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Research Article

Response of selected chemical properties of extremely acidic soils on the application of limes, rice husk biochar and zeolite

Gina Aliya Sopha[1*], Catur Hermanto[1], Huub Kerckhoffs[2], Julian A Heyes[3], James Hanly[3]

[1] Research Center for Horticultural and Estate Crops, National Research and Innovation Agency (BRIN), Bogor, West Java, Indonesia
[2] Start-A-Fresh, Mount Manganui, New Zealand
[3] Massey University, Palmerston North 4472, New Zealand

[*]corresponding author: ginasopha80@gmail.com, gina006@brin.go.id

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Abstract

Extremely acidic soils have low pH, high concentration of exchangeable Al^{3+} and low cation exchange capacity (CEC) that cause severe growth for most plants. The study was conducted in the soil laboratory of the Indonesian Vegetable Research Institute, Lembang, from June to August 2019. A randomised complete block design with seventeen treatments, three replications, and three incubation times (3, 30 and 60 days) was deployed to assess the effect of rates of soil amendments, namely 5 to 30 t liming materials ha^{-1}, 5 to 20 t rice husk biochar ha^{-1}, and 5 to 20 t zeolite ha^{-1} on extremely acidic soils. The results showed that lime materials, i.e., lime, agriculture limestone, and hydrated lime had a similar effect on increasing soil pH and reducing exchangeable Al^{3+}. Calcium super seemed more effective in increasing soil pH and reducing exchangeable Al^{3+} than local lime due to the high CCE value. However, there was no significant response to the highest rice husk biochar and zeolite rate on soil pH and exchangeable Al^{3+}. Rice husk biochar increased the concentration of K^+ and zeolite raised the concentration of Na^+. However, the effect was minimal. About 3 t lime ha^{-1} or 2.5 t calcium super ha^{-1} or equivalent to 1.5 to 2 times exchangeable Al^{3+} is required to obtain the soil pH target of 4.8, where the exchangeable Al^{3+} was less than 0.5 $cmol_{(+)}$ kg^{-1}.

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Introduction

The majority of weathered tropical soils are leached, have high annual precipitation, and are acidic, with a soil pH of less than 5.2 (Juo and Franzluebbers, 2003). About one-third of the tropical lands are very acidic and contain a high concentration of exchangeable aluminium (Al) that potentially harm crop growth (Cristancho et al., 2014).

Many upland shallot production areas in West Java are acidic, with soil pH below 5.5 (Sopha et al., 2019). Moreover, the natural process and human disturbance accelerate acidifying process through precipitation, leaching, crop nutrient removal, soil organic matter, ion exchanges, chemical reactions and fertiliser application (Havlin, 2014). Soil amendments are used to improve soil chemical properties and reduce the negative effects of acidity. Liming is a common practice to increase soil pH and mitigate the adverse effect of soil acidity. However, the effectiveness of lime in improving the chemical properties of acidic soils varies, depending on the lime material characteristics, liming method and lime rate.

Lime application increases soil pH, and total base cations that increase base saturation (Fageria and Baligar, 2008; Cristancho et al., 2014). Moreover, the solubility of Al depends on the soil pH; the concentration of exchangeable Al^{3+} reduces when the soil pH increases (Moir and Moot, 2010). Application of 1 t lime ha^{-1} increased soil pH from 3.94 to 4.17 and reduced exchangeable Al^{3+} from 1.60 to 1.16 $cmol_{(+)}$ kg^{-1} (Sopha et al., 2021). This Al value is still high, more than 0.5 $cmol_{(+)}$ kg^{-1}, which might cause aluminium toxicity. Therefore, a higher rate of lime should be investigated further. Despite lime, biochar was reported to have a positive effect on soil chemical properties. A specific amount of elemental nutrients from biochar ash might be added due to biochar application and increased soil pH (Glaser et al., 2002). Zeolite also was reported give a positive impact on acidic soils. Application of 5 t zeolite ha^{-1} + 150 kg TSP ha^{-1} increased soil pH from 4.6 to 5.46 (Aainaa et al., 2018). However, the effect of biochar and zeolite on soil properties could diversly depend on soil chemical properties and material characteristics.

This study aimed to identify the effect of lime and other soil amendments on soil pH, exchangeable Al^{3+}, base cations and CEC of extremely acidic soil from West Java, Indonesia.

Materials and Methods

The research was conducted from June to August 2019 in the soil laboratory of the Indonesian Vegetable Research Institute, Lembang, West Java, Indonesia. Air-dried soil samples of 100 g were placed in a plastic cup, and all soil amendments were added. The soil amendments rates per ha were determined using a tillage depth of 20 cm and bulk density of 1020 kg m^{-3}. The soil amendments treatments are presented in Table 1. The soil and soil amendments were mixed and wetted with deionised water to 70% of the field water holding capacity of the soil.

Table 1. The treatments of soil amendments.

Treatments	Soil amendments	Rate (t ha^{-1})	Rate (g 100 g^{-1} soil)
1	Control	0	0
2	Local lime	10	0.5
3	Local lime	20	1.0
4	Local lime	30	1.5
5	Agricultural limestone	20	1.0
6	Hydrated lime	20	1.0
7	Calcium Super	5	0.25
8	Calcium Super	10	0.5
9	Rice husk biochar	5	0.25
10	Rice husk biochar	10	0.5
11	Rice husk biochar	20	1.0
12	Zeolite	5	0.25
13	Zeolite	10	0.5
14	Zeolite	20	1.0
15	Local lime + biochar	10 +10	0.5 + 0.5
16	Local lime + zeolite	10 +10	0.5 + 0.5
17	Local lime + biochar + zeolite	10 + 5+ 5	0.5 + 0.25 + 0.25

Notes: Calcium carbonate equivalent (%) of local lime = 71%, agricultural limestone = 90%, hydrated lime = 109%, calcium super = 108%. pH of rice husk biochar = 7.07 and zeolite pH = 8.57. Calcium super contains 37% of CaO and 8% of MgO.

The soil was sampled at 0, 30, and 60 days from incubation and replicated three times for each incubation time. The soil was air-dried and passed through a 2 mm sieve before chemical characteristic analysis. The parameters are soil pH_{H2O}, exchangeable Al^{3+}, base cations and CEC. Soil pH was measured using a Hanna pH meter (HI 2550) with a soil: water ratio of 1:5 (Miller and Kissel, 2010). Exchangeable Al^{3+} was extracted by KCl and was determined by the titrimetric method (Eviati and Sulaeman, 2009). The exchangeable base cations (Ca^{2+}, Mg^{2+}, K^{+}, and Na^{+}) were extracted from the soil with NH_4^{+} using 1 M ammonium acetate pH 7 and the CEC was measured by spectrocolorimetry with λ = 636 nm (Eviati and Sulaeman, 2009).

Results and Discussion

pH, exchangeable Al^{3+}, exchangeable Ca^{2+}, and exchangeable Mg^{2+}

The initial soil pH was 4.20, and exchangeable Al^{3+} was 1.68 $cmol_{(+)}$ kg^{-1}. The base cation concentrations were low, being 2.60 $cmol_{(+)}$ kg^{-1} of Ca^{2+}, 0.59 $cmol_{(+)}$ kg^{-1} of Mg^{2+}, 0.60 $cmol_{(+)}$ kg^{-1} of K^{+} and 0.04 $cmol_{(+)}$ kg^{-1} of Na^{+}, which provided a 32% Base Saturation of the soil's CEC of 12 $cmol_{(+)}$ kg^{-1}. All liming materials (lime, agricultural limestone, hydrated lime and calcium super) and the combination of lime and biochar or zeolite significantly increased soil pH in all incubation times compared to biochar and zeolite alone (Table 2). The control treatment soil, which did not receive lime and other soil amendments, had an average soil pH between 4.12 to 4.33 over the 60 days duration of the incubation experiment. Three days after the incubation period, all treatments containing liming materials showed significant increases in soil pH. Application of 10, 20 and 30 t lime ha^{-1} increased soil pH values to 5.64, 6.66 and 6.96 at 3 days after incubation, and the pH continued to increase over time, being 6.33, 7.20 and 7.73 at 60 days, respectively. The recommended optimum pH of vegetable crops is 6 to 6.5, which was achieved by 10 t local lime ha^{-1} within 30 days of application.

All the liming materials succeeded in raising the soil pH above 5.0, and the exchangeable Al^{3+} concentration downed to zero points (Table 2). The control treatment soil, which received no lime or other soil amendments, had an average exchangeable Al^{3+} between 1.43 to 1.56 cmol$_{(+)}$ kg^{-1} over the 60 days duration of the incubation experiment. The lowest rate of liming material was 5 t calcium super ha^{-1} which decreased the exchangeable Al^{3+} to 0 cmol$_{(+)}$ kg^{-1}. This significant reduction in exchangeable Al^{3+} was obtained with a lower rate of lime than in other studies, which might be due to the differences in soil buffering capacity and lime quality. For example, Andrade et al. (2002) reported that 8.8 t lime ha^{-1} reduced exchangeable Al^{3+} from 1.23 to 0.22 cmol$_{(+)}$ kg^{-1} and Sopha et al. (2021) reported that the application of 1 t lime ha^{-1} decreased the exchangeable Al^{3+} from 0.27 to 0.04 cmol$_{(+)}$ kg^{-1}.

All types and rates of liming materials increased the concentration of Ca^{2+}, but this effect was not significant for rice husk biochar and zeolite treatments (Table 2). The control treatment soil, which received no soil amendments, had an exchangeable Ca^{2+} between 2.40 and 3.62 cmol$_{(+)}$ kg^{-1} over the 60 days duration of the incubation experiment. Three days after the incubation period, all treatments containing lime materials gave significant increases in exchangeable Ca^{2+}. For the local lime treatments, the 10, 20 and 30 t lime ha^{-1} achieved exchangeable Ca^{2+} 14.95, 23.28 and 29.87 cmol$_{(+)}$ kg$^{-1,}$ respectively. However, either all exchangeable Ca^{2+} changes occurred within the first three days, with little or no change occurring between 30 and 60 days after the incubation period. On average, every 1 t lime ha^{-1} increased the Ca^{2+} concentration by 1.07 cmol$_{(+)}$ kg^{-1}, while the calcium super increased the concentration of Ca^{2+} by 1.09 cmol$_{(+)}$ kg^{-1} after 60 days of incubation. A lower result was reported in sandy clay loam soil by Mosharrof et al. (2021) that every 1 t dolomite ha^{-1} increased the concentration of exchangeable Ca^{2+} by 0.27 cmol$_{(+)}$ kg^{-1} after 60 days of incubation.

Calcium super, which was the only soil amendment to contain significant quantities of Mg^{2+}, increased the concentration of exchangeable Mg^{2+} in proportion to the amount added (Table 2). No other soil amendments changed the soil exchangeable Mg^{2+} significantly. In addition, exchangeable Mg^{2+} was uninfected by incubation times, apart from a minor decline when biochar or zeolite was added in the presence of lime. The incorporation of calcium super enhanced the Mg^{2+} linearly due to Mg concentration of calcium super. On average, every 1 t calcium super ha^{-1} increased the concentration of Mg^{2+} by 0.21 cmol$_{(+)}$ kg^{-1}. The result was similar to Fungenzi et al. (2021), who reported a linear function for dolomite (22% MgO) addition on the concentration of exchangeable Mg^{2+}.

Exchangeable K^{+} and Na^{2+}, and CEC

Biochar treatments raised the concentration of K^{+} in incubated soils after three days of incubation time (Table 3). The increasing K concentration in the soil solution may come from cation substances from biochar. Rice husk biochar may contain about 175 mg kg^{-1} of K (Milla et al., 2013), increasing K^{+} concentration. A significant change was reported by Masulili et al. (2010) that the application of 10 t ha^{-1} rice straw biochar increased K^{+} ions by 0.31 cmol$_{(+)}$ kg^{-1} from 0.21 to 0.51 cmol$_{(+)}$ kg^{-1}. In this experiment, the application of 10 t ha^{-1} rice husk biochar increased the concentration of K^{+} by only about 0.08 cmol$_{(+)}$ kg^{-1} from 0.67 to 0.75 cmol$_{(+)}$ kg^{-1}. The difference result of K^{+} changing might be due to the differences in pyrolisis temperature, heating rate, holding time and particle size that may affect the rice husk biochar characteristics (Ji-Lu, 2007). It is important to note that by 60 days of incubation, this small change was no longer present, and all incubated soils showed the same amount of exchangeable K^{+}.

Zeolite significantly increased the exchangeable sodium (Na^{+}) compared to other treatments (Table 3). If the exchangeable Na^{+} was higher than 15% of cation exchange capacity (CEC), it might lead to serious soil physical problems, such as crusting that reduces water infiltration and inhibits plant growth (Laker and Nortje, 2019). In this experiment, the highest Na^{+} saturation was 2.12% (Na^{+} = 0.274 cmol$_{(+)}$ kg^{-1}, CEC = 12.91 cmol$_{(+)}$ kg^{-1}) which is much lower than the critical value. Therefore, it seems that zeolite application at this rate should not negatively impact plant growth. The increase in Na^{+} due to zeolite content has previously been ascribed to Na_2O in the zeolite, which dissolves when applied to soil (Wang et al., 2012). At the end of the incubation time (60 days after incubation), the cation exchange capacity (CEC) was improved significantly by the application of 20 t local and hydrated lime ha^{-1}, 10 t calcium super and zeolite ha^{-1}, 10 t local lime ha^{-1} + 10 t biochar ha^{-1} and 10 t local lime ha^{-1} + 5 t biochar ha^{-1} + 5 t zeolite ha^{-1} but not with other treatments (Table 3). There was also no significant difference in CEC over time. It seems that in specific values, lime affected the CEC more significantly than biochar and zeolite. Application of lime increased CEC or negative charge commonly because of the detachment of H^{+} from organic materials (Bolan et al., 2003).

Table 2. The effects of soil amendments and incubation time on soil pH, exchangeable Al^{3+}, Ca^{2+}, and Mg^{2+}.

Treatments	**pH**			**Al^{3+} (cmol$_{(+)}$ kg^{-1})**			**Ca^{2+} (cmol$_{(+)}$ kg^{-1})**			**Mg^{2+} (cmol$_{(+)}$ kg^{-1})**		
(*)	**3 days**	**30 days**	**60 days**	**3 days**	**30 days**	**60 days**	**3 days**	**30 days**	**60 days**	**3 days**	**30 days**	**60 days**
1	4.16 d	4.33 g	4.12 e	1.43 b	1.56 b	1.51 a	2.40 e	3.56 f	3.62 f	0.54 c	0.59 cd	0.57 c
2	5.64 c	6.24 e	6.33 c	0.00 c	0.00 b	0.00 b	14.95 c	12.76 d	13.78 c	0.56 c	0.55 cd	0.53 c
3	6.66 ab	7.27 c	7.20 b	0.00 c	0.00 b	0.00 b	23.38 b	17.44 c	21.14 b	0.57 c	0.56 cd	0.54 c
4	6.96 a	7.73 a	7.73 a	0.00 c	0.00 b	0.00 b	29.87 a	24.85 a	26.12 a	0.57 c	0.56 cd	0.53 c
5	6.82 a	7.39 bc	7.41 ab	0.00 c	0.00 b	0.00 b	23.56 b	19.55 bc	24.63 ab	0.52 c	0.51 d	0.51 c
6	6.80 a	7.55 ab	7.62 a	0.00 c	0.00 b	0.00 b	23.98 b	21.83 b	24.44 ab	0.57 c	0.53 cd	0.51 c
7	5.64 c	5.64 f	5.49 d	0.00 c	0.00 b	0.00 b	8.31 de	7.80 e	8.16 de	1.75 b	1.91 b	1.77 b
8	6.32 ab	6.66 d	6.58 c	0.00 c	0.00 b	0.00 b	12.42 cd	11.32 d	12.08 cd	2.27 a	2.75 a	2.67 a
9	4.12 d	4.35 g	4.09 e	1.74 ab	1.56 a	1.34 a	2.22 e	3.88 f	3.69 ef	0.55 c	0.57 cd	0.56 c
10	4.04 d	4.35 g	4.08 e	1.81 ab	1.62 a	1.53 a	2.09 e	3.70 f	3.67 e	0.57 c	0.59 cd	0.59 c
11	4.13 d	4.35 g	4.13 e	1.69 ab	1.40 a	1.56 a	2.32 e	3.68 f	3.50 f	0.58 c	0.61 cd	0.59 c
12	4.13 d	4.35 g	4.08 e	1.75 ab	1.51 a	1.46 a	2.21 e	3.76 f	3.70 ef	0.55 c	0.58 cd	0.56 c
13	4.10 d	4.38 g	4.11 e	1.86 a	1.52 a	1.46 a	2.32 e	3.66 f	3.60 f	0.55 c	0.57 cd	0.55 c
14	4.10 d	4.35 g	4.19 e	1.83 ab	1.50 a	1.51 a	2.38 e	3.54 f	4.02 ef	0.56 c	0.55 cd	0.59 c
15	5.73 c	6.38 e	6.26 c	0.00 c	0.00 b	0.00 b	14.19 cd	12.90 d	13.98 c	0.58 c	0.56 cd	0.53 c
16	5.74 c	6.38 e	6.32 c	0.00 c	0.00 b	0.00 b	14.33 cd	13.34 d	14.18 c	0.57 c	0.56 cd	0.52 c
17	5.75 c	6.40 e	6.37 c	0.00 c	0.00 b	0.00 b	14.74 c	12.80 d	13.80 c	0.58 c	0.56 cd	0.51 c
p-value	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
CV (%)	8.6	1.1	2.0	19.5	16.7	15.8	13.9	8.8	12.8	5.5	3.5	7.0

Notes: Treatments (*) see Table 1. Tukey's method for means comparison; means presenting the same small letters in the same column and the same capital letters in the same row, are not significantly different at α=5%.

Table 3. The effect of soil amendments and incubation time on exchangeable K^+, Na^{2+}, and CEC.

Treatments (*)	**K^+ ($cmol_{(+)}$ kg^{-1})**			**Na^+($cmol_{(+)}$ kg^{-1})**			**CEC($cmol_{(+)}$ kg^{-1})**		
	3 days	**30 days**	**60 days**	**3 days**	**30 days**	**60 days**	**3 days**	**30 days**	**60 days**
1	0.68 ef	0.74 abcd	0.67 a	0.06 cd	0.05 c	0.06 c	11.9 ns	11.4 d	11.5 e
2	0.67 f	0.71 bcde	0.62 ab	0.05 d	0.05 c	0.07 c	11.2	11.8 cd	12.4 abcde
3	0.67 f	0.71 bcde	0.64 ab	0.05 d	0.05 c	0.04 c	13.1	13.2 ab	13.2 abc
4	0.66 f	0.71 bcde	0.59 ab	0.05 d	0.04 c	0.07 c	12.9	12.8 abcd	12.7 abcde
5	0.68 ef	0.73 bcde	0.56 ab	0.09 cd	0.05 c	0.05 c	12.6	12.5 abcd	12.4 abcde
6	0.69 def	0.73 abcde	0.60 ab	0.06 cd	0.06 bc	0.06 c	14.1	13.4 a	12.7 abcd
7	0.68 ef	0.73 bcde	0.58 ab	0.06 cd	0.05 c	0.05 c	13.1	12.8 abcd	12.2 abcde
8	0.67 f	0.70 bcde	0.46 b	0.06 cd	0.04 c	0.04 c	12.2	12.8 abcd	13.5 ab
9	0.75 a-d	0.79 abc	0.72 a	0.06 cd	0.06 bc	0.07 c	11.9	11.7 cd	11.5 de
10	0.78 ab	0.79 ab	0.71 a	0.07 cd	0.06 bc	0.06 c	12.1	11.9 bcd	11.6 cde
11	0.80 a	0.84 a	0.75 a	0.07 cd	0.05 c	0.06 c	12.0	11.8 bcd	11.7 cde
12	0.67 f	0.69 cde	0.60 ab	0.12 cd	0.09 bc	0.13 bc	12.8	12.5 abcd	12.2 abcde
13	0.71 cdef	0.66 de	0.62 ab	0.11 cd	0.14 bc	0.18 b	12.1	12.4 abcd	12.7 abcd
14	0.69 cdef	0.64 e	0.63 ab	0.30 a	0.22 a	0.31 a	12.2	11.8 bcd	11.5 de
15	0.75 abc	0.76 a-d	0.65 ab	0.07 cd	0.07 bc	0.05 c	12.7	12.9 abc	13.1 abcd
16	0.68 ef	0.66 de	0.59 ab	0.21 b	0.11 bc	0.18 b	12.6	12.7 abcd	12.7 abcde
17	0.73 b-e	0.73 abc	0.62 ab	0.13 c	0.09 bc	0.14 b	12.7	13.3 a	13.9 a
p-value	<0.01	<0.01	<0.01	<0.01	< 0.01	< 0.01	0.39	0.04	0.01
CV (%)	2.6	4.8	9.6	24.2	34.4	36.0	8.80	5.84	6.93

Notes: Treatments (*) see Table 1. Tukey's method for means comparison; means presenting the same small letters in the same column and same capital letters in the same row, are not significantly different at α=5%.

The effect was more significant when the soils contain high clay minerals with pH-dependent surface charge (Cherian and Arnepalli, 2015). Exchangeable Al^{3+} was quantified when the soil pH was below 5.42 (Figure 1). No data of exchangeable Al^{3+} were found in the soil pH range of 4.45 and 5.42. However, from the trendline, it was determined that when the pH was above 4.8, the concentration of exchangeable Al^{3+} was lower than 0.5 $cmol_{(+)}$ kg^{-1}. The point is the threshold level when the adverse effect of Al^{3+} on crop growth is negligible (Sopha et al., 2021). However, this finding should be investigated further.

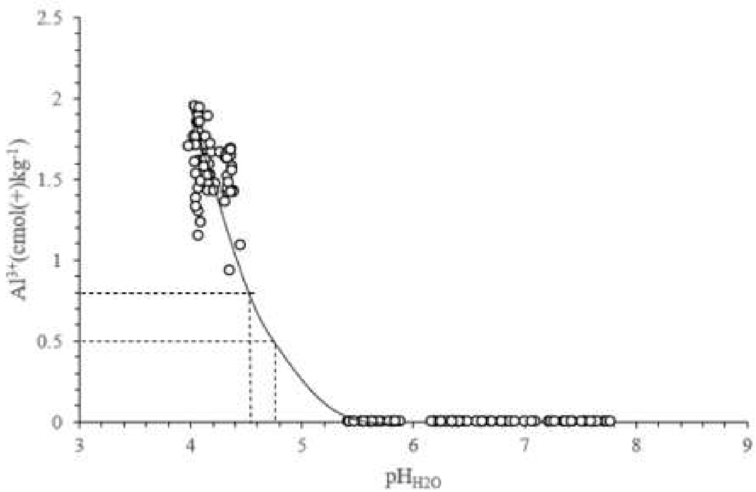

Figure 1. The scatter points between pH_{H2O} and exchangeable Al^{3+} concentration, n = 153.

Conclusion

Lime materials, i.e. lime, agricultural limestone and hydrated lime, had a similar effect on increasing soil pH and reducing the exchangeable Al^{3+} in extremely acidic soil. In contrast, calcium super seems more effective in increasing soil pH and reducing exchangeable Al^{3+} than local lime. To reach the soil pH target, 4.8 (exchangeable Al^{3+} of <0.5), about 3 t lime ha^{-1} or 2.5 t calcium super ha^{-1} or equivalent to 1.5 to 2 times exchangeable Al^{3+} is required.

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