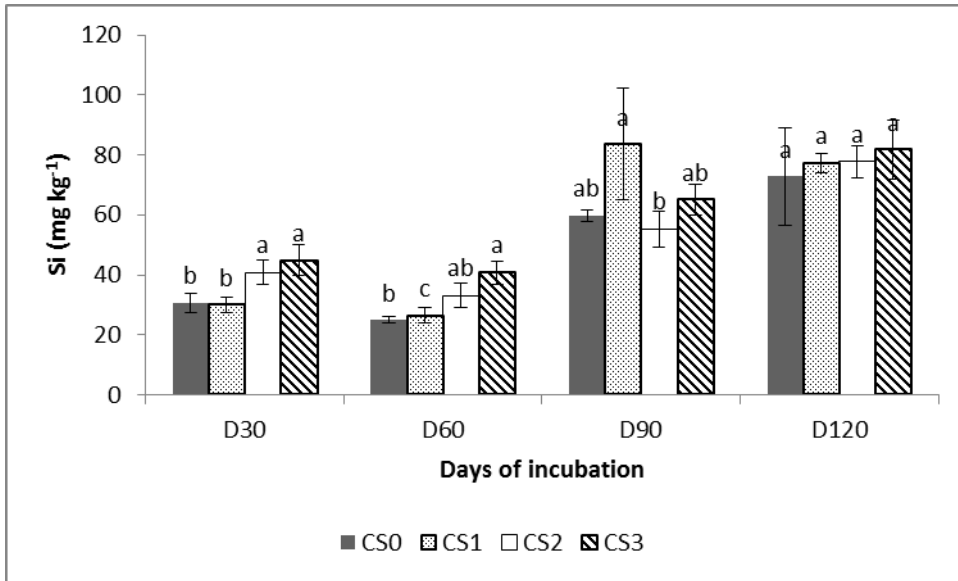
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Figure 2. Effects of calcium silicate application on exchangeable aluminum. Means marked with the same letter for each incubation day are not significantly different at $p < 0.05$ (Tukey's Test).



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Figure 3. Effects of calcium silicate application on exchangeable calcium. Means marked with the same letter for each incubation day are not significantly different at $p < 0.05$ (Tukey's Test).



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Figure 4. Effects of calcium silicate application on silicon content. Means marked with the same letter for each incubation day are not significantly different at $p < 0.05$ (Tukey's Test).

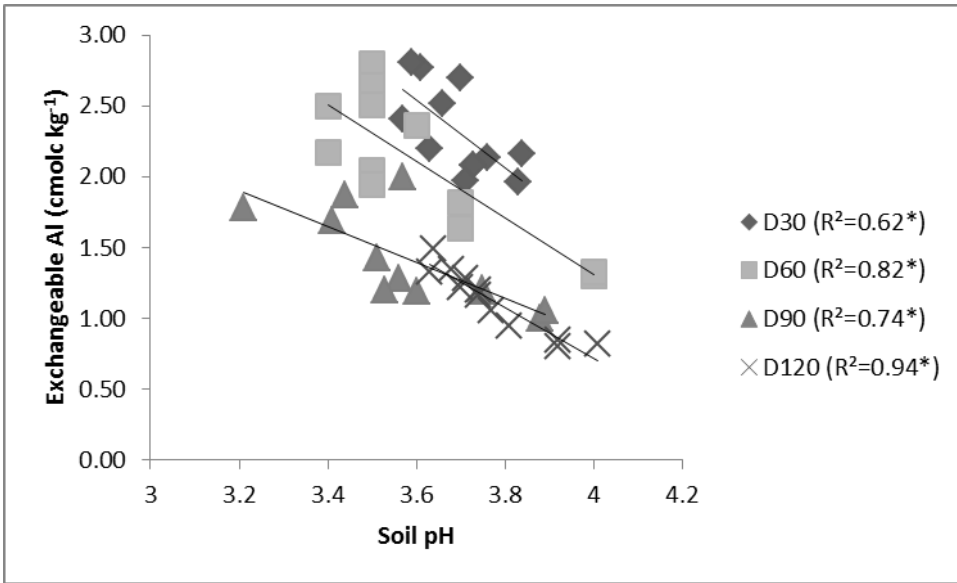
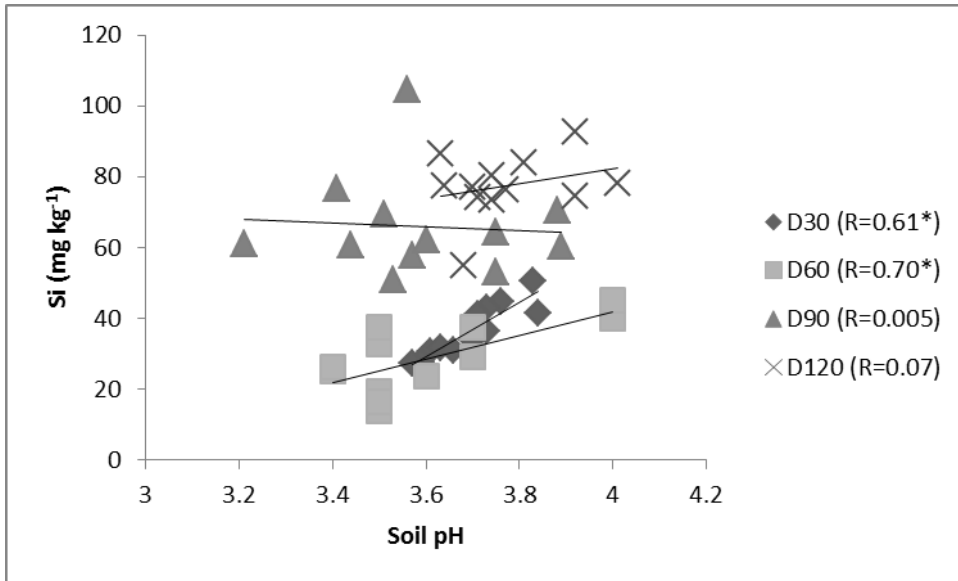


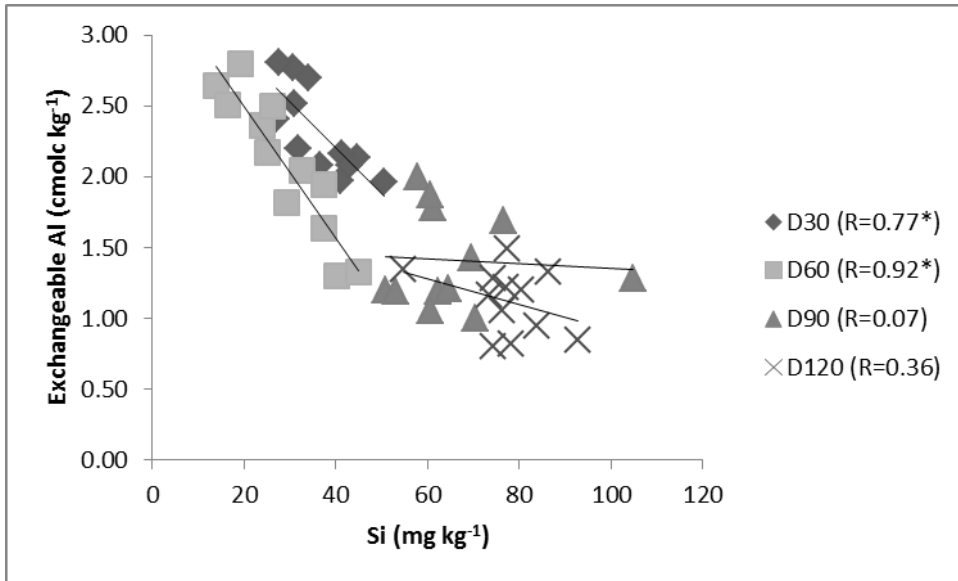
Figure 5. Relationship between exchangeable Al and soil pH (* p < 0.05)

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Figure 6. Relationship between Si content and soil pH throughout the incubation period (* p < 0.05)



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