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EFFECT OF LIME APPLICATION ON SOIL PROPERTIES AND SOYBEAN YIELD ON TIDAL LAND

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ABSTRACT

The problems of soybean cultivation on tidal land are low in soil fertility, aluminum (Al) toxicity and poor availability of macro nutrients. Soil acidity and Al toxicity are often fixed by liming. The research aimed to determine the calculation method of lime requirement and its application method for soybean on tidal land. The research was conducted on tidal land in South Kalimantan, Indonesia. Treatment consisted of two factors and arranged in randomize complete block design, replicated three times. The first factor was the method of lime rate calculation: (1) no liming, (2) liming based on 10% of Al saturation, (3) liming based on 20% of Al saturation, (4) liming based on 30% of Al saturation, (5) liming based on 0.5 x exchangeable Al, and (6) liming based on 1 x exchangeable Al. The second factor was the method of application: (1) surface and (2) mixed within 20 cm soil depth. The results showed that liming by mixing dolomite with soil within 20 cm depth resulted in 8% higher plant height compared to that applied on the soil surface. The highest yield was obtained when liming at rate equivalent to 10% of Al saturation was mixed with soil within 20 cm depth.

Keyword: acidity; aluminium saturation; liming; soybean; tidal land

INTRODUCTION

Soybean has been an important food crop in Indonesia since ten years ago. Tofu and fermented soybean (tempe) made of soybean seeds are the main component of daily dietary food. Indonesia needs 2.0 million tons of soybean per year, but the domestic production only meet 30% (Marwoto *et al.,* 2008), and therefore Indonesia is a net importer of soybean. The consumption of soy-based products has increased from 14.21 kg capita^{-1} year^{-1} in 2009 to 15.01 kg capita^{-1} year^{-1} (Sutyorini and Waryanto, 2013). Despite increasing the soybean productivity, expanding the production area to suboptimal land such as tidal land has become the target of Indonesian government.

Sudana (2005) reported that potential of tidal land for agriculture in Indonesia is approximately 9.5 million ha and spread in Sumatra (3.9 million ha), Papua (2.8 million ha) and Kalimantan (2.7 million ha). The total of tidal land cultivated it here claimed by the local residents or the government through transmigration program was about 44% of total area.

The main constraints of tidal land for plant growth are water-saturated and anaerobic condition in rhizosphere; presence of pyrite or sulfidic materials; toxicity of Al, Fe and Mn; very acid soil reaction; and low N, P, K, Ca and Mg contents (Muhrizal *et al*., 2006; Kawahigashi *et al*., 2008; Anda *et al*., 2009). Oxidation of pyrite increases concentration of Al, Mn and Fe^{3+}, as well as decreases soil pH and macro nutrients availability. Rising groundwater to the surface due to water logged conditions increased soil pH and reduced toxicity of Al and Mn, solubilized Fe^{2+}, H_2S, CO_2 and organic acids in water that are potentially toxic to the plants (Konsten *et al*., 1994; Shamshuddin *et al*., 2004; Anda and Subardja, 2013).

Beside facing excess water problem, soybean cultivation on tidal land had low soil fertility, very high soil acidity (pH 3-4), deficiency of macro (Ca, P, K, Mg) and micro (Cu and Zn) nutrients and the presence of toxic elements of Al^{3+}, Fe^{2+}, and SO_4^{2+} (Saragih *et al*., 2001). Lime, organic matter and fertilizers application reduced soil acidity, Al toxicity and nutrient deficiency (Chao *et al*., 2014). Lime application is very prominent

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and there are some methods to calculate the lime. However, the method and the amount of lime applied on tidal land to increase soybean yields have not yet been studied**.** The research therefore, was aimed to determine the method of calculating and applying of lime requirement for soybean on tidal land.

MATERIALS AND METHODS

Location and Experimental Set Up

The research was conducted on C-type tidal land at Simpang Jaya village, Wanaraya sub district, Barito Kuala district, South Kalimantan province in 2012. Treatment consisted of two factors that were arranged in random complete block design, and replicated three times. The first factor was calculating the method of lime requirement: (1) no liming, (2) liming based on 10% of Al saturation, (3) liming based on 20% of Al saturation, (4) liming based on 30% of Al saturation, (5) liming based on 0.5 x exchangeable Al and (6) liming based on 1 x exchangeable Al. The second factor was the application method: (1) spread on soil surface and (2) mixed within 20 cm soil depth. Dolomite was used as lime material, and it was applied one week before planting. The soybean seed of Argomulyo variety was sown with two seeds per hole on plot sizing of 3 m by 4 m with 40 cm and 15 cm intra row spacing. Phonska fertilizer (15% N-15% P_2O_5-15% K_2O) at rate of 300 kg ha^{-1} was basally applied at planting time. Weeding was done in 15th days after sowing (DAS) and 45 DAS. Pest and disease monitored regularly and controlled using chemical pesticide.

Observation and Data Analysis

The observed parameters were initial and post harvest soil analysis that consisted of soil pH (electrode, 1 : 2.5); total N (Kjedhal method); available P (Bray I method); organic C (Kurmis method); exchangeable K, Ca, Mg and Na (saturation of 1 N NH_4 Acetatep H7); exchangeable Al and H (1 N KCl extraction); available SO_4 and Fe (DTPA extraction). The observed crop parameters were plant height, number of pods $plant^{-1}$, seed weight $plant^{-1}$ and 100 seeds weight.

Analysis of variance of crop data was processed using Mstat-C and mean comparison with Duncan Multiple Range Test (DMRT) at 5% probability. Linear regression and correlation as well as graphical presentation were performed using Microsoft Excel Program.

RESULTS AND DISCUSSION

Soil Properties

The soil on experimental site was very acidic, poor in macro nutrient, rich in toxic element such as Al and Fe, very high in C-organic content and moderate total N content (Table 1).

Table 1. Chemical properties of soil on tidal land in South Kalimantan, Indonesia

Soil variable	Value	Criteria*)
pH-H_2O	4.20	Very acid
C-organic (%)	5.47	Very High
N-total (%)	0.25	Moderate
C/N ratio	21.9	-
P-Bray I (ppm P_2O_5)	6.16	Very Low
K-exchange (cmol(+) kg^{-1})	0.36	Low
Na-exchange (cmol(+) kg^{-1})	0.14	Low
Ca-exchange (cmol(+) kg^{-1})	0.48	Very Low
Mg-exchange (cmol(+) kg^{-1})	0.27	Very Low
Al-exchange (cmol(+) kg^{-1})	5.48	-
H-exchange (cmol(+) kg^{-1})	3.85	-
Al saturation (%)	52	Very high
Fe (ppm)	25.4	High
Mn (ppm)	1.40	Moderate

Remarks: *) Indonesian Center for Agricultural Soil Resources Research and Development (ICALRD) (2009)

Table 2. Effect of lime rate and application method on soybean plant height on tidal land in South Kalimantan

Lime rate	Plant height (cm)		Means[1)]
	Surface application	Mixed within 20 cm soil depth	
No lime	55.5	54.5	55.0
10% of Al saturation	56.6	61.9	59.3
20% of Al saturation	52.5	60.1	56.3
30% of Al saturation	53.3	56.1	54.7
0.5 x Al-exchangeable	51.0	53.7	52.4
1.0 x Al-exchangeable	45.4	55.1	50.3
Means[1)]	52.4 b	56.6 a	

Remarks: [1)] Means in same row followed by same letter were not significantly different based on Duncan Multiple Range Test at 5% level

Table 3. Effect of lime rate and application method on number of pods plant^{-1} on tidal land in South Kalimantan

Lime rate	Number of pods plant^{-1}		Means[1)]
	Surface application	Mixed within 20 cm soil depth	
No lime	13.8	12.9	12.8 b
10% of Al saturation	18.4	20.4	19.4 a
20% of Al saturation	18.8	21.3	20.1 a
30% of Al saturation	19.1	20.2	19.7 a
0.5 x Al-exchangeable	19.2	18.5	18.8 a
1.0 x Al-exchangeable	17.7	22.9	20.3 a
Means	18.2	18.8	

Remarks: [1)] Means in same column followed by same letter were not significantly different based on Duncan Multiple Range Test at 5% level

Organic carbon to N ratio of 21.9 indicated that the organic matter decomposition and mineralization inhibited. Water table at the site was between 30 cm and 40 cm from soil surface. In this condition, decomposition and mineralization of organic matter were inhibited, and so that low soil N content. Agehara and Warncke (2005) reported that soil moisture has an effect on mineralization of organic matter. Tidal land is a flooded area, caused low microorganisms population (Unger *et al*., 2009). Microorganism responsible for organic matter decomposition, low of microorganism decrease of organic matter decomposition (Bossio *et al*., 2006).

Acidic soil reaction with Al saturation level above 50% was potentially toxic to soybean. Al toxicity causes direct damage to the root system (Schuch *et al.*, 2010; Silva *et al*., 2010). Aluminum which is located around the roots will hinder meristem cell division section and will stop the extension of the root sand causes root penetration weak (Pavlovkin *et al.*, 2009). While at the cellular level, the large of Al in plants can disrupt cell division, the protoplasm, the cell wall, reduction of membrane and DNA synthesis. At the high Al concentration on soybean plants can cause plasmolysis and rupture the cell walls (Yu *et al.*, 2011). Optimum soil pH for soybean growth was 6.8, and the critical value ranged from 4.0 to 5.5 (Follet *et al*., 1981). Sumarno and Manshuri (2007) suggested that optimum soil pH for soybean was 6.0 to 6.5. Critical value of Al saturation for soybean was 20% (Hartatik and Adiningsih, 1987). Critical limit to Al toxicity of some Indonesian soybean varieties ranged from 0.55 to 1.33 me Al.100 g^{-1} (Wijanarko, 2005; Hanum *et al*., 2007). The P content in the soil was very low, the critical value of P for soybeans growth was 7 ppm P (Tandon and Kimmo, 1993), while according to Franzen (2013) was between 6-10 ppm P. It can be concluded that the soil is not suitable for growing soybean and liming is important to improve soil fertility.

Effect of Lime Application on Soybean Growth and Yield

Plant height at harvest was affected significanly by lime application, while lime rates and its interaction did not significantly affectplant height. Liming by mixing dolomite with soil within

20 cm depth resulted in 8% higher plant height compared to that applied on the soil surface (Table 2).

Number of pods per plant was significantly affected by lime rate. There were no significant effect of methods of lime application and its interaction with lime rate for number of pods per plant (Table 3). Liming increased number of pods by 48-49% compared with no lime application. It means that lime rate calculated based on Al saturation and Al-exchangeable had similar effectiveness. According to Taufiq *et al.* (2011) application of 750 kg ha^{-1} dolomite on tidal land increased plant height, number of pods $plant^{-1}$, and yield by 11.6%, 36.0% and 24.5% compared to no dolomite, respectively. Furthermore Costa and Rosolem (2007) reported that liming equivalent to 2.25 t ha^{-1} on acid soil (pH 4.5) decreased Al-exchangeable and increased soybean yield about 20% compared no liming.

Soybean seed yield was affected significantly by interaction between lime rate and methods of lime application. It means that lime required to produce optimum seed yield depended on method of lime application. Highest yield was obtained when liming at rate equivalent to 10% of Al saturation was mixed with soil within 20 cm depth (Table 4). Incorporation of lime at that rate increased seed yield by 166-188% compared to without lime application. Decreasing lime rates from equivalent to 10% of Al saturation to 20% and 30% of Al saturation decreased soybean yield by 36% and 51%, respectively. The results indicated that liming with very high Al saturation had an important role in increasing soybean yield on tidal land, and maximizing yield required high rate of lime. Lime has been known as effective ameliorant to reduce soil acidity, decrease exchangeable Al as well as Al saturation (Caires *et al*., 2008; Sadiq and Babagana, 2012; Chimdi *et al*., 2012).

Application of lime by mixing within 20 cm of soil depth gave better effect than by surface application as shown by 21% yield increase. Lime will quickly react with soil when incorporated into soil, and so simultaneously improved soil chemical properties. In contrast, on surface application, the vertical movement of $CaCO_3$ was very slow, and OH^- released was quickly neutralized by soil acidity which left Ca^{2+}. Ca^{2+} ions could be absorbed by soil coloid. Therefore, application of $CaCO_3$ or $Ca(OH)_2$ on soil surface had little effect on Al and/or soil Ca concentration in the subsoil (Ernami *et al*., 2004). Therefore, acidic subsoil could be effectively improved by incorporating the lime into subsoil. Some researchers showed that thelime incorporation in sub soils increased soil pH, decreased of Al-exchangeable and Al saturation and increased growth and yield of crops (de Oliveira and Pavan, 1996; Caires *et al*., 2008; Nora *et al*., 2014). It should be informed that the mobility of lime on acidic soil depended on the amount and time of lime application, soil type, soil pH, fertilizer management, climate and crop cultivation (Gascho and Parker, 2001; Conyers *et al.,* 2003; Ernani *et al.,* 2004; Caires *et al.,* 2005).

Table 4. Effect of lime rate and application method on soybean seed yield (kg ha^{-1}) on tidal land in South Kalimantan

Lime rate	Soybean seed yield (kg ha^{-1})		Means
	Surface application[1)]	Mixed within 20 cm soil depth	
No lime	632 e	746 de	689
10% of Al saturation	1,294 c	2,151 a	1,722
20% of Al saturation	1,293 c	1,575 bc	1,434
30% of Al saturation	1,178 cd	1,423 c	1,301
0.5 x Al-exchangeable	1,228 cd	1,048 cde	1,138
1.0 x Al-exchangeable	1,238 cd	1,985 ab	1,612
Means	1,190	1,441	

Remarks: [1)] Values in same column followed by same letter were not significantly different based on Duncan Multiple Range Test at 5% level

Table 5. Effect of lime rate and application method on 100 seeds weight (g) on tidal land in South Kalimantan

Lime rate	100 seeds weight (g)		Means[1)]
	Surface application[1)]	Mixed into 20 cm soil depth	
No lime	15.0	15.5	15.3
10% of Al saturation	17.0	17.1	16.7
20% of Al saturation	17.0	16.5	17.1
30% of Al saturation	15.2	16.9	16.1
0.5 x Al-exchangeable	15.5	16.9	16.2
1.0 x Al-exchangeable	16.0	16.3	16.1
Means	15.9	16.6	

Remarks: [1)] Means followed by same letter were not significantly different based on Duncan Multiple Range Test at 5% level

Table 6. Effect of lime rate and application method on pH, N-total, C-organic, P-Bray I and K-exchangeable on tidal land, South Kalimantan

Lime rate	pH		N (%)		C-organic (%)		P (ppm)		K (cmol(+) kg^{-1})	
	A[1)]	B	A	B	A	B	A	B	A	B
No lime	4.3	4.4	0.41	0.41	5.26	5.28	17.47	14.72	0.35	0.33
10% of Al saturation	4.5	4.5	0.44	0.45	6.52	6.35	20.83	38.86	0.42	0.84
20% of Al saturation	4.4	4.5	0.42	0.45	6.49	6.33	22.90	28.54	0.56	0.52
30% of Al saturation	4.5	4.5	0.43	0.44	6.33	6.33	39.72	35.95	0.50	0.64
0.5 x Al-exchangeable	4.6	4.6	0.42	0.44	6.32	6.28	36.68	35.80	0.33	0.56
1.0 x Al-exchangeable	4.5	4.6	0.40	0.44	6.37	6.37	35.59	33.63	0.48	0.75
Means	4.47	4.52	0.42	0.43	6.22	6.16	28.87	31.25	0.44	0.61

Remarks: [1)] A = Surface application; B = Mixed into 20 cm soil depth

Table 7. Effect of lime rate and application method on Ca, Mg, Al-exchangeable and Al saturation on tidal land, South Kalimantan

Lime rate	Ca (cmol (+). kg^{-1})		Mg (cmol (+). kg^{-1})		Al-exchangeable (cmol (+). kg^{-1})		Al-Sat (%)	
	A[1)]	B	A	B	A	B	A	B
No lime	2.78	2.72	0.30	0.32	3.10	3.16	47.47	48.39
10% of Al saturation	2.87	3.63	0.47	0.49	0.75	0.50	16.63	9.16
20% of Al saturation	3.21	3.43	0.45	0.46	1.19	1.09	22.00	19.82
30% of Al saturation	2.85	3.42	0.46	0.48	2.25	2.05	37.13	31.11
0.5 x Al-exchangeable	3.54	3.12	0.48	0.47	2.85	2.16	39.58	34.23
1.0 x Al-exchangeable	3.57	3.35	0.52	0.49	2.71	2.37	37.23	34.05
Means	3.14	3.28	0.45	0.45	3.26	3.05	44.72	41.27

Remarks: [1)] A: Surface application, B: Mixed into 20 cm soil depth

Application of lime into sub soil improved soil physical properties. Nora *et al.* (2014) reported that application of lime and gypsum into sub soil decreased bulk density and soil strength, and increased soybean yield by 18% compared to the control. Rhizosphere modification by lime, manure and sawdust stimulated root development and increased the yield of sorghum from 4,322 to 5,987 kg ha^{-1} (Bradford and Blanchar, 1977).

Lime rates and its application methods did not significantly affect 100 seeds weight (Table 5). Weight of 100 seeds of Argomulyo variety in this study ranged from 15.2 g to 17.1 g, and the value was in accordance with 100 seeds weight of normal growth of this variety (16 g.100 $seeds^{-1}$).

Effect of Lime Application on Soil Chemical Properties

Soil chemical analysis after harvest showed that liming both through surface application and incorporated into 20 cm soil depth increased soil pH, soil N, organic C, available P, exchangeable of K and Mg, decreased of Al-exchangeable and Al saturation compared with no lime treatment (Table 6 and 7). Liming by surface application could not improve subsoil chemical properties, because lime had low mobility. Caires *et al*. (2008) showed that liming increased Ca concentration and reduced Al-exchangeable and Al saturation at 20 cm and 40 cm soil depth after 9 months and two years of application, respectively. Although it takes a long time, the movement of lime into the deeper layers may occur through (1) the process complexes formation of Ca or Mg with soluble organic matter so that it can move to deeper soil layers, (2) the activity of organism, especially macrofauna and (3) lime with a microsize is relatively soluble (Miyazawa *et al*., 2002; Chan, 2003).

Table 8. Effect of lime rate and application method on available P at 10 and 30 cm soil depths on tidal land in South Kalimantan

Lime rate	Available P (ppm) on surface application			Available P (ppm) mixed into 20 soil depth		
	10 cm soil depth	30 cm soil depth	Increase (%)[1)]	10 cm soil depth	30 cm soil depth	Increase (%)[1)]
No lime	17.47	18.05	3.30	14.72	15.10	2.60
10% of Al saturation	20.83	28.10	20.50	38.86	52.30	34.60
20% of Al saturation	22.90	24.10	5.20	28.54	39.20	37.30
30% of Al saturation	39.72	45.30	14.00	35.95	50.20	39.60
0.5 x Al-exchangeable	36.68	40.20	9.60	35.80	52.30	46.10
1.0 x Al-exchangeable	35.59	39.80	11.80	33.63	48.30	43.60
Means	28.87	32.09	11.15	31.25	42.90	37.28

Remarks: [1)] Net P was computed from $P_{30cm} - P_{10cm}$

Table 9. Effect of lime rate and application method on Ca-exhangeableat 10 and 30 cm soil depth on tidal land in South Kalimantan

Lime rate	Ca exchangeable ($cmol^{(+)}.kg^{-1}$) on surface application			Ca exchangeable ($cmol^{(+)}.kg^{-1}$) on mixed into 20 soil depth		
	10 cm soil depth	30 cm soil depth	Increase (%)[1)]	10 cm soil depth	30 cm soil depth	Increase (%)[1)]
No lime	2.78	2.79	0.36	2.72	2.75	1.10
10% of Al saturation	2.87	2.91	1.39	3.63	3.96	9.09
20% of Al saturation	3.21	3.22	0.31	3.43	3.89	13.41
30% of Al saturation	2.85	2.89	1.40	3.42	3.76	9.94
0.5 x Al-exchangeable	3.54	3.60	1.69	3.12	3.69	18.27
1.0 x Al-exchangeable	3.57	3.61	1.12	3.35	3.75	11.94
Means	3.14	3.17	1.05	3.28	3.63	10.63

Remarks: [1)] Net Ca-exchangeable was computed from $Ca_{30cm} - Ca_{10cm}$

Table 10. Effect oflime rate and application method on Al saturation (%) at 10 and 30 cm soil depths on tidal land in South Kalimantan

Lime rate	Surface Application			Mixed into 20 soil depth		
	10 cm soil depth	30 cm soil depth	Decrease (%)[1)]	10 cm soil depth	30 cm soil depth	Decrease (%)[1)]
No lime	47.47	46.59	1.85	48.39	48.20	0.39
10% of Al saturation	16.63	15.96	4.02	9.16	8.10	11.57
20% of Al saturation	22.00	21.69	1.40	19.82	16.89	14.78
30% of Al saturation	37.13	38.90	4.76	31.11	25.60	17.71
0.5 x Al-exchangeable	39.58	37.29	5.78	34.23	32.50	5.05
1.0 x Al-exchangeable	37.23	35.89	3.59	34.05	27.90	18.06
Means	44.72	32.72	3.57	41.27	26.53	11.26

Remarks: [1)] Net Al saturationwas computed from $Al_{30cm} - Al_{10cm}$

Liming increased the P availability, both at 10 cm and 30 cm soil depth. Increasing of P availability was higher when lime was applied by mixing within 20 cm soil depth than by surface application by 37.3% and 11.2%, respectively (Table 8). Because of slow dissolution of lime, the incorporating of lime into the 20 cm soil depth will accelerate the presence of calcium in the deeper layers. In accordance with P, Ca concentration at 30 cm soil depth, they were increased by 9.6% (Table 9) while Al saturation reduced by 8% (Table 10), when lime incorporated within 20 cm soil depth compared to those obtained by surface application.

The Correlation between Observations

Lime application improved soybean growth and yield that correlated positively to the increasing availability of P and Ca (Figure 1 and Figure 2), and decreasing Al saturation (Figure 3). The correlation values were higher when lime was incorporated into 20 cm soil depth. This result implied that liming by incorporation into 20 cm soil depth was more effective and efficient in increasing nutrient availability and reducing Al-exchangeable and Al saturation. Liming increase bases cation dan soil pH. Alsolubility is strongly influenced by soil pH. Increase soil pH will decrease of Al solubility in soil (Ritchie, 1995).

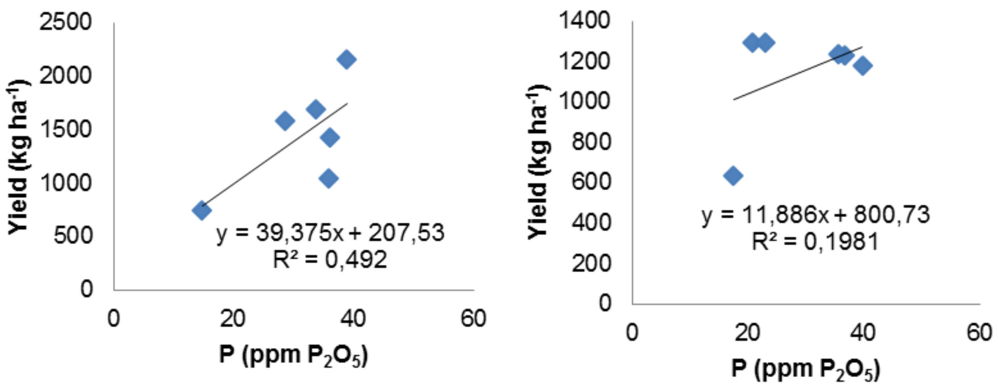

Figure 1. Correlation between soybean yields with available P (left: mixed into 20 soil depth, right: surface application)

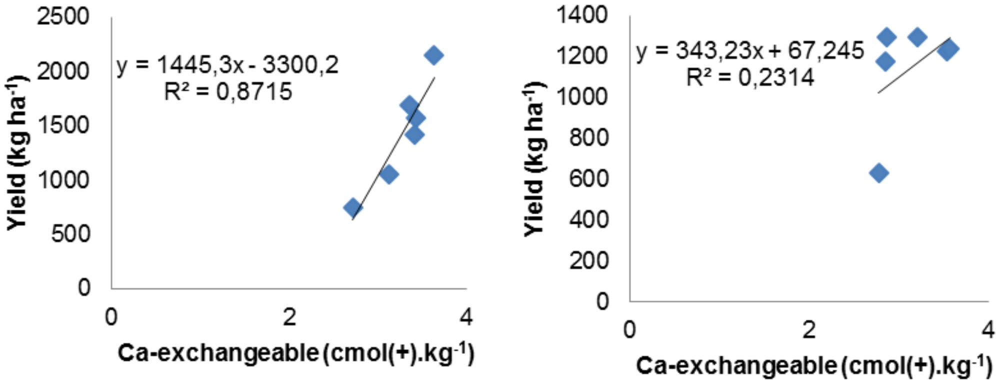

Figure 2. Correlation between soybean yields with exchangeable Ca (left: mixed into 20 soil depth, right: surface application)

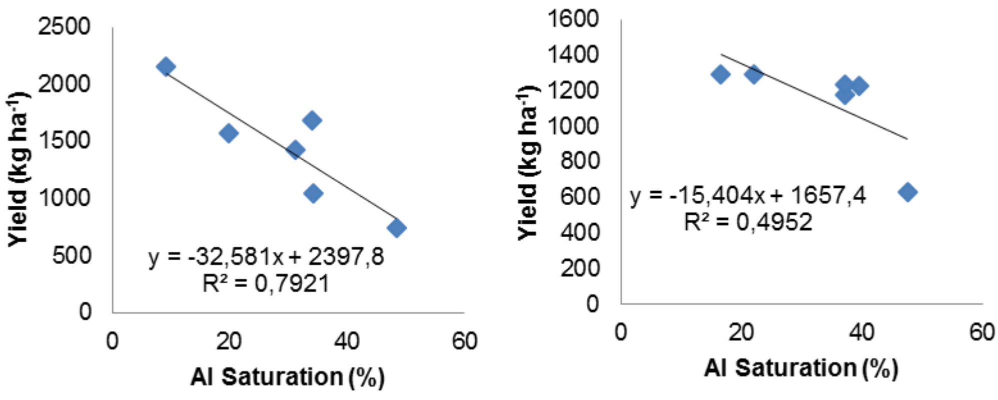

Figure 3. Correlation between soybean yields with Al saturation (left: mixed into 20 soil depth, right: surface application)

CONCLUSION

On tidal land at south Kalimantan, liming both by surface application and incorporation into 20 cm soil depth increased soil pH, soil N, organic C, available P, K and Mg-exchangeable, decreased Al-exchangeable and Al saturation. The improvement of chemical soil properties increased soybean yield. Lime application at the rate of equivalent to 10% of Aluminum saturation and applied by incorporated into 20cm soil depth gave the highest soybean yield.

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