The hydraulic lift response under media moisture conditions on the cashew (*Anacardium occidentale* L.)

J Pitono*, N Maslahah, H Nurhayati, Setiawan, S Suhirman, and RA Permadi

Indonesian Spices and Medicinal Crops Research Institute Jl. Tentara Pelajar No.3 Bogor, West Java 16111 Indonesia

Corresponding author email: pitono2014@gmail.com; jokopitono@litbang.pertanian.go.id

Abstract. Cashew was reported to have hydraulic lift (HL) ability, which vertically transferred water from the moister bottom layer to the drier upper one. However, it was tested under homogenous moisture conditions on the bottom soil layer, whereas its response under heterogeneous one was still unclear. Therefore, this study evaluated the HL response under heterogeneous moisture on the bottom soil layer on 10 months old cashew. It was conducted in the ISMCRI greenhouse from September to October 2020. The cashew was grown, and its roots were developed into three compartments filled with growth media: one top compartment (T) and two bottom compartments (B₁ and B₂). The media was subjected to four conditions 1) the whole media in moist conditions, 2) T was dry, B₁ and B₂ were moist, 3) T and B₁ were dry, B₂ was moist, and 4) the whole media were dry. The cashew HL was not significantly reduced in the condition where the half part of the lower root was in dry condition. This result indicated that cashew HL was strong enough under heterogeneous soil moisture conditions in the bottom layer. Thus, cashew was potential as a component of water bio-conservation of the land in the dry climate.

Keywords: *Anacardium occidentale* L., root, soil moisture, water transfer, bio-conservation

1. Introduction

The cashew development target in Indonesia was in the dry land with a dry climate, especially in eastern Indonesia [1][2]. Commonly, open space between cashew stands during the rainy season was used to cultivate various seasonal crops such as peanuts, maize, and other cash crops [3]. Extending the cultivation of cash crops in the dry season is one of the main strategies to increase farmers' income.

The utilization of soil water conservation technologies such as *rorak* in cashew plantations was reported to be effective and could increase productivity [4]. Further studies revealed that cashew plants also possessed hydraulic lift (HL) capabilities, transferring soil water from a moister bottom layer to a drier shallow layer through root activity at night [5, 6, 7, 8]. The HL ability of cashew was evaluated both on a field scale [5] and on a pot scale [6, 7]. Report on the pot scale trial indicated cashew HL ability to transfer water to the drier part in the upper media; hence the maize planted next to the cashew could utilize the water to support its growth and maintain tissue water status [6]. This similar HL phenomenon were also reported in several other desert plant species [9, 10, 11, 12, 13, 14, 15].

Naturally, the distribution of rainwater infiltration into the soil tended to vary following the toposequence and the nature of the aggregates that formed the soil [16, 17]. As a result, this varied soil moisture level in the bottom layers might affect the plant HL process. Furthermore, studies on Norway
spruce, European beech, and English oak, indicated their ability to detect hydraulic redistribution even at moderate gradients of soil water potential [18].

All of the cashew HL had been evaluated under uniform bottom soil moisture conditions. Thus, the effect of moisture variations on the bottom soil layer on cashew HL activity was still unclear. Therefore, it was required to assess the variations effects in media moisture on the cashew HL.

2. Materials and method
This study was performed in the greenhouse of Indonesian Spices and Medicinal Crops Research Institute (ISMCRI), Bogor Indonesia. The superior variety of cashew B-02 was grown, and its roots were developed into three media compartments until 10 months old, and then its HL response under various media moisture conditions was evaluated from September – October 2020.

2.1. Media compartment construction
The pot was modified and split into three compartments which consisted of one top compartment (T) and two bottom compartments (B1 and B2) and filled with the recommended growth media (soil and sand, 1:1) for the cashew HL evaluation on the potted scale [7]. The top compartment was made from PVC pipes with 10 cm in diameter and 20 cm in height, and both of the bottom ones used a 600 ml bottle of mineral water (Figure 1).

2.2. Cashew planting and splitting root growth
Cashew seeds were imbibed for 24 hours in tap water, then put in moist sand media for 12 days to germinate. The germinated seed was planted in the middle of the upper media compartment; hence the root would proportionally grow into a split three-compartment media. The plastic fins were installed at the bottom surface of the top media compartment (T) to allow the proportional root cashew distribution into the two bottom media compartments (B1 and B2).

2.3. Plant maintenance
The cashew plants were maintained on an adequate water level by providing periodic irrigation into the three media compartments using plastic hose access. In addition, to avoid a nutrient shortage, the cashew plants were fertilized following the recommended dose at 7.0 g NPK/kg media [18].

2.4. Root separation
A week before HL evaluation, the roots at each joint section of the compartment were separated from growth media following the previous method [6, 7]. Water was sprayed carefully on the roots in the bottom compartments to remove growth media and avoid mechanical root injury at once. This root separation will eliminate the effect of the diffusion force of media particles on the water transfer process among the media compartment.
2.5. Experimental design
Ten months after planting, when the root enough developed into the three media compartments, the cashew were subjected to four conditions: (1) the whole media (upper media compartment, T also the two bottom media compartments, B\textsubscript{1} and B\textsubscript{2}) were always in moist condition, (2) T was withheld irrigation, B\textsubscript{1} and B\textsubscript{2} were in moist conditions, (3) T and B\textsubscript{1} were withheld irrigation, and B\textsubscript{2} was on moist conditions, and (4) the whole media were withheld irrigation. The study was arranged in a complete randomized design with six replications.

2.6. Observation
Soil moisture, leaf water potential, vegetative growth, and greenhouse microclimate (temperature and humidity) were all measured. Following the earlier cashew hydraulic lift measurement method [6] [7], soil moisture was checked every 20 minutes with a soil moisture sensor linked to the data recorder device. The soil moisture sensor was placed 20 cm from the pot's bottom. A Wescor HR-33T Dew Point Microvoltmeter was used to monitor leaf water potential to establish the response of the canopy's water status. During the hydraulic lift evaluation phase, the leaf water potential parameter was measured on fully grown young leaves every day. During the evaluation period, the greenhouse microclimate (air temperature and relative humidity) was also evaluated. The air temperature and relative humidity parameters were measured every 20 minutes using a DHT-11 sensor connected to the datalogger unit.

3. Results
3.1. The moisture of the top media compartment
In this study, the main parameter for evaluating HL was the moisture dynamic of the top media compartment (Figure 2). The media moisture of all plants gradually decreased along the irrigation withholding period, except for the P\textsubscript{0} plant. However, on the fifth day after withholding irrigation, the moisture of the top media compartment in P\textsubscript{1} and P\textsubscript{2} plants was consistently higher than in P\textsubscript{3}. It denoted the transfer of a certain amount of water from the moister bottom media compartment to the drier top media compartment. And this water transfer was clearly driven by HL activities, because the soil capillary force between the three media compartments was already eliminated by the prior root separation process. Moreover, the effect of whether both bottom media (P\textsubscript{1} plant) or just one bottom media (P\textsubscript{2} plant) on moist conditions showed similar moisture values on the top media compartment that indicated no HL variation among them.

![Figure 2. The moisture of the top media compartment (θ\textsubscript{top media}) on P\textsubscript{0}, P\textsubscript{1}, P\textsubscript{2}, and P\textsubscript{3} treatments. The values were mean ± se of 6 sample plants.](image-url)
3.2. **Leaf water potential**
Because of the total interruption of water input after irrigation withholding treatment, the P3 plant’s leaf water potential (leaf) was consistently higher than the other plants. (Figure 3). However, the $\Psi_{\text{leaf}}$ did not differ among $P_0$, $P_1$, and $P_2$ plants with a similar response pattern at 2.3 – 3.3 MPa.

![Figure 3](image)

**Figure 3.** The leaf water potential ($\Psi_{\text{leaf}}$) on $P_0$, $P_1$, $P_2$, and $P_3$ plants. The values were mean ± se of 6 sample plants.

3.3. **Plant morphology prior to HL evaluation**
Prior to HL evaluation, the vegetative growth of plants was kept uniform to minimize the risk that affected the HL values. As a result, sample plant growth among the treatments was relatively similar, as shown in Figure 4.

![Figure 4](image)

**Figure 4.** The plant height of cashew on $P_0$, $P_1$, $P_2$, and $P_3$ plants. The values were mean ± se of 6 sample plants.

3.4. **Microclimate**
The greenhouse’s daily air temperature ranged from 19 to 33°C, with relative humidity ranging from 20 to 90% (Figure 5). These conditions were effective enough in promoting the drought conditions of the potting media required for HL evaluation in cashew, as indicated the level moisture of top media compartment on the $P_1$ and $P_2$ plants being considerably higher than the $P_3$ plant (Fig. 2). However, the moisture variation of the bottom media compartment still could not drive the HL disparities among them under these microclimate circumstances.
4. Discussion

The evaluation of top media moisture confirmed the existence of vertical water transfer by root cashew from the moister bottom media to the drier top media, as shown by P₁ and P₂ plants (Fig. 2). It approved the previous reports about the cashew HL ability [5, 6, 7, 8]. Currently, further studies on HL have been conducted on forest and desert plant species [9, 10, 11, 12, 13, 14], but still rarely done on agricultural crop species. In field application, cashew HL was expected to support the extension of cash crops cultivation during the dry season. In the previous pot-scale study, cashew HL clearly supported maize growth and maintained its leaf water potential when drought stress was experienced [6]. Therefore, the field study in this area would be an interesting challenge.

This study also provides additional information that the water transfer to the top media was relatively unaffected by the proportion of the water amount in the bottom media (Fig. 2). Furthermore, the cashew HL was relatively similar in whole (P₁) or half (P₂) moist bottom media, which indicated that the cashew HL was quite strong. However, the validation using larger bottom media sizes was still compulsory, considering the bottom media used in this study was only about 0.6 liters per unit.

Furthermore, water transfer to the top media compartment was purely due to the HL activity since the risk of bias due to plant morphological variations were eliminated by maintaining a fairly uniform plant vegetative growth before HL evaluation. The root separation procedure was also applied before the HL assessment for eliminating the potential of bias due to soil capillary force.

The temperature and RH of the greenhouse during the HL test were lower (Fig. 5) than the microclimate conditions in the previous HL studies. This circumstance might affect the leaf water potential response, which did not show a significant pattern of increase in values during the HL evaluation, contrasted with the previous studies [6][20]. Moreover, the change of soil temperature might also be a crucial factor for cashew HL evaluation, however it was not observed in this study and would be an important clue on the next studies.

5. Conclusion

The pattern of top media moisture during the irrigation withholding period clearly indicated the presence of cashew HL activity, signified by water transfer from the moister bottom media to the drier top media. The variation of moisture level in bottom media compartment did not significantly affect the cashew HL. It implied that the cashew HL might be stronger especially under moderate microclimate condition. Furthermore, cashew HL was highly regarded as an important component in the development of soil moisture bio-conservation technology for agricultural development in dry climate land areas.
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Contributorship
JP was the main contributor; MS, NM, HN, S, SS and RAP were co-contributors

References
[1] Ditjenbun. Jambu mete. Jakarta: Sekretariat Jenderal Kementerian Pertanian RI; 2019.
[2] Rosman R. Peningkatan produksi jambu mete nasional melalui perbaikan teknologi budidaya berbasis ekologi. Perspektif. 2018;17(2):166–74.
[3] Pranowo D, Purwanto E. Pemanfaatan Lahan Diantara Tanaman Jambu Mete Muda di Lahan Marginal. J Tanam Ind dan Penyegar. 2011;2(2):199–206.
[4] Firman C. Teknik peningkatan produksi jambu mete (Anacardium occidentale L.) melalui teknologi rorak. Bul Tek Pertan. 2006;11(2):64–6.
[5] Pitono J, Maslahah N, Setiawan, Permadi RA, Suciantini, Nandar T. Hydraulic lift and dynamika lengas tanah harian pada pertanaman jambu mete. Bul TRO. 2016;27(2):104–14.
[6] Pitono J, Maslahah N, Setiawan S. peran hydraulic lift jambu mete pada pemeliharaan lengas tanah dan status air jagung saat kekeringan. J Penelit Tanam Ind. 2017;23(1):55.
[7] Pitono J, Maslahah N, Setiawan, Permadi RA. Recovery lengas tanah harian jambu mete pada variasi media tanam. In: Supriadi, Tombe M, Laba IW, Rostiana O, Wahyuno D, Bermawie N, et al., editors. Forum komunikasi jambu mete nasional II. Bogor Indonesia: IAARD Press; 2016. p. 233.
[8] Maslahah N, Pitono J, Syakir M, Siswanto. Biokonservasi Lengas Tanah Pada Pola Tanam Jambu Mete-Kopi. In: Supriadi, Tombe M, Laba I W, Rostiana O, Wahyuno D, Bermawie N, et al., editors. Forum komunikasi jambu mete nasional II. Bogor Indonesia: IAARD Press; 2016. p. 233.
[9] Caldwell M M, Dawson T E, Richards J H. Hydraulic lift: Consequences of water efflux from the roots of plants. Oecologia. 1998;113(2):151–61.
[10] Besson TM, Mcclronet AJ, Jackson RB. Water uptake and hydraulic redistribution across large woody root systems to 20 m depth. Plant, Cell Environ. 2010;33(12):2132–48.
[11] Prieto I, Armas C, Pugnaire F I. Water release through plant roots: New insights into its consequences at the plant and ecosystem level. New Phytol. 2012;193(4):830–41.
[12] Prieto I, Armas C, Pugnaire FI. Tansley review Water release through plant roots: new insights into its consequences at the plant and ecosystem level. New Phytol [Internet]. 2012;193(4):830–41. Available from: http://www.ncbi.nlm.nih.gov/pubmed/22250761
[13] David TS, Pinto CA, Nadezhdina N, Kurz-Besson C, Henriques MO, Quilho T, et al. Root functioning, tree water use and hydraulic redistribution in Quercus suber trees: A modeling approach based on root sap flow. For Ecol Manage [Internet]. 2013;307:136–46. Available from: http://dx.doi.org/10.1016/j.foreco.2013.07.012
[14] Rocha S, Duarte F, Da Silva L, Waechter, Luiz J. Positive association between Bromelia balansae (Bromeliaceae) and tree seedlings on rocky outcrops of Atlantic forest. J Trop Ecol. 2014;31(02):195–8.
[15] Evaristo J, Jasechko S, McDonnell JJ. Global separation of plant transpiration from groundwater and streamflow. Nature. 2015;525:91–4.
[16] Rosyidah E, Wirosodarmo R. Pengaruh sifat fisik tanah pada konduktivitas Hidrolik. Agritech. 2013;33(3):340–5.
[17] Ahuja L, Ma L, Green TR. Effective soil properties of heterogeneous areas for modeling infiltration and redistribution. SSSAJ. 2010;74(5):1469–82.
[18] Hafner BD, Tomasella M, Héberle K, Goebel M, Matyssek R, Grams TEE. Hydraulic
redistribution under moderate drought among English oak, European beech and Norway spruce determined by deuterium isotope labeling in a split-root experiment. *Tree Physiol.* 2017;37:950–60.

[19] Trisilawati O, Towaha J, Daras U. Pengaruh mikoriza dan pupuk NPK terhadap pertumbuhan dan produksi jambu mete muda. *Bul Littri*. 2012;3(1):91–8.

[20] Pitono J, Nurhayati H, Syakir M. The hydraulic redistribution on cashew (*Anacardium occidentale* L.) at nursery stage. *IOP Conf Ser Earth Environ Sci*. 2020;418(1).