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PHOTOSYNTHESIS, TRANSPIRATION AND WATER USE EFFICIENCY OF *RHIZOPHORA APICULATA* AND *RHIZOPHORA MUCRONATA* AT SG. HAJI DORANI, MALAYSIA

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ABSTRACT

The study on transpiration and water use efficiency of mangrove species was still lacking. Information on the hydrological characteristic of the mangrove plant related to its physiology traits is often neglected. Therefore, the study has been undertaken to fill in the gap of information as a value-added to the conservation effort of mangrove. This information is also important to clarify gas exchanges at the different forest ecosystem level and in this case, is the mangrove forest. Such studies have been conducted to clarify gas exchanges in dipterocarp forest but less has been done for mangrove forest species. The observation was conducted in the morning and afternoon using Li6400XT on Rhizophora apiculata (bakau minyak) and Rhizophora mucronata (bakau kurap). This paper, report the result of the observation in selected mangrove species at Sg. Haji Dorani, Selangor, Malaysia. Generally, the Rhizophora apiculata has a higher rate of photosynthesis and transpiration, however, the WUE is high in Rhizophora mucronata during morning and afternoon observation. The photosynthesis and transpiration rates regulate the WUE in Rhizophora apiculata and Rhizophora mucronata. The transpiration of mangrove at Sg. Haji Dorani was affected by the opening of the leaf stomatal (r2 = 0.99). The stomatal opening and transpiration also are inversely proportional with leaf heat (vapour pressure deficit, VPD). The stomatal opening increased when the VPD is between 3.15 and 3.25 kPa and gradually decreases as VPD increases to prevent water losses. This data is of importance to understand the physiology processes in mangrove forest which have not been well explored in Malaysia. It is suggested that similar study be conducted in longer-term with additional variables to understand mangrove ecosystem and its roles in assessing and monitoring of climate change impact.

Key words: Photosynthesis, stomatal conductance, gas exchange, Rhizophora spp., water cycle

INTRODUCTION

The plant needs water for physiological processes including photosynthesis and transpiration. Water used in photosynthesis will be released to the atmosphere by transpiration process. The ratio of photosynthesis and transpiration in the plant explain the water use efficiency (WUE) of the plant.

Photosynthesis and transpiration are the processes that control the water use efficiency in plants. The rate of carbon dioxide (CO_2) assimilation to transpiration is termed as water use efficiency (WUE). At the leaf level, the ratio of photosynthesis to stomatal conductance called intrinsic WUE (iWUE). According to UNEP (1994), the efficiency of mangrove water use will be enhanced, and there will be specific species variation in response to elevated CO_2. Due to the increase in WUE, mangroves may benefit because decreased water loss *via* transpiration will accompany CO_2 uptake (Ball and Munns, 1992). However, increases in CO_2 do not necessarily affect mangrove growth when salinity is too high for a species to maintain water uptake (UNEP, 1994).

The increase in ambient temperature causes the difference in water vapour pressure (VPD) to increase. Increased VPDs will cause plant stomatal to be open for transactional processes. However, at the same time with the increase in VPD, will affect stomatal activity to control the loss of water and therefore affects the process of photosynthesis by stomatal closure. The fluctuation of transpiration rate in tropical forests is heavily influenced by the amount of energy and VPD as well as the amount of groundwater content (Marryanna et al., 2017).

Mangroves comprise the woody plants occupying the margin between land and sea in low latitudes (Alongi, 2014) and are also one of the primary natural resources of the coastlines throughout the tropical and subtropical regions of the world. Mangroves are indicated by the presence of trees that mainly occur in the intertidal zone, between land and sea, sedimentation and tidal currents (Aksornkoea,1993; Nagelkerken et al. 2008). They provide a wide range of ecological services that protect the coast from erosion, buffer adjacent marine ecosystems (often coral reefs) from terrestrial inputs, and are nursery grounds for important commercial fish species and habitats for migratory birds. Mangroves are a group of highly salt-tolerant woody plants. The high water use efficiency of mangroves under saline conditions suggests that the regulation of water transport is a crucial component of their salinity tolerance (Ruth & Catherine, 2015). Since water acquisition is more energetically costly in saline than in non-saline soils, mangroves have evolved a range of adaptations that facilitate efficient water use during photosynthetic carbon gain during the day and reduce losses of water to saline soils at night. Mangroves have a number of properties, from the scale of the arrangement of leaves in the canopy to microscopic structures within leaves, which contribute to high photosynthetic water use efficiencies. Mangrove plant filtrates saline water and transpires fresh water into the air. These processes are useful in cloud formation and source for rainwater. Therefore, mangrove plays an important role in maintaining the water cycle.

Adaptations of mangrove species influence water uptake, transport and loss while maintaining photosynthetic carbon gain. The mangrove adaptation is important for salinity tolerance. Mangrove species is not only plays some important roles in saline water filtration but also supporting the water cycle through transpiration process. The ratio of carbon assimilation and water loss during the transpiration process reflect how much water have been recycled by the forest stand. More transpiration occurred means more water is filtered and released into the air. Water released into the air will evaporate to form clouds and become a source of rain. Based on its important conservation features, we need to first study the response of mangrove species WUE due to transpiration and photosynthesis activities at the different species.

There are not much ecophysiology baseline data available for a mangrove forest in Malaysia. We need baseline data to clarify various aspect related to the mangrove forest. Therefore, the objective of this study is to measure the value of photosynthesis, transpiration and WUE rates by selected mangrove species at Sg Haji Dorani as baseline data for conservation. Ecophysiology study of this unique species would be beneficial to understand the physiological and hydrological aspect of mangrove species for research advancement.

METHOD

Description of the study area

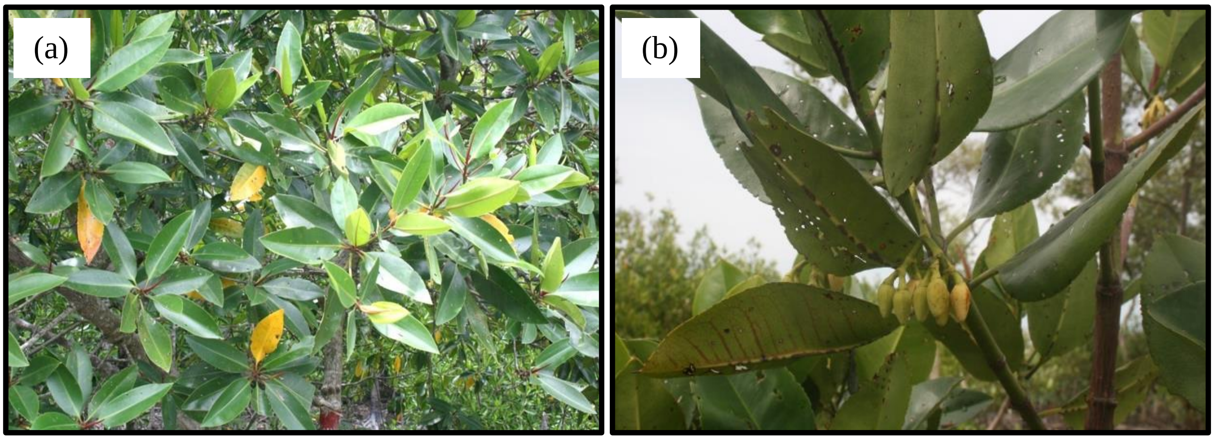
The study was conducted at Sg. Haji Dorani in Kuala Selangor, Selangor, Malaysia (Figure 1). It is located about 90 km to the north of Kuala Lumpur, near Sabak Bernam at the west coast of Peninsular Malaysia. The measurement was conducted at the 200m x 75m mangrove innovative experimental plot. It was a 12 years old mangrove stand dominated by *Rhizophora spp*. and *Avicennia spp*. The highest temperature was recorded in October at 27.7 ºC while the lowest was in July at 26.2ºC with average annual temperature was 26.9ºC. (Wan Rasidah et al., 2019). The Sg Hj Dorani beach is predominantly covered by mud deposits. Based on a hydrometer analysis with samples taken from the restoration area at depths of 5–100 cm, the mud contains a mixture of 22% clay (<2µm), 56% silt, 17% fine sand (coarser than 60 µm), and 5% organic matter on average (Hashim et al. 2010). The study area is subjected to climate of Peninsular Malaysia which is mainly influenced by two monsoons during the year; the Southwest monsoon from May to September and the Northeast monsoon from November to March. The period of change between the two monsoons is a transitional period which occurs in April and October. Heavy rainfall often occurs during these two transitional periods (Desa et al., 2001; Suhaila and Jemain, 2007). Tropical climate is experienced year-round with an average annual precipitation of 1790 mm. The relative humidity ranges from 80 to 90% and the temperature averages from 22 to 33 ºC throughout the year.

Figure 1. The location of the study area at Sungai Hj. Dorani, Kuala Selangor, Malaysia

Mangrove species selection

Two species were selected in this study; *Rhizophora apiculata* (Bakau minyak) and *Rhizophora mucronata* (Bakau kurap) (Figure 2). The *Rhizophora* is a family from tropical and sub-tropical group. It has 16 genera with 120 species which consists of woody plant or shrubs. *Rhizophora* is a dominant genus of the most widespread mangrove family, the Rhizophoraceae. The genus is relatively old amongst cosmopolitan mangrove genera, and it has notable disjunct species distributions in both the Atlantic East Pacific and Indo West Pacific (Lo et al., 2014). All *Rhizophora* taxa are characterized by large water-buoyant propagules with a remarkable ability for long-distance dispersal (Rabinowitz, 1978). Studies revealed that *Rhizophora apiculata* was effective in reducing both water depth and current velocity (Tanaka et al., 2007). Usually, the *R. apiculata* found in muddy firm substrates in mangrove areas while *R. mucronata* normally present along both sides of rivers and alongside streams and creeks in mangrove areas suggesting that *R. mucronata* needs more fresh water input as compared to *R. apiculata* (Nasir et al, 2016).

Figure 2. Species selected are (a) *Rhizophora apiculata* (Bakau minyak) and (b) *Rhizophora mucronata* (Bakau kurap)



Leaf gas-exchange measurement

Measurements were carried out in the field using LI-6400 portable photosynthesis system (LI-COR, Lincoln, NE, USA) connected to a standard 6 cm^2 cuvette. Fully expanded, sunlight leaves were clamped in the sensor cuvette, maintaining their natural position. The leaves were flushed with ambient air (flow rate 500 mol m^{-2} s^{-1}), of which temperature and relative humidity were simultaneously recorded. Gas-exchange measurements, including CO_2 fixation rate (A), stomatal conductance to water vapour (gs), and transpiration rate (E), were logged after readings reached stable (1–3 min). Infra-red gas analyser was matched to reach equilibrium before every measurement. Measurements were conducted with ambient temperature, while CO_2 reference concentration was maintained at 400 µmol mol^{-1}. The photosynthetic photon flux density was set at 1600 µmol $m^{-2}s^{-1}$ to ensure that light-saturated photosynthesis rates were reached. The data were obtained from 6 plants of *R. apiculata* and *R. mucronata*, approximately 3 m high and 12 years old, randomly selected within the forests. These measurements were taken on the 31 January and 1st February 2020. Water use efficiency (WUE) at the leaf level was calculated as the ratio of carbon assimilation and water loss through transpiration (WUE=A/E). All measurements were performed in the morning (between 9:00 and 12:00 h) and afternoon (between 02:00 and 04:00 h). Data that has negative values were excluded from the analysis and thus the presence of *gs* with 0.0 value also excluded with the assumption that there were no stomatal conductance activities occurred.

RESULTS

Photosynthesis, transpiration and water use efficiency rates of *R. mucronata* and *R. apiculata* in the morning and afternoon observations

R. mucronata shows to have low photosynthesis (*A*) rates during both observations compared to *R. apiculata* (Figure 3, Table 1a &b). The rates of *A* in *R.mucronata* were ranges between 0.07 µmol CO_2 m^2 m^1 in the morning and increase to 25.00 µmol CO_2 m^2 m^1 in the afternoon with the average of 9.34 µmol CO_2 m^2 m^1 (±7.46) in the morning and 10.16 µmol CO_2 m^2 m^1 (±8.79) in the afternoon. However, the transpiration (*E*) rates were small at 0.30 mmol H_2O m^2 m^1 in (± 0.11) the morning and 0.50 mmol H_2O m^2 m^1 (±0.38) in the afternoon. The ratio of assimilation rates to transpiration for *R. mucronata* for both observations was 32.88 µmol CO_2 $mmol^{-1}$ H_2O (±23.50) in the morning and 23.82 µmol CO_2 $mmol^{-1}$ H_2O (±21.92) in the afternoon. In the *R.apiculata*, *A* is ranges between 0.04 µmol CO_2 m^2 m^1 to 28.20 µmol CO_2 m^2 m^1 with an average of 13.39 µmol CO_2 m^2 m^1 (±8.81) in the morning and slightly increase to an average of 13.56 µmol CO_2 m^2 m^1 (±9.10) in the afternoon. The average rates of *E* were 0.84 mmol H_2O m^2 m^1 (±0.29) in the morning and 0.81 mmol H_2O m^2 m^1 (±0.48) in the afternoon. The ratio of assimilation rates to transpiration in *R. apiculata* was 16.55 µmol CO_2 $mmol^{-1}$ H_2O (±11.49) in the morning and 16.30 µmol CO_2 $mmol^{-1}$ H_2O (±11.73) in the afternoon. Based on the summary of data, both species in the study area perform more *A* in the afternoon however, the trend in *E* differed between morning and afternoon observation for both species. *R. apiculata* has a higher average rate of *A* and *E* compared to *R. mucronata*. However, *R. mucronata* has a higher WUE average rate than the *R. apiculata* at both observations.

Figure 3. The observation of (a) photosynthesis (b) transpiration and (c) water use efficiency of *R. mucronata* and *R. apiculata* in the morning and afternoon

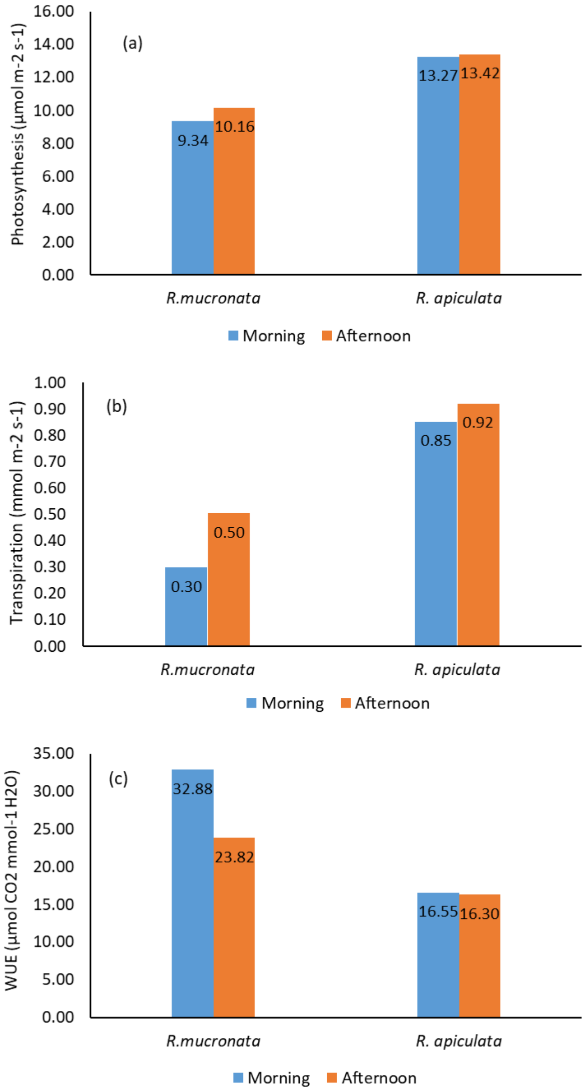


Table 1a. Morning and afternoon observations of *R. mucronata* physiological data. The n value of all observations was not the same after eliminating all the –ve values of *A* and *E* and also 0.00 values in *gs*.

	R.mucronata (Bakau kurap)									
	Morning					Afternoon				
	Mean	Min	Max	SD	n	Mean	Min	Max	SD	n
Photosynthesis (µmol m^{-2} s^{-1})	9.34	0.07	25.00	7.46	27	10.16	0.17	32.50	8.79	19
Stomata Conductance, gs (mol H_2O m^{-2} s^{-1})	0.01	0.01	0.01	0.00	27	0.02	0.01	0.05	0.01	19
Transpiration (mmol m^{-2} s^{-1})	0.30	0.16	0.53	0.11	27	0.50	0.18	1.61	0.38	19
Leaf Vapour Pressure Deficit (kPa)	3.31	3.17	3.81	0.20	27	3.20	2.97	3.34	0.10	19
Water use efficiency (µmol CO_2 $mmol^{-1}$ H_2O)	32.88	0.30	75.47	23.50	27	23.82	0.30	79.94	21.97	19

Table 1b. Morning and afternoon observations of *R. apiculata* physiological data

	R. apiculata (Bakau minyak)									
	Morning					Afternoon				
	Mean	Min	Max	SD	n	Mean	Min	Max	SD	n
Photosynthesis (µmol m^{-2} s^{-1})	13.27	0.04	27.20	8.91	35	13.42	0.39	28.20	9.26	32
Stomata Conductance, gs (mol H_2O m^{-2} s^{-1})	0.03	0.01	0.04	0.01	35	0.03	0.01	0.05	0.01	32
Transpiration (mmol m^{-2} s^{-1})	0.85	0.24	1.33	0.28	35	0.92	0.25	1.58	0.42	32
Leaf Vapour Pressure Deficit (kPa)	3.30	3.16	3.49	0.10	35	3.16	2.99	3.35	0.12	32
Water use efficiency (µmol CO_2 $mmol^{-1}$ H_2O)	16.55	0.10	42.31	11.49	35	16.30	0.48	39.95	11.73	32

The relationship between transpiration rate (*E*) and water use efficiency (WUE)

The *E* and WUE of the *R. mucronata* and *R. apiculata* are negatively correlated (Figure 4 & 5) however, the morning observation of *R.mucronata* has no relationship between *E* and WUE. In general, increasing in *E* cause decreasing in WUE. The intercellular activities during the photosynthesis affect the WUE value. A lower intercellular CO_2 concentration during the photosynthesis will correspond to a higher WUE (Cernusak, 2018). This means that the WUE depends on the extent of drawdown in the CO_2 concentration from the atmosphere to leaf interior.

Figure 4. The association between transpiration (*E*) and water use efficiency (WUE) in *R. mucronata* during morning and afternoon observations

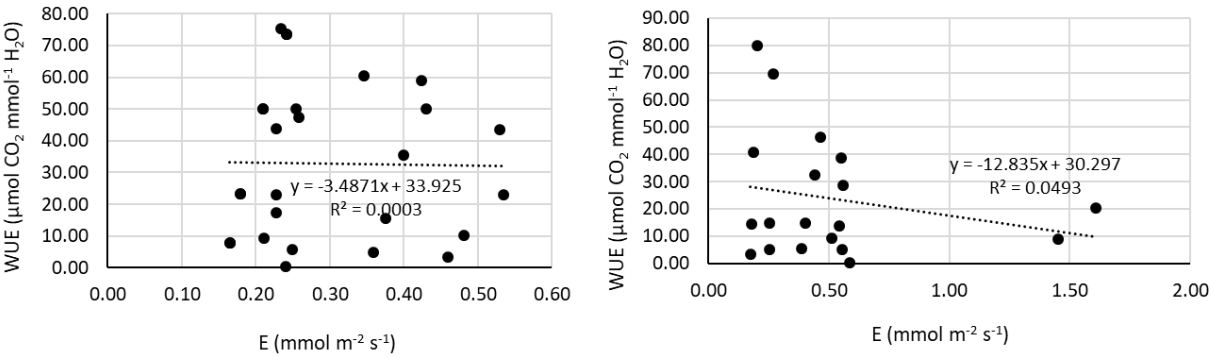
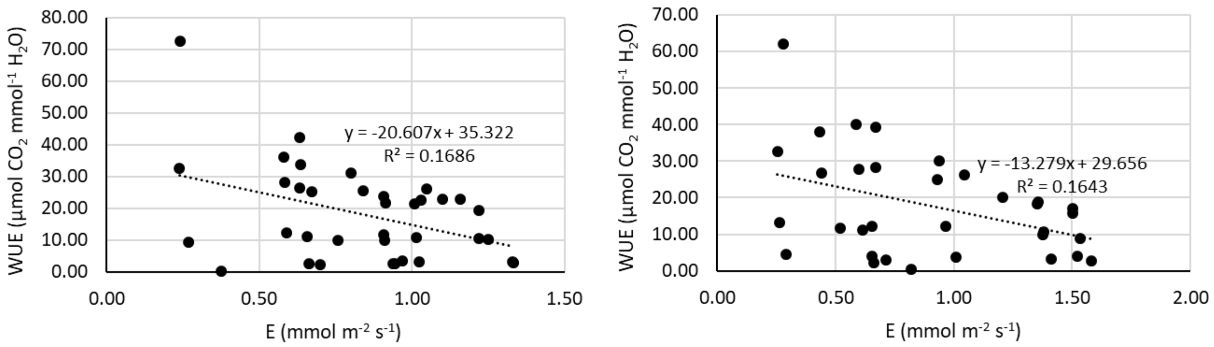


Figure 5. The association between transpiration (*E*) and water use efficiency (WUE) in *R. apiculata* during morning and afternoon observations



The effect of stomatal conductance and VPD on transpiration rate and WUE of *R.mucronata* and *R.apiculata*

Two variable that regulates the transpiration and WUE in the plant; stomata opening and VPD. Stomata are important portals for gas and water exchange in plants and have a strong influence on characteristics associated with photosynthesis and transpiration (Yuping et al., 2017). Based on the observation on the *R.mucronata* and *R.apiculata*, it was found that transpiration rates are strongly correlated with the increase in stomatal conductance (Figure 6). The association between *E* and *gs* ranges between $r^2=0.93$ and 0.98 in the morning and increasing to $r^2=0.99$ in the afternoon for both species. VPD positively correlated with *E* at $r^2=0.49$ for *R.mucronata* and $r^2=0.64$ for *R.apiculata* in the morning observation (Figure 7). In the afternoon the association was $r^2=0.54$ in *R. mucronata* and $r^2=0.59$ in *R.apiculata*. On the other hand, WUE and *gs* were negatively weak correlated and positively weak correlated with VPD.

Figure 6. The association of stomatal conductance on transpiration in (a) R. mucronata and (b) R. apiculata during the observation

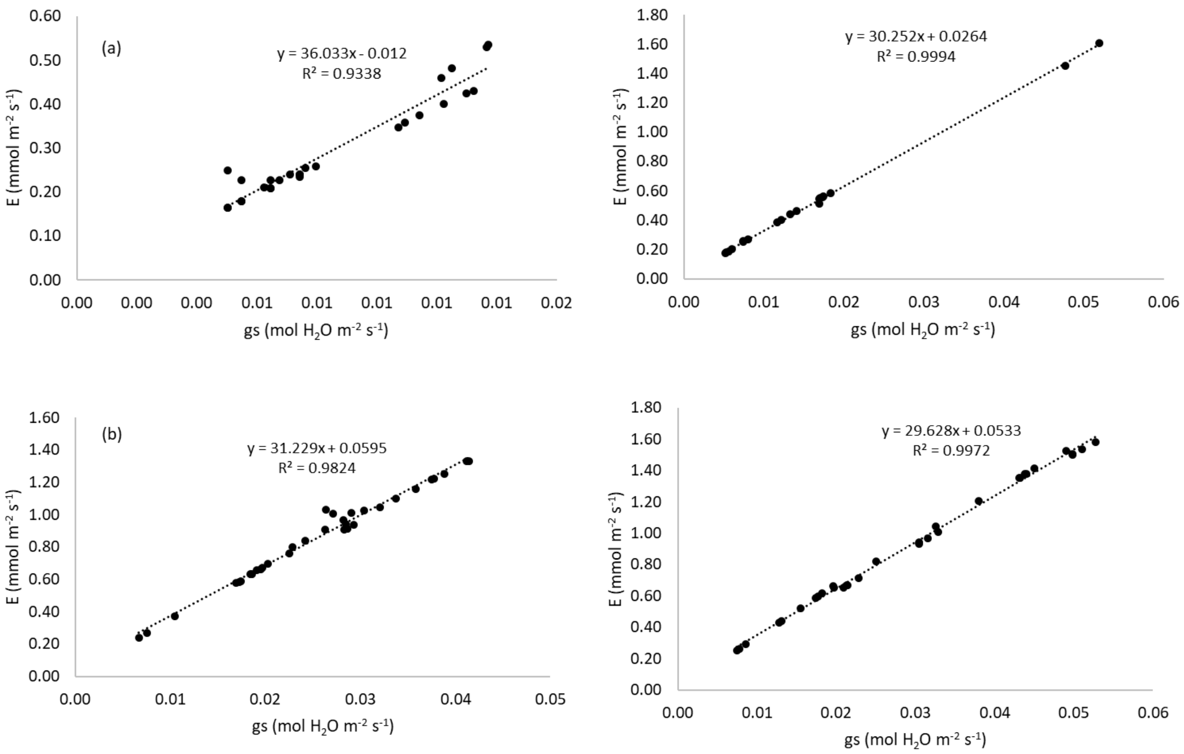
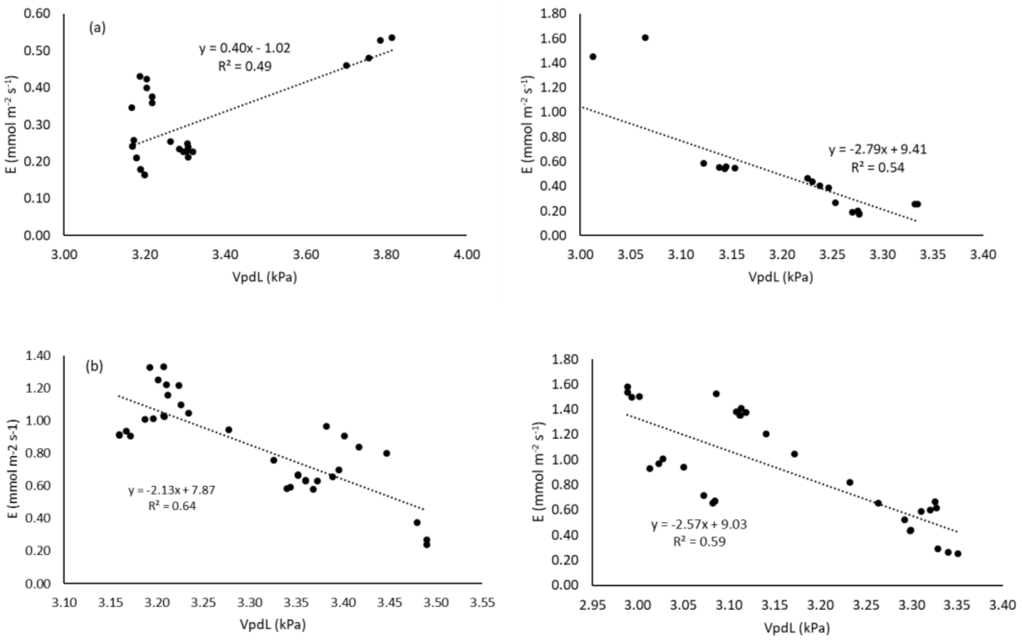


Figure 7 The association of leaf VPD on transpiration in (a) R. mucronata and (b) R. apiculata during the observation



DISCUSSION AND CONCLUSION

Generally, the photosynthesis and transpiration rates of *R.apiculata* is higher during morning and afternoon compared to *R.mucronata*, however, the WUE in *R.mucronata* was higher compared to the *R.apiculata* for the whole observations. It shows that the *gs* and leaf VPD plays an important role in regulating the transpiration rate in the *R.mucronata* and *R.apiculata*. The transpiration rate was correlated proportionally with the increase in stomatal conductance, however; WUE is more independent and not influenced much by the stomatal conductance and VPD because it regulates by the fluctuation in the assimilation rates and thus transpiration. At a certain level, the plant will regulate stomatal opening to prevent excessive water loss and therefore, the ratio of photosynthesis to transpiration became smaller and thus WUE. As stomatal control temperature and WUE, they are vital to the existence of the plant. VPD is an important regulator for plant growth. It influences several physiological parameters such as stomatal opening, CO_2 uptake, transpiration and plant stress. This data is of importance to understand the physiology processes in mangrove forest which have not been well explored in Malaysia. The present findings were based on the short-term observation, therefore, it is suggested a similar study to be conducted in longer-term and includes more variables to understand mangrove ecosystem and its roles in assessing and monitoring of climate change impact. It was mentioned in several literatures that salinity have an influence on the WUE in mangrove species. Hence, it is suggested to include this variable in future study related to ecophysiology of mangrove species. Some limitation to the observation was due to the tidal fluctuation and rainfall occurrences besides some technical issues.

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