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Increased relative humidity in the dry season during stomata opening promotes growth, leaf area, and biomass of CAM orchid: *Dendrobium* Sonia 'Earsakul'

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Abstract

Dendrobium cut-flower producers commonly employ sprinkler systems with high water consumption. Our study aimed to identify a more water-efficient irrigation method for orchids. Specifically, we investigated the optimal timing of water application during a day in the dry season, intending to minimize water usage. The research used a 3x2x2 completely randomized factorial design, factoring in the times of the day for irrigation (dawn, morning, and evening), the type of sprinkler head (standard or large vs. mini), and the duration of irrigation (6 minutes vs. 4 minutes). The study revealed that adjusting these factors could reduce the standard water volume used by 30 to 60% without negatively affecting the orchids' growth or flower quality. Over five months of testing various irrigation techniques, metrics such as the height of the front pseudobulb, leaf count on the front pseudobulb, total leaf number per plant, pseudobulb count, and inflorescence quality (like length, number of flowers, and vase life) remained consistent across different methods. A notable discovery was that irrigating at either dawn or evening using a standard-sized sprinkler led to higher fresh and dry leaf weights and a greater leaf area than morning irrigation. Impressively, these results were observed even when the irrigation time was reduced to just 4 minutes, a 30% reduction from typical water usage. In summary, our research suggests that during the dry season, *Dendrobium* orchid growers can potentially reduce irrigation water usage by 30% without sacrificing the growth or quality of their plants.

Keywords: Cut-flower, inflorescence, leaf area, pseudobulb, vase life, water use

Introduction

Orchid cut-flower production is a leading floral commodity in Southeast Asia, particularly in Thailand, which stands out as a major exporter. In 2021, Thailand's export value for this commodity reached approximately 45 million USD, as the Office of Agriculture Economics reported in 2022. Among the various orchids, *Dendrobium* is the primary cultivar used in Thailand's cut-flower industry. Intriguingly, *Dendrobium* is a Crassulacean acid metabolism (CAM) epiphyte, a type of photosynthetic plant. Notably, CAM plants require less water. Yet, they exhibit the highest water use efficiency compared to other photosynthetic processes. This efficiency is attributed to their unique nocturnal CO_2 fixation pattern (Jindamol *et al.,* 2019; Nobel and Jordan, 1983).

CAM photosynthesis behaviour can be divided into four phases. Phase I is when light is absent, CO_2 is fixed by the PEP carboxylase (PEPC) enzyme, and phase II is the CO_2 fixation peak during the dark-light transition due to PEP carboxylase and Rubisco enzymes fixing CO_2. Phase III is when a light reaction happens while stomata are closing, and phase IV usually happens if favourable conditions occur during the light-dark transition (Smith and Lüttge, 1985). Traditional irrigation for orchid production starts from morning until noon, during phase III when the stomata are closed. This encouraged our hypothesis that if we change the irrigation time of the day to increase relative humidity (RH) during open plant stomata, which are Phase II and IV, at dawn and evening, respectively, plants will show better growth and yield quality and quantity. We found that increased RH can promote plant growth, yield, leaf area, and photosynthetic capacity in many plants. For example, CAM orchid, *Doritaenopsis* 'NewCandy' had higher fresh and dry weight, leaf size, and photosynthetic efficiency under higher RH (Jeon *et al.,* 2006). In addition, growth, biomass, leaf area index, CO_2 fixation rate, and yield of tomatoes (*Solanum lycopersicum* L.) were significantly higher when providing micro-fog to increase RH inside the greenhouse (Zhang *et al.,* 2015).

Under global warming and climate change, water scarcity is one of the significant problems. The agriculture sector accounts for the most extensive freshwater consumer, around 92 %, in the South East Asia region (Aquastat, 2014). Currently, cultivation practice for *Dendrobium* production in Thailand is based on the farmer's experience to decide when and how much to irrigate by climate observations. However, the CAM epiphyte orchid requires less water than other plant types (Winter and Smith, 2012). Hence, the current cultivation method showed overuse, inefficient water consumption, and caused run-off water from agricultural fields to contaminate the environment. Therefore, finding a way to minimise water use for the orchid producer will benefit farmers in terms of cost reduction and indirectly benefit the community by having a higher freshwater resource availability during the dry season and reducing water resource contamination from the agricultural run-off.

In this article, we represented the growth, physiological response, and inflorescence quality of *Dendrobium* at different irrigation times of the day, in addition, the reduction of irrigation water used by another type of irrigation head and irrigation duration for the long term during the dry season to summer monsoon in Thailand.

Materials and methods

Plants cultivation and treatment application: Young *Dendrobium* Sonia 'Earsakul' propagated by meri-cloning was transferred to 23x35 cm coconut husk block, four plants for each block, in February 2021. The culture at Horticultural Research Field 1 under the lath house has sunlight filtration of about 50 % and a PAR value of approximately 678 µmol s^{-1} m^{-1} at midday, Horticulture Department, Kasetsart University Kamphaeng Saen Campus, Nakorn Pathom province. Ten months after the transplant, different irrigation water systems were applied continuously for five months (from January-May 2022). January-March was the dry season, and the total rainfall was less than 45 mm (Fig. 2). April-May was the early period of the rainy season. The total precipitation was 76 to 128 mm (Fig. 2). The experiment was designed as a Factorial in CRD, which had 3x2x2 levels of treatment comprising the period of giving the irrigation (dawn 4.00 to 5.00, morning 8.00 to 9.00, and evening 18.00 to 19.00), type of irrigation head (big-PVC sprinkler head (600 litre/hour), mini sprinkler head (200 litre/hour)), duration of giving the irrigation (average water volume given by farmer, 6 minutes), decrease given time (minimise water volume, 4 minutes). We collected irrigation water volume from eight *Dendrobium* cut-flower production farms and found that the standard average water volume was 310 mL per one growing media per time. Hence, each treatment received a water volume, as shown in Table 1.

Table 1. Treatment combination and irrigation water volume for each treatment per one growing media per time

Time of the day	Sprinkler type	Irrigation duration (min)	Average irrigation volume per growing media (mL)	Compared with control (%)
Morning	Big	6	310±12	100
Morning	Big	4	220±38	71
Morning	Mini	6	177±35	60
Morning	Mini	4	136±44	43
Evening	Big	6	310±12	100
Evening	Big	4	220±38	71
Evening	Mini	6	177±35	60
Evening	Mini	4	136±44	43
Dawn	Big	6	310±12	100
Dawn	Big	4	220±38	71
Dawn	Mini	6	177±35	60
Dawn	Mini	4	136±44	43

The irrigation system was controlled using an electric solenoid valve and a Sonoff smart Wi-Fi switch to control the irrigation water's timing and duration. The average relative humidity during the first three months ranged from 47 to 94 %; in the last two months, it was 51 to 90 % (Fig. 1a, b). The average temperature was 22 to 36 °C and 24 to 36 °C during the first three months and last two months, respectively, Fig. 1 c, d). An arrow indicates the different irrigation timing. The rainfall accumulation during the first three months was 10.6 to 39.8 mm. The last two months were the summer monsoon season with high rainfall from 76.4 to 128.7 mm (Fig. 1e). Each treatment contains four replications, each containing four growing media (16 plants) accounting for 0.5 cm^2 of growing area.

Physical and physiological assessment: The physical responses, the height, number, and diameter of the front pseudobulb and leaf number were measured 3 and 5 months after treatment. Carbon exchange rate (CER), transpiration rate (Tr), and stomatal conductance (g_s) were measured five months after giving different irrigation treatments using four plants per treatment by a portable photosynthesis system (Licor-6400XT; Licor Inc.; Lincoln, NE, USA) on the 3rd leaf of the front pseudobulb. The measurement was done at dusk-dawn transition (04.00 to 07.00), where the peak of CO_2 fixation happens under fixed CO_2 air concentration at 600 ppm, leaf temperature at 25 °C, and relative humidity at 72 to 75 % conditions. After that, whole plants of each treatment were harvested and immediately brought to the laboratory for physiological assessment. First, leaf and pseudobulb were separated and fresh weight, then leaf area of the leaves was measured using leaf area meter LI-3000 (LI-COR Lincoln, Nebraska, USA). Next, the 3rd leaf from the front pseudobulb position was punched into a circle shape by a cork borer (1 cm^2 diameter) and used for chlorophyll and carotenoid extraction in acetone (80 %) (Lichtenthaler and Buschmann, 2001). Then, leaf and pseudobulb tissue were dried using Thermotec 2000 hot air oven at 70 °C for 7 to 10 days, and water content was calculated (Jin *et al.,* 2017). The dry sample was ground by cross beater mill Retsch SK100 ("Retsch Co.", Germany) until fine powder and 0.05 g were used for total non-structure carbohydrate analysis. The extraction procedure followed Smith *et al.* (1964) by using 0.2 N H_2SO_4. The TNC determination followed Nelson (1944) for photometry determination using glucose as a standard using a UV-VIS spectrophotometer (T80 UV/VIS spectrophotometer, PG Instrument Ltd., UK).

Inflorescence quality assessment*:* Inflorescence quality assessment was done by randomly harvesting 20 inflorescences per treatment, at 50% bloom in the inflorescence stage. After cutting, the inflorescence length was measured, and the number of flowers was counted. The length and width of the lowest flower were measured. After that, inflorescences were brought to the laboratory for vase life evaluation. Vase life evaluation was done under 27 ± 2°C and 12 hours of lights on condition. Inflorescence stems were cut again under water to prevent air bubbles in a vascular bundle and transferred to a test tube containing distilled water. The end of vase life was determined by 50% of floret dropped or wilted (Ketsa *et al.,* 1995). The number of inflorescences was collected throughout the experiment.

Statistical analysis: Statistical analyses were performed using the one-way variance analysis or independent sample t-test. In addition, mean differences were evaluated by using Duncan's new multiple range test at $P < 0.05$ significance level.

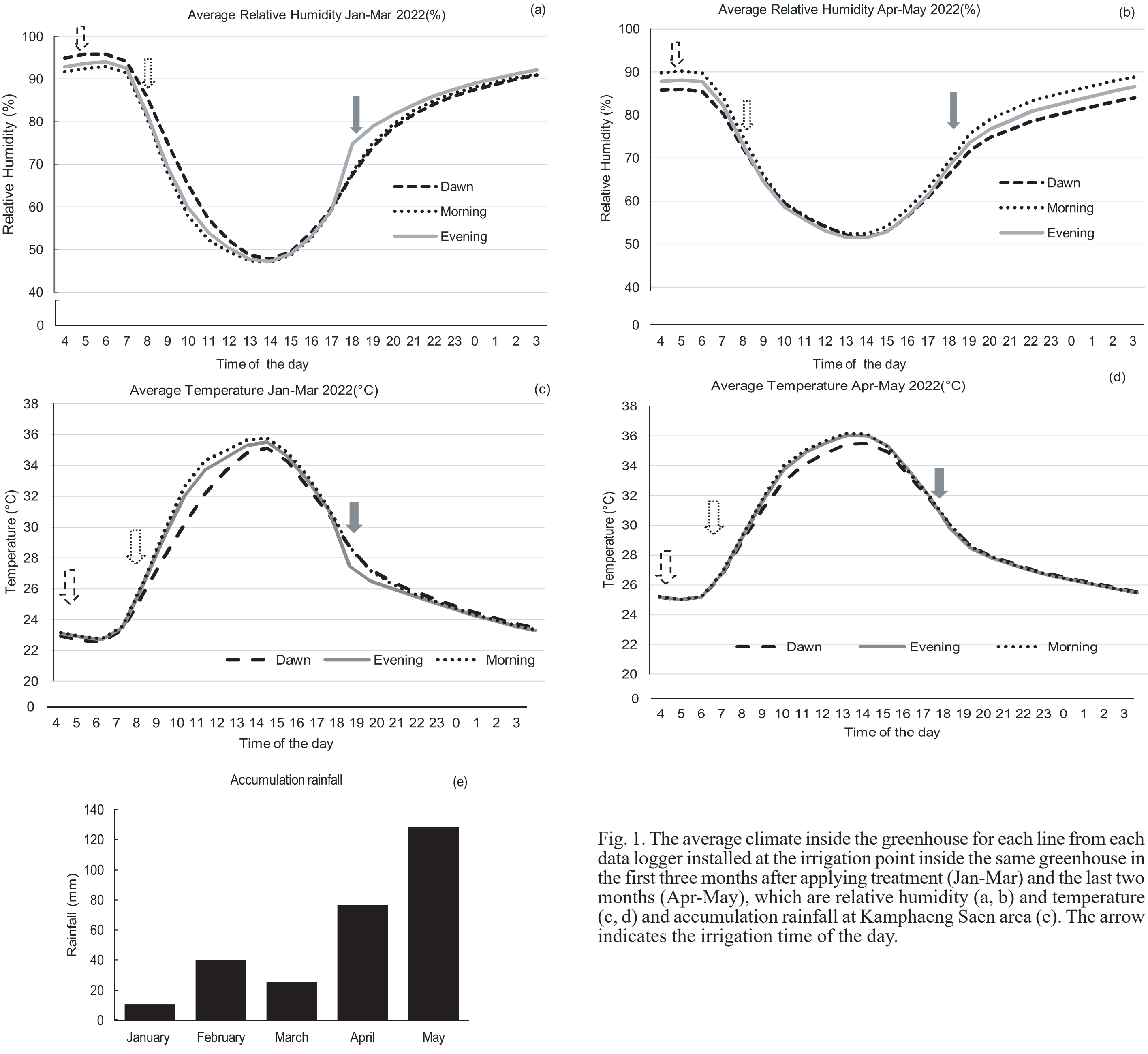

Fig. 1. The average climate inside the greenhouse for each line from each data logger installed at the irrigation point inside the same greenhouse in the first three months after applying treatment (Jan-Mar) and the last two months (Apr-May), which are relative humidity (a, b) and temperature (c, d) and accumulation rainfall at Kamphaeng Saen area (e). The arrow indicates the irrigation time of the day.

Table 2. Physical change after giving the different irrigation treatments for 3 and 5 months

Factor	Front pseudobulb height (cm)		Front pseudobulb diameter (cm)		Pseudobulb number per plant		Leaf number per plant	
	3 months	5 months	3 months	5 months	3 months	5 months	3 months	5 months
Factor 1 Time of the day (A)								
Dawn	31.7±0.7a	33.7±0.8	1.45±0.01	1.4±0.03	3.8±0.14	4.4±0.1b	12.3±0.7	12.5±0.7
Morning	30.7±0.7b	34.0±1.1	1.5±0.03	1.4±0.06	3.7±0.11	4.9 ±0.2a	11.1±0.5	11.1±0.7
Evening	32.4±0.4a	34.7±0.6	1.5±0.01	1.4±0.03	3.9±0.07	4.7±0.2ab	12.3±0.3	11.7±0.5
Factor 2 Type of sprinkler head (B)								
Big	32.1±0.4a	34.8±0.6	1.5±0.02	1.5±0.02	3.9±0.09	4.8±0.1	12.3±0.5	12.3±0.6
Mini	31.1±0.6b	33.4±0.7	1.4±0.02	1.4±0.04	3.7±0.08	4.6±0.2	11.5±0.4	11.2±0.4
Factor 3 Duration (C)								
Normal (6 min)	31.5±0.5	34.5±0.1	1.5±0.02	1.5±0.03	3.9±0.11	4.6±0.1 b	12.1±0.5	12.1±0.6
Short (4 min)	31.7±0.7	33.8±0.5	1.5±0.02	1.4±0.02	3.7±0.05	5.0±0.2 a	11.7±0.5	11.5±0.4
F-test/T-test								
A	*	ns	ns	ns	ns	**	ns	ns
B	*	ns	ns	ns	ns	ns	ns	ns
C	ns	ns	ns	ns	ns	*	ns	ns

Note: The data are means ±SE. Different letters indicate significant differences at $P < 0.05$ between treatments within the same factor.

Results

Physical response to different irrigation treatments: After applying different irrigation treatments for 3 and 5 months, the eyes barely detected the physical difference between each treatment. We found a statistically different front pseudobulb height at another irrigation time and type of sprinkler head at three months. Giving water at dawn and evening showed 31.7 and 32.4 cm height, respectively, while it was only 30.7 cm in the morning. The big-head sprinkler measured 32.1 cm, whereas the mini-sprinkler measured 31.1 cm height (Table 2). However, height was not statistically different in 5 months, varying from 33.7 to 34.7 cm.

In contrast, we found significantly higher pseudobulb number when irrigated in the morning, with a shorter time of five months. Irrigation in the morning had an average of 4.9 pseudobulbs, while in the evening and dawn, had 4.7 and 4.4 pseudobulbs, respectively (Table 2). Giving shorter irrigation time had five pseudobulbs per plant while only 4.6 pseudobulbs per plant were recored if water was given at regular timing. The diameter of the front pseudobulb and leave number per plant were not statistically different among irrigation treatments 3 and 5 months after the treatment (Table 2).

Physiological response to different irrigation treatments: Big-headed sprinkler irrigation had a significantly higher CER than the mini sprinkler, which was 6.81 and 5.62 µmol CO_2 $m^{-2}s^{-1}$, respectively (Table 3). However, the different periods of the day and the irrigation duration did not show any statistical differences, ranging from 6.1 to 6.45 µmol CO_2 $m^{-2}s^{-1}$. The g_s and Tr were also not significantly different between each irrigation treatment, ranging from 0.081 to 0.092 mol H_2O $m^{-2}s^{-1}$ and 0.63 to 0.69 mmol H_2O $m^{-2}s^{-1}$, respectively (Table 3). Although photosynthetic activity was different, pigment content in the leaves, chlorophyll a, b, total chlorophyll, and carotenoid were not significantly different among treatments (data not shown). Interestingly, irrigation at dawn showed significantly higher fresh leaf weight (FLW), dry leaf weight (DLW), and leaf surface area, followed by evening and morning irrigation. The FLW was 76.12, 67.72, and 56.55 grams, the DLW were 7.24, 6.56, and 5.59 grams, and the leaf area was 576.95, 525.28, and 435.37 cm^2 in the dawn, evening, and morning irrigation time, respectively (Table 4). The FLW was also significantly higher using a big headspring than a mini sprinkler, 72.35 and 61.24, respectively. However, different irrigation times and levels did not affect the water content of plants, which was between 88.09 and 88.92 % (Table 4).

Table 3. CO_2 exchange rate (CER), stomatal conductance (g_s), and transpiration rate (Tr) at five months after different irrigation treatments

Factor	CO_2 exchange rate (µmol CO_2 $m^{-2}s^{-1}$)	Stomatal conductance (mol H_2O $m^{-2}s^{-1}$)	Transpiration rate (mmol H_2O $m^{-2}s^{-1}$)
Factor 1 Time of the day (A)			
Dawn	6.11±0.31	0.084±0.005	0.67 ±0.04
Morning	6.10±0.42	0.091±0.006	0.68±0.04
Evening	6.45±0.32	0.083±0.006	0.63±0.04
Factor 2 Type of sprinkler head (B)			
Big	6.81±0.20 a	0.091±0.004	0.69±0.03
Mini	5.62±0.31 b	0.082±0.005	0.63±0.04
Factor 3 Duration (C)			
Normal (6 min)	6.23±0.27	0.081±0.005	0.64±0.04
Short (4 min)	6.20±0.30	0.092±0.004	0.68±0.03
F-test/T-test			
A	ns	ns	ns
B	*	ns	ns
C	ns	ns	ns

Note: The data are means ±SE. Different letters indicate significant differences at $P < 0.05$ between treatments within the same factor.

Table 4. Fresh leaf weight (FLW), dry leaf weight (DLW), leaf area, and whole plant water content (WC) at five months after different irrigation treatments

Factor	Fresh leaf weight (g)	dry leaf weight (g)	Leave area (cm^2)	Whole plant water content (%)
Factor 1 Time of the day (A)				
Dawn	76.12±5.7 a	7.24±0.52 a	576.95±45.7 a	88.82±0.37
Morning	56.55±3.8 b	5.59±0.36 b	435.37±32.3 b	88.61±0.46
Evening	67.72±5.2 ab	6.56±0.49 ab	525.28±42.3 ab	88.10±0.52
Factor 2 Type of sprinkler head (B)				
Big	72.35±4.37 a	6.92±0.4	553.03±35.2	88.92±0.28
Mini	61.24± 4.04 b	6.01±0.4	472.04±32.5	88.09±0.43
Factor 3 Duration (C)				
Normal (6 min)	66.75±4.56	6.43±0.42	513.36±1.29	88.39±0.36
Short (4 min)	66.85±4.16	6.50±0.38	511.71±1.09	88.63±0.38
F-test/T-test				
A	*	*	*	ns
B	*	ns	ns	ns
C	ns	ns	ns	ns

Note: The data are means ±SE. Different letters indicate significant differences at $P < 0.05$ between treatment within the same factor.

Considering the total non-structure carbohydrate (TNC) in plants after receiving different irrigation treatments, we found that the shorter irrigation caused a significantly higher accumulation of TNC than normal irrigation time, which had 4.99 and 4.34 mg glucose equivalent/g DW, respectively (Table 5). In contrast, other irrigation methods showed no statistical difference between 4.45 and 4.70 mg glucose equivalent/g DW.

Table 5. Total non-structure carbohydrate (TNC) in the whole plant after receiving different irrigation treatments for five months

Factors	Total non-structure carbohydrate (TNC) (mg Glucose equivalent/gDW)
Factor 1 Time of the day (A)	
Dawn	4.45 ±0.14
Morning	4.70 ±0.26
Evening	4.74 ±0.20
Factor 2 Type of sprinkler head (B)	
Big	4.60 ±0.16
Mini	4.67 ±0.17
Factor 3 Duration (C)	
Normal (6 min)	4.34 ±0.17b
Short (4 min)	4.99 ±0.14a
F-test/T-test	
A	ns
B	ns
C	*

Note: The data are means ±SE. Different letters indicate significant differences at $P < 0.05$ between treatments within the same factor.

Inflorescence quality to different irrigation treatments: After five months of different irrigation treatments, the quality of the inflorescences did not differ statistically from each other. The inflorescence lengths ranged from 33.84 to 35.64 cm, while the diameter of the flowers ranged from 0.47 to 0.49 cm (Table 6). The number of flowers for each inflorescence ranged from 8 to 8.63. In addition, the total yield and lifespan were not statistically different in providing irrigation at a different time of day or duration, with a yield from 17 to 31.5 inflorescences per 0.5 m^2 and vase life around 11.88 to12.66 days after harvest (Table 6).

Table 6. Inflorescence quality assessment by inflorescence length, flower diameter, flower number per inflorescence, yield and vase life after cut at five months after the different irrigation treatments

Factor	Inflorescence length (cm)	Flower diameter (cm)	Flower number per inflorescence	Total inflorescence per 16 plant (0.5 m^2)	Vase life (day)
Factor 1 Time of the day (A)					
Dawn	34.57 ±0.93	0.49 ±0.008	8.00±0.19	17.25±3.0	12.30±0.43
Morning	35.26 ±1.00	0.48 ±0.007	8.63±0.20	17.0±2.9	12.31±0.50
Evening	34.39 ±0.96	0.48 ±0.011	8.34±0.22	22.0±3.0	12.20±0.40
Factor 2 Type of sprinkler head (B)					
Big	35.64 ±0.65	0.49±0.008	8.41±015	31.5±2.2	12.31±0.37
Mini	33.84 ±0.85	0.47±0.006	8.23±0.19	24.75±3.6	12.23±0.34
Factor 3 Duration (C)					
Normal (6 min)	34.92 ±0.63	0.49±0.006	8.42±0.16	28±2.7	11.88±0.38
Short (4 min)	34.56 ±0.91	0.48±0.008	8.22±0.19	28.25±3.2	12.66±0.32
F-test/T-test					
A	ns	ns	ns	ns	ns
B	ns	ns	ns	ns	ns
C	ns	ns	ns	ns	ns

Note: The data are means ±SE. Different letters indicate significant differences at $P < 0.05$ between treatments within the same factor.

Discussion

Conventional irrigation methods for orchid farmers usually start from 8.00 until the afternoon. However, we found that irrigation during the stomata opening of CAM plants (dawn and evening) can promote growth, leaf area, and dry matter (Table 4). Even though the CER at peak hour was not statistically different between different times of the day (Table 3), the whole night CER must be considered. The dawn irrigation can prolong higher RH around plants almost until midday (Fig. 1a), extending the opening of stomata when light is present at phase II (peak of CO_2 fixation), and also evening irrigation immediately decreases the temperature and increases RH. This caused a favourable condition for stomata opening (phase IV) and might increase CO_2 fixation time. In CAM, epiphytes like *Dendrobium* and *Tillandsia recurvate,* it was found that stomata respond directly to air humidity. Therefore, the increased air humidity promotes stomata opening and CO_2 fixation during the nighttime (Lange and Medina, 1979). Similarly reported in the CAM orchid, *Doritaenopsis* 'NewCandy', the acclimatization under high relative humidity conditions exhibited better physical development, which is leaf size, leaf area, and CER slightly higher at phase II and IV of CAM photosynthesis (Jeon *et al.,* 2006).

Adjusting the irrigation method using a smaller irrigation head and shorter duration can reduce water from up to 71% of normal practice (Table 1). Even though the irrigation water was reduced, it did not affect physical growth (Table 2,3,4) and inflorescence quality (Table 6) when given the treatment for the long term. We found that with shorter irrigation time, the pseudobulb number was statistically increased in five months while at three months it was not different (Table 2). The shorter irrigation time could cause mild drought stress to plants during the first three months and then recovery from drought by the rain during the summer monsoon (Fig. 1e). There was a report that drought promotes shoot budding after re-watering like it was reported in European beech seeding (Hájíčková *et al.,* 2017). The accumulation of TNCs also did not decrease as a result of water reduction. However, it was slightly higher in treatments that received lower water volume in shorter time irrigation (Table 5). It represents that the carbohydrate pool did not get depleted from the water reduction. As reported in *Averrhoa carambola*, the increase in TNC could be because of the mild drought that promotes carbohydrate accumulation (Wu *et al.,* 2017). The pseudobulb organ is the key organ acting as a reservoir during water deficit. It helps plants maintain water status and physiological activity during the first three months. Moreover, long-term water reduction did not affect the water status in long-term cultivation because the water content was not significantly different among treatments (Table 4). *Dendrobium* showed high tolerance to drought, even withholding water for a month, still maintaining relative water content in tissue higher than 95 % (Yang *et al.,* 2016).

Neither reduced irrigation water nor different irrigation times affected the quality and grade of inflorescence yield in a growing area of 0.5 cm^2 (Table 6). However, further observation is needed on a larger scale because irrigation in the evening and using a larger irrigation head resulted in a higher yield of inflorescence. While using the larger head yielded more than the mini sprinkler, the difference was not statistically significant. Additionally, we observed that the larger irrigation head resulted in a higher grade for longer inflorescences. This may be attributed to the larger sprinkler head's ability to cover a wider radius and deliver more water per minute, thereby maintaining a higher relative humidity compared to a mini sprinkler.

This study will be advantageous for orchid cut-flower producers as it provides reliable information that reducing water usage during irrigation, even in the dry season, will not have a long-term impact on growth and the quality and quantity of inflorescences. This benefits orchid producers by reducing costs and indirectly benefits the community by increasing the availability of freshwater during dry periods. Furthermore, these findings suggest that changing the irrigation schedule from the traditional morning time to dawn or evening can also enhance growth and increase the quantity of inflorescences. This could encourage farmers to adopt and integrate IoT technology into their farms, thereby addressing the shortage of human resources in the near future.

A reduction of approximately 30% in irrigation water for orchids can be achieved either by reducing the duration of irrigation or by changing the type of sprinkler head used. Our findings indicate that even during the dry season, long-term cultivation of orchids is not significantly affected in terms of growth and the quality of inflorescences. Although slight differences were found between each method, a reduction in irrigation time was recommended because it was convenient and did not cost the farmer more. Furthermore, irrigation at dawn and evening showed better growth and yield than the conventional method, which is irrigation from morning until noon.

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Reference

Aquastat, 2014,<http://www.fao.org/nr/aquastat>

Hájíčková, M., R. Plichta, D. Volařík and R. Gebauer, 2017. Effects of drought and rewatering on growth and transpiration in European beech seedlings late in the growing season. *New Forests,* 48: 773-784.

Jeon, M.W., M.B. Ali, E.J. Hahn and K.Y. Paek, 2006. Photosynthetic pigments, morphology and leaf gas exchange during *ex vitro* acclimatization of micropropagated CAM Doritaenopsis plantlets under relative humidity and air temperature. *Environ. Expt. Bot.,* 55: 183-194.

Jin, X., C. Shi, C.Y. Yu, T. Yamada and E.J. Sacks, 2017. Determination of leaf water content by visible and near-infrared spectrometry and multivariate calibration in Miscanthus. *Front. Plant Sci.,* 8: 721.

Jindamol, H., P. Kasemsap and P. Boonkorkaew, 2019. Water use and photosynthesis of *Dendrobium* Sonia 'Earsakul'under water deficit stress. *Agr. Natural Resources,* 53: 61-65.

Ketsa, S., Y. Piyasaengthong and S. Prathuangwong, 1995. Mode of action of $AgNO_3$ in maximizing vase life of *Dendrobium* 'Pompadour'flowers. *Postharvest Biol. Tech.,* 5: 109-117.

Lange, O. and E. Medina, 1979. Stomata of the CAM plant *Tillandsia recurvata* respond directly to humidity. *Oecologia,* 40: 357-363.

Lichtenthaler, H.K. and C. Buschmann, 2001. Chlorophylls and carotenoids: Measurement and characterization by UV-VIS spectroscopy. *Current Protocols in Food Anal. Chemistry,* 1: F4. 3.1-F4. 3.8.

Nelson, N. 1944. A photometric adaptation of the Somogyi method for the determination of glucose. *J. Bio. Chem.,* 153: 375-380.

Nobel, P.S. and P.W. Jordan, 1983. Transpiration stream of desert species: resistances and capacitances for a C3, a C4, and a CAM plant. *J. Expt. Bot.,* 34: 1379-1391.

Office of Agriculture Economics, 2022, <http://impexp.oae.go.th/service/export.php?S_YEAR=2564&E_YEAR=2565&PRODUCT_GROU*P*=5432&wf_search=&WF_SEARCH=Y#export>

Smith, D., G. Paulsen and C. Raguse, 1964. Extraction of total available carbohydrates from grass and legume tissue. *Plant Physiol.,* 39: 960.

Smith, J. and U. Lüttge, 1985. Day-night changes in leaf water relations associated with the rhythm of crassulacean acid metabolism in *Kalanchoë daigremontiania*. *Planta,* 163: 272-282.

Winter, K. and J. A. C. Smith. 2012. *Crassulacean Acid Metabolism: Biochemistry, Ecophysiology and Evolution* (Vol. 114). Springer Science & Business Media

Wu, P., C. Wu and B. Zhou, 2017. Drought stress induces flowering and enhances carbohydrate accumulation in *Averrhoa carambola*. *Hortic. Plant J.,* 3: 60-66.

Yang, S.J., M. Sun, Q.Y. Yang, R.Y. Ma, J.L. Zhang and S.B. Zhang, 2016. Two strategies by epiphytic orchids for maintaining water balance: thick cuticles in leaves and water storage in pseudobulbs. *AoB Plants,* 8. doi.org/10.1093/aobpla/plw046.

Zhang, D., Z. Zhang, J. Li, Y. Chang, Q. Du and T. Pan, 2015. Regulation of vapor pressure deficit by greenhouse micro-fog systems improved growth and productivity of tomato via enhancing photosynthesis during summer season. *PLoS One,* 10: e0133919.

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