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Root Morphology and Growth Response of Oil Palm (*Elaeis guineensis* Jacq) Hybrid to Al Toxicity at Nursery

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ABSTRACT

The aim of this study was to determine the response of eight oil palm hybrids to aluminum (Al) toxicity through their growth and root morphological changes. The research was conducted in Sleman, Yogyakarta in June 2014–June 2015. The study was prepared in a Factorial Randomized Block Design, consisting of three blocks as replications. The first factor was the addition of aluminum in two rates (0 ppm and 300 ppm). The second factor was the use of eight oil palm hybrids (Yangambi, Avros, Langkat, PPKS 239, Simalungun, PPKS 718, PPKS 540 and Dumpy). The research was conducted at nursery stage. Observed variables include total root length, total root area, root volume, root diameter, aluminum uptake in root, fractal dimension, and fresh and dry root and shoot weight. The data obtained were analyzed by analysis of variance (ANOVA) at α= 5% level, followed by Duncan Multiple Range Test (DMRT) to determine the significant difference between the treatments. Aluminum at 300 ppm significantly changed the morphological characteristic of root, thereby inhibiting root growth and biomass. All the hybrids performed the same root morphological and growth variables responses.

Keywords: aluminum, hybrids, root, seedling

INTRODUCTION

Oil palm (*Elaeis guineensis* Jacq) is an important crop as a world oil producer widely cultivated in Malaysia, Indonesia, and Thailand (Wilcove and Koh, 2010). The soil in wet tropical environment is generally acid and typical of most land area across Indonesia. There are 67% of the total land area in Indonesia that reacts acids spread out in oil palm development areas. In acidic soils, which account for about 40% of the earth's land, aluminum (Al^{3+}) toxicity has been identified as a major limiting factor in crop productivity (Taylor, 1991).

Under acidic conditions, Al mineral solubilizes into trivalent Al^{3+}, which is highly toxic to animals, plants and microbes (Zioła-Frankowska and Frankowski, 2018). Acidic soil has various syndromes including nutrient deficiency and mineral toxicity. In some cases, Al plays the role in maintaining the nutrient balance in plants through inhibitory effects on toxic minerals and stimulatory effect on deficient nutrients (Muhammad *et al*., 2018). The toxicity of aluminum is associated with root growth inhibition (Taylor, 1988). Rooting system becomes short and stubby as a result of inhibition of primary and lateral root (Foy, 1974). Al tolerance in plants has therefore been associated with increased accumulation of Al^{3+} in the rhizosphere and roots but reduced concentration in photosynthetic shoots (Sanjay *et al*., 2018).

The case of Aluminum toxicity has become an alarming problem, and the incidence continues to increase over time (Shafaqat *et al*., 2011). Some approaches can be taken to overcome the problem of Aluminum toxicity, such as the use of aluminum resistant hybrids and agronomic manipulations. However, information related to oil palm hybrids resistant to Aluminum toxicity is still limited, yet not existed.

The resistance of an oil palm hybrid against Al toxicity is thought to be expressed in shoot or root. The expression on rooting system due to Aluminum toxicity allegedly arises earlier, therefore the studies to recognize oil palm hybrids resistant to Aluminum toxicity based on rooting character are important to be conducted.

MATERIALS AND METHODS

The research was conducted in Bendosari, Madurejo, Prambanan, Sleman, Yogyakarta and Laboratory of Crop Science and Production, Faculty of Agriculture, Universitas Gadjah Mada in June 2014–July 2015. The research was arranged in Randomized Complete Block Design (RCBD) with two factors of treatment. The first factor was the addition of aluminum in two rates (0 ppm and 300 ppm). The second factor was eight oil palm hybrids (Yangambi, Avros, Langkat, PPKS 239, Simalungun, PPKS 718, PPKS 540 and Dumpy) produced by the Indonesian Oil Palm Research Institute (IOPRI).

This research used double stage nursery system, in which the germinated seeds of oil palm were grown in pre-nursery for three months then continued with main nursery for 9 months. Aluminum was applied in the eight week after transplanting from pre-nursery to the main nursery. Aluminum application was carried out using Aluminum sulfate compound with 17% Al_2O_3 at a concentration of 300 ppm which is the critical threshold of Al toxicity on oil palm seedlings (Sutarta and Winarna, 2009). Aluminum was dissolved first in water and then applied along with watering. Aluminum application was given to the plant through watering to the media as solution at a volume of 0.5 liters per plant per day.

Plant height was measured from the base of the stem (above soil surface) to the longest leaf tip. The number of leaves was observed by counting the number of leaves that exist on each plant, starting on the youngest leaves that have been opened perfectly. The measurement of stem diameter was performed using a digital vernier calipers at 1 cm above soil surface.

Root and shoot biomass were observed at 48 weeks after transplanting at the main nursery. The root and shoot fresh weight were observed right away after the oil palm seedlings were harvested. Root and shoot dry biomass were calculated based on oven dry weight at temperature of 60–80°C for at least 48 hours until a constant weight. Total root length and area were measured at 48 weeks after transplanting at the main nursery. Total root length was measured with line intersection read by video camera area meter (Indradewa, 2002). The length of root then was converted to the root standard. Copper wire with a range of diameter as root standard was used (Indradewa, 2002).

The root projection on area meter was measured to get the root surface area with assumption that the root has cylindrical shape so that the root area projection is = 2 *rp*, in which r is the radius, and p is the root length, thus r value can be calculated. The root surface area is = 2 πrp (Indradewa, 2002). Root diameter then was calculated (2*r* of the root surface area). The root volume was observed by using volumetric method.

Fractal dimension was observed with box counting method. The root system was placed on the needle pin-board then cleaned from the soil by watering. After that, the root system was placed under the square frame with some length variation which were (*r*) 1; 2; 2,5; 4; 5; 10; 12,5; 20; 25; and 50 cm with frame size of 1m x 1m. (Tatsumi *et al*., 1989). The intersection between the boxes and roots was then counted as $N(r)$. After that, log r in every size of boxes (r) was determined. A regression then was made with log $N(r)$ as dependent variable (Y) and log (r) as independent variable (X). The equation is as follow: $\log N(r) = -D \log r + \log K$, where K (intercept) is constant and $N(r) = -D$ (Eghball, 1993). The Fractal dimension (D) is in a range of $1 \leq D \leq 2$.

Aluminum content in root and shoot was determined after digestion in HNO_3 and $HClO_4$ with Atomic Absorption Spectronic (AAS). Aluminum absorbed (Al Abs) in shoot and root was counted with formula by Frageria *et al*. (1988); Astutiningsih (2005), in which: Al Abs= Al Content × Wd, where Wd is dry weight.

The response of root and shoot growth to aluminum toxicity was analyzed by Fischer and Maurer (1978) equation as follow:

$$\Delta\, Response = \frac{Y\ control - Y\ toxicity}{Y\ control}\ x\ 100\%$$

Data were analyzed with analysis of variance (ANOVA) and continued with Duncan's Multiple Range Test at α= 5%.

RESULTS AND DISCUSSION

Root is the most important organ in absorbing nutrient and water because the root lies in the planting medium. If the soil is contaminated, the root will be the first organ affected before other organs such as stem or leaf are affected. Marschner (1986) states that nutrients are absorbed from the smelly complex or from a solution in a planting medium of cation and anion. Proklamasiningsih *et al*. (2012) state that the form of aluminum compound on various pH of

Table 1. Al Content and absorption in root tissue of oil palm hybrids at 48 weeks after transplanting

Treatment	Al content in root tissue (ppm)	Al absorption in Root (mg)
Al Treatment		
0 ppm	7106.05 b	207.42 a
300 ppm	12494.07 a	159.01 b
Oil palm hybrids		
Yangambi	10968.57 p	183.00 p
Avros	10840.48 p	219.63 p
Langkat	11130.84 p	225.73 p
PPKS 239	8767.56 p	170.45 p
Simalungun	9025.28 p	192.57 p
PPKS 718	9294.40 p	163.85 p
PPKS 540	9264.03 p	145.63 p
Dumpy	9109.32 p	164.85 p
Interaction	(-)	(-)
CV	18.16	29.82

Remark: Means followed by the same letters in the same column are not significantly different based on Duncan's multiple range test at α= 5%; (-) indicates there is no interaction between the factors.

Table 2. Al content in leaf tissues of oil palm hybrids at 48 weeks after transplanting

Al Treatment	Al Content in leaf Tissue								Mean
	Yangambi	Avros	Langkat	PPKS 239	Simalungun	PPKS 718	PPKS 540	Dumpy	
0 ppm	258.03 k	534.02 h	152.07 n	215.69 l	160.52 n	313.85 i	195.15 m	270.63 j	262.49
300 ppm	2327.46 a	1115.77 e	1320.90 d	924.92 f	705.50 g	1497.66 c	1910.59 b	1307.95 d	1381.34
Mean	1292.74	824.89	736.48	570.30	433.01	875.75	1052.87	789.29	(+)
CV	0.74 %								

Remark: Means followed by the same letters in the same column are not significantly different based on Duncan's multiple range test at α= 5%; (-) indicates there is interaction between the factors.

Table 3. Responses of oil palm hybrids root growth to Al-toxicity at 48 weeks after transplanting

Oil Palm Hybrids	Δ Responses on Root Growth (%)				
	Root length	Root area	Root diameter	Root volume	Fractal dimension
Yangambi	66.06 a	-1585.49 a	-5378.19 a	60.94 a	4.02 a
Avros	-1841.57 a	-3371.23 a	-26.34 a	56.32 a	4.16 a
Langkat	45.72 a	-1345.96 a	-3799.99 a	52.65 a	2.22 a
PPKS 239	50.54 a	-1818.99 a	-3491.40 a	58.57 a	2.46 a
Simalungun	28.01 a	-2508.13 a	-3971.00 a	33.90 a	-0.76 a
PPKS 718	-15.90 a	-2074.56 a	-820.96 a	53.17 a	2.02 a
PPKS 540	28.41 a	-2005.93 a	-4576.05 a	43.62 a	2.48 a
Dumpy	45.30 a	-1926.02 a	-3075.14 a	52.54 a	2.32 a
Mean	-199.18	-2079.54	-3142.38	51.46	2.36
CV (%)	39.42*	21.00*	21.00*	28.61	13.97*

Remark: Means followed by the same letters in the same column are not significantly different based on Duncan's Multiple Range Test at α= 5%; (*)Data were transformed using √ (X + 0.5)

Table 4. Responses of oil palm hybrids fresh and dry biomass to Al-toxicity at 48 weeks after transplanting

Oil PalmHybrids	Δ Responses on fresh biomass (%)			Δ Responses on dry biomass (%)		
	Root	Shoot	Total	Root	Shoot	Total
Yangambi	49.12 a	65.44 a	64.15 a	63.99 a	49.98 a	53.03 a
Avros	27.01 ab	41.86 ab	44.33 ab	65.15 a	28.14 a	38.31 a
Langkat	5.06 ab	32.96 ab	38.15 ab	55.07 a	19.82 a	32.00 a
PPKS 239	37.49 ab	26.60 ab	29.31 ab	56.93 a	37.82 a	42.40 a
Simalungun	13.50 ab	12.41 b	15.32 b	44.65 a	14.28 a	21.07 a
PPKS 718	31.08 ab	41.54 ab	41.87ab	56.56 a	34.48 a	39.90 a
PPKS 540	-11.14 b	34.93 ab	33.46 ab	41.85 a	32.01 a	33.92 a
Dumpy	25.23 ab	40.06 ab	39.13 ab	51.42 a	39.54 a	42.85 a
Mean	22.17	36.97	38.21	54.45	32.01	37.94
CV (%)	16.44*	28.15*	28.13*	22.28	26.96*	23.38*

Remark: Means followed by the same letters in the same column are not significantly different based on Duncan's multiple range test at α= 5%; (*) Data were transformed using √ (X + 0.5)

Table 5. Responses of oil palm hybrids root and shoot biomass to Al-toxicity at 48 weeks after transplanting

Oil palm hybrids	Δ Responses on shoot growth (%)		
	Plant height	Total leaf	Stem diameter
Yangambi	15.46 a	15.85 a	20.17 a
Avros	7.86 a	18.75 a	14.59 a
Langkat	13.64 a	11.30 a	14.93 a
PPKS 239	13.27 a	4.87 a	15.85 a
Simalungun	24.50 a	8.47 a	14.43 a
PPKS 718	26.32 a	12.38 a	19.75 a
PPKS 540	23.03 a	3.93 a	12.33 a
Dumpy	14.73 a	3.98 a	8.48 a
Mean	17.35	9.94	15.07
CV (%)	28.20*	14.46*	22.69*

Remark: Means followed by the same letters in the same column are not significantly different based on Duncan's Multiple Range Test at α= 5%; (*) Data were transformed using √ (X + 0.5)

planting medium is very influential on the concentration of aluminum in root tissue.

Table 1 shows that there is no interaction between treatments given on the Al content in plant tissues and its uptake. The addition of Al significantly increased Al content in plant root tissue at 48 weeks after transplanting, but Al absorption was higher in plants without Al addition. This is thought to be related to root dry weight in plants without Al addition which were higher than the root dry weight in those given Al 300 ppm. Al absorption value was used to calculate the amount of Al that can be absorbed by plant roots. Different hybrids showed the same response of Al content and its absorption.

According to the comparison of Al content in leaves and in roots (Table 1 and Table 2), all the hybrids tested have one of the tolerant criteria. According to Kochian (1995), most of Al is retained in the roots and slightly translocated to the top of the plant. All of the oil palm hybrids tested in this study experienced an increase in Al concentration in leaf tissues when exposed to Al. Yangambi hybrid showed the highest Al content, while the Simalungun hybrid showed the lowest one. The interaction between Al application and hybrids shows that each hybrid has different capabilities in storing Al metals in leaf tissues.

Aluminum toxicity is associated with stunted root growth (Taylor, 1988). The inhibition of primary and lateral root extension results in short and stubby root systems (Sopandie, 2013). As shown in Table 3, all of the oil palm hybrids tested gave the same responses, showing the inhibition of root extension, except on the Avros and PPKS 718 hybrids that were still capable of performing root extension. All hybrids showed increased values of root diameter. The same response was also observed on root surface area, showing that all hybrids tested increased the root surface area, however, only Simalungun hybrids were able to distribute the roots evenly as shown in the fractal dimension value. According to Yang *et al*. (2013), the fractal dimension value of ~1 indicates that the growth of the leaves or roots lies in the rim/root region, while the the fractal dimension value of ~2 indicates that the leaves/roots are evenly distributed throughout its surface. The response of root volume showed that all hybrids experienced the inhibition of root volume growth. According to Polled and Konzak (1990), root damage by Aluminum causes disruption of nutrient uptake and transport, making it sensitive to drought, thus ultimately affecting plant growth and productivity.

Almost all hybrids tested showed a decrease in fresh weight of both root and shoot as affected by the addition of Al. Yangambi hybrid showed the highest decrease in the fresh weight of root, while PPKS 540 hybrid showed an increase in the root fresh weight. Simalungun hybrid showed the lowest decrease in shoot/canopy fresh weight. However, all hybrids showed the same response, which was the decrease in root and shoot/canopy dry weight (Table 4).This is because the accumulation of dry matter was inhibited, thus decreasing the dry weight of the plant.

Al toxicity can inhibit shoot growth by inhibiting the supply of nutrients, water, and cytokines from roots due to poor root penetration to subsoil or low root hydraulic conditions (Marschner, 1995). The morphological response in the form of root tip thickening inhibits the nutrient uptake, which can interfere with the metabolism process of plants, thereby resulting in the inhibition of plant growth as shown in Table 5.

CONCLUSIONS

The addition of Al inhibited root growth as observed on several variables such as root length, root volume, and root surface area. The root diameter was enlarged due to the thickening of root cell as a response to aluminum toxicity. Eight oil palm hybrids performed relatively the same morphological and growth responses.

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