ORIGINAL ARTICLE

Use of an infrared thermometer for assessment of plant water stress in neck orange (*Citrus reticulata* Blanco)

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Abstract

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In general, water stress causes stomatal closure in citrus, and this leads to higher leaf temperature. Recently, it has been reported that infrared thermometry technique can be used for detecting stomatal closure indirectly to assess plant water stress. Therefore, it was proposed to apply to neck orange. An experiment was arranged as a completely randomized design. There were 3 treatments of watering levels: 1) well-watering (W1), 2) 3-day interval watering (W2), and 3) 6-day interval watering (W3) with 6 replicates. Eighteen 2-year-old trees of neck orange were used, and each tree was grown in a container (0.4 m^3) filled with mixed media of soil, compost and sand (1:1:1). During 18 days of the experimental period, it was found that leaf water potential and stomatal conductance of the plants in W2 and W3 treatments decreased with the progress of water stress. There was high correlation ($r^2 = 0.71^{**}$) between leaf water potential and stomatal conductance as a linear regression ($Y = 0.0044X-1.8635$). Canopy temperature (Tc) and air temperature (Ta) of each tree were measured by an infrared thermometer, and Tc-Ta was assessed. At the end of the experimental period, it was found that Tc-Ta was significantly highest in the W3 treatment (3.5ºC) followed by the of W2 treatment (2ºC), while it was lowest in the W1 treatment (1ºC). The relationship between Tc-Ta and

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stomatal conductance was high as polynomial ($Y = 0.0002X^2-0.0572X+3.9878$, $r^2 = 0.70^{**}$). This indicated that stomatal closure or decreasing stomatal conductance caused increasing of Tc-Ta in the leaves. Hence, it suggests that infrared thermometer is a convenient device for the assessment of plant water stress in neck orange.

Key words : infrared thermometer, canopy temperature, stomatal conductance, leaf water potential

บทคัดย่อ

สายัณห์ สดุดี และ พรทิพย์ แก้วคง

การใช้อินฟราเรดเทอร์โมมิเตอร์ประเมินสภาวะเครียดน้ำของส้มจุก

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โดยทั่วไปสภาวะเครียดน้ำมีผลทำให้ปากใบของพืชตระกูลส้มปิด ส่งผลให้อุณหภูมิของใบสูงขึ้น มีรายงานว่าวิธีการใช้อินฟราเรดเทอร์โมมิเตอร์สามารถนำไปใช้ตรวจวัดการปิดปากใบของพืชโดยอ้อมเพื่อประเมินสภาวะเครียดน้ำของพืชได้ ดังนั้นจึงนำไปประยุกต์ใช้กับส้มจุก โดยวางแผนการทดลองแบบสุ่มตลอด มี 3 วิธีทดลอง ดังนี้ 1) ให้น้ำทุกวัน (W1) 2) ให้น้ำทุก 3 วัน (W2) และ 3) ให้น้ำทุก 6 วัน (W3) โดยทำ 6 ซ้ำ ใช้ต้นส้มจุกอายุ 2 ปี จำนวน 18 ต้น โดยแต่ละต้นปลูกในบ่อซีเมนต์ขนาด 0.4 ลบ.ม. ที่บรรจุดินผสมที่มีส่วนผสมของ ดิน:ปุ๋ยหมัก:ทราย (1:1:1) ในช่วงการทดลอง 18 วัน พบว่า ค่าศักย์ของน้ำในใบและค่าการชักนำปากใบของพืช ในวิธีทดลองที่ 2 และ 3 ลดลงเมื่อสภาวะเครียดน้ำเพิ่มขึ้น ค่าศักย์ของน้ำในใบกับค่าการชักนำปากใบมีความสัมพันธ์กันสูง ($r^2 = 0.71^{**}$) โดยมีความสัมพันธ์เชิงเส้นตรง $Y = 0.0044X-1.8635$ สำหรับค่าอุณหภูมิทรงพุ่ม (Tc) และอุณหภูมิอากาศ (Ta) ของพืชแต่ละต้น ซึ่งวัดโดยใช้อินฟราเรดเทอร์โมมิเตอร์ พบว่าในช่วงการทดลอง ความแตกต่างของ Tc-Ta สูงที่สุดอย่างมีนัยสำคัญในวิธีทดลองที่ 3 (3.5°C) รองลงมาคือ วิธีทดลองที่ 2 (2°C) ส่วนวิธีทดลองที่ 1 มีค่าความแตกต่างต่ำที่สุด (1°C) โดยมีความสัมพันธ์ระหว่าง Tc-Ta กับค่าการชักนำปากใบ เป็นแบบโพลีโนเมียล $Y = 0.0002X^2-0.0572X+3.9878$, $r^2 = 0.70^{**}$ แสดงให้เห็นว่าเมื่อปากใบปิดหรือค่าการชักนำปากใบลดลงส่งผลให้ค่าความแตกต่างของ Tc-Ta เพิ่มขึ้น ดังนั้นแนะนำได้ว่าอินฟราเรดเทอร์โมมิเตอร์เป็นเครื่องมือที่ใช้ได้สะดวกสำหรับประเมินสภาวะเครียดน้ำของส้มจุก

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Among the cultivated tropical fruit-trees in southern Thailand, the neck orange (*Citrus reticulata* Blanco.) is one of the most localized in relation to its habitat and area of cultivation, particularly in Songkhla province (Department of Agricultural Extension, 2000). In recent years, the neck orange has been subjected to renewed interest because of its unique fruit shape and flavour, and attempts are now being made to study this crop in more detail. With an increasing interest in the specialized production of neck orange on a commercial production, physiological responses to limitation factors need to be investigated. Water stress is one of the limiting factors in citrus production, because water stress causes stomatal closure; this is an adaptive mechanism to drought allowing the plant to regulate water loss more effectively (Ruiz-Sanchez *et al.*, 2000). Gomes *et al.* (2004) investigated the effect of water stress on 'Pera' orange trees. It was found that abscisic acid content increased with consequent stomatal closure and decreased leaf water potential values. Stomatal closure is generally much more sensitive to soil water status than is the leaf water potential itself (Bates and Hall, 1981; Jones, 1990; Davies and Zhang,1991). In neck orange, Chuchird (2004) found that the plants exposed to water stress condition causing decrease of leaf water potential and stomatal conductance; produced higher foliar carbohydrate with higher C/N, comparing with the well-watered plants. Therefore, water stress by water-withholding induced high flowering of neck orange. Braun (1990) suggested that water stress causes a decrease of stomatal conductance in citrus, and this consequently increases leaf temperature. Canopy temperature can be measured by an infrared thermometer (Rahkonen and Jokela, 2003). Therefore, infrared thermometers are convenient devices for measuring the temperature of crop canopies (Kocsis and Ligetvari, 1992; Wanjura and Upchurch, 1991)

For these reasons, the aim of this study was to present the use of infrared thermometer for measuring change of canopy temperatures to assess the response of neck orange to water stress periods.

Materials and methods

Experimental site and layout

The experiment was conducted at the Department of Plant Science, Prince of Songkla University, Southern Thailand. Eighteen two-year-old trees (average plant height = 115.10±5.20 cm) of neck orange on rootstock (neck orange), were grown under open area in containers (1 plant in each container) containing mixed media (0.4 m^3) of sand, compost and soil (1:1:1). The experiment was arranged as a completely randomized design. There were six replicates with three levels of watering: 1) daily waterings (control or W1), 2) 3-day interval watering (W2) and 3) 6-day interval watering (W3). An amount of water was applied to each tree at each watering to keep soil moisture about field capacity.

Weather and soil water potential conditions

The weather conditions were recorded at an adjacent meteorological station (about 1 km from the experimental site) at the Rubber Research Station, Songkhla province. Soil moisture was monitored using Theta probes (Delta-T Devices, Burwell, UK) installed at a 15 cm depth in each treatment.

Leaf water potential and stomatal conductance measurements

Diurnal changes of leaf water potential and stomatal conductance were determined using a pressure chamber (PMS, USA), and AP4 porometer (Delta-T Device, UK), respectively. Young fully-expanded leaves were used for the measurements, which were done during mid-day (11.00-13.00) at 3-day intervals during the experimental period (18 days).

Leaf temperature measurements

Canopy temperature was also determined during mid-day using an infrared thermometer (TFI20, "ebro", Germany). It was measured by pointing the infrared thermometer to the canopy at a distance of 30 cm from canopy skin, after that ambient air temperature was also measured by using the infrared thermometer. The measurement was done from 4 directions (N, S, E and W) of each tree, and the values were averaged as the canopy temperature of each tree. Then, the difference between canopy temperature (Tc) and air temperature (Ta) was assessed as Tc-Ta.

Results and discussion

The experiment was conducted during summer (January 16th - February 3rd, 2006), so there was high daily evaporation around 4 mm (Figure 1). While there was light showers during the experimental period, this caused water deficit in the W2 and W3 treatments. The maximum temperature was around 34ºC, and minimum temperature was about 24ºC.

In the treatment of daily watering W1, soil moisture remained high around 25-30% during the experimental period, while average soil moisture in the treatment of W2 and W3 decreased during the progress of water stress. Soil moisture in W2 and W3 treatments fluctuated because of interval rewatering, soil moisture in W2 and W3 dropped to 17% and 13%, respectively, on the last day of the experiment.

The changes of leaf water potential, stomatal

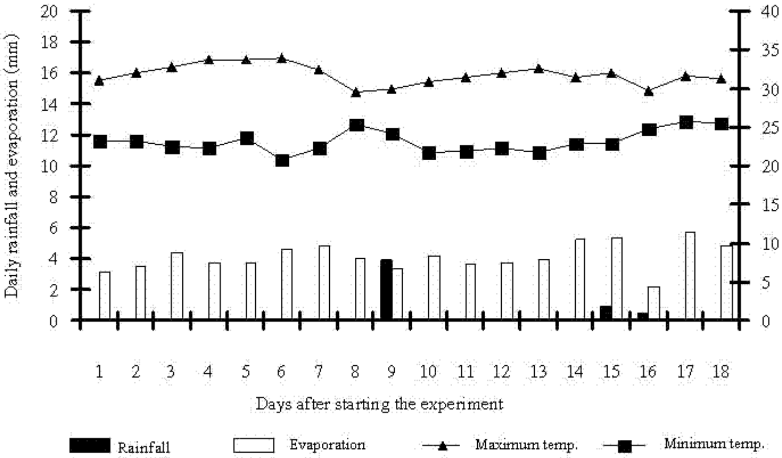

Figure 1. Daily rainfall, evaporation, maximum and minimum temperature during the experimental period (January 16th - February 3rd 2006). Data from Koh Hong Meteorological Station, Hatyai, Songkhla, Thailand.

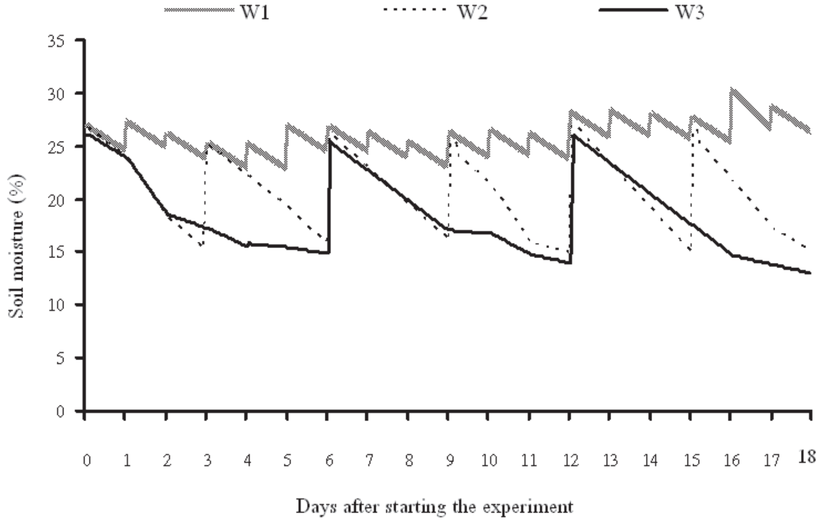

Figure 2. Changes of soil moisture in the treatments of W1, W2 and W3 during the experimental period.

condutance from the first day to the end of the drying period (Figure 3a, b) were a consequence of the change of soil moisture in the treatments (W1, W2 and W3). The changes of both parameters were syncronized. The leaf water potential and stomatal conductance in the W1 treatment remained high along the experimental period, while those in the W2 and W3 dropped sharply on day 6 after starting the experiment, then declined to the last day of the drying period. Leaf water potential and stomatal conductance of W3 treatment were lowest around -1.8 MPa and 40 mmol $m^{-2}s^{-1}$, respectively, and those in W2 treatment dropped to -1.5 MPa and 60 mmol m^{-2} s^{-1}, respectively. It was remarkable that the stomatal conductances of W2 and W3 were significantly different from that of W1 from day 6 through the end of experimental period, while leaf water potentials of W2 and W3 were significantly lower than that of W1 from day 9 to day 18. This supports the finding that stomatal

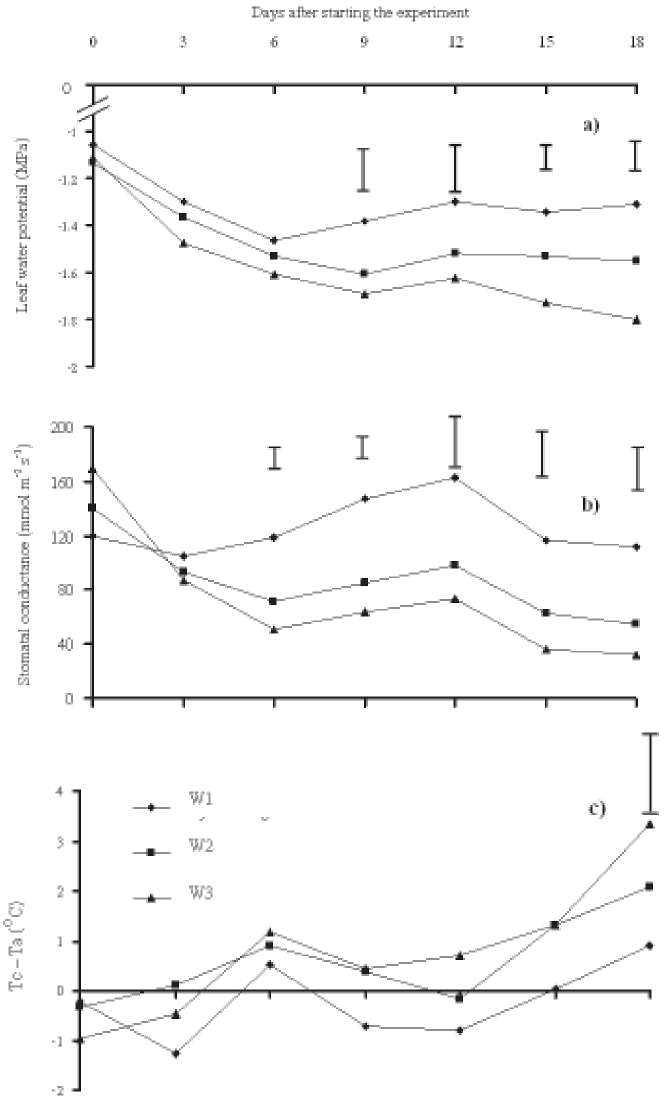

Figure 3. Changes of mid-day leaf water potential (a), stomatal conductance (b) and Tc-Ta (c) in the treatment of W1, W2 and W3 during the experimental period (Vertical bars indicate LSD0.05).

closure is much more sensitive to soil water status than is leaf water potential as reported by Davies and Zhang (1991).

The difference of Tc-Ta among the treatments was low during the early stage of water stress period. At the end of the experimental period, on day 15 and 18, the differences of Tc-Ta of W2 and W3 were markedly higher than that of W1. On day 18, the value of Tc-Ta in W3 was significantly highest (3.5ºC), followed by W2 (2ºC) and W1 (1ºC), respectively. This indicated that an important consequence of the stomatal closure that occurs when plants are subjected to water stress is that energy dissipation is decreased, so leaf temperature tends to rise. Therefore, the idea of using leaf or canopy temperature as an indicator of plant water stress has been applied (Idso *et al.*, 1981; Jackson *et al.*, 1981; Jones, 1999; Tokei and Dunkel, 2005).

There was high correlation ($r^2 = 0.71$)

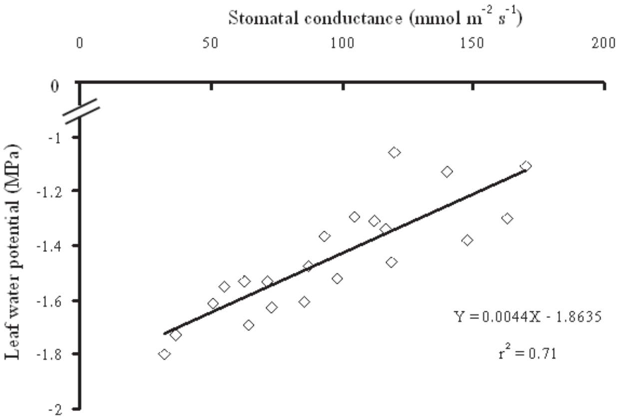

Figure 4. Leaf water potential versus stomatal conductance of neck orange trees submitted to water stress.

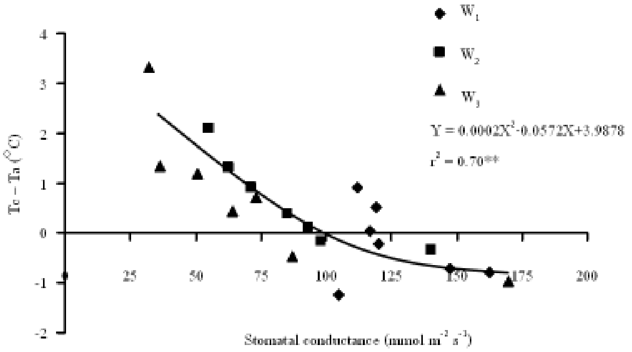

Figure 5. The canopy (skin) and air temperature difference (Tc-Ta) versus stomatal conductance of neck orange trees submitted to water stress.

between leaf water potential and stomatal conductance (Figure 4). This indicates that a decrease of stomatal conductance is a sensitive parameter of water stress during the loss of water from the leaves or a decrease of leaf water potential. Tardien *et al.* (1996) reported for several species that stomatal conductance was generally correlated with leaf water potential. Gomes *et al.* (2004) found the relationship between abscisic acid (ABA), leaf water potential and stomatal conductance in 'Pera' orange trees leaves. Water stress in orange trees increased ABA content with consequent stomatal closure and decreased leaf water potential of leaves.

Figure 5 shows the strong relationship between Tc-Ta and stomatal conductance as a polynomial ($Y = 0.0002X^2 - 0.0572X + 3.9878$, $r^2 = 0.70^{**}$). This indicates that the canopy and air temperature difference increased with a decrease of stomatal conductance. This is due to plant adaptation to water stress by closing stomata to reduce water loss from the leaves. However, this causes an increase of leaf temperature because of the limitation of energy dissipation (Tanner, 1963). In neck orange, it was also evident that a marked decrease of stomatal conductance caused high Tc-Ta. Jones (1999) suggested the use of infrared thermometry as a technique for detecting stomatal closure as a measure of plant water stress in humid environments. Therefore, this technique can be used for estimation of stomatal conductance as a potential aid for irrigation scheduling. Ben-Asher *et al.* (1992) applied the use of infrared thermometer for detection of crop water stress symptoms, and this enabled the system operator to translate it into a crop water stress index (CWSI). However, this investigation in neck orange was only a preliminary study in a container trial. Further study needs to be made under field condition. Tokei and Dunkel (2005) commented that in the measurement of air and canopy temperatures, the other factors of relative humidity and radiation should be considered. Besides, it should be considered that Tc-Ta sensitivity is less than that of stomatal sensitivity when the plant is imposed to water stress.

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