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Application of Lime and Adaptable Variety to Increase Tomato Productivity at Potential Acid Sulphate Soil

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ABSTRACT

High soil acidity is the most important problem that causes low tomato (*Lycopersicum esculentum*) productivity at potential acid sulphate soil. Soil quality improvement by using ameliorant, such as lime, and introducing adaptable variety are options to increase tomato productivity in the soils. Field experiment was conducted to evaluate the effect of lime and varieties of tomatoes to increase its productivity in a potential acid sulphate soil of Belandean, Barito Kuala District, South Kalimantan during dry season of 2011. The research was arranged in a split-plot design with three replicates. The main plots were two tomatoes varieties, *i.e*. Permata and Ratna, while sub plots were five levels of lime, *i.e*: 0, 0.5, 1.0, 1.5, and 2.0 Mg ha^{-1}. The results showed that liming improved soil quality and tomato yield. It significantly increased soil pH and reduced soil Al-saturation, and increased soil exchangeable-Ca and Mg. It was assumed that due to pyrite oxidation, however, soil pH decreased and Al-saturation increased, while soil exchangeable-Ca and Mg decreased significantly at nine weeks after planting. Liming also increased plant growth and yield variables (plant height, size, number and weight of fruit, and fruit yield) for both varieties. The better variables of Permata variety at control treatment than those of Ratna variety indicated that the first variety was more adaptive than the other variety in potential acid sulphate soil.

***Keywords**:* Adaptable variety, lime, potential acid sulphate soil, tomato

INTRODUCTION

Tidal swampland is a land which has frequent floading all year around. It has several kinds of soil which is potential for agriculture, *i.e.*: potential acid sulphate soil, actual acid sulphate soil, peat/peaty soil, and saline soil. It is estimated that the total area of tidal swampland in Indonesia is about 20.1 million ha, where about 4.19 million ha have been reclaimed and only about 0.73 million ha have been cultivated (Widjaya Adhi *et al.* 1992). This indicated that Indonesia still has huge areas of lands which can be developed as agricultural production areas. Most of the swampland areas are spread over big islands of Sumatera, Kalimantan, Sulawesi, and Papua.

Local and transmigration farmers in tidal swampland cultivate the land with food crops, such as: rice, soybean, corn, as well as horticulture crops like citrus and vegetables. Several vegetables, such as: lettuce, eggplant, and tomato are grown in those areas but their yield are low. Low tomato yields in tidal swampland were related to many complex contrains, such as soil acidity (pH 3.0-4.0), nutrients deficiency (Ca, P, K, Mg) and Al toxicity (Alihamsyah and Noor 2003). Ryan and Delhaize (2010) reported that Al toxicity will occurred at pH < 5.5. Aluminium toxicity is the main stress factor for plant growth on acid sulphate soil. Acidic condition enhances the presence of trivalent cations (Al^{3+}) which are the most toxic of Al to plant (Kochian *et al.* 2005). Aluminium toxicity results an alteration of physiological and biochemical processes of plants and then to their productivity. Decrease in root growth is one of an initial and most evident symptoms of Al-toxicity. Then, upper organs may be also affected by Al phytotoxicity (Rengel and Zhang 2003).

To overcome the limitation of Al phytotoxicity, lime ameliorant is an agronomic practice which is commonly used to reduce acidity and Al-toxicity in acid soils. Amelioration is one of an effective technology to repair: (1) physical properties (enhancing granulation to increase aeration), (2) chemical properties (decreasing ion H, Fe, Al, and Mn, as well as increasing available-Ca, Mg, and P), and (3) biological properties (increasing microbacterial activities) (Soepardi 1983; Merifio *et al.* 2010). There are many studies reporting the beneficial Ca effect in ameliorating Al-toxicity in tidal swampland. Liming increased rice production (Indrayati *et al.*

2011), soybean production (Koesrini *et al.* 2011), corn production (Raihana *et al*. 2011) and snap bean production (Koesrini and William 2009) on tidal swampland.

Planting horticulture crops has developed at potential acid sulphate soils. Its economic value can increase farmer income. Tomato is potentially developed in this soil. Introducing adaptable variety can increase yields. Koesrini and William (2009) reported that using adaptable variety of Snapbean (Bravo) increased yield 30% higher than sensitive variety (Perkasa) on these soils. They also reported that combination between amelioration and variety improved land quality and its productivity in the soil.

The objective of this research was to evaluate the effect of lime and tomato variety on the tomato productivity at potential acid sulphate soil.

MATERIALS AND METHODS

This research was conducted at Experimental Station of Belandean, Barito Kuala District, South Kalimantan (S03°10' E114°31') at dry season of 2011. Tipology of the site was potentially acid sulphate soil with water flooding type B. Initial soil analyses are described at Table 1. The research was arranged in a split-plot design with three replicates. The main plots were two tomato varieties, *i.e*. Permata and Ratna varieties, while sub plots were five levels of lime, *i.e*.: 0, 0.5, 1.0, 1.5, and 2.0 Mg ha^{-1}.

Land preparation was done manually consisting of cleaning areal from weeds, and pluging the soil until ready to plant. Plotting areal was according to treatment design. Every plot had size of 3 x 5 m and plant space of 0.75 x 0.50 m (50 plant $plot^{-1}$). Making hole was according to plant space, then at every hole, ameliorant with dosage according the treatment was given two weeks before planting. Tomatoes seedling which had three-four foliar were ready to plant. Base fertilization with dosages of 54 kg N + 100 kg P_2O_5 + 50 kg K_2O ha^{-1} were applied, while the second fertilizations were applied at four weeks after planting (WAP) with a dosage of 54 kg N ha^{-1}. Intensive plant management was done to obtain optimum growth, while harvest was done gradually on ripe fruit.

Observation on soil chemical properties consisted of soil analysis before experiment, 3, and 9 WAP, while plant variables were 3, 6, and 9 WAP. The first variables were soil pH (H_2O), organic-C, exchangeable-Ca, Mg, K, Al, and H, as well as CEC (Cations Exchange Capacity). Observation on plant variables consisted of plant height at 3, 6 and 9 WAP, fruit number/plant, fruit weight, fruit length, fruit diameter, and fruit yield**.** Data were analyzed by using anova. If significance exist they were then tested with a *Duncan's Multiple Range Test (DMRT).*

RESULTS AND DISCUSSION

Soil Chemical Properties

The main constraints of tidal swampland were high soil acidity, nutrient deficiency on macro element, especially Ca, and high Al-saturation. These were reflected from initial soil analysis data which is shown at Table 1. It showed that the main problems of the soil in this site were soil acidity (pH = 3.29), low soil exchangeable-Ca, Mg, and K (0.56, 0.65, and 0.18 $Cmol^{(+)}kg^{-1}$ respectively) and high Al saturation (55%). High soil acidity and Al saturation had negative effect on plant growth and yield. Poschenrieder *et al.* (2008) reported that Al inhibits the absorption of nutrient, especially Ca, Mg, Fe and Mo and less available P. The low macro nutrients (Ca, Mg, and K) content resulted deficiency of the

Table 1. Initial soil analyses at potential acid sulphate soil in Experimental Station of Belandean, Barito Kuala District, South Kalimantan.

Soil properties	Unit	Value	Criteria*
pH H_2O		3.29	Very acid
Organic-C	%	3.39	High
Exchangeable Ca	$Cmol^{(+)}kg^{-1}$	0.56	Very low
Exchangeable Mg	$Cmol^{(+)}kg^{-1}$	0.65	Low
Exchangeable K	$Cmol^{(+)}kg^{-1}$	0.18	Low
Exchangeable Na	$Cmol^{(+)}kg^{-1}$	0.20	Low
Exchangeable Al	$Cmol^{(+)}kg^{-1}$	2.75	-
Exchangeable H	$Cmol^{(+)}kg^{-1}$	0.65	-
Cations Exchange Capacity	$Cmol^{(+)}kg^{-1}$	28.3	High
Al saturation	%	55.0	High

*Criteria by Soil Center Research (1983).

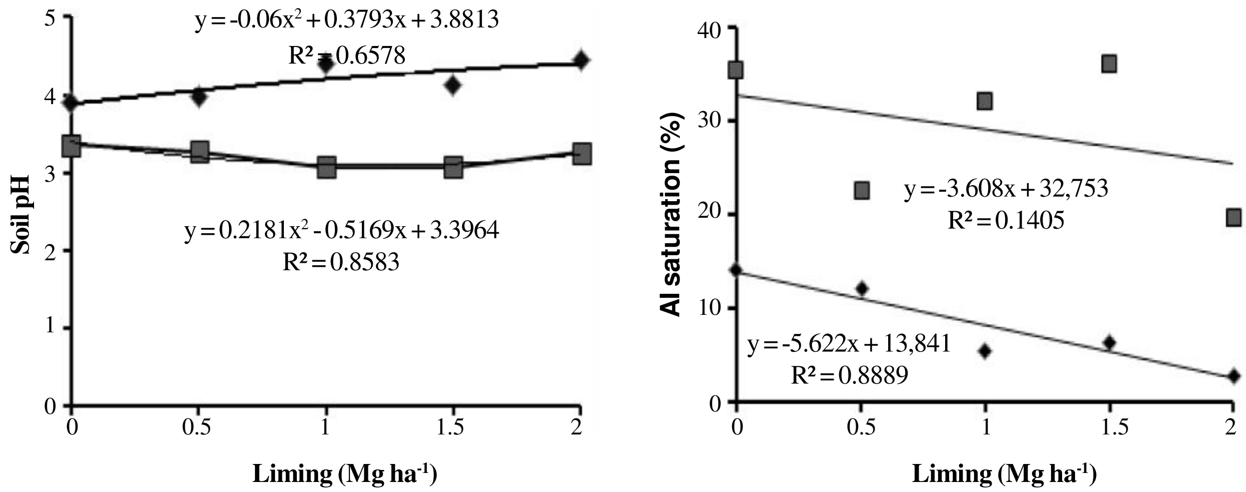

Figure 1. Effect of liming on soil pH and Al saturation of acid sulphate soil of Belandean, Barito Kuala District, South Kalimantan. ◆ : 3 WAP, ■ : 9 WAP.

nutrients for plant growth. Thus, site specific technology were required to overcome the problems.

Application of lime was one of technologies which could improve soil fertility. It significantly increased soil pH (R^2 = 0.657) and decreased Al saturation (R^2 = 0.888) at 3 WAP. While at 9 WAP, the application did not significantly effect both variables. The application of lime until 2 Mg ha^{-1} increased soil pH from 3.89 to 4.46 at 3 WAP. Soil Al- saturation decreased from 14.20 to 2.92% with lime until 2 Mg ha^{-1} at 3 WAP. Average soil pH at 3 WAP was higher than that of at 9 WAP, while soil Al-saturation at 3 WAP was lower than that of at 9 WAP (Figure 1). Mora *et al.* (2006) reported that the major direct benefits of liming was the increasing pH, particularly those having level below 5.0-5.5. Hanson and Berkheimer (2004) also reported that adding lime 1.100 kg ha^{-1} in the field caused the soil pH values increased from 4.2 to 5.0. Other benefits of liming was decreasing toxic concentrations of Al (Caires *et al.* 2006) and alleviating Al toxicity (Illera *et al.* 2004). Application of lime did not significantly affect soil exchangeable-K at both 3 WAP (R^2 = 0.450) and 9 WAP (R^2 = 0.256). But it significantly increased soil exchangeable-Ca at both 3 WAP (R^2 = 0.914) and 9 WAP (R^2 = 0.999) as well as significantly increased soil exchangeable-Mg at both 3 WAP (R^2 = 0.991) and 9 WAP (R^2 = 0.525). Lime application until 2 t ha^{-1} increased soil exchangeable-Ca from 7.61 to 21.58 $Cmol^{(+)}kg^{-1}$ at 3 WAP as well as from 0.72 to 1.21 $Cmol^{(+)}kg^{-1}$ at 9 WAP. Soil exchangeable-Mg also increased from 2.20 to 8.76 $Cmol^{(+)}kg^{-1}$ at 3 WAP and from 0.21 to 0.30 at 9 WAP by using lime until 2 Mg ha^{-1}. Average of soil K, Ca, and Mg at 3 WAP was higher than those of at 9 WAP (Figure 2). Mora *et al.* (2002) also reported that the benefits of liming was restoring available Ca for plant.

Application of lime in the soil will increase Ca and Mg in both soil solution and soil adsorption complex so that the exchangeable-Ca and Mg increase as shown at reaction equation (1). The CO_3^{2-} will realize hydrolysis with water molecules and produce OH^- which cause soil pH increase (Equation 2). Then, Al^{3+} in both soil solution and adsorption complex react with OH^- resulting $Al(OH)_3$ (Equation 3) so that exchangeable-Al and Al-saturation decrease.

$$Ca\,Mg(CO_3)_2 \rightleftharpoons Ca^{2+} + Mg^{2+} + 2\,CO_3^{2-}. \quad .....(1)$$

$$2\,CO_3^{2-} + 4\,H_2O \rightleftharpoons 2\,H_2CO_3 + 4OH^- \quad ....(2)$$

$$3\,Al^{3+} + 3OH^- \rightleftharpoons Al(OH)_3 \quad ....(3)$$

The same results had been reported by Koesrini and William (2009) in farming snap bean at acid sulphate soil. Lime application significantly increased soil pH, *i.e.* from 3.44 to 4.93 (increase of 43.4%) and exchangeable-Ca from 0.41 to 15.19 $Cmol^{(+)}$ kg^{-1} (3,604%) at acid sulphate soil. Koesrini *et al.* (2011) also reported that liming improved soil fertility through increasing soil pH and decreasing soil Al-saturation as well as increased soybean yield at the same soil.

There were very significant changes of soil condition (soil chemical properties) from 3 WAP to 9 WAP. Average of soil pH decreased from 4.17 to 3.21, while average of soil Al- saturation increased from 8.22 to 61.27% (Figure 1). Other cations, *i.e.* average of soil exchangeable-K also decreased from 1.70 to 0.25 $Cmol^{(+)}kg^{-1}$, Ca from 14.56 to 0.88 $Cmol^{(+)}kg^{-1}$, and Mg from 6.00 to 0.25 $Cmol^{(+)}kg^{-1}$ (Figure 2). These phenomena indicated that pyrite

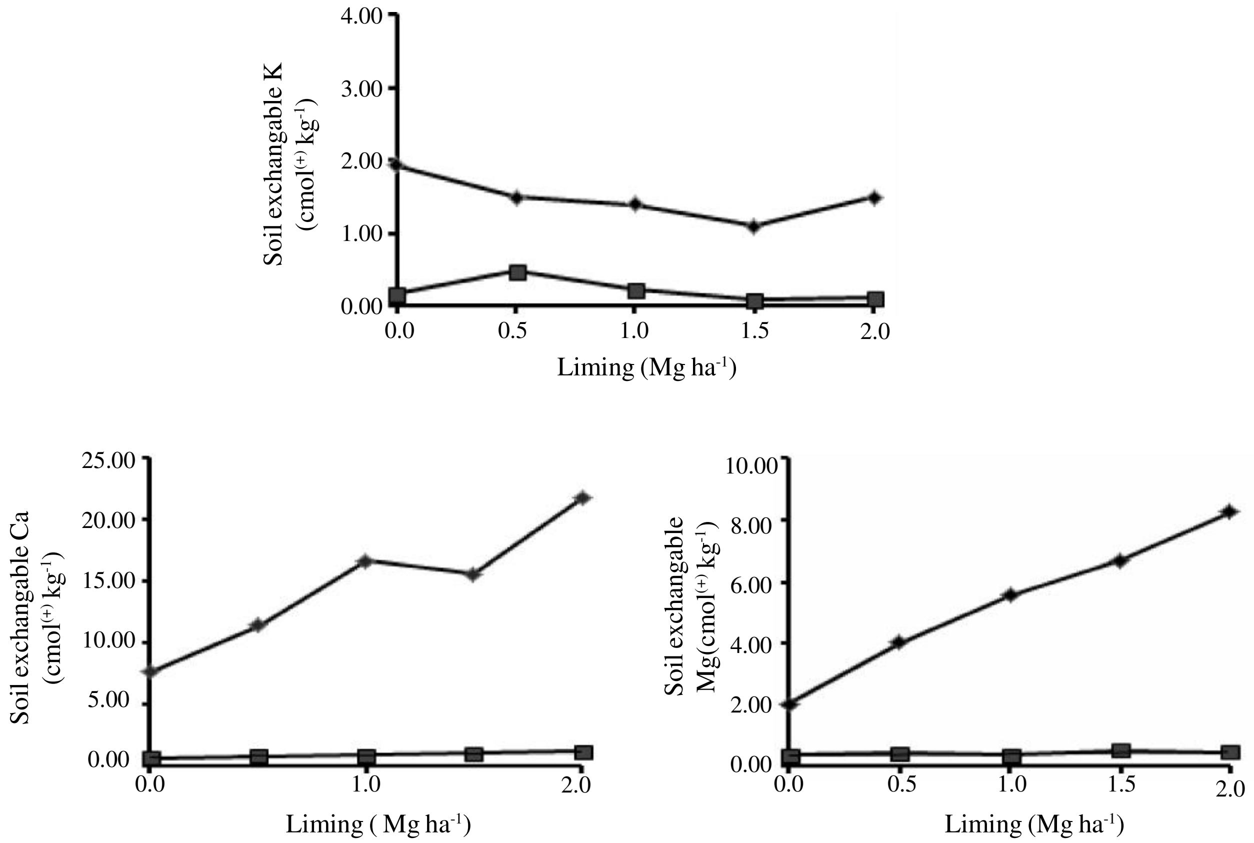

Figure 2. Effect of liming on soil exchangeable-K, Ca, and Mg of acid sulphate soil of Belandean, Barito Kula District, South Kalimantan. 3 WAP: —◆—, 9 WAP: —■—.

compound in the soil might be oxidized producing soil acidity. In addition, in line with running time, the effect of lime also declined because OH^- from lime was neutralized by H^+ from pyrite oxidation.

Farming tomato crop at potential acid sulphate soil needs aerobic condition in order to plant roots grow well. To achieve this purpose, we had to drain excess water so that water table decrease. This condition bring about pyrite to be oxidized resulting sulphate acid which may make the soil more acid with soil pH around 3.0. Konsten *et al.* (1994) described this phenomena with Equation 4 and 5. At acidic condition, Al will be released to soil solution so that Al-saturation increases, conversely Ca and Mg decrease.

$$2\,FeS_2 + 7\,O_2 + 2\,H_2O \rightleftarrows 2\,Fe^{2+} + 4\,H_2SO_4 \quad .....(4)$$

$$H_2SO_4 \rightleftarrows 2\,H^+ + SO_4^{2-} \quad ....(5)$$

Plant Growth

Scoring on vegetative and generative phase showed that both tomato varieties had good adaptability to high soil acidity (pH<5.5) and Al saturation (55%) (data not shown). Dierolf *et al.* (2001) classified crop tolerance to Al-saturation into three groups, *i.e.* low tolerance, tolerance, and high tolerance plants. Crop was categorized as low tolerance when it could grow well at Al-saturation of 0-40%; tolerance plant at 40-70%, and high tolerance plants at greater than 70%. According to this classification, tomato was categorized to tolerance crop at potential acid sulphate soil. At field experiment, plant performance showed that it could grow well at soil condition with initial pH of 3.29 and Al-saturation of 55% and its growth was normal.

Acidic condition enhances the presence of trivalent cation (Al^{3+}) (Kochian *et al.* 2005), which is the most toxic of all Al species available to plant. Al-toxicity resuts in alterations of the physiological and biochemical processes of plant and its productivity (Mora *et al.* 2006). Effect of liming and variety on plant height of tomato grown at acid sulphate soil was presented at Figure 3. It showed that in line with time, plant height increased from 3 WAP to 6 WAP and 9 WAP at both varieties of Permata and Ratna. Liming increased plant height at observation time of 3 WAP, 6 WAP, and 9 WAP of both varieties. Plant height of Permata was higher than that of Ratna at all observation time. Performance and vigor of plant growth of Permata in the field was better than that of Ratna.

Increase of plant height of both tomato varieties with liming was very close relationship with improving soil characteristics, such as soil pH, Al-saturation, exchangeable- Ca and Mg by application

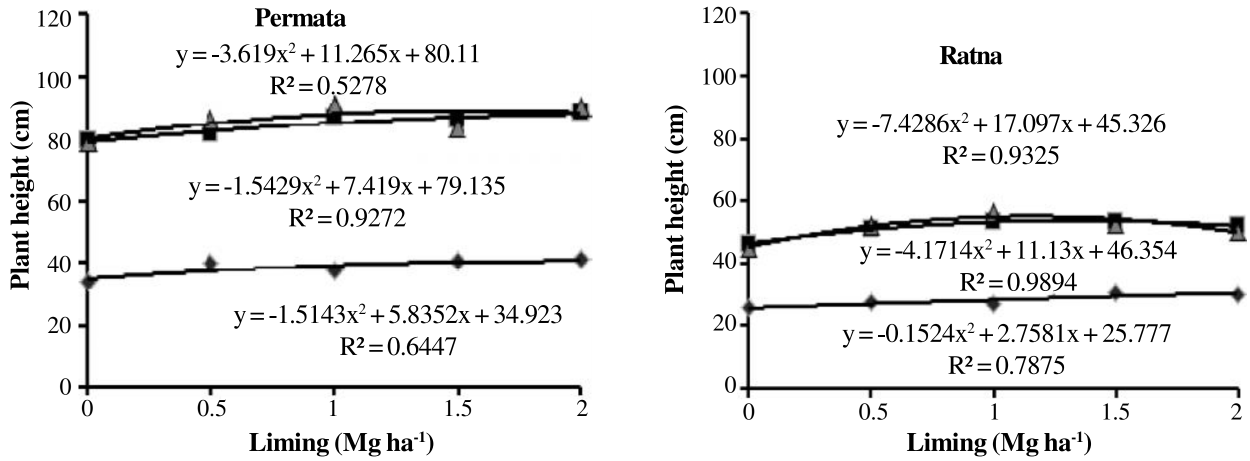

Figure 3. The Effect of liming and varieties on plant height of tomato grown on acid sulphate soil of Belandean, Barito Kula District, South Kalimantan. ◆: 3 WAP, ■: 6 WAP, ▲: 9 WAP.

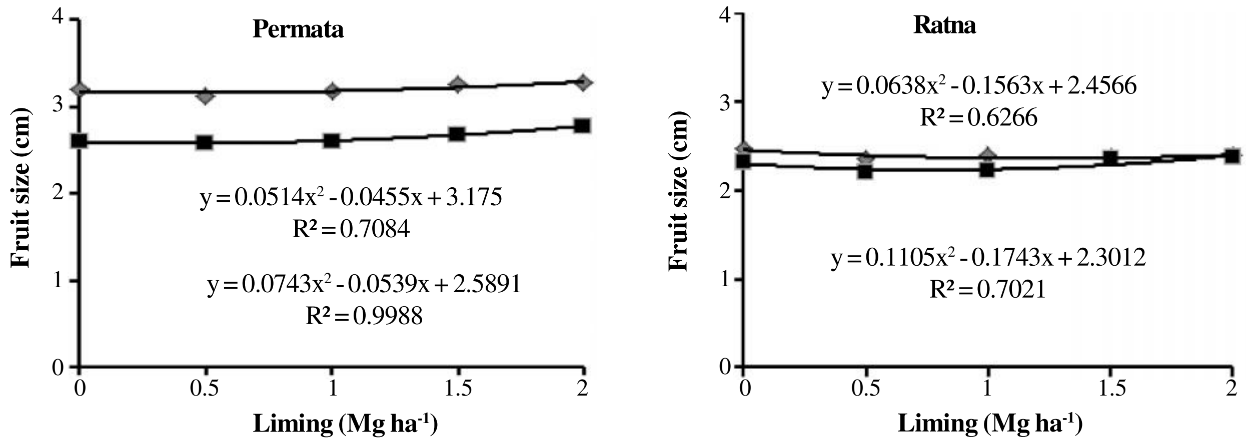

Figure 4. The Effect of liming and varieties on fruits size of tomato grown on acid sulphate soil of Belandean, Barito Kula District, South Kalimantan. ◆: Lenght, ■: Diameter.

of the lime (Figure 1 and 2). The soil improvement stimulated plant growth of the varieties. Plant growth of Permata which was better than Ratna indicated that Permata was more adaptive on acid sulphate soil condition than Ratna.

Similar to plant height (Figure 3), liming also increased fruits size (fruits length and diameter) on both varieties (Figure 4). The variables on Permata was higher than those of Ratna. Increase of fruits size with liming treatment and more bigger in Permata than Ratna were caused by same reasons with increase of plant height. It means that liming did not only increase plant height, but also improved quantity and quality of tomato. High Al concentration as Al^{3+} represents typical condition of acid sulphate soil which will effect on crops growth in the soils. The most recognized effect of Al-toxicity to plant was observed on roots, and upper part of plant (stems, leaves and fruits). The plant height and fruits size of Permata were higher than those of Ratna at all observation times. This indicated that Permata was more adaptive to soil acidity and high Al saturation than Ratna. In actual acid sulphate soil, this variety also had better adaptation than Ratna and Paduka varieties (Koesrini and Pangaribuan 2009). They also reported that appearance of Permata had solid stems, high yield, and quite tolerant to bacterial wilt disease which is commonly affected tomato.

In line with other growth variables, liming also increased number of fruits/plant and weight of fruit/ each fruit of both varieties (Figure 5). The variables of Permata was also higher than those of Ratna. The increase of both variables with lime application and a more number of fruit/plant and weigh of fruit of Permata than Ratna were caused by same reasons as mentioned above. The first plant responses to Al-toxicity was damage in root system resulting in a decrease of nutrient uptake (Wang *et al*. 2006) and also affected upper organs (Peixoto *et al*. 2002). It was reflected by plant height (Figure 3), fruit size (Figure 4), and number of fruit/plant as

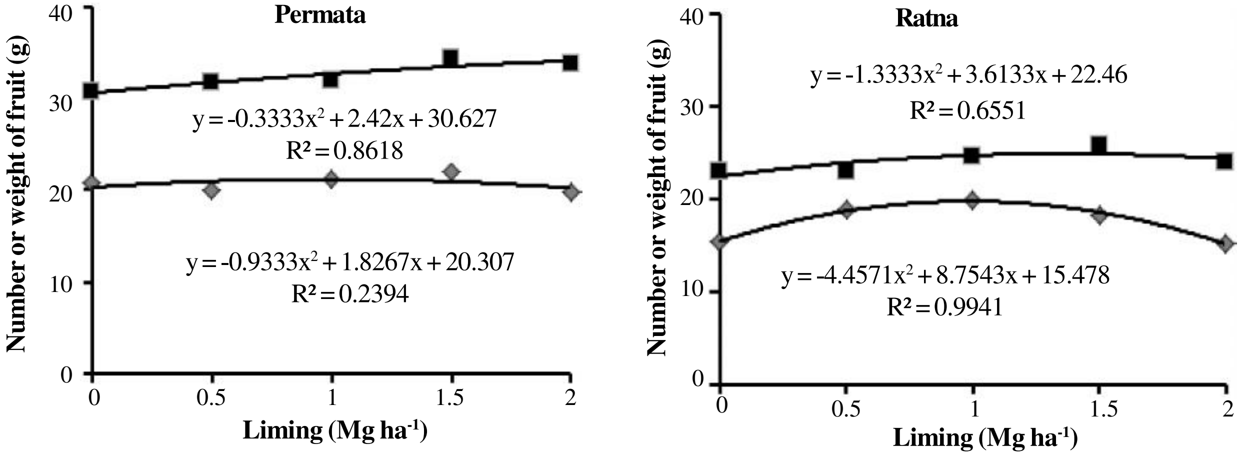

Figure 5. The Effect of liming and varieties on number and weight of fruit of tomato grown on acid sulphate soil of Belandean, Barito Kula District, South Kalimantan. ◆: Fruits number/plant, ■: Fruit weight (g).

well as weight of fruit (Figure 5) at control, all were lower than those of lime treatment. Liming application may decrease the negative effect of Al-toxicity, because liming reduces soil acidity as well as Ca and Mg sources for plant growth. As a divalent cation, Ca^{2+} plays an important role in cell wall structure and cell membranes, while Mg as a part of chlorophyll for photosynthesis. Ca is also participated in root and stem elongation (White and Brodley 2003).

Plant Yields

Effect of liming and varieties on plant yield of tomato grown at acid sulphate soil is presented at Figure 6. Variant analysis results of the yield and interaction between varieties tested and liming application are presented at Table 2. The figure showes that liming significantly increased yield of both tested varieties, while the table indicated that mean yield of Permata was significantly higher than that of Ratna variety. Permata variety was more tolerant to soil acidity and high Al saturation than Ratna variety. In control condition, this variety produced 10.060 Mg ha^{-1} of fresh fruit, while Ratna variety was only 4.754 Mg ha^{-1}. The different yield between Permata and Ratna varieties was so high, *i.e.* 5.306 Mg. These differences was a tendency that the increase of applied lime quantity increased these different yield. The highest differences occurred at 2,0 Mg ha^{-1} treatment, *i.e.* 9.077 Mg ha^{-1}. Mean yield of Permata and Ratna varieties were 12.473 and 6.624 Mg ha^{-1}, respectively (Table 2) or the first variety was about 88.3% higher than the other variety. Koesrini and Pangaribuan (2009) also reported a similar result that the adaptation and yield of Permata variety was better than those of Ratna and Paduka at actual acid sulphate soil. They reported further that Permata variety yielded 11.49 Mg ha^{-1}, while Ratna and Paduka varieties only yielded 9.10 and 0.16 Mg ha^{-1}, respectively.

Many studies reported that there were many beneficial Ca effects in ameliorating Al toxicity with different crops grown at acid soils. Wang *et al.* (2000) reported that weight of each organ of tomato cultivated at acid soil (pH 4.4) was smaller than that cultivated at neutral soil (pH 6.2). This indicated that acid soil stunted or inhibited growth of tomato plant. By rising soil pH from 4.8 to 6.0 with liming

Table 2. The Effect of liming and varieties on mean of fruit yield of Permata and Ratna varieties grown on potential acid sulphate soil of Belandean, Barito Kuala District, South Kalimantan.

Liming (Mg ha^{-1})	Fruit yield (Mg ha^{-1})		Mean yield (Mg ha^{-1})	Different yield (Mg ha^{-1})
	Permata	Ratna		
0	10.060 c*	4.754 f	7.407 c	5.306
0.5	9.924 cd	7.596 de	8.760 bc	2.328
1.0	12.669 b	7.007 e	9.838 ab	5.662
1.5	14.382 ab	7.509 de	10.946 a	6.873
2.0	15.331 a	6.254 ef	10.793 a	9.077
Mean	12.473	6.624	9.549	5.849

*Same number at the same column showed no significant differences with DMRT test 5%.

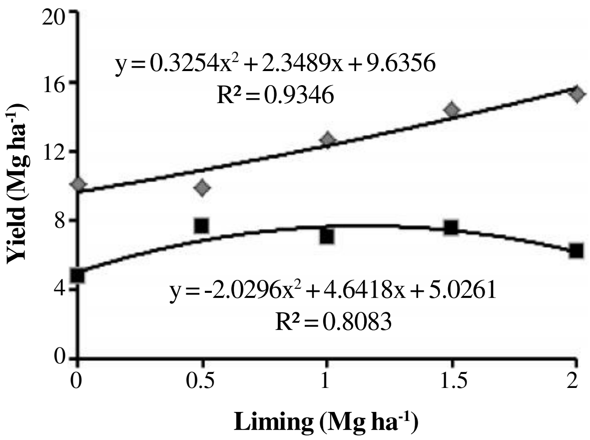

Figure 6. The Effect of liming and varieties on plant yield of tomato grown on acid sulphate soil of Belandean, Barito Kula District, South Kalimantan. ◆: Permata, ■: Ratna.

Table 3. The increase of yield for Permata and Ratna varieties with liming treatment at potential acid sulphate soil of Belandean, Barito Kuala District, South Kalimantan.

Liming ($Mg\ ha^{-1}$)	Increase of yield (%)		Mean of increase of yield (%)
	Permata	Ratna	
0	-	-	-
0.5	-1.35	59.8	29.22
1.0	25.9	47.4	36.65
1.5	42.9	57.9	50.40
2.0	52.4	31.6	42.00
Mean	29.9	49.2	39.55

management, seed yield and quality of tomato plant was improved (Rahman *et al.* 1996). Tuna *et al.* (2007) reported that increasing yield occurred by liming on tomato under salt stress. Koesrini and William (2009) also reported that Ca application significantly increased yield of snap bean, *i.e.* from 3.16 to 5.74 Mg ha^{-1} at tidal swampland, South Kalimantan. In this research, a similar result also occurred, *i.e.* liming significantly increased tomato yield at potential acid sulphate soil.

This experiment showed that the highest increase of yield was obtained at 2 Mg ha^{-1} of lime treatment at Permata (52.4%) and 1.5 Mg ha^{-1} at Ratna (59.8%). Mean of increase of yield at Ratna (49.2%) was higher than that at Permata (29.9%) (Table 3). It indicated that Ratna was more responsive to liming than Permata variety.

CONCLUSIONS

Liming improved soil quality and tomato yield at potential acid sulphate soil. It significantly increased soil pH and reduced soil Al-saturation as well as increased soil exchangeable-Ca and Mg. It is assumed that due to pyrite oxidation, however, soil pH decreased and Al-saturation increased, while soil exchangeable-Ca and Mg decreased significantly at 9 WAP. The liming also increased plant growth and yield variables (plant height, size, number and weight of fruit, and fruit yield) at both tested varieties. The better variables of Permata at control treatment than those of Ratna indicated that the first variety was more adaptive than the other in potential acid sulphate soil.

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