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WATER TRANSPORT AND GROWTH OF CASHEW (*Anacardium occidentale* L.) UNDER SOIL MECHANICAL IMPEDANCE

Transportasi Air dan Pertumbuhan Jambu Mente (Anacardium occidentale *L.*) *pada Berbagai Hambatan Mekanik Tanah*

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ABSTRACT

The ability to adapt to soil mechanical impedance was considered to support cashew growing in drought prone areas, since those areas are sometimes aggravated by problem on soil mechanical impedance. The response of water transport and growth under soil mechanical impedance was evaluated at two productive cashew accessions. Two cashew accessions, A3-1, that adapt well to drought stress, and a local accession Pangkep, and four levels of soil bulk densities of 0.75 g cm^{-3}, 0.90 g cm^{-3}, 1.00 g cm^{-3} and 1.24 g cm^{-3} under sufficient soil moisture conditions, were arranged in factorially completely randomized design with five replications. The response of shoot and root growth, transpiration and hydraulic conductance were evaluated. The results showed that the accession of A3-1 indicated a better to maintain root growth under soil mechanical impedance that produced thick root/total root length ratio and xylem area/transversal root area ratio more than Pangkep. On the other hand, A3-1 was faster in reducing leaf area than Pangkep when subjected to increased level of soil bulk density treatments. Although the hydraulic conductance was not varied among the cashew accessions and had not a specific response trend to soil bulk density treatments, however, the increase of diurnal transpiration induced by increased level of soil bulk density treatment in A3-1 was higher than it in Pangkep. It is suggested that the ability to regulate the root and shoot growth and water transport under soil mechanical impedance condition was better in A3-1 than in Pangkep. Moreover, it might be a part attribute of drought tolerance on A3-1 accession.

Keywords: cashew, soil mechanical impedance, growth, water transport

ABSTRAK

Kemampuan adaptasi terhadap hambatan mekanik tanah diperkirakan membantu pengembangan jambu mente di wilayah berlahan kering, mengingat kondisi wilayah tersebut sering diperparah oleh masalah hambatan mekanik tanah. Respon transportasi air tanaman dan pertumbuhan terhadap hambatan mekanik tanah dievaluasi pada dua aksesi jambu mente. Dua aksesi jambu mete, A3-1 yang adaptif terhadap stres kekeringan dan aksesi lokal, Pangkep, serta 4 level padatan tanah 0.75 g.cm^{-3}, 0.90 g.cm^{-3}, 1.00 g.cm^{-3}, dan 1.24 g.cm^{-3} dengan kondisi lengas tanah dijaga selalu cukup, disusun dalam rancangan faktorial acak lengkap dengan lima ulangan. Respon pertumbuhan akar dan tajuk, transpirasi, dan daya hantar air tanaman dievaluasi. Hasil penelitian menunjukkan bahwa A3-1 lebih mampu menjaga pertumbuhan akar pada kondisi hambatan mekanik tanah dengan nilai rasio panjang akar tebal/panjang total akar dan rasio luas xylem/luas melintang akar lebih lebih besar daripada Pangkep. Pada sisi lain, A3-1 mengurangi luas daun lebih cepat dibanding Pangkep saat diberikan kenaikan perlakuan berat isi tanah. Meskipun tidak ada perbedaan daya hantar air tanaman di antara kedua aksesi dan tidak adanya pola respon spesifik terhadap perlakuan padatan tanah, namun terjadi kenaikan transpirasi harian lebih besar pada A3-1 daripada Pangkep. Hasil ini mengindikasikan bahwa kemampuan A3-1 mengatur pertumbuhan dan transportasi air saat mengalami hambatan mekanik tanah lebih baik daripada Pangkep. Hal ini mungkin merupakan bagian dari sifat toleransi terhadap kekeringan pada aksesi A3-1.

Kata kunci: jambu mente, hambatan mekanik tanah, pertumbuhan, transportasi air

INTRODUCTION

The establishment of cashew in the marginal dry climate areas in the eastern Indonesia is often limited by prevailing soil mechanical impedance such as hardpan and heavy clay soil, where the soil with high mechanical impedance area achieves about 20% of arable lands (ABDULLAH and LAS, 1985). Soil mechanical impedance impacts crop yields and soil productivity in various ways. It is widely accepted that soil mechanical impedance is detrimental to crops.

The response of shoot growth to soil mechanical impedance is inconsistent among plant species. Some researchers reported that soil mechanical impedance reduced the shoot growth in wheat (FILHO *et al.*, 2013; NOSALEWICZ and LIPIEC, 2014), *Azadirachta excelsa* (SHUKOR *et al.*, 2015) and the yield in cereal crops (WHALLEY *et al.*, 2008; ARVIDSSON and HAKANSSON, 2014; BONVIM-SILVA *et al.*, 2014; CHAMEN *et al.*, 2015). However, in other studies, the shoot growth was not affected by soil mechanical impedance such as in dwarf line wheat (FILHO *et al.*, 2013) and barley seedling (HALING *et al.*, 2013). No effect of soil mechanical impedance was also reported in the yield of oil palm cultivated on a clay textured soil (YAHYA *et al.*, 2010).

On the other hand, the effect of soil mechanical impedance on the root growth was relatively consistent. The root elongation rate or root length is inversely proportional to the level of soil mechanical impedance (LIPIEC, *et al.*, 2012; GRZESIAK *et al.*, 2014). The plant's ability to grow root under soil mechanical impedance varied within crop species, such as in maize (CHIMUNGU *et al*, 2015), wheat (ACUNA and WADE, 2005; ACUNA *et al.*, 2007; KUBO *et al.*, 2006, 2008) barley (HALING *et al.*, 2013) and triticale species (GRZESIAK *et al.*, 2014). HALING *et al.* (2013) demonstrated that genotypes with root hairs were found to have an advantage for root penetration into high-strength layers of soil relative to root hairless genotypes on barley and conclude that root hairs are a valuable trait for plant growth and nutrient acquisition under combined soil stresses. Moreover, the study with X-ray microtomography demonstrated that maize roots elongated more rapidly with increasing root-soil contact, as long as the mechanical impedance was not limiting root elongation, while lupin was less sensitive to changes in root-soil contact (GREGORY *et al.*, 2013).

Reduction in root growth under soil mechanical impedance conditions may directly limit the potential of soil-water uptake and cause the reduction in transpiration. Stomatal conductance and transpiration rate decreased due to soil mechanical impedance in maize and triticale (GRZESIAK, 2009). The change of root growth under soil mechanical impedance conditions may indirectly affect the transpiration via the change in the plant hydraulic conductance. Transpiration rate was higher in the plants with a higher hydraulic conductance (COMSTOCK, 2002). Furthermore, the previous study found that compaction stress in sandy-loam soil decreased xylem vessel diameter and proportion of xylem cross section area in root of *Franxinus angustifolia* Vahl., which is related to percentage area for water conduction (ALAMEDA and VILLAR, 2012).

Considering there is a large consistency in the response of root growth to soil mechanical impedance in several plant species (LIPIEC, *et al.*, 2012; GRZESIAK *et al.*, 2014), the adaptability of cashew to soil mechanical impedance might be properly evaluated on the performance of root growth and the other physiological factors that closely related to the root growth such as transpiration and plant hydraulic conductance. Thus, the productive cashew accession, A3-1 that adapts well to drought stress (PITONO and TSUDA, 2012) and a local productive accession, Pangkep, from South Sulawesi, Indonesia were proper to be evaluated.

The objective of this study was to examine whether soil mechanical impedance affected growth and water transport of cashew at the seedling stage, and whether the ability to maintain growth and water transport under soil mechanical impedance could be a part attributed to drought tolerance in cashew.

MATERIAL AND METHODS

Plant materials

Cashew accession A3-1 that adapts well to drought prone environments (PITONO and TSUDA, 2012) and a local strain, Pangkep, originated from South Sulawesi were used. The seeds were soaked in water for 24 hours and then incubated on moist sand. When the radicles were emerged (2-3 cm long), the germinated seeds were transplanted to the pots (33.0 cm height; 7.5 cm in diameter) then the plants were placed in a vinyl house of Faculty of Agriculture, Okayama University. The average of daily air temperature and daily relative humidity fluctuated from 22°C to 30°C and from 60% to 99% respectively, and the irradiance ranged 200-800 $mol.m^{-2}.day^{-1}$ with average 506 $mol.m^{-2}.day^{-1}$. This microclimate condition was suitable for a normal growing cashew seedling (ABDULLAH and LAS, 1985).

The pots contained 20 cm height of column of soil mechanical impedance and 10 cm height of sand column in the upper part. The sand column was provided for proper growth of the germinated seeds. The level of soil mechanical impedance was designed on various of soil bulk density as 0.75 $g.cm^{-3}$ (loose soil, R_0), 0.90 $g.cm^{-3}$ (light level, R_1), 1.00 $g.cm^{-3}$ (moderate level, R_2) and 1.24 $g.cm^{-3}$ (severe level, R_3). The Japanese commercial granuled clay soil "*Akadama Tsuchi*" were mixed with synthetic compound fertilizer ($N:P_2O_5:K_2O$ = 10:10:10) at the rate of 3 g per kg of soil. After thorough mixing, the soil water content was brought to near 15% (w/w) and then homogenously packed to a required level of bulk density. Bulk densities of the soil was achieved by manually packing a known dry weight of soil into a set volume using a wood piston with diameter equal to the internal diameter of the pots. The soil dry weight (W_d) was determined as $W_d = W_a$ (1- SWC/100) where W_a and SWC were the actual soil weight and soil water content (%) that previously determined by drying soil sample in an oven at 90°C for ten days, respectively (MC KENZIE *et al.*, 2002). The surface of pots was quickly covered with a vinyl sheet to prevent the evaporation from the soil. Our aim was to vary soil strength without complications in soil moisture, so the lost water was daily replaced to maintain soil water content became near its original value. The mechanical resistance (R_s, in $kg.cm^{-2}$) of the soil was recorded at the end of experiment. Four points for every pot were determined by a Yamanaka Cone Penetrometer and R_s was calculated as $100 \times C/\{0.795 \times (40 - C)^2\}$, where C was the Cone Penetrometer reading in mm (MEIGH, 1987).

Shoot growth

Stem length was measured weekly from the soil surface to the tip of main stem, and the stem diameter with bark was determined at 2 cm above the soil surface. Area of individual leaf (A_i) was approximated using a previously determined linier regression function as $A_i = 0.6802 \times L_i \times M_i - 0.1927$; $r^2 = 0.980$, where L_i and M_i were the leaf length and the maximum leaf width, respectively. Leaf area of one plant was the sum of A_i.

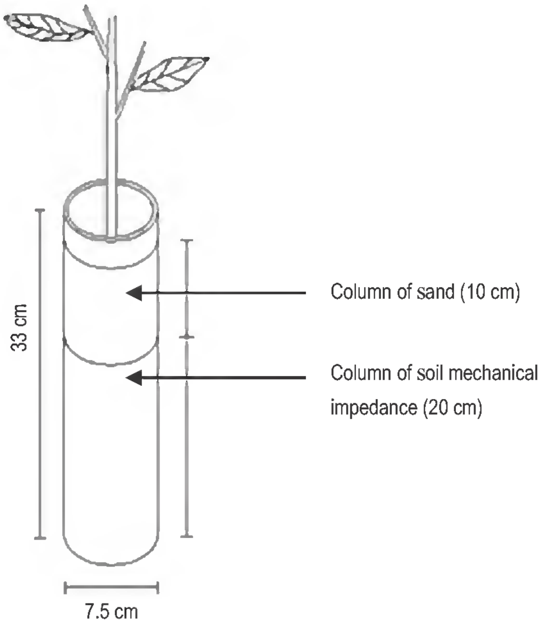

Figure 1. The pots contained 20 cm height of column of soil mechanical impedance and 10 cm height of sand column in the upper part

Gambar 1. Pot terbagi dalam kolom tahanan mekanik tanah setinggi 20 cm dan kolom pasir setinggi 10 cm pada bagian atasnya

Transpiration

Transpiration was measured using a gravimetric method from 06:00 to 18:00 on the sunny days. The pot surface was sealed with an aluminum foil and vinyl sheet to avoid water loss due to the soil evaporation. The initial pot weight (W_i) was recorded at 06:00 after covering bottom surface of the pots with vinyl sheet to prevent soil water loss. Transpiration rate (T) was estimated from the difference of weight between W_i and the pot weight measured at 18:00 (W_l) as $T = (W_i - W_l)/(A \times t)$, where A and t were leaf area and the actual time of the observation period, respectively (TSUDA and TYREE, 2000).

Hydraulic conductance

The hydraulic conductance in the roots, shoots and whole plant were determined during period of 54-60 days after planting (DAP) using a high pressure flow meter (HPFM) as described by TSUDA and TYREE (2000). The reason of defined HPFM measurement at 54-60 DAP was as suitable time in which the based stem diameter equal to the size of the HPFM access tube, around 6 mm. Briefly, the stem was cut about 2 cm above the soil surface and the shoot immediately immerse in water. The root stump was connected to the HPFM systems with a tight seal. The root conductance was determined from the values of water flow into root (F) and applied pressure (P) which gradually increased at the constant rate of 3-7 kPa s^{-1} up to 500 kPa. The root conductance (k_{root}) was calculated as the slope of the plot of F versus P: $k_{root} = dF/dP$. After that, the stem base was connected to HPFM and the shoot conductance (k_{shoot}) was measured. Hydraulic conductance in whole plant (k_{plant}) was determined as the reciprocal of ($1/k_{root} + 1/k_{shoot}$).

Root length

The roots were carefully extracted from the soil by washing over a 2 mm wire screen and then kept in the vinyl bags with ethanol 50% after the measurement of the hydraulic conductance. Root length was determined in two ways, first) the length of roots with diameter > 1 mm was measured manually and second) the root length in diameter < 1 mm was estimated using a line intercept method (NEWMAN, 1966). The roots were placed in 3-4 mm height of water in a transparent vinyl box (20 by 20 cm) and then arranged to minimize overlap of the roots. The vinyl box was placed on a scanner (Cannon) that linked to a PC-based Adobe Photoshop 6.0 to scan the roots on a resolution of 150 dpi. Then, the length of those scanned roots (R_L) was estimated using a soft program Scion Image which based on intercept method as $R_L = \pi/4 \times N \times S$, where N and S were the root numbers that crossed to a square grid and the length of the grid-side (0.85 cm), respectively. Total root length per plant was determined as the sum of root length with diameter more than 1 mm and less than 1 mm.

Root xylem area

A root xylem area indicated the potency of root water transport was observed. One root (5 mm in diameter) each plant in the part of the soil mechanical impedance was sampled to determine the xylem area. The transverse section of roots with about 0.5 mm thickness was mounted on a microscope slide. A photographic image of the root xylem was captured on 20 x magnification of a light microscope, which was equipped with a digital camera (Fijix digital camera HC-300-I) that was linked to a PC-based Adobe Photoshop 5.0. The area of xylem and whole root surface were determined on the PC-based Scion Image. Then, the xylem area was divided by the whole root surface area and described as the xylem area/ transversal root area ratio.

Experimental design and statistics

The treatments of cashew accession and soil bulk density were arranged in factorially completely random design with five replications. After checking normal data distribution, the anova and further test were analysed with SAS program and Duncan test.

RESULTS AND DISCUSSION

A variation of the soil mechanical impedance was created by leveling soil bulk density, and the values of soil mechanical resistance increased about four times, ten times and thirty five times of the control (R_0) in R_1, R_2 and R_3, respectively (Table 1). These results also confirmed that the existence of cashew accession did not affect the change of soil mechanical resistance (Table 3).

The effect of soil mechanical impedance to shoot growth was clearly detected on the leaf area only. The response data on stem length and stem diameter were not showed. The effect of interaction treatment of soil bulk density and accession to variation of leaf area revealed from 27 days after planting, DAP (Table 2). Although the increased level of soil bulk density was clearly declined leaf area on both accession, however, the decrease of leaf area was faster in A3-1 than Pangkep. When subjected to severe soil mechanical impedance (bulk density 1.24 g.cm^{-3}), the leaf area of both accessions decreased to be around 50% of the control plants. A similar case found in wheat (MAURICIO *et al.*, 2013; FILHO *et al.*, 2013), maize and triticale seedlings (GRZESIAK, 2009), however no effect of soil mechanical impedance to shoot growth detected in dwarf line wheat (FILHO *et al.*, 2013) and barley seedling (HALING *et al.*, 2013). It was indicated before that leaf expansion is decreased when involved in hard soils, due to direct signalling between root and shoot associated with the mechanism physiological response to mechanical impedance (FAGERA *et al.*, 2006; GRZESIAK *et al.*, 2013). MAURICIO *et al.* (2013) also reported that the gibberellin signallling pathway roled the leaf elongation response to mechanical impedance to root growth in wheat.

Table 1. The mean values of soil mechanical resistance (Rs), root length, thick root length/total root length ratio, hydraulic conductance in root (k_{root}), shoot (k_{shoot}), and plant (k_{plant}) under treatment of soil bulk density.

Tabel 1. Nilai tengah tahanan mekanik tanah (Rs), panjang akar, rasio panjang akar tebal/panjang akar total, daya hantar air di akar (k_{akar}), tajuk (k_{tajuk}), dan tanaman ($k_{tanaman}$) akibat perlakuan padatan tanah.

Treatment of soil bulk density (g.cm^{-3}) *Perlakuan padatan tanah (g.cm^{-3})*	Soil mechanical resistance, Rs (Mpa) *Tahanan mekanik tanah, Rs (MPa)*	Total root length (m.plant^{-1}) *Panjang akar total (m.tanaman^{-1})*	Thick root length/total root length ratio *Rasio panjang akar tebal/panjang akar total*	Hydraulic conductance, k (x 10-6 kg.MPa^{-1}.s^{-1}.m^{-2}) *Daya hantar air, k (x 10-6 kg.MPa^{-1}.s^{-1}.m^{-2})*		
				k_{root} k_{akar}	k_{shoot} k_{tajuk}	k_{plant} $k_{tanaman}$
0,75 (R_0)	0,061 ^{c}	6093,0 ^{a}	0,070 ^{a}	6,084 ^{ab}	2,320 ^{a}	4,796 ^{a}
0,90 (R_1)	0,375 ^{c}	6031,2 ^{a}	0,066 ^{a}	4,881 ^{c}	1,972 ^{b}	3,784 ^{b}
1,00 (R_2)	0,973 ^{b}	5291,2 ^{a}	0,060 ^{a}	6,486 ^{a}	1,798 ^{b}	4,826 ^{a}
1,24 (R_3)	3,567 ^{a}	3758,3 ^{b}	0,034 ^{b}	5,272 ^{bc}	1,064 ^{c}	3,473 ^{b}
CV/*KK* %)	22,9	22,4	27,6	18,5	18,1	15,1

Note: Number followed by the same letter in the same coloum are not significantly different at Duncan test, $P \leq 0{,}01$.

*Keterangan: Angka yang diikuti huruf yang sama dalam kolom yang sama tidak berbeda nyata menurut uji Dunca*n pada $P \leq 0{,}01$.

Table 2. The mean values of leaf area under interaction treatment of accession and soil bulk density at 27, 33,40, and 47 days after planting (DAP).

Tabel 2. Nilai tengah luas daun pada interaksi perlakuan aksesi dan padatan tanah pada 27, 33, 40, dan 47 hari setelah tanam (DAP).

Treatments / *Perlakuan*		Leaf Area (m^2.plant^{-1}) / *Luas daun (m^2.tanaman^{-1})*			
Accession *Aksesi*	Soil Bulk Density (g.cm^{-3}) *Padatan tanah (g.cm^{-3})*	27 DAP	33 DAP	40 DAP	47 DAP
A3-1	0,75 (R_0)	204,2 ^{bc}	288,1^{ab}	439,0 ^{bc}	542,6 ^{bc}
	0,90 (R_1)	175,9 ^{cd}	262,9 ^{bc}	394,8 ^{cd}	476,0 ^{c}
	1,00 (R_2)	163,8 ^{d}	208,5 ^{cd}	365,5 ^{cd}	433,3 ^{c}
	1,24 (R_3)	145,9 ^{d}	185,3 ^{d}	286,2 ^{d}	298,9 ^{d}
Pangkep	0,75 (R_0)	227,9 ^{ab}	259,4 ^{bc}	395,1 ^{cd}	524,9 ^{c}
	0,90 (R_1)	259,9 ^{a}	340,6 ^{a}	570,7 ^{a}	716,2 ^{a}
	1,00 (R_2)	260,8 ^{a}	334,9 ^{a}	520,5 ^{ab}	662,7 ^{ab}
	1,24 (R_3)	221,3 ^{bc}	290,4 ^{ab}	387,9 ^{cd}	478,8 ^{c}
CV/*KK* (%)		12,9	17,0	19,0	19,0

Note: Number followed by the same letter in the same coloum are not significantly different at Duncan test, $P \leq 0{,}01$

Keterangan: Angka yang diikuti huruf yang sama dalam kolom yang sama tidak berbeda nyata menurut uji Duncan pada $P \leq 0{,}01$

The soil bulk density and accession were independently affected to root growth (Table 1 and 3). Although the total root length was genetically higher on Pangkep than A3-1, however the thick root length/total root length ratio was higher in A3-1 (Table 3). The suppression of total root length and thick root length/total root length ratio by soil mechanical impedance were detected on the highest level of bulk density (R_3) only, where reduction of the total root length achieved 38%. The previous study also reported that soil mechanical impedance decreased root length approximately 50% and 79% on barley (Hordeum vulgare) and triticale (Triticosecale Wittmack), respectively (LIPIEC, *et al.*, 2012); and about 55% on maize (GRZESIAK, 2009). Eventhough, the soil impedance causes physical limitation to root growth with a typical soil penetrometer resistance of 2.0 MPa as the threshold root elongation (BENGOUGH *et al.*, 2011), however our results showed that the accession of A3-1 was able to penetrate slightly to the severe soil mechanical impedance level with soil penetrometer resistance of 3.5 MPa. These results suggested that there is genetic variation of root growth in chasew species and it affected by soil mechanical impedance as in the case of wheat, barley, maize, and triticale (HALING *et al.*, 2013; MAURICIO *et al.*, 2013; GRZESIAK *et al.*, 2014). These results also approved that soil mechanical impedance did not reduce the total length of roots only, but also increased the root diameter of cashew as the case in wheat (TRACY *et al.*, 2012; LIPIEC *et al.*, 2012; NOSALEWICZ and LIPIEC, 2014), and rye (LIPIEC *et al.*, 2012). Increasing total cross section area of roots was reported to be about 9,5% in wheat and 132% in rye seedling when subjected to soil mechanical impedance condition (LIPIEC *et al.*, 2012). It was reported that the stress combination of soil mechanical impedance and mechanical stress induced increase of root diameter and xylem area in tobacco (ALAMEDA *et al.*, 2012), and the water uptake in wheat correlated with the length of thick roots, in which it was increasing with increased level of soil mechanical impedance (NOSALEWICZ and LIPIEC, 2014). Additionally, thicker roots are more resistant to buckling and defletion when encountering soil mechanical impedance (JIN *et al.*, 2013; CHIMUNGU *et al.*, 2015), and some studies on anatomical root also reported that anatomical phenes such as root cortical aerenchyma, small living cortical area, cortical cell file number, and large cortical cells have been associated with root ability to adapt soil resistance (ZHU *et al.*, 2010; JARAMILLO *et al.*, 2013; LYNCH, 2013,2014; CHIMUNGU *et al.*, 2014a,b; LYNCH *et al.*, 2014; HUMMEL *et al.*, 2007).

Table 3. The mean values of soil mechanical impedance (Rs), root length, thick root length/total root length ratio, hydraulic conductance in root (k_{root}), shoot (k_{shoot}), and plant (k_{plant}) under accession treatment

Tabel 3. Nilai tengah tahanan mekanik tanah Rs), panjang akar, rasio panjang akar tebal/panjang akar total, daya hantar air di akar (k_{akar}), tajuk (k_{tajuk}), and tanaman ($k_{tanaman}$) akibat perlakuan aksesi

Treatment of accession *Perlakuan aksesi*	Soil mechanical resistance, Rs (MPa) *Tahanan mekanik tanah, Rs (MPa)*	Total root length (m.plant^{-1}) *Panjang akar total (m.tan^{-1})*	Thick root length/total root length ratio *Rasio panjang akar tebal/panjang akar total*	Hydraulic conductance, k (x 10-6 kg.MPa^{-1}.s^{-1}.m^{-2}) *Daya hantar air, k (x 10-6 kg.MPa^{-1}.s^{-1}.m^{-2})*		
				k_{root} k_{akar}	k_{shoot} k_{tajuk}	k_{plant} $k_{tanaman}$
A3-1	1,223 ^{a}	4371,2 ^{b}	0,069 ^{a}	5,851 ^{a}	1,799 ^{a}	4,303 ^{a}
Pangkep	1,265 ^{a}	6215,7 ^{a}	0,046 ^{b}	5,511 ^{a}	1,777 ^{a}	4,137 ^{a}
CV/*KK* (%)	22,9	22,4	27,6	18,5	18,1	15,1

Note: Number followed by the same letter in the same coloum are not significantly different at Duncan test, $P \leq 0{,}01$.

Keterangan: Angka yang diikuti huruf yang sama dalam kolom yang sama tidak berbeda nyata menurut uji Duncan pada $P \leq 0{,}01$.

These results approved that soil mechanical impedance could change the root morphological and/or anatomical as well as the hydraulic conductance in cashew seedlings (Table 1 and 3). In general, the hydraulic conductance in root (k_{root}), shoot (k_{shoot}), and plant (k_{plant}) were decrease with increased level of soil bulk density treatments. However, those hydraulic conductances were not different among the accession. These results may be elucidated that besides the steep decrease in the leaf area, the combined large values in the proportion of thick root length/total root length and the xylem area/transversal root area ratio might induce the root hydraulic conductance of A3-1 not be lower than Pangkep. In line with these results, the study in cotton plant reported that the water flux through roots was positively related to secondary xylem development and increased xylem vessel number (OOSTERHUIS and WULLSCHLEGER, 1987). The relationship between the root anatomy and hydraulic conductance in roots also found in several plant species such as in sugarcane (SALIENDRA and MEINZER, 1992) and Psilotum nudum (SCHULTE *et al.*, 1987).

Xylem area/transversal root area ratio is considered to be an indication of water transport efficiency in the roots (OOSTERHIUS and WULLSCHLEGER, 1987). The proportion of xylem cross section area dedicated to vessels, which related to percentage area for water conduction in Fraxinus angustifolia Vahl, was decrease when subjected to soil mechanical impedance conditions (ALMEDA and VILLAR, 2012). However, our results showed that there was no effect of soil mechanical impedance on xylem area/transversal root area ratio in A3-1, and just a slight decrease detected at moderate level of soil bulk density, R_2 (Table 4). In contrary, the xylem area/transversal root area ratio was clearly decreased with increase of soil bulk density treatment level in Pangkep. Due to unavailable representative root samples, there was no data at severe soil bulk density level, R_3 in both accessions to be exposed. Overal, the xylem area/transversal root area ratio was higher in A3-1 than Pangkep, and it might help the root hydraulic conductance under soil mechanical impedance conditions in A3-1 was as good as in Pangkep.

In case of maize and triticale, the soil mechanical impedance stress not only affected morphological structure of roots but also decrease in net photosynthetic rate, transpiration rate, stomatal conductance, and leaf water potential (GRZESIAK, 2009; GRZESIAK *et al.*, 2013). Decreased photosinthesis by soil mechanical impedance also reported in pearl millet and cowpea (LIZARAZU *et al.*, 2006). On the other hand, our results showed that increased level of soil bulk density treatment was not accompanied by any decrease in transpiration rate of both cashew accessions (Table 4). When subjected to soil mechanical impedance conditions, the transpiration rate in A3-1 was clearly higher about 25% than in Pangkep. These results clearly exhibited that A3-1 accession with low leaf area and k_{root} as good as Pangkep could maintain transpiration well over Pangkep accession. Therefore, it could be considered that cashew has good ability to regulate balance between root hydraulic conductance and leaf area, so may cope the environmental stress induced by soil mechanical impedance. In this context, A3-1 might have a benefit over Pangkep under soil mechanical impedance conditions.

Table 4. The mean values of diurnal transpiration and xylem area/ transversal root area ratio under interaction treatment of accession and soil bulk density.

Tabel 4. Nilai tengah transpirasi harian dan rasio luas xylem/luas melintang akar pada interaksi perlakuan aksesi dan padatan tanah.

Treatments *Perlakuan*		Diurnal transpiration (g.cm^{-2}.day^{-1}) *Transpirasi harian (g.cm^{-2}.hari^{-1})*		Xylem area/transversal root area ratio *Rasio luas xylem/luas melintang akar*
Accession *Aksesi*	Soil bulk density (g.cm^{-3}) *Padatan tanah (g.cm^{-3})*	42 DAP	48 DAP	
A3-1	0,75 (R_0)	0,184 ^{c}	0,119 ^{bc}	0,566 ^{a}
	0,90 (R_1)	0,188 ^{c}	0,123 ^{bc}	0,581 ^{a}
	1,00 (R_2)	0,244 ^{b}	0,158 ^{a}	0,552 ^{ab}
	1,24 (R_3)	0,310 ^{a}	0,164 ^{a}	0 ^{d}
Pangkep	0,75 (R_0)	0,184 ^{c}	0,123 ^{bc}	0,561 ^{a}
	0,90 (R_1)	0,128 ^{d}	0,112 ^{c}	0,552 ^{ab}
	1,00 (R_2)	0,150 ^{cd}	0,135 ^{b}	0,431 ^{c}
	1,24 (R_3)	0,229 ^{b}	0,123 ^{bc}	0 ^{d}
CV/*KK* (%)		13,5	9,6	8,0

Note: Number followed by the same letter in the same coloum are not significantly different at Duncan test, $P \leq 0{,}01$.

Keterangan: Angka yang diikuti huruf yang sama dalam kolom yang sama tidak berbeda nyata menurut uji Duncan pada $P \leq 0{,}01$.

CONCLUSION

The response of growth and plant water transport to soil mechanical impedance in cashew seedlings depended on the cashew accession. The accession A3-1 showed a better ability to regulate the growth balance in root and shoot resulting a good maintenance in diurnal transpiration when subjected to soil mechanical impedance conditions. Furthermore, this ability might be a part attribute of drought tolerance on A3-1 accession and would be suitable parameter for evaluating drought tolerance of cashew at the seedling stage.

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