

## Stem water potential as a drought stress indicator in Durian cv. Monthong under farmer best practice irrigation

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**ABSTRACT:** Durian (*Durio zibethinus* Murray) cv. ‘Monthong’ cultivated in Chanthaburi, Thailand, faces water management challenges from unpredictable rainfall, making sufficient water during reproductive stages essential for flower initiation, fruit set, and yield. This study evaluated plant–soil water relations and physiological responses to identify reliable drought stress indicators in Durian cv. Monthong under Farmer best practice irrigation method. Pre-dawn soil water potential (PSWP) showed a strong dependence on volumetric soil water content ( $\theta_v$ ), with values below 0.19 m<sup>3</sup>/m<sup>3</sup> causing sharp declines in PSWP (<–48 kPa) and visible drought symptoms. Stem water potential (STWP) was more consistent than leaf water potential (LWP), exhibiting clear thresholds of –0.66 to –0.90 MPa at 11:00 AM and –0.80 to –0.98 MPa at 1:00 PM during stop watering for flower bud initiation, which coincided with significant reductions in net photosynthetic rate ( $A$ ), stomatal conductance ( $g_s$ ), and transpiration rate ( $E$ ). In contrast, LWP values were variable and weakly correlated with soil parameters, limiting its use as a drought indicator. STWP was strongly associated with PSWP and pre-dawn volumetric soil water content ( $P\theta_v$ ) under drought condition, while  $g_s$  was highly responsive to soil moisture changes, with values below 0.06 mol H<sub>2</sub>O/m<sup>2</sup>/s effectively signaling drought stress. These findings show that the integration of STWP, soil water indicators, and leaf gas exchange provides an effective approach for early drought detection and precise irrigation management in durian orchards.

**Keywords:** durian; drought; photosynthesis; soil moisture; plant water potential

### Introduction

Agricultural productivity has been significantly affected by severe environmental disruptions. Plants exposed to environmental stresses face multiple challenges, including waterlogging, drought, heat, cold, and salinity (Ashraf et al., 2018; Benevenuto et al., 2017; Arunanondchai et al., 2018). In Thailand, agriculture is particularly vulnerable due to its reliance on a monsoon climate and limited irrigation coverage. Thailand experiences three distinct seasons: the rainy season (mid-May to mid-October), the winter season (mid-October to mid-February), and the summer season (mid-February to mid-May) (Land Development, 2014). Annual precipitation ranges from 998 to 4,603 mm, while average temperatures fluctuate between 24.4°C and 29.3°C (Chainuvati and Athipanan, 2001). Thailand is also

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recognized for its complex biodiversity, which varies across regions (Wikramanayake et al., 2002). The Eastern region of Thailand, particularly Chanthaburi Province, is characterized by a tropical climate with high humidity and substantial rainfall (Phumkokrux, 2021). This unique environment strongly supports tropical fruit production, making Chanthaburi a major hub for Durian cultivation (Hau et al., 2023). Durian production in this region occurs from mid-April to mid-September, under hot and humid conditions with temperatures ranging from 10°C to 46°C and annual rainfall of at least 2,000 mm (Ketsa et al., 2020; Lim, 2009). However, optimal yield requires careful water management (Naor, 2000). Although 82% of Thailand's agriculture is rainfed, only 18.7% of farmland benefits from irrigation (Panichapong, 1988), making water availability a critical challenge. Durian orchards, in particular, demand a consistent water supply. Orchards require 3,750–5,000 m<sup>3</sup>/ha annually, with daily evaporation rates between 4.9 and 9.5 mm (Somsri, 2018). Mature trees consume up to 360 liters of water per day, with salt concentrations not exceeding 1,400 mmol to maintain healthy growth (Brown, 1997; Hiranpradit et al., 1987).

Water scarcity has also been reported to affect other fruit crops such as peaches (*Prunus persica*) (Miras-Avalos et al., 2013), olives (*Olea europaea*) (Brito et al., 2019), plums (*Prunus domestica*) (Paudel et al., 2020), citrus (*Citrus* spp.) (Silva et al., 2023), longan (*Dimocarpus longan*) (Fukuda et al., 2018), mango (*Mangifera indica* L.) (Nel et al., 2024), langsat (*Lansium parasiticum*), rambutan (*Nephelium lappaceum*), and mangosteen (*Garcinia mangostana*) (Kamariah et al., 2011; Lerslerwong et al., 2014). In Durian, water deficit during reproductive stages disrupts fruit development, leading to reduce fruit set and yield (Liu et al., 2013). Drought stress in fruit trees suppresses vegetative growth and promotes leaf senescence, while simultaneously damaging flowering, fruit set, yield, and fruit quality. Water limitation typically leads to reduce fruit size, poor coloration, lower sugar accumulation, and shortened postharvest longevity. Prolonged drought further decreases tree vigor and increases susceptibility to pests and diseases (Liu et al., 2023). Repeat drought further threaten orchard sustainability by reducing tree longevity, decreasing yield and income, and increasing sensitivity to climate fluctuations, particularly in tropical fruit production systems (Chaves et al., 2009; Liu et al., 2023). At the physiological level, drought regulate physiological responses through activation of antioxidant defense systems, osmotic adjustment via abscisic acid (ABA) signaling, and down regulation of leaf CO<sub>2</sub> gas exchange (dos Santos et al., 2022; Sathapondecha et al., 2024). Furthermore, drought stress reduces cell turgor and plant water potential, resulting in suppressing root, stem, and leaf growth, enhancing leaf senescence, and reducing biomass accumulation. These lead to decrease crop productivity (Hemati et al., 2022). At the molecular level, drought stress stimulates the expression of transcription factors such as DREB, NAC, and MYB, activates both ABA-dependent and ABA-independent signaling pathways, and promotes the synthesis of late embryogenesis abundant (LEA) proteins and dehydrins, which protect cellular structures from dehydration damage (Yang et al., 2021; Ali et al., 2025). In Durian, proper water and nutrient management during the vegetative stage is crucial to support flowering (Salakpetch, 2005). Strategic irrigation practices, such as temporarily stop watering to induce flower bud initiation followed by rewatering, have been shown to enhance flowering and fruit development (Diczbalis and Westerhuis, 2005; Salakpetch, 2005). Thus, precise irrigation management is vital for maintaining tree health, flower initiation, fruit development, and yield. Nevertheless, Durian orchards in Chanthaburi face ongoing challenges due to variable rainfall and limited irrigation infrastructure. Irrigation strategies matched to growth stages can enhance productivity and sustainability under

changing climates. However, limited research has integrated plant-based indicators such as stem water potential (STWP) and leaf water potential (LWP) with soil water potential and soil water content measurements to comprehensively assess plant water status. Furthermore, the studies evaluating leaf CO<sub>2</sub> gas exchange to quantify CO<sub>2</sub> and H<sub>2</sub>O fluxes in Durian remain under explore.

Therefore, this study aims to investigate the correlations between key physiological parameters, including stem and leaf water potential (STWP and LWP), net photosynthetic rate (A), stomatal conductance (g<sub>s</sub>), and transpiration rate (E), and environmental factors, such as pre-dawn soil water potential (PSWP), pre-dawn volumetric soil water content (P $\theta_v$ ), and volumetric soil water content ( $\theta_v$ ) as reliable tools for detecting drought responses in Durian and to evaluate their potential application as plant-based sensors for precision irrigation scheduling.

## Materials and Methods

### Plant material and experimental setup

The experiments were performed using 3.5-year-old durian trees (*Durio zibethinus* Murray cv. Monthong) cultivated on the mound 70 cm to 1 m high, spaced 6x8 m apart, in an orchard surrounded by perimeter trenches. The experiment was conducted between 2020 and 2021 at the Chanthaburi Horticultural Research Center, Chanthaburi Province, Thailand. During the vegetative growth stage, Durian trees were managed to simulate healthy shoot and new leaves development. These involved plant protection methods, including pest and disease control, watering schedule, fertilizer application, and weed management. Besides, biological control using active substances such as metalaxyl, carbendazim, and phosphonic acid was applied following the recommendations of Department of Agriculture, Thailand (2020). Fertilizer with an N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O ratio of 15:15:15 was applied at a rate of 1 kg per tree, three times.

The watering schedule in this experiment followed the Farmer best practice irrigation method, using mini sprinklers delivering water at a 7 liter per min, and was aligned with six growth stages as follows: 1) tree preparation (0 DA 3<sup>rd</sup> NLF) was well-watered for 60 mins to stimulate new leaf flushing and maintain healthy foliage for flowering and fruit setting, 2) flower bud induction (22 DA 3<sup>rd</sup> NLF) was stop watering for 9 days until dropping leaves and after that, 1/3 of well-watering was applied for 20 mins to trigger flowering, 3) flowering (51 DA 3<sup>rd</sup> NLF) was well-watered for 40 mins to stimulate flower development, 4) small fruit setting (106 DA 3<sup>rd</sup> NLF) was well-watering for 60 mins to support fruit growth and prevent fruit drop, 5) medium fruit setting (155 DA 3<sup>rd</sup> NLF) was well-watering for 90 mins to induce fruit quality, and 6) harvesting (192 DA 3<sup>rd</sup> NLF) was well-watering for 40 mins to protect fruit rot.

### Weather data

At the experimental site, a weather station with a data logger developed by the National Electronics and Computer Technology Center (NECTEC), Thailand was set up at 5 m from the durian tree to record aboveground climate condition, including average air temperature (T<sub>avr</sub>), relative humidity (RH<sub>air</sub>), vapor pressure deficit (VPD<sub>air</sub>), photosynthetically active radiation (PAR), and rainfall. For belowground climate condition was set up with a digital sensor under durian tree canopy, including the ML3x sensor (Delta-T Devices Ltd., UK) using for measuring volumetric soil water content ( $\theta_v$ ) at a soil depth of 30 cm and tensiometer developed by the National Electronics and Computer Technology Center (NECTEC), Thailand, using for measuring pre-dawn soil water potential (PSWP) at the

same soil depth. All weather measurements were performed during 6 growth stages, in a diurnal pattern with every 5 mins interval.

### Physiological measurements

#### *Plant water potential*

Plant water potential, including stem and leaf water potential, was measured between 12:00 AM to 14:00 PM during six growth stages, using a pressure chamber (Model 3000F01 Plant Water Status Console). Leaf water potential was investigated using three leaves collected from the lower canopy of each durian tree, with four trees included per measurement session. Stem water potential was determined by measuring durian leaves covered by aluminium foil and plastic bag for two hours to achieve internal equilibrium between the non-transpiring petiole and leaves, water-impermeable bags. This approach improved the accuracy of evaluating plant water status under field conditions. For stem water potential measurement, one leaf from the lower canopy of each durian tree was used, with four trees included per measurement session.

#### *Leaf CO<sub>2</sub> gas exchange*

Leaf CO<sub>2</sub> gas exchange parameters, including net photosynthetic rate ( $A$ ), stomatal conductance ( $g_s$ ) and transpiration rate ( $E$ ), were investigated between 12:00 AM to 14:00 PM during six growth stages, using LI-COR 6400XT Portable Photosynthesis System (LI-COR Inc., Lincoln, Nebraska, USA) equipped with a Sun Sky Chamber. The measurement condition was set up with 400  $\mu\text{mol CO}_2/\text{m}^2/\text{s}$ , flow rate = 500  $\mu\text{mol}/\text{s}$ , and leaf area = 6  $\text{cm}^2$ .

All physiological parameters, including stem and leaf water potential (STWP and LWP), net photosynthetic rate ( $A$ ), stomatal conductance ( $g_s$ ), transpiration rate ( $E$ ), as well as weather data, including pre-dawn soil water potential (PSWP), pre-dawn volumetric soil water content ( $P\theta_v$ ) and volumetric soil water content ( $\theta_v$ ) were considered for correlation between the paired parameters.

### Data analysis

The experiment was designed in a randomized complete block design (RCBD) with four replications. Pearson's linear correlation coefficients among considered traits were calculated following the method described by Gomez and Gomez (1984). Combined data analysis was carried out to evaluate the relationships among plant growth stages, physiological traits, and environmental variables at the time of measurement. Statistical analyses were conducted using R software (version x64 4.1.1; [www.r-project.org](http://www.r-project.org)) and Statistix 10. Data visualization was conducted using Sigma Plot for Windows (version 15.0).

## Results

### Pre-dawn soil water potential related volumetric soil water content of Durian cv. 'Monthong' indicated by soil water retention curve

The relationship between pre-dawn soil water potential (PSWP) and volumetric soil water content ( $\theta_v$ ) of Durian cv. Monthong under farmer best practice irrigation method is illustrated in the soil water retention curve (**Figure 1**). During watering period at 0, 51, 106, 155, and 192 DA 3<sup>rd</sup> NLF,  $\theta_v$  values ranged from 0.24 to 0.35  $\text{m}^3/\text{m}^3$ , while PSWP remained relatively high (between -1.65 and -0.95 kPa). Minimum values of  $\theta_v$  and PSWP were recorded 0.15  $\text{m}^3/\text{m}^3$  and -29.95 kPa, respectively, while maximum reached 0.25  $\text{m}^3/\text{m}^3$  and 0.00 kPa. In contrast, during stop

watering at 22 DA 3<sup>rd</sup> NLF,  $\theta_v$  declined below 0.19 m<sup>3</sup>/m<sup>3</sup>, PSWP dropped rapidly to more negative (up to -100 kPa). At this threshold, visible drought symptoms such as leaf drooping were also observed. Thus, these suggested that  $\theta_v$  strongly influenced PSWP, especially under stop watering period. At higher  $\theta_v$  ( $\geq 0.25$  m<sup>3</sup>/m<sup>3</sup>), PSWP remained close to 0 kPa. Maintaining  $\theta_v$  above 0.19 m<sup>3</sup>/m<sup>3</sup> is essential for sustaining healthy Durian cv. Monthong growth, while its levels below this threshold may promote flower bud initiation in Durian. However, prolonged exposure this threshold can lead to severe drought stress. In addition, the soil water retention curve effectively indicates the negative relation between  $\theta_v$  and PSWP in Durian.

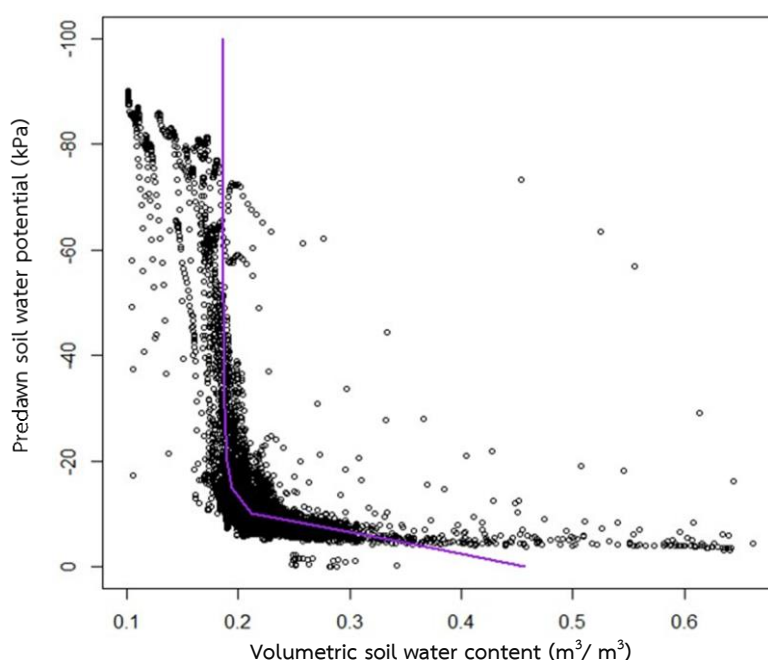


**Figure 1** The correlation between predawn soil water potential (PSWP) and volumetric soil water content ( $\theta_v$ ) at six growth stages of Durian cv. Monthong as follows: tree preparation, flower bud induction, flowering, small fruit setting, medium fruit setting, and harvesting stages. Data were collected throughout the entire experiment, starting prior to the tree preparation stage and continuing until the harvesting stage.

#### The relationship between leaf water potential and stem water potential in Durian cv. 'Monthong'

Leaf water potential (LWP) and stem water potential (STWP) in Durian cv. Monthong under farmer best practice irrigation method were investigated at six growth stages during watering period and stop watering period. At 11:00 AM, STWP during watering ranged from -0.30 to -0.58 MPa, whereas STWP declined to -0.66 to -0.90 MPa during stop watering period. At 1:00 PM, STWP further decreased, ranging from -0.80 to -0.98 MPa. LWP values were more variable, with overlapping distributions across growth stages. Correlation analysis (**Figure 2A-B**) revealed contrasting patterns. At 11:00 AM, LWP and SWP showed a significant negative correlation across watering period ( $r = -0.53$ ), but a positive correlation under stop watering period ( $r = 0.49$ ). At 1:00 PM, the relationship between LWP and SWP were positively correlated during watering ( $r = 0.49$ ) but showed no correlation under stop watering ( $r = 0.02$ ). These

results suggested that STWP was more consistent and sensitive indicator of drought stress in Durian cv. Monthong compared to LWP. This finding showed STWP thresholds of -0.66 to -0.90 MPa (11:00 AM) and -0.80 to -0.98 MPa (1:00 PM) were identified as critical for severe drought stress in Durian cv. Monthong. In contrast, LWP was less reliable for indicating drought stress because its values overlapped across growth stages.

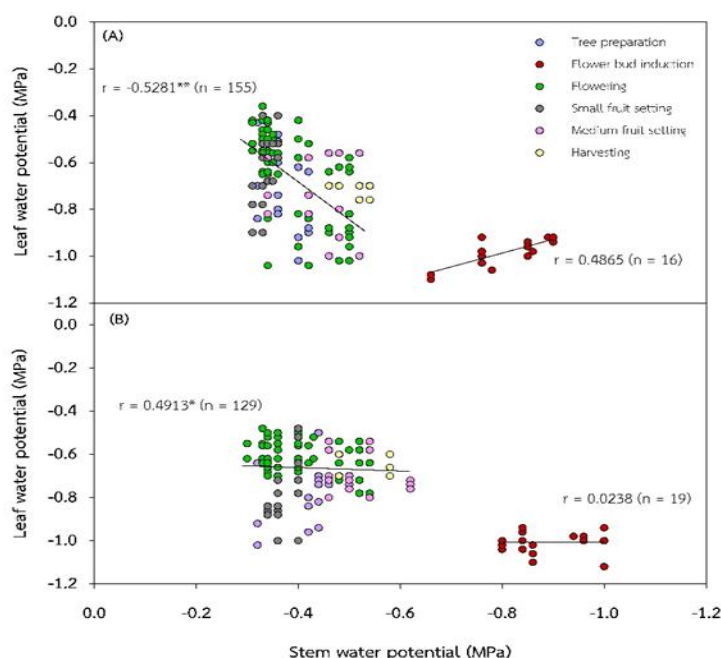


**Figure 2** The correlation between leaf and stem water potential of Durian cv. ‘Monthong’ was evaluated at 11:00 AM and 01:00 PM across six growth stages: tree preparation (purple), flower bud induction (red), flowering (green), small fruit setting (grey), medium fruit setting (pink), and harvesting (yellow). Measurements were taken during watering (tree preparation-harvesting excluding flower bud induction) and stop watering periods (flower bud induction).

### The relation between stem water potential and pre-dawn soil water potential, as well as volumetric soil water content in Durian cv. ‘Monthong’

In this study, stem water potential (STWP), pre-dawn soil water potential (PSWP), pre-dawn volumetric soil water content ( $P\theta_v$ ) and volumetric soil water content ( $\theta_v$ ) were assessed during watering period, and during stop watering period in Durian cv. ‘Monthong’ under farmer best practice irrigation method (**Figure 3**). Under stop watering period, PSWP declined sharply to -48 to -75 kPa, and STWP dropped to -0.76 to -1.02 MPa (**Figure 3A**). As same as stop watering period,  $P\theta_v$  fell below 0.16 m<sup>3</sup>/m<sup>3</sup>, STWP rapidly declined to more negative values (-0.76 to -0.96 MPa) as shown in **Figure 3B**. The correlation analysis revealed no significant relationship between PSWP and STWP under watering period ( $r = 0.32$ ), but a strong positive correlation during stop watering ( $r = 0.72$ ). These results suggested that when soil dries, pre-dawn soil water status is closely linked with plant water status. In addition,  $P\theta_v$  also showed strong associated with STWP (**Figure 3B**). Under watering period, STWP was positively correlated with  $P\theta_v$  ( $r = 0.74$ ), while during stop watering period, the relationship was strongly negative ( $r = -0.72$ ). In contrast,  $\theta_v$

showed only weak correlated with STWP in both under watering ( $r = 0.16$ ) and stop watering periods ( $r = -0.23$ ) (Figure 3C). This suggests that STWP responds more strongly to pre-dawn soil parameters (PSWP and  $P\theta_v$ ) than to daytime volumetric soil water content ( $\theta_v$ ). Thresholds indicate that when  $P\theta_v < 0.16 \text{ m}^3/\text{m}^3$ , STWP fell below  $-0.76$  to  $-0.96 \text{ MPa}$ , showing severe drought stress during stop watering for flower bud induction. Thus, STWP proved to be a reliable indicator of drought stress, especially at flower bud induction.

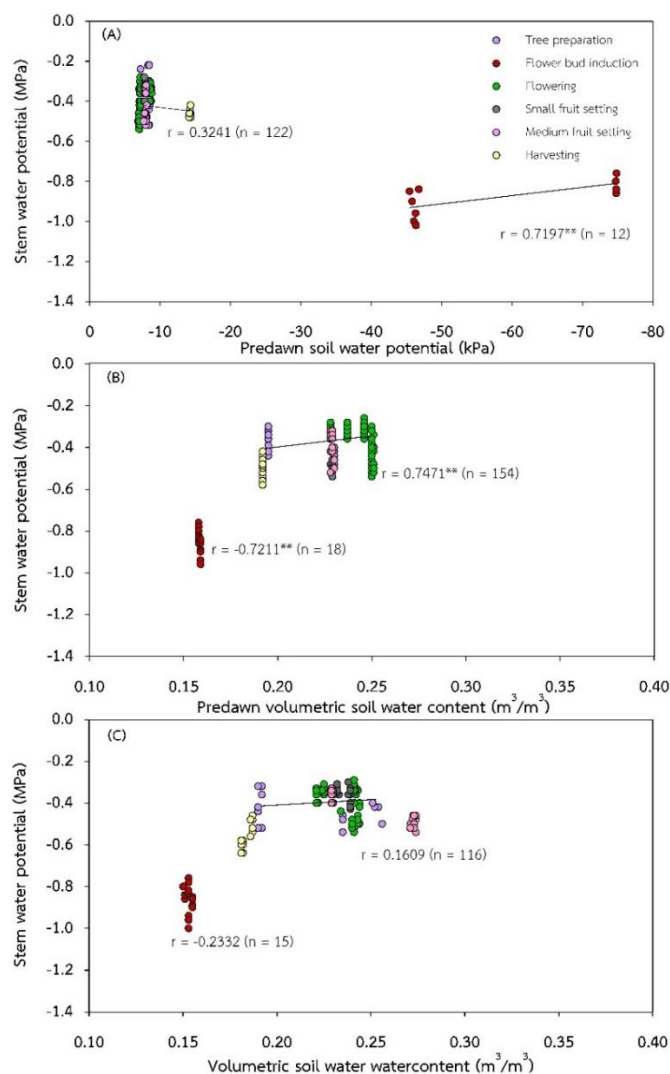


**Figure 3** The correlations between stem water potential and (A) pre-dawn soil water potential, (B) pre-dawn volumetric soil water content, and (C) volumetric soil water content at 30 cm depth were examined across six growth stages of Durian cv. 'Monthong': tree preparation (purple), flower bud induction (red), flowering (green), small fruit setting (grey), medium fruit setting (pink), and harvesting (yellow). Measurements were taken during watering (tree preparation-harvesting excluding flower bud induction) and stop watering periods (flower bud induction).

### The relationship between leaf water potential and soil water potential, and volumetric soil water content in Durian cv. 'Monthong'

In this study, leaf water potential (LWP), predawn soil water potential (PSWP), pre-dawn volumetric soil water content ( $P\theta_v$ ) and volumetric soil water content ( $\theta_v$ ) were assessed during watering, and stop watering periods in Durian cv. 'Monthong' under farmer best practice irrigation method (**Figure 4**). The results showed that PSWP values were relatively high (–8 to –14 kPa) during watering period, but declined to –48 and –75 kPa during stop watering period (**Figure 4A**). However, no significant correlation was found between LWP and PSWP ( $r = 0.15$  during watering;  $r = 0.13$  during stop watering). Similarly, LWP did not correlate with both  $P\theta_v$  and  $\theta_v$  across growth stages ( $r = 0.007$  during watering;  $r = 0.17$  during stop watering) (**Figures 4B-C**). There was no significant correlation between LWP and soil water indicators at either the watering or stop watering periods. These findings suggest that LWP is not an effective indicator for detecting drought stress in Durian cv. 'Monthong' under farmer best practice irrigation method.

### The relationship between stem water potential and leaf CO<sub>2</sub> gas exchange in Durian cv. 'Monthong'

Stem water potential (SWP) was evaluated with leaf CO<sub>2</sub> gas exchange parameters, including net photosynthesis ( $A$ ), stomatal conductance ( $g_s$ ), and transpiration rate ( $E$ ) in Durian cv. 'Monthong' under farmer best practice irrigation method (**Figure 5**). Measurements were taken during watering, and stop watering periods. During watering period, high gas exchange activity was recorded, with  $A$  ranging from 4.0 to 12.0  $\mu\text{mol CO}_2/\text{m}^2/\text{s}$ ,  $g_s$  from 0.07 to 0.21  $\text{mol H}_2\text{O}/\text{m}^2/\text{s}$ , and  $E$  from 2.1 to 6.0  $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$ , at STWP values of –0.3 to –0.6 MPa (**Figures 5A-C**). In contrast, during stop watering period, when STWP declined to –0.76 to –0.96 MPa, gas exchange was markedly reduced:  $A$  dropped to 0.4–2.8  $\mu\text{mol CO}_2/\text{m}^2/\text{s}$ ,  $g_s$  to 0.01–0.04  $\text{mol H}_2\text{O}/\text{m}^2/\text{s}$ , and  $E$  to 0.64–1.43  $\text{mmol H}_2\text{O}/\text{m}^2/\text{s}$ . Correlation analysis revealed weak relations between STWP and  $A$  ( $r = 0.11$  during watering,  $r = 0.01$  during stop watering),  $g_s$  ( $r = 0.13$  and  $r = 0.37$ ), and  $E$  ( $r = 0.18$  and  $r = 0.17$ ), indicating no strong linear association. However, leaf CO<sub>2</sub> gas exchange responses were still sensitive to drought stress even if the correlations were low. The  $A$ ,  $g_s$ , and  $E$  were physiologically indicators of drought stress.

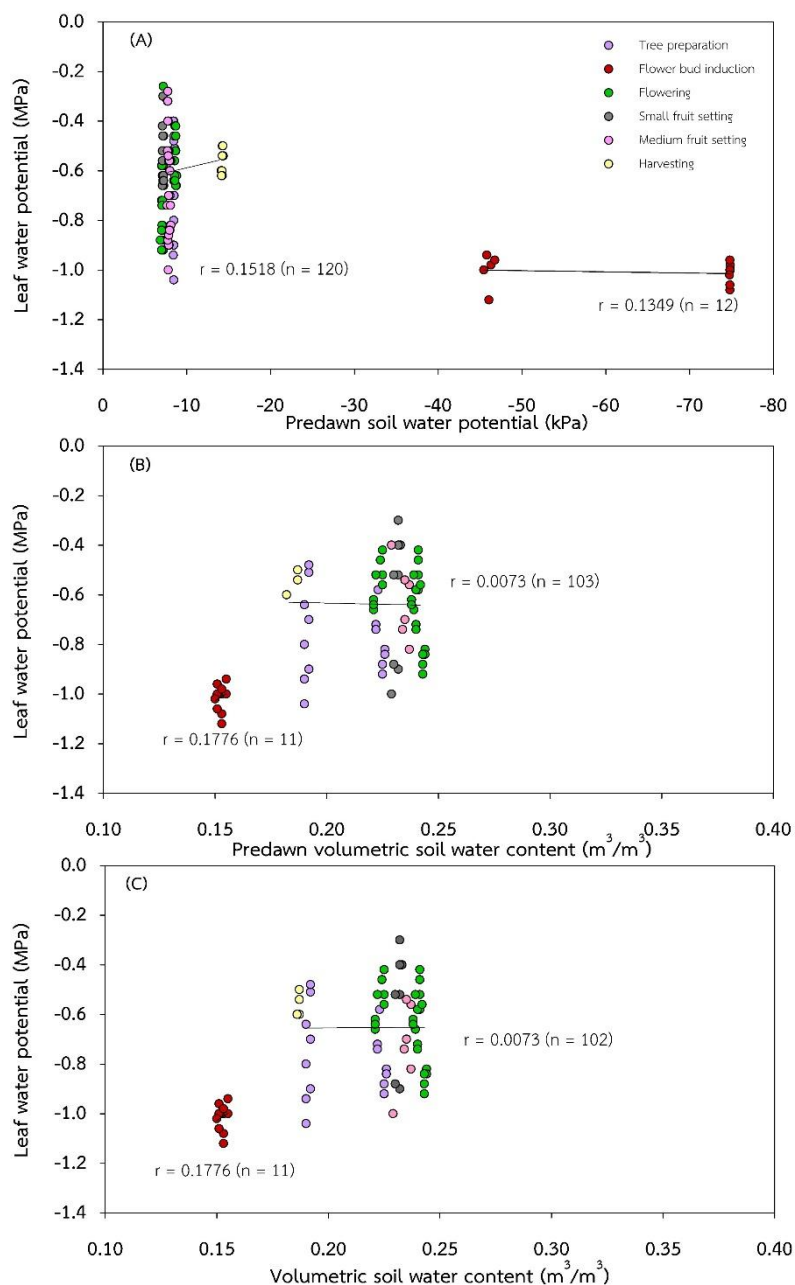


**Figure 4** The correlations between leaf water potential and (A) pre-dawn soil water potential, (B) pre-dawn volumetric soil water content, and (C) volumetric soil water content at 30 cm depth were assessed across six growth stages of Durian cv. 'Monthong': tree preparation (purple), flower bud induction (red), flowering (green), small fruit setting (grey), medium fruit setting (pink), and harvesting (yellow). Measurements were taken during watering (tree preparation-harvesting excluding flower bud induction) and stop watering periods (flower bud induction).

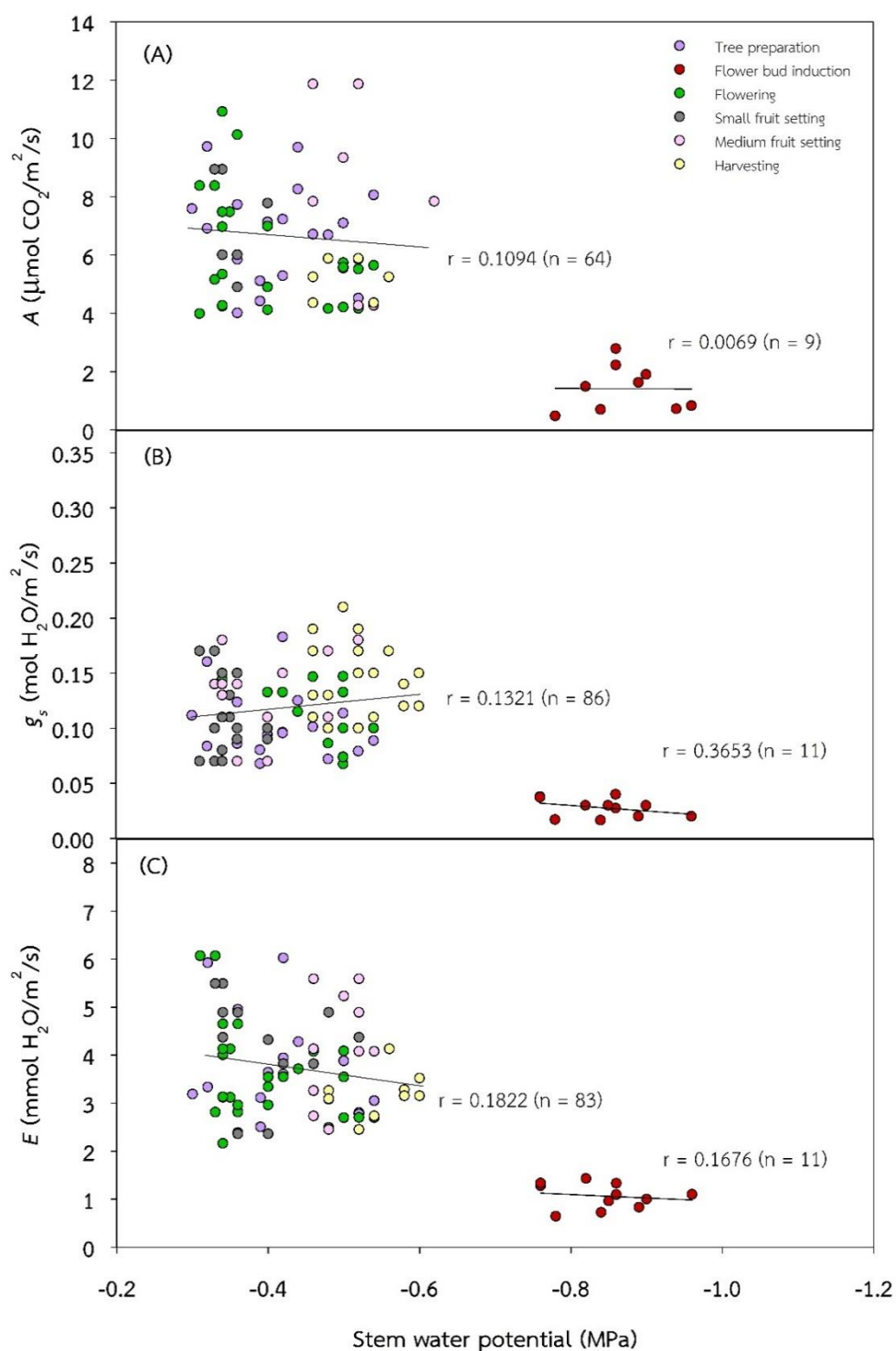


**Figure 5** The correlations between stem water potential and leaf gas exchange parameters, including net photosynthetic rate (A), stomatal conductance ( $g_s$ ) (B), and transpiration rate (E) (C) were evaluated across six growth stages of durian trees: tree preparation (purple), flower bud induction (red), flowering (green), small fruit setting (grey), medium fruit setting (pink), and harvesting (yellow). Measurements were taken during watering (tree preparation-harvesting excluding flower bud induction) and stop watering periods (flower bud induction).

### The relationship between volumetric soil water content and leaf CO<sub>2</sub> gas exchange in Durian cv. ‘Monthong’

The relationship between volumetric soil water content ( $\theta_v$ ) and leaf CO<sub>2</sub> gas exchange parameters, including stomatal conductance ( $g_s$ ) in Durian cv. ‘Monthong’ under Farmer best practice irrigation method (Figure 6). Measurements were taken during watering, and stop watering periods. The results revealed that  $g_s$  generally increased with increasing  $\theta_v$ . The less positive correlation was observed during watering period ( $r = 0.1354$ ), where  $g_s$  ranged from 0.05 to 0.15 mol H<sub>2</sub>O/m<sup>2</sup>/s at higher  $\theta_v$  (0.19–0.24 m<sup>3</sup>/m<sup>3</sup>). In contrast, a stronger correlation ( $r = 0.8595$ ) was detected during stop watering period, when  $g_s$  dropped to the lowest levels (0.01 mol H<sub>2</sub>O/m<sup>2</sup>/s) as  $\theta_v$  decreased below 0.15 m<sup>3</sup>/m<sup>3</sup>. Thus,  $g_s$  was sensitivity to  $\theta_v$  variation, when the lowest  $g_s$  served as an effective indicator of drought stress in Durian cv. Monthong, particularly under stop watering for flower bud induction.

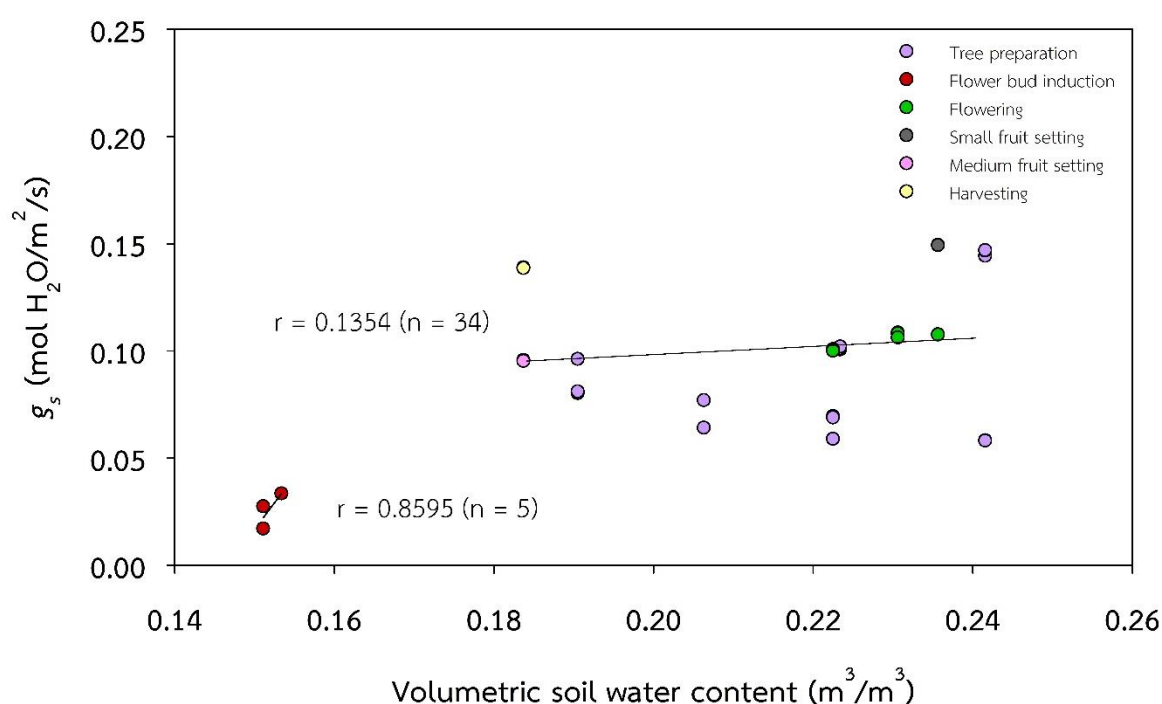


**Figure 6** The correlations between volumetric soil water content and leaf gas exchange parameters, including stomatal conductance ( $g_s$ ) was evaluated across six growth stages of durian trees: tree preparation (purple), flower bud induction (red), flowering (green), small fruit setting (grey), medium fruit setting (pink), and harvesting (yellow). Measurements were taken during watering (tree preparation-harvesting excluding flower bud induction) and stop watering periods (flower bud induction).

### Discussion

Plant-based indicators are widely recognized as reliable tools for assessing plant water status and physiological responses to drought stress (Jones, 2004). Among these, leaf water potential (LWP) and stem water potential (STWP) are frequently employed to evaluate plant drought stress (Jackson et al., 1981; Carella et al., 2024). In this study, both LWP and STWP were evaluated in Durian cv. ‘Monthong’ under the farmer best practice irrigation method. During the flower bud induction stage (22 days after the 3<sup>rd</sup> NLF), irrigation was withheld for 9 days until visible drought symptoms appeared, including reduced leaf turgor and leaf drop. Interestingly, LWP did not clearly

differentiate between watering and stop watering treatments (**Figures 2 and 4**). In contrast, STWP proved more reliable in detecting changes in plant water status under different irrigation regimes. Severe drought stress in Durian was identified when STWP values declined to  $-0.66$  to  $-0.90$  MPa at 11:00 AM and  $-0.80$  to  $-0.98$  MPa at 1:00 PM. This observation is consistent with previous reports indicating that LWP is less stable under fluctuating environmental conditions (Jones, 2004), whereas STWP, especially at midday, correlates more consistently with soil water availability and transpiration (Williams and Trout, 2005; Deb et al., 2012).

Soil water dynamics directly influence plant water status, as water uptake is driven by the potential gradient between plant tissues and the surrounding soil. Soil water potential depends on soil texture and water content (Fernández and Clothier, 2009). Under drought condition, STWP decreases, triggering drought stress responses such as stomatal closure, reduced photosynthesis, and growth inhibition. In severe drought cases, water potential may drop so low that plants are unable to regain turgor even after rewatering, leading to wilting and death (Taiz and Zeiger, 2002; Blum, 1989). Therefore, STWP has been identified as a more reliable indicator of soil water status due to its close relationship with both SWP and transpiration (Williams and Trout, 2005; Taylor and Gush, 2014). Its application for irrigation scheduling has been demonstrated in various fruit trees, including grapevines (Williams and Araujo, 2002) and lemon trees (Ortuno et al., 2006), supporting its use in durian (Naor, 2000).

In this study, withholding irrigation during the flower bud induction stage significantly reduced  $\Psi_{SWP}$ ,  $P\theta_v$ , and  $\theta_v$ , leading to declines in  $\Psi_{STWP}$  (**Figures 3A–C**). The soil water retention curve revealed that when  $\theta_v$  dropped below  $0.19 \text{ m}^3/\text{m}^3$ ,  $\Psi_{SWP}$  sharply declined up to  $-100 \text{ kPa}$  (**Figure 1**). These conditions corresponded to STWP values of  $-0.66$  to  $-0.90$  MPa at 11:00 AM and  $-0.80$  to  $-0.98$  MPa at 1:00 PM, which we identified as thresholds for severe drought stress in Durian. In addition, STWP more accurately represented the combined effects of soil water availability and plant physiological response.

Drought condition induces extreme xylem tension, loss of turgor, and stomatal closure. Christmann et al. (2007) reported that 50% turgor loss occurs at increasingly negative water potentials due to hydraulic signal attenuation in mesophyll cells, while Scholz et al. (2007) emphasized the buffering role of stem water storage against diurnal water loss. Similarly, reductions in soil water content decrease photosynthetic rate ( $A$ ), stomatal conductance ( $g_s$ ), and transpiration ( $E$ ) across species (Pou et al., 2012). Zhang et al. (2013) also showed that under normal conditions, wood species maintain less negative STWP, which declines sharply under high transpiration demand. In our study, reductions in STWP during stop watering for flower bud induction coincided with declines in  $A$ ,  $g_s$ , and  $E$  (**Figures 5A–C**). Gerhards et al. (2019) further demonstrated that stomatal closure under low soil water content or high VPD is strongly linked to soil moisture. Our results indicated that drought stress led to decline in  $g_s$  (**Figure 6**), consistent with findings in poplar plant, where stomatal closure was triggered by low soil water content and/or high VPD (Costa et al., 2013).

## Conclusion

Our findings demonstrated that STWP is a more reliable and consistency indicator of drought stress in Durian cv. 'Monthong' than LWP, particularly under farmer best practice irrigation method. Critical STWP thresholds of  $-0.66$  to  $-0.90$  MPa (at 11:00 AM) and  $-0.80$  to  $-0.98$  MPa (at 1:00 PM) were identified during stop watering for flower

bud induction stage, corresponding with substantial reductions in photosynthesis, stomatal conductance, and transpiration rate. In contrast, LWP showed high variability and weak correlations with soil water indicators, making it less effective for drought detection. PSWP and  $P\theta_v$  were strongly associated with STWP under drought conditions, indicating that belowground measurements can effectively reflect plant water status. Maintaining  $\theta_v$  above 0.19 m<sup>3</sup>/m<sup>3</sup> was essential for sustaining growth, while values below this threshold induced drought stress and flower bud initiation. Furthermore, stomatal conductance ( $g_s$ ) proved sensitive to changes in soil moisture, with values below 0.06 mol H<sub>2</sub>O/m<sup>2</sup>/s serving as a practical drought indicator. Thus, these results indicate that the combining of STWP, soil water indicators, and leaf gas exchange offers a reliable approach for early drought detection and precise irrigation management in Durian orchards.

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