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Aluminum stress on 11 soybean genotypes in nutrient cultures

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Abstract A soilless culture experiment was set up to evaluate the degree of sensitivity of 12 soybean varieties to alumnium stress. The results showed that Al stress caused Dega 1, Dena 1, Dena 2, Gepak Kuning to be sensitive varieties (0.5; 0.7 and 0.9 mM Al), Deja 2 to be tolerant varieties (0.5 mM) and sensitive (0.5 and 0.9 mM Al), Detam 4 became tolerant varieties (0.5 mM and 0.7 mM) and sensitive (0.9 mM Al), Devon 1, Demas, Detam 1, Agromulyo and Grobogan became a tolerant variety (0.5; 0.7 and 0.9 mM). Staining with hematoxylin showed that the aluminum stress showed that the root damage was getting worse by increasing the aluminum stress.

Keywords: Soybean varieties, Sensitive, Tolerant

Introduction

Soybean is a strategic food commodity in Indonesia whose needs continue to increase in line with population growth. One of the efforts to increase national soybean production is to expand the planting area by utilizing acid lands with enormous potential. According to Mulyani *et al*. (2011), the area of marginal land in Indonesia reaches 148 million hectares, an estimated 102.8 million of which are acid soils. The constraint of soybean cultivation in acid soil is low productivity. This is due to low soil fertility because acid soils are characterized by low pH and high solubility of Aluminum (Al). High Al solubility causes Al to be toxic to plants and the binding of nutrients needed by plants, such as phosphorus. Symptoms of poisoning that can be observed in plants are root growth disorders, so the absorption of water and nutrients needed by plants is also disrupted (Caniato *et al*., 2007; Ojo and Ayuba, 2012). The cultivation approach that can be taken to obtain optimal productivity in acid soils is to plant soybean varieties that are tolerant to Al stress.

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Al stress is a problem in plant cultivation in acid soils (pH 5.5). Soil with high Al content can cause plants to lose 25-80% yield (Singh *et al.,* 2011). Symptoms of Al poisoning are root growth inhibition (Zhang *et al*., 2007). Root growth inhibition will reduce plant vigor and yield (Rengel and Zhang, 2003). Al inhibited root elongation within hours by affecting the cell elongation zone (Ryan *et al*., 1995; Sivaguru *et al*., 1999).

The main effect of Al stress in inhibiting the growth of plant roots appears to be short and thick (Yu *et al.*, 2011; Delhaize *et al.*, 2012; Li *et al.*, 2012). The results showed that the Al concentration of 50 ppm in wheat inhibited root growth (Rincon and Gonzales, 1992). In soybeans, Al concentration at 8 ppm inhibited root growth of susceptible cultivars (Sapra *et al.,* 1982). Al toxicity in plants is a major limiting factor for plant growth in acid soils (Basu *et al.,* 1994). A common symptom of Al toxicity in plants is root growth inhibition (Foy *et al.,* 1978). According to Sasaki *et al.* (1995), Al inhibited growth only at the tip (meristem) of the root. Several physiological characters of plant tolerance to Al indicate that plant trait that is more tolerant to Al stress can: 1) accumulate less Al so that Al toxicity is relatively tiny; 2) induces a higher rhizosphere pH close to the optimal pH for plant growth synthesize dicarboxylic acids such as malic, oxalic, citric, and fulfatic compounds and phenyl propanoate such as caffeate as Al chelators so that their toxicity is low; 3) increase the proton pump activity of H+-ATPase, which regulates the proton ion balance between inside and outside the plasma membrane so that depolarization occurs in the plasma membrane in a chain affecting the metabolic activities of its derivatives, such as the activity of K-channel and Ca-transporter, each of which plays a role in in the detoxification process of Al; 4) synthesize membrane-specific proteins and specific proteins from root tips that were not found in the sensitized genotypes, and 5) increase the activity of certain enzymes such as nitrate reductase (Sopandie, 2014).

Research on Al stress on soybeans conducted by Noya (2014) showed that the double stress of Al and Fe obtained by Anjasmoro and Yellow Biloxi genotypes were tolerant genotypes at the highest stress limit of 0.5 mM Al + 0.2 mM Fe, while Tanggamus and Lawit were sensitive genotypes. Shamsai *et al*. (2008) showed that the double stress of Al and Cr on soybeans caused a more significant effect (synergistic additive) on soybean growth. Al and Cr stress in barley caused more oxidative stress than single stresses at pH 4 (Ali *et al*., 2011).

The objectives were to evaluate the effects of aluminum stress, the effect of soybean varieties, and their interaction on the growth of 11 soybean cultivars grown in water culture at the greenhouse.

Materials and methods

Time and location of research

The research was carried out from June to August 2022. The location of the experiment was in the greenhouse of the Agronomy Laboratory, Faculty of Agriculture, Bengkulu University.

Research materials

Eleven soybean varieties were used to evaluate Al stress-tolerant varieties. Dega 1, Dena 1, Dena 2, Gepak Kuning, Deja 2, Devon 1, Demas, Detam 1, Agromulyo, Grobogan, and Detam 4.

The chemical composition used as a nutrient solution according to Sopandie (1990) with a concentration of 1/3 strength consisted of : 1.5 mM $Ca(NO_3)_2.4H_2O$; 1.0 mM NH_4NO_3; 1.0 mM KCl; 0.4 mM $MgSO_4.7H_2O$; 1.0 mM KH_2PO_4; 0.50 ppm $MnSO_4.4H_2O$; 0.02 ppm $CuSO_4.5H_2O$; 0.05 ppm $ZnSO_4.7H_2O$; 0.50ppm H_3BO_3; 0.1 ppm $(NH_4)_2$ $(M_7O_2)_4.4H_2O$ and 0.068 mM $FeSO_4.7H_2O$. Aluminium is given in the form of $AlCl_3.6H_2O$. The equipment consisted of a 2-liter capacity container, a hose, an inch PVC pipe, an air pump, a pH meter, a measuring device, a stirrer, and a scale.

Research design

The study was using 2-factor factorial in completely randomized design (CRD) with three replications. The first factor was the concentrations of Al, namely: without Al (A0); 0.5 mM Al (A1); 0.7 mM Al (A2) and 0.9 mM (A3). The second factor was 11 soybean varieties: Dega 1, Dena 1, Dena 2, Gepak Kuning, Deja 2, Devon 1, Demas, Detam 1, Agromulyo, Grobogan, and Detam 4. The observational data were analyzed using the F test. If the treatment showed a significant effect at the 5% level, the analysis was continued with DMRT (Duncan Multiple Range Test) at the level $\alpha = 5\%$.

Soybean tolerance to drought stress was assessed using the stress tolerance index (STI) (Fernandez 1993) with the formula:

$$ST = (Yp \times Ys) / \overline{p}$$

Ys : observed value for one genotype under optimal conditions
Yp : observed value for one genotype in stressed condition
$\overline{p}$: the average value of observations for all genotypes under optimal conditions

Research stage

Soybean seeds were germinated on sand media for five days. Plant criteria were used when transplanting based on root length and plant height uniformity. The seeds on the sand medium were carefully removed, rinsed with distilled water, clamped with foam, and placed on the styrofoam that was perforated. Each pot contained 2 L of the solution was planted with five soybean seeds. Aerators are used to create oxidative conditions.

Plants were transferred to media containing a nutrient solution with a pH value of 4. The Al stress treatment was carried out two days after the plants maintained for two days. The pH value of the solution was maintained at pH four by using 1 N NaOH and 1 N HCl. In contrast, the volume of the solution was maintained by adding an amount of evaporated ion-free water. The activity is carried out every three days.

Observation variables

The observed variables were plant height, leaves number, leaf greenness, root length, root volume, fresh weight shoots, fresh weight roots, dry weight shoots, and dry weight roots.

Results

The results showed that aluminum stresses significantly affected all variables measured, varieties significantly affected all variables measured, and their interaction significantly affected all variables measured, except for dry weight of root (Table 1).

Table 1. Recapitulation of Analysis Variance

Variable	F-Hit			CD(%)
	Al stress	Variety	Interaction	
Plant height (cm)	22.54*	38.06*	3.62*	10.85%
Leaves number	35.00*	5.30*	4.23*	6.55%
Leaf greenness	6.49*	11.74*	3.91*	5.75%
Root length (cm)	10.21*	5.62*	4.89*	14.89%
Root volume (mm^3)	58.34*	4.96*	2.50*	25.69%
Fresh weight of shoots (g)	4.44*	3.64*	2.31*	35.16%
Dry weight of shoots (g)	19.87*	6.52*	2.39*	19.22%
Fresh weight of roots (g)	25.95*	2.48*	2.37*	32.36%
Dry weight of roots (g)	16.5*	4.58*	1.41 ns	30.33%

Notes: * = Significant effect based on F Table 0.05, ns = Not significant effect, CD = coefficient of diversity.

Interaction between varieties and aluminum stress

The eleven soybean varieties were varied in plant height growth. The effect of different soybean varieties was shown to be very significant on plant height variables. Variable plant height under aluminum stress conditions (0.5 mM Al) showed significant differences between soybean varieties, where Agromulyo variety had the highest plant height of 95.50 cm and Demas variety had the lowest plant height of 55.33 cm. Meanwhile, plant heights for the varieties Grobogan, Detam 1, Dega 1, and Dena 1 were not significantly differed under aluminum stress conditions (0.5 mM Al) of 94.75 cm, 90.83cm, 86.67 cm, and 86 cm, respectively.

Table 2. Interaction between aluminum concentration and soybean varieties on plant height variables

Variety	Concentration Al stress			
	0 mM	**0,5 mM**	**0,7 mM**	**0,9 mM**
Dega 1	95.50 A a	86.67 AB A	96.97 A a	106.83 A A
Dena 1	80.17 A ab	86.00 A A	86.67 A a	83.15 A A
Dena 2	60.83 A c	58.83 AB D	66.33 A e	37.10 C D
Gepak Kuning	75.50 B e	77.83 B B	96.97 A a	56.27 C Cd
Deja 2	76.33 AB b	80.67 A Ab	79.67 A ab	63.25 B b
Devon 1	70.83 A b	69.33 A Bc	75.67 A b	52.63 B c
Demas	61.83 A c	55.33 B D	60.33 A c	43.33 C cd
Detam 1	79.83 B ab	90.83 A A	75.33 B b	46.22 C cd
Agromulyo	72.83 B b	95.5 A A	93.33 A a	82.17 AB a
Grobogan	90.33 AB a	94.75 A A	86 AB a	91.83 A a
Detam 4	53.33 B d	61.33 A C	63 A c	41.17 B cd

Note: Numbers followed by lowercase letters are read vertically and numbers followed by uppercase letters are read horizontally

Gepak Kuning variety showed higher plant height than the other ten soybean varieties under aluminum stress conditions (0.7 mM Al). The Gepak Kuning variety was significantly differed from the Demas and Detam 4 varieties, where the average plant height of the Gepak Kuning variety was 96.97 cm. The Demas and Detam 4 varieties were 60.33 cm and 63.00 cm, respectively. Meanwhile, under aluminum stress conditions (0.9 mM Al), the Dega 1 variety was the highest plant height performance compared to the other ten varieties, which was 106.83 cm and Dena 2 variety was the lowest plant height at 37.10 cm (Table 2). It can be concluded that Dega 1, Dena 1, Agromulyo, and Grobogan varieties gavebetter tolerance level to alumin um stress concentrations ranging from 0 mM Al to 0.9 mM Al when compared to the other seven soybean varieties.

The results of further test showed an interaction between soybean varieties and aluminum stress on the number of leaves variable. Aluminium stress treatment ranging from 0.5 mM Al to 0.9 mM Al affected the number of leaves of the eleven soybean varieties (Table 3). A variable number of leaves under aluminium stress conditions (0.5 mM Al) showed an insignificant difference between soybean varieties, where Dega 1 and Dena 1 varieties had the highest number of leaves at 6.00 leaves. In contrast, Dena 2 varieties had the lowest number of leaves at 5.00. Dega 1 and Dena 1 varieties were not significantly differed from Deja 2 (5.33 leaves), Detam 4 (5.33 leaves), Demas 1 (5.16 leaves), Agromulyo (5.16 leaves), and Gepak Kuning (5.12 pieces). Meanwhile, under aluminium stress conditions (0.7 mM Al), Detam 1 and Detam 4 varieties had the highest number of leaves at 5.33. In contrast, Demas variety had the lowest number of leaves at 4.50. However, the Detam 1 and Detam 2 varieties were not significantly differed from the Dena 1 (4.83 strands), Dega 1 (4.67 strands), Dena 2 (4.67 strands), and Deja 2 (4.67 strands) varieties under aluminium stress conditions (0.7 mM Al) sequentially.

The aluminium stress condition (0.9 mM Al) showed that the Devon 1 variety was the highest number of leaves of 6.17, while the Gepak Kuning variety had the lowest leave number of 4.67. Meanwhile, the Devon 1 variety was not significantly differed rom the Agromulyo variety, which was 5.50 strands. However, it was not significantly different from the varieties Detam 4 (5.33 strands), Dega 1, Dena 2, Deja 2, and Grobogan with 5.16 strands each (Table 3).

The difference in root length indicateds that each soybean variety had different root responses in the face of aluminum stress by describing its root system. The eleven soybean varieties had varied root lengths (Table 4).

The root lengths of the eleven soybean varieties were significantly varied under aluminium stress conditions ranging from 0.5 mM Al to 0.9 mM Al. Under aluminium stress conditions (0.5 mM Al), the Dena 1 variety had mostly extended root length of 37.00 cm, and Detam 4 was the shortest root length of 17.00 cm. The root length of the Dena 1 variety was not significantly differed from that of the Dena variety (35.55 cm) and the Detam 1 variety (33.33 cm). However, it was significantly different from the varieties of Gepak Kuning (28.33 cm), Grobogan (26.67 cm), Devon 1 (26.33), Agromulo (25.00 cm), Demas (24.67 cm), and Deja 2 (23.67 cm).

Meanwhile, under aluminium stress conditions (0.7 mM Al), the Dena 2 variety had mostly extended root length of 35.00 cm, and the Deja 2 and Demas varieties had the shortest root length of 20.00 cm each. The Dena 2 variety was not significantly differed from the Devon 1 and Agromulyo varieties, which were 29.83 cm and 27.33 cm, respectively. Meanwhile, aluminum stress conditions (0.9 mM Al) showed that the Devon 1 variety had the most extended root length of 33.43 cm, and Detam 4 was the shortest root length of 24.17 cm. The Devon 1 variety was not significantly different from the Dena 1 variety, which was 32.70 cm, but it was significantly different from the other nine soybean varieties (Table 4).

Table 3. Interaction between aluminum concentration and soybean varieties on leaves number variables

Variety	**Concentration Al stress**			
	0 mM	**0.5 mM**	**0.7 mM**	**0.9 mM**
Dega 1	6.00A Ab	6.00A A	4.67 B ab	5.16 B ab
Dena 1	5.00 AB C	6.00A A	4.83 B ab	5 AB b
Dena 2	5.00 A C	5.00 A B	4.67 AB ab	5.16 A ab
Gepak Kuning	7.00A A	5.16 B Ab	5.33 B a	4.67 C c
Deja 2	6.00A Ab	5.33 AB Ab	4.67 B ab	5.16 AB ab
Devon 1	6.00A Ab	5.83 AB A	4.67 B ab	6.17 A a
Demas	5.33 A B	5.16 A Ab	4.50 B b	4.83 B c
Detam 1	6.00A Ab	5.50 A A	5.33 AB a	4.83 B c
Agromulyo	5.67 A Ab	5.16 AB Ab	5.16 AB ab	5.5 A a
Grobogan	6.00A Ab	5.50 A A	5.50 A a	5.16 B ab
Detam 4	6.00A Ab	5.33 AB Ab	5.33 AB a	5.33 AB ab

Note: Numbers followed by lowercase letters are read vertically and numbers followed by uppercase letters are read horizontally vertically

Table 4. Interaction between aluminium concentration and soybean varieties on root length variables

Variety	Concentration Al stress			
	0 mM	0,5 mM	0,7 mM	0,9 mM
Dega 1	30.38 A A	24.33 B Bc	34.67 A a	26.55 B b
Dena 1	34.67 A A	37.00 A A	23.50 B b	32.70 A a
Dena 2	29.50 AB Ab	35.55 A A	35.33 A a	25.40 B bc
Gepak Kuning	28.33 AB B	28.33 AB B	33.33 A a	26.10 B bc
Deja 2	26.50 A B	23.67 B Bc	20.00 C c	24.28 B bc
Devon 1	20.67 B C	26.33 B B	29.83 A ab	33.43 A A
Demas	31.67 A A	24.67 B Bc	20.00 C c	25.17 B Bc
Detam 1	39.33 A A	33.33 A A	22.17 B b	22.92 A C
Agromulyo	35.00 A A	25.00 B C	27.33 B ab	26.67 B B
Grobogan	27.17 A B	26.67 B Bc	20.67 C bc	22.33 C C
Detam 4	39.50 A A	17.00 C D	22.83 B b	24.17 B C

Note: Numbers followed by lowercase letters are read vertically and numbers followed by uppercase letters are read horizontally

The interaction between soybean varieties and aluminum stress was also shown in the root volume variable. The root volume of each variety shows different variations. The aluminum stress condition (0.5 mM Al) showed that the Detam 1 variety had the highest root volume of 4.08 ml, and the Agromulyo variety had the lowest root volume of 1.50 ml. Meanwhile, the Detam 1 variety was not significantly differed from five other soybean varieties, namely Devon 1 93.33 ml), Gepak Kuning (3.27 ml), Detam (3.27 ml), Demas (3.25 ml), and Dena 2 (2.60 ml) (Table 5).

Under conditions of aluminium stress (0.7 mM Al), the Demas variety had the highest root volume of 3.05 ml, and the Agromulyo variety had the lowest root volume of 1.62 ml. The Demas variety had a higher root volume than the other ten soybean varieties. Meanwhile, under aluminium stress conditions (0.9 mM Al), the Detam 4 variety had the highest root volume of 3.90 ml, and the Dega 1 variety had the lowest root volume of 1.78 ml. However, the Detam 4 variety was not significantly different from the other five soybean varieties, namely Gepak Kuning (3.75 ml), Devon 1 (3.67 ml), Demas (3.67 ml), Dena 2 (3.33 ml), and Agromulyo (3.25 ml) (Table 5).

Table 5. Interaction between aluminum concentration and soybean varieties on root volume variables

Variety	Concentration Al stress			
	0 mM	**0,5 mM**	**0,7 mM**	**0,9 mM**
Dega 1	3.50 A b	1.67 AB C	2.00 AB bc	1.78 B C
Dena 1	4.67 A ab	2.17 B B	2.33 B B	2.40 B Bc
Dena 2	3.67 A b	2.60 B Ab	2.00 B bc	3.33 A A
Gepak Kuning	3.58 A b	3.27 A Ab	2.33 B B	3.75 A A
Deja 2	5.42 A a	2.92 B Ab	2.67 B B	2.00 C C
Devon 1	3.50 A b	3.33 A Ab	2.02 B bc	3.67 A A
Demas	6.17 A a	3.25 B Ab	3.05 B A	3.67 B A
Detam 1	4.50 A ab	4.08 A A	2.08 B bc	2.67 B B
Agromulyo	6.02 A a	1.50 C D	1.62 C C	3.25 B A
Grobogan	4.13 A ab	1.75 C C	2.33 B B	2.50 B B
Detam 4	6.58 A a	3.27 B Ab	2.37 C B	3.80 B a

Note: Numbers followed by lowercase letters are read horizontally and numbers followed by uppercase letters are read vertically

Effect of soybean varieties on dry weight of root

Results showed that soybean varieties had significantly affected on root dry weight variables. Root dry weight of each soybean variety varies greatly. The Dena 1 variety had the highest root dry weight of 0.35 g, and the Dega 1 variety had the lowest dry weight of 0.20 g. It can be seen that the Agromulyo variety was not significantly differed from the Grobogan variety. Likewise, the Demas variety was not significantly differed from the Detam 1, Dega 1, Detam 4, and Devon 1 varieties (Figure 1).

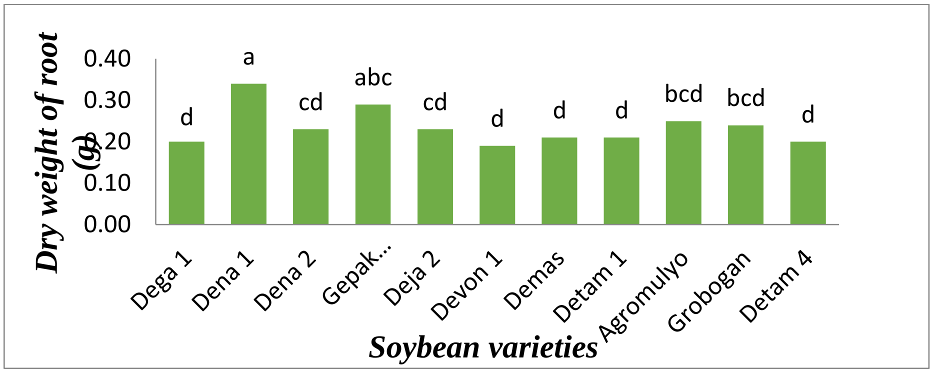

Figure 1. Effect of Soybean varietis on dry weight of root

Based on the variables of plant height, the number of leaves, root length, root volume, wet shoot weight, shoot dry weight, root wet weight, and root dry weight of the eleven soybean varieties, Dega 1, Dena 1, Gepak Kuning, and Detam 4 varieties showing an index of sensitivity of aluminium stress was more tolerant when compared to the other seven soybean varieties in both both conditions of 0.5 mM Al, 0.7 mM Al, and 0.9 mM Al aluminium stress. Meanwhile, the Devon 1 and Demas 1 varieties showed more sensitive aluminum stress sensitivity index when compared to the other nine varieties, in 0.5 mM Al, 0.7 mM Al, and 0.9 mM Al aluminum stress conditions (Table 6). It revealaed that the Grobogan variety showed differences in the aluminum sensitivity index which expressed more concentration of aluminum stress and sensitive to aluminium stress (Table 6, Figure 2).

Table 6. Aluminium Sensitivity Index of Eleven Soybean Varieties

Varieties	0.5 mM	0.7 mM	0.9 mM
Dega 1	Tolerant	Tolerant	Tolerant
Dena 1	Tolerant	Tolerant	Tolerant
Dena 2	Toleran	Toleran	Sensitive
Gepak Kuning	Tolerant	Tolerant	Tolerant
Deja 2	Tolerant	Tolerant	Sensitive
Devon 1	Sensitive	Sensitive	Sensitive
Demas	Sensitive	Sensitive	Sensitive
Detam 1	Tolerant	Tolerantt	Sensitive
Agromulyo	Tolerant	Toleran	Sensitive
Grobogan	Tolerant	Sensitive	Sensitive
Detam 4	Tolerant	Tolerant	Tolerant

Figure 2. Performance of Grobogan Soybean Varieties. A = control, B = tolerance 0.5mM, C = sensitive 0.7mM, and D = sensitive 0.9mM.

Correlation analysis between variables showed a solid correlation (Table 7). The correlation between the root volume variable and fresh root weight weresignificantly affected with r = 0.85. The greater the root volume, the greater the fresh weight of the roots was revelaed. The correlation between the fresh weight of shoot showedsignificantly related with the dry weight of shoot and the fresh weight of the roots with r values of 0.54 and 0.50. The higher the fresh weight of shoot revealed, the greater the dry weight of shoot and the fresh weight of the roots. The Shoot dry weight variable showed significantly related between fresh root weight (r=0.52) and root dry weight (r=0.49). The greater the dry weight of the canopy revealed, the greater the fresh weight of the roots and the dry weight of the roots. The root fresh weight variable showed significantly related with the root dry weight variable with a value of r = 0.41. The greater the fresh weight of the root revealed, the greater the dry weight of the root.

Table 7. Correlation between observational variables of Soybean

Variabel	**PH**	**LN**	**LG**	**RL**	**RV**	**SFW**	**SDW**	**RDW**
LN	0.14 ns							
LG	-0.18 ns	0.08 ns						
RL	0.05 ns	0.19 ns	0.22 ns					
RV	-0.37*	0.35 *	0.25 ns	0.37*				
SFW	0.18 ns	0.25 ns	0.40**	0.41 **	0.27 ns			
SDW	0.38 *	0.32*	0.12 ns	0.32*	0.41 **	0.54***		
RFW	-0.27 ns	0.35*	0.30*	0.27 ns	0.85***	0.50**	0.52**	
RDW	-0.03 ns	0.26 ns	0.15 ns	0.18 ns	0.32*	0.28ns	0.49***	0.41**

Note :PH= Plant Height, LN = Leaves Number, LG = Leaf Greenness, RL = Root Length, RV = Root Volume, SFW = Shoot Fresh Weight, SDW = Shoot Dry Weight, RFW = Root Fresh Weight, RDW = Root Dry Weight

Discussion

Plant height is a measure that is often observed as an indicator of growth and as a variable used to measure the effect of the type of treatment, as well as a feature that determines plant production and is closely related to the photosynthesis process (Wibowo, 2010). The eleven soybean varieties have varying plant height growth. The Dega 1 variety had higher plant height performance when compared to the Dena 2 and Devon 1 varieties under 0.9 mM Al aluminum stress conditions. The increase in the concentration of aluminum can inhibit the growth of the soybean plant height. This shows that the Dega 1 variety has a better tolerance for aluminum stress when compared to the Dena 2 and Devon 1 varieties. Zhang *et al*. (2007) and de Macedo *et al.* (2009) suggested that one of the symptoms of plant poisoning in aluminum is the inhibition of plant and root height growth. In addition, the main effect of aluminum stress in inhibiting plant growth will appear to have a shorter plant height with a short and thick root system (Yu *et al*., 2011; Li *et al*., 2012), where aluminum stress inhibits the process of cell division and photosynthesis (Marshner, 2012) so that it becomes an obstacle in plant production in acid soils (Zheng, 2010).

In addition to plant height, the variable number of leaves also showed an interaction between soybean varieties and aluminum stress. The Detam 4 variety (5.33 leaves) had more leaves than the Demas variety (4.83 leaves) under 0.9 mM Al aluminum stress. As the concentration of aluminum stress increased, it inhibited the growth of the number of leaves on soybean plants. The decrease in the number of leaves is one of the indicators in determining the level of tolerance to aluminum stress. This is under the results of Arief's research (2001). The number of leaves of legumes in soils with high aluminum saturation is less than in soils with low aluminum saturation. Dropping leaves due to aluminum poisoning indicates physiological mechanisms in plants (Manpaki *et al*., 2017).

The results showed that the Demas variety had shorter roots when compared to the Dena 1 variety at an aluminum stress concentration of 0.9 mM Al .The administration of exogenous Al concentration inhibited the growth of soybean root length. It indicated that the Dena 1 variety had better root length performance against aluminum stress concentrations (0.9 mM Al) when compared to the Demas variety. Root length character can be used as a selection character because root length greatly determines the tolerance level of plants to aluminum stress (Pineros *et al*., 2005; Roslim *et al.*, 2010; Ye *et al.*, 2011). The ability to have longer roots is thought to determine the tolerance level of the Dena 1 variety to aluminum stress because plants that are tolerant to acid soils are plants whose root growth is not inhibited under aluminum stress (Maron *et al.*, 2008; Silva *et al.*, 2012). It is in contrast to the Ministry of Agriculture (2012), which stated that the Demas variety is recommended tocultivate in acid soils with high aluminum concentrations.

The results also showed an interaction between soybean varieties and aluminum stress on the variable shoot wet and dry weight. The interaction between soybean varieties and aluminum stress on wet shoot weight and canopy dry weight on soybean plants was related to the average root length of each variety in adapting to aluminum stress conditions. Damage to root structure and function will reduce the ability of roots to absorb nutrients and water available in the soil so that the translocation of nutrients and water to the shoot is reduced (Lakitan, 2013). Based on the explanation above, it is suspected that the potential for groundwater under aluminum stress conditions is shallow so that the roots cannot absorb water; as a result, cells in the shoot tissue lose turgor which has an impact on the low value of the shoot weight of soybeans. In addition to inhibiting nutrient absorption, the activity of the enzyme nitrate reductase also decreased. Karti (2004) reported that nutrient deficiency and decreased activity of this enzyme could inhibit critical metabolic processes in plants so that the growth of the upper part of the plant is also inhibited and causes a decrease in plant biomass partition, namely the dry weight of the plant shoot.

Correlation analysis described the close relationship between one variable and another; if the correlation value between two variables is close to 1 or -1, it shows that the relationship between the two variables is very close (Mattjik and Sumertajaya, 2002). Aluminum stress generally had positively correlated between soybean growth variables. The dry weight of shoot was a *significant* variable to estimate the potential production of plants and determined the growth and development rate of plants under aluminum stress conditions. It showed that the wet weight of the canopy had a positively correlated with the dry weight of shoot. The decreased in dry shoot weight was caused by the inhibition of plant growth rate against aluminum stress. Karti (2004) stated that abiotic stress could reduce leaf size, thereby reducing the ability to photosynthesize the formation of photosynthate decreased, resulting in decreased canopy dry weight production.

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