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Monitoring Water Stress Responses of *Ipomoea Aquatica* (Forssk.) by Thermal Imaging in Different Soil Materials of Northern Thailand

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Abstract

Water morning glory, *Ipomoea aquatica* (Forssk.), is a widely used leafy vegetable throughout Southeast Asia and China. The fast growing plant produces high biomass with a soft watery tissue. This study focuses on the responses of water morning glory to water deficit under controlled conditions.

Two cemented soil basins (8 m x 1 m x 1 m) under a plastic shelter were filled with soil material representative for Northern Thailand, taking care that the natural layering and bulk density was altered to the least extend possible. The original soil bodies were Regosol (a well-drained loamy sand developed on a middle terrace) from Mae Jo, Sansai District and Vertisol (a brown, clayey alluvial soil deposited on flood plain) from Mae Ai District.

I. aquatica (cv. 'Reptan') was planted and three weeks drip irrigated keeping the soil close to field capacity (<-100 mbar) until complete soil cover. Each soil basin was divided into two longitudinal segments. On one segment of each soil basin irrigation was continued for control and on the other segment irrigation was stopped for monitoring water stress responses.

Weather data were collected on site and matric potential was monitored with tensiometers. Stomatal resistance was determined once a day by a porometer (Decagon SC-1) and thermal images were acquired with an IR-camera (Infratec Variocam) at the same time. Crop water stress index (CWSI) was calculated as $(T_C - T_{base}) / (T_{max} - T_{base})$, where T_C is the mean canopy temperature, T_{max} is the upper threshold temperature of leaves where transpiration is suppressed by vaseline coating and T_{base} is the temperature of water sprayed leaves and therefore the threshold for maximum evaporative cooling. After ten days of drought the plant material was harvested for determining above ground fresh and dry biomass.

CWSI based on thermal imaging showed a higher correlation with matric potential as with stomatal resistance. It was possible to visualize the differences between well-watered and stressed plants by thermal imaging before visible signs of wilting started.

Introduction

Early detection of drought stress is an important pre-requisite for developing new irrigation strategies and operating irrigation control systems. The determination of leaf temperature by infrared (IR) sensors is a quick and non-invasive method for stress assessment via stress indices (Idso et al. 1981). However, as a method for field water stress assessment it was not widely used until the introduction of thermal imagery (Jones 1999). Since then, plenty of studies have been conducted showing the applicability of thermal imaging for identification of mutants (Merlot et al. 2002), phenotyping (Romano et al. 2011), remote sensing (Meron et al. 2010) and water stress monitoring in perennial crops (Grant et al. 2007) and annual crops (Zia et al. 2011).

Increased leaf temperature is an effect of reduced transpiration under water stress. Thus a high correlation between temperature and stomatal aperture of a single leaf is to be expected. Further, it was shown that this correlation exists between the canopy surface temperature measured by thermal imaging and stomatal resistance measured by porometry (Grant et al. 2006). However, stomatal aperture varies largely within a cropped area and even within a single plant. Soil matric potential on the other hand is a reliable – even though indirect – crop water stress indicator. Replacing matric potential monitoring with thermal imagery would avoid the need of invasive measurements in the root zone. The aim of this study was, thus, to correlate the degree of plant water stress measured by thermal imagery to the matric potential in different soil materials. Water morning glory (*Ipomoea aquatica* (Forssk.)) was used as a test crop as it reacts sensitively to water stress.

Material and Methods

The experiments were conducted at Mae Jo University (Sansai District, Chiang Mai Province, Thailand, 18° 53' N 99° 01' E). Two longitudinal cement containers (8 x 1 x 1 m) were filled with different soil materials, typical for Northern Thailand, taken from two different soils in Chiang Mai Province: (1) Regosol from Mae Jo (18° 55' N 99° 01' E); texture of the top soil: sandy loam (68% sand, 6% clay, 26% silt); field capacity (FC): 12.8%, permanent wilting point (PWP): ~6.0 %. (2) Vertisol from Mae Ai (20° 01' N 99° 17' E); texture of the top soil: clay (23% sand, 61% clay, 16% silt), FC: 48.2 %, PWP: ~37.0 %. The A and B horizons were collected separately and filled respective to the original layering. Layer by layer were manually re-compacted to obtain a similar bulk density as in the field. The containers are placed under a plastic shelter, which is open in NW – SE direction.

Soil matric potential was monitored daily by use of tensiometers at a depth of 5 cm and 30 cm. Water was supplied by three drip lines at a distance of 25 cm, equipped with online drippers (2 l/h) at 20 cm spacing. *I. Aquatica* was sown in three rows along the drip lines and kept well-watered (100 mbar) until full ground cover was reached. When the experiment started, irrigation was stopped for one half of each container, while the other half served as well irrigated control and was further kept at FC (100 mbar). Stomatal conductance was measured once a day in the early afternoon on 6 plants per treatment by a steady state diffusion porometer SC-1 (Decagon, USA). After measuring stomatal conductance leaf temperature was determined by thermal imaging using an IR camera type VarioCam 384sl (Infratec, Germany). Thermal images were analysed for crop water stress index (CWSI) as introduced by Idso et al. (1981): $(T_C - T_{base}) / (T_{max} - T_{base})$. The canopy temperature (T_C) was the average temperature of the canopy, which was determined by using the standard averaging function of the IRBIS 3.0 computer software (Infratec, Germany) when analysing the thermal images. T_{base} was the temperature of a portion of plants sprayed with water 30 seconds prior to image acquisition. T_{max} was the temperature of a portion of plants with leaves coated with petroleum jelly in order to close the stomata. T_{base} and

T_{max} represented the maximum cooling of a leaf by evaporation and the leaf temperature without evaporative cooling at the time of image acquisition, respectively.

Results and Discussion

Figure **1** shows the drying process of two different soil materials, suggesting a better root development of the plants in the heavy clay soil where the water in the subsoil was depleted more quickly by the plants. From the 10th day on the matric potential in both soils was as high as to expect water stress.

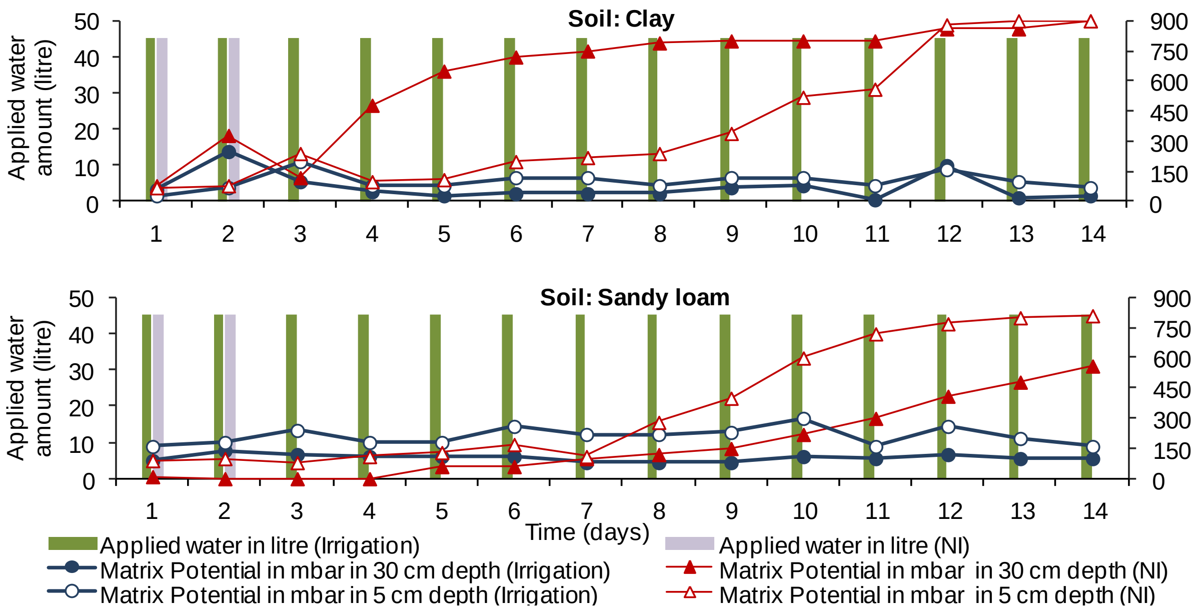


Figure 1. Irrigation and soil matric potential at a depth of 5 and 30 cm during the experiment

With thermal imaging, water stress was effectively visualized as shown in Figure 2: The beginning water stress by increased T_C on the clay soil (right side) was only visible by thermal imaging. However severe water stress on the sandy loam soil was visible with the bare eye.

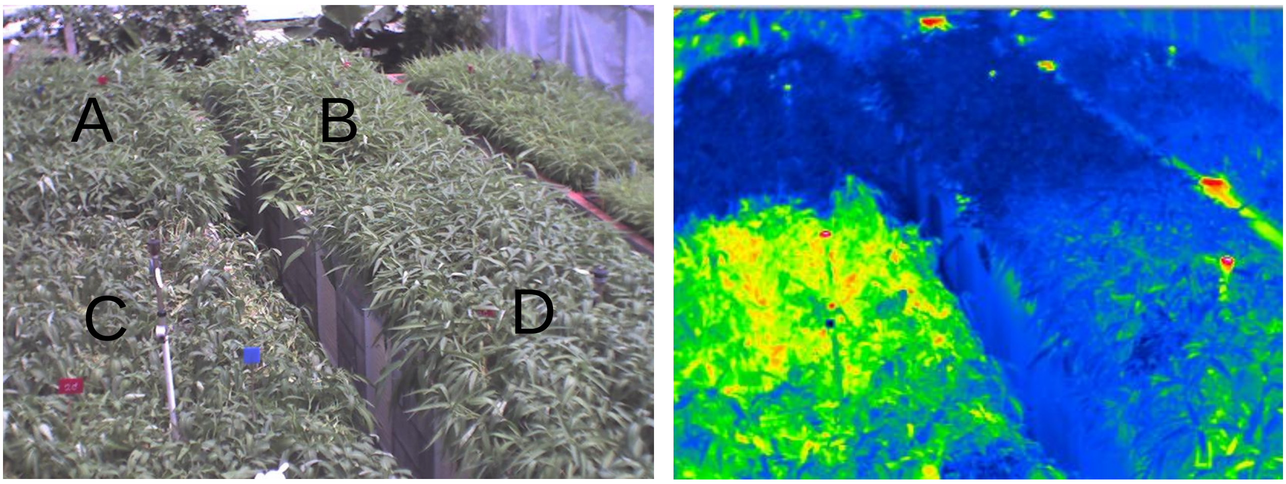
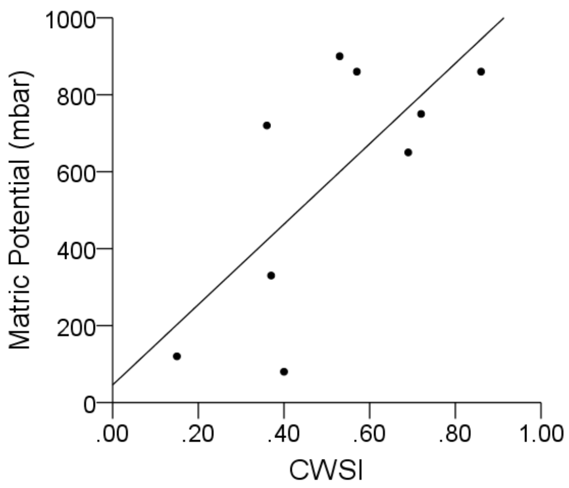


Figure 2. Real color (left) and false color (right) image of *I. Aquatica*. Irrigated control on sandy loam soil (A) and clay soil (B). Severe water stress after 12 days without irrigation on sandy loam

soil (C) and light stress on clay soil (D)

By the calculation of CWSI, water stress could be well correlated to the progressively drying soil. While a significant correlation was found on both soils, the correlation factor was especially high on the clay soil, where CWSI and matric potential correlated at $R^2 = 0.75$.



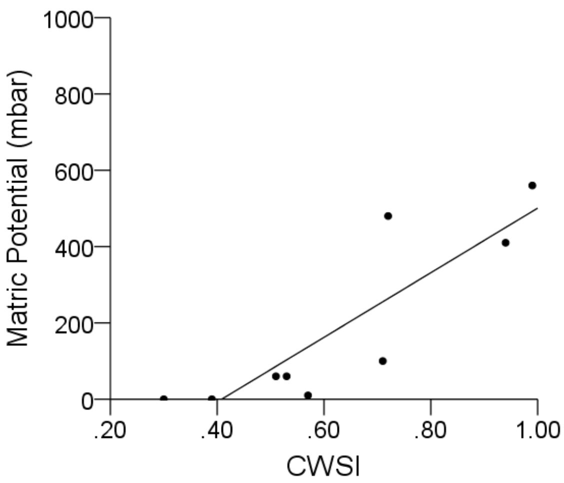
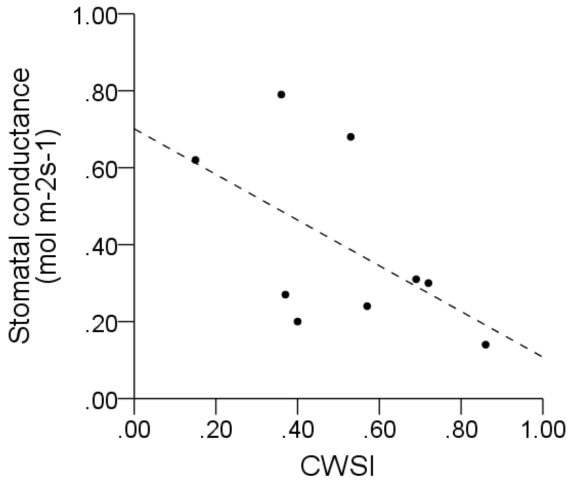


Figure 3. Correlation of CWSI and matric potential on sandy loam soil (left) and clay soil (right) under no irrigation (NI) with (a) r = 0.71* and $R^2 = 0.50$; (b) r = 0.87** and $R^2 = 0.75$.

*The correlation is significant on the significance level of 0.05. **The correlation is significant on the significance level of 0.01.

On the other hand the correlation between CWSI and stomatal conductance was not as high as expected, even though a trend could be observed (Figure 4).



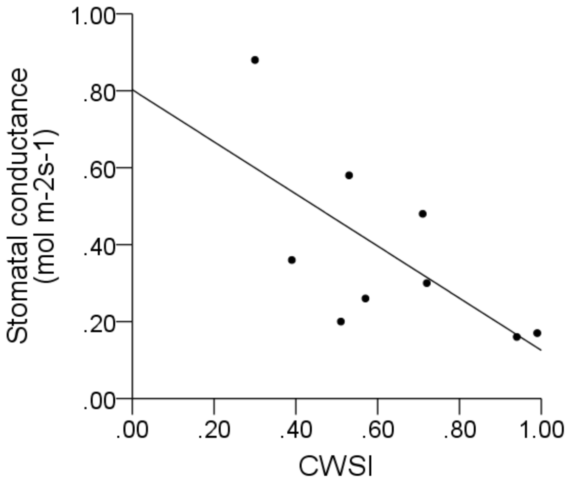


Figure 4. Correlation of CWSI and stomatal conductance on sandy loam soil (left) and clay soil (right) - under no irrigation (NI) with (a) r = -0.55 and $R^2 = 0.31$; (b) r = -0.67* and $R^2 = 0.45$.

*The correlation is significant on the significance level of 0.05.

Presumably, the sample size for stomatal conductance was not high enough as to give a clear image of the degree of actual water stress. Especially at beginning water stress the stomatal closure is not uniform within the cropped area and there are even differences within single plants. With thermal imaging, the variability can be captured more effectively. Thus, it is suggested that stress monitoring of a cropped area by thermal imaging is more suitable than monitoring of the stomatal conductance of single leaves.

Conclusions and Outlook

Thermal imaging was successfully applied to visualize water stress on different soil materials. The correlation between the stress monitoring by thermal imaging and stomatal conductance was low. However, a high correlation to the soil water status in terms of matric potential was found on a clay soil and on a sandy loam soil, indicating a low influence of soil texture on the determination of water stress by thermal imaging. Thus, it was shown that thermal imaging has a potential to be a surrogate for water stress monitoring based on soil water status data.

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