Response of Leaf Temperature to Soil Water Deficit in Cashew (Anacardium occidentale L.) Seedlings

Joko PITONO¹, Makoto TSUDA²* and Yoshihiko HIRAI²

¹ Graduate School of Natural Science and Technology, Okayama University, Okayama 700-8530, Japan
² Faculty of Agriculture, Okayama University, Okayama 700-8530, Japan
* To whom correspondence should be addressed. E-mail: tsuda@cc.okayama-u.ac.jp

Abstract The control of transpiration in cashew seedlings is important to enable them to cope with drought-prone environments. The response of the leaf temperature to soil water deficit, as an indicator of transpiration, was examined in 10 cashew strains from Indonesia. The seedlings were grown in 4.3 liter pots filled with soil for about 3 months, and irrigation was withheld from half of these pots to reduce the content of soil water, while the remaining pots were well-watered. During midday on sunny days, the leaf temperature of the well-watered plants and plants subjected to the soil water deficit was determined with a handheld infrared thermometer as well as the temperature of a wet filter paper and a dry leaf. Soil water content was also determined. Based on these data, the leaf temperature ratio (LTR) as a relative value of leaf transpiration to potential evaporation (wet filter paper) was calculated. In MDR and A3-1, LTR was smaller than in the other eight strains. LTR in the well-watered plants (LTR0) ranged from 0.74 - 0.87, and strains MDR and A3-1 showed a low LTR0. In these two strains, LTR decreased more sensitively in response to the decrease of the soil water content. These results indicate that MDR and A3-1 may conserve soil water better because their transpiration rate was low under both well-watered and drought conditions.

Key Words: Infrared thermometry, Model leaves, Transpiration rate

Introduction

Cashew is an important cash crop in drought-prone areas in Indonesia as adult trees are drought-resistant. However, during the period of establishment, the seedlings are not drought-resistant and can be damaged by prolonged dry spells. Strains resistant at the seedling stage are suitable for such areas. In our previous study (Pitono et al. 2002), we reported that there were differences in the xylem vulnerability to dysfunction among Indonesian cashew strains; one strain, A3-1, which was most tolerant to xylem dysfunction, may be able to maintain water continuity in the xylem under severe drought, and may thus be drought-resistant.

Appropriate control of transpiration is another component of drought resistance besides the xylem vulnerability (Turner, 1979). Low transpiration rate under high soil water conditions and early reduction of the transpiration rate with the progression of the soil water deficit may enable to conserve soil water, whereas a high transpiration rate accompanied by a high photosynthetic rate may enable to maintain growth under drought. However, the response of the transpiration rate to the soil water deficit has not been well documented among Indonesian cashew strains.

Leaf temperature is an appropriate indicator of the transpiration rate since the leaf temperature decreases due to evaporative cooling when the transpiration rate increases (Jackson et al. 1981; 1988; Inoue, 1987). When the leaf temperature is measured and compared with instantaneous measurement of the temperature of dry and wet references, which indicate the zero and maximum or potential transpiration rate, respectively, the relative transpiration rate to the potential one could be estimated (Fuji et al. 1996; Inoue and Hayashi, 1996; Furuta and Tsuda, 1997; Jones, 1999ab). In the present study, the response of the leaf temperature to soil water deficit was studied to examine the response of the transpiration rate among ten cashew strains from Indonesia.

Materials and Methods

Plant material

Ten cashew (Anacardium occidentale L.)
strains from Indonesia were used. Strains B-02, PCK, F2-10 originated from West Java, C6-1, A3-1 and Wonogiri from Central Java, G-85, G180 and MDR from East Java, and Maros from South Sulawesi. Other characteristics of the strains were described in the report of Pitono et al. (2002).

The seeds were imbibed for 1 day and planted in sand. When the radicles emerged, seeds were transplanted to 1.2 liter pots. Single seedling grown for one month was transplanted to 4.3 liter pots. Pots were filled with soil from upland fields and a synthetic compound fertilizer (N:P:K=10:10:10) was applied at the rate of 16.5g per pot. There were 10 plants for each strain. The plants were kept in a greenhouse, and irrigation was withheld from five pots for each strain from Aug. 8, while the other five pots remained well-watered.

Measurements of soil water content and leaf temperature
Measurements were conducted from 10 hr to 12 hr on sunny days from Aug. 8-27. Leaf temperature was measured on the uppermost expanded leaves of the plants that were well-watered and to which irrigation was withheld, respectively, with a handheld infrared thermometer (Horiba, IT-550F). Temperature of the wet filter paper was the reference temperature under the maximum or potential evaporation rate in the environment, while the temperature of the dry leaf was the reference for the absence of evaporation (Furuta and Tsuda, 1997). These temperatures were also measured with the thermometer. Leaf temperature ratio (LTR) was calculated as \( \frac{(T_d - T_l)}{(T_d - T_w)} \), where \( T_l \) is the leaf temperature and \( T_w \) and \( T_d \) are the temperature of the wet filter paper and dry leaf, respectively (Fujii et al. 1996; Furuta and Tsuda, 1997; Jones, 1999ab). Due to the effect of evaporative cooling, \( T_d \) was highest and \( T_w \) lowest. Since \( T_l \) decreased in proportion to the increase in transpiration, LTR indicates the relative value to potential evaporation; a value of one indicates that the leaves transpired at the rate of potential evaporation, and zero indicates the absence of transpiration.

The whole weight of a pot containing a plant and soil was measured, and differences between that weight and the weight of the plant and pot, measured at the end of the experiment, was considered to correspond to the soil weight \( W \). Soil water content at the time of the measurement was calculated as \( \frac{(W - W_d)}{W_d} \times 100 \% \), where \( W_d \) is the dry weight of the soil in the pot determined at the end of the experiment.

Results and Discussion
Leaf temperature ratio of various soil water contents
Measurements were conducted when the soil water content (SWC) decreased from ca. 25% (well-watered plants) to ca. 5% (leaves were dead) (Fig. 1). The leaf temperature ratio (LTR) was high from 0.7 to around 1.0 at a SWC over 20%, indicating that the leaves transpired at the rate near the potential evaporation. As SWC decreased, LTR decreased to ca. zero at a SWC near 5%, indicating the absence of transpiration. LTR differed at the same SWC among the strains. For the convenience of comparison, dotted lines were drawn from the origin to the point (25, 1), and straight lines indicated the simple regression: \( \text{LTR} = a + b \times \text{SWC} \). Generally, the values of LTR were scattered around the dotted lines, but were relatively lower in A3-1 and MDR.

To demonstrate the differences in LTR under soil water deficit between the strains, LTR corresponding to SWC=15%, which was around the center of the range of SWC, was estimated. The value of LTR at SWC=15% (LTR(swc=15%)) was calculated by substituting 15 for SWC in each regression shown in Fig. 1, and summarized in Fig. 2(a). LTR(swc=15%) ranged from 0.49 and 0.50 in MDR and A3-1 to 0.59 and 0.61 in G-85 and Maros, indicating that the transpiration rates of MDR and A3-1 were lower. The lower values of LTR, or lower transpiration rates, might be due to either a lower LTR under well-watered conditions, sensitivity of LTR to the decrease in SWC. In the following sections, these factors will be examined.

Factors affecting LTR under drought conditions
The LTR values in the well-watered plants (LTR0) are listed in Fig. 2(b). There were differences in LTR0 between the strains. Maximum value of LTR0 as large as 0.87 was observed in G-180, and in six out of the ten strains, the LTR0 value exceeded 0.83. Minimum value of LTR0 was 0.74 in MDR, followed by 0.78 in A3-1, suggesting that the transpiration rate in the two
Soil water content (%)

Fig. 1 Relationship between leaf temperature ratio (LTR) and soil water content in ten cashew strains from Indonesia.

LTR was calculated as \((T_d - T_1) / (T_w - T_d)\), where \(T_1\) is the leaf temperature and \(T_w\) and \(T_d\) are the temperature of a wet filter paper and dry leaf, respectively. Straight lines indicate a simple linear regression, and dotted lines correspond to \(y = 0.04x\) for the convenience of comparison.

Since LTR\(_0\) differed among the strains, the relative values (LTR) of \(T_1\) to \(T_0\), which corresponded to the leaf temperature of the well-watered plants, were calculated to analyze the response of the leaf temperature to the soil water deficit as follows; LTR\(_r\) = \((T_d - T_i) / (T_d - T_0)\). As the soil water content decreased, LTR\(_r\) decreased proportionally. Regressions of LTR\(_r\) on SWC were significant in the ten strains. The
Fig. 2 Four variables related to the leaf temperature in 10 cashew strains from Indonesia.

(a) Leaf temperature ratio at soil water content of 15% (LTR(swc=15%).

(b) Leaf temperature ratio under well watered conditions (LTR0).

(c) Regression coefficients of relative leaf temperature ratio (LTRr) on soil water content. LTRr was calculated as LTRr = (Td - Tl) / (Td - To), where Tl is the leaf temperature and T0 and Td are the temperature of the leaf of well-watered plant and of a dry leaf, respectively.

(d) Soil water content where LTRr decreased by 50% (SWC at LTRr 0.5), calculated from regressions of LTRr on soil water content.

Regression coefficients ranged from 0.037 in G-180 to 0.059 in MDR and the coefficient of A3-1 was relatively larger, 0.051 (Fig. 2(c)). Larger values of the regression coefficients indicate that LTR decreased faster with the progression of the soil water deficit. Therefore, it was considered that MDR, C6-1, Wonogiri and PCK responded sensitively to the soil water deficit, whereas the sensitivity of A3-1 was moderate.

SWC that affected the transpiration rate was assessed as SWC where LTR decreased to 50% of the value of the well-watered plants, or SWC at LTRr 0.5 (Fig. 2(d)). The values were calculated from the regressions of LTRr on SWC. Higher values of that SWC indicated that LTR or the transpiration rate decreased with the small decrease of the soil water deficit. The SWC at LTRr 0.5 was highest in MDR and Wonogiri by about 12%, whereas LTRr decreased to 50% at a SWC value as low as 10% in Maros. The SWC at LTRr 0.5 was relatively high, exceeding 11.5% in A3-1, C6-1, F2-10 and B0-2.

Relationships between the factors affecting LTR

LTR(swc=15%) was regressed on the three
factors and the data are presented in Fig. 3. The three regressions were significant at P<0.01 and 0.05, and the coefficient of determinant was largest in the relationship between SWC at LTRr 0.5 and LTR(swc=15%), followed by the relationship between LTR0 and LTR(swc=15%). The two strains MDR and A3-1 showed a relatively low LTR0 and a high sensitivity to soil water deficit as already depicted in Fig. 2.

Since the three factors were related to LTR(swc=15%), we used a multiple regression to examine the variation in LTR(swc=15%), and the results were as follows:

\[ Y = 0.401 + 0.652 X_1 - 0.0446 X_2 + 2.31 X_3 \]

where Y is LTR(swc=15%), X1 is LTR0, X2 is SWC at LTR 0.5, and X3 is the regression coefficient of LTRr on SWC. A constant and three coefficients have significant values (P<0.01 and P<0.0005), and \( r^2 \) was 0.972 (P=4.88 \( \times \) 10\(^{-4} \)). The standardized partial regression coefficients were 0.797, -0.772 and 0.493 for X1, X2 and X3, respectively. This multiple regression indicated that a low LTR under soil water deficit could be obtained when LTR0 was low, and that LTR decreased sensitively when the soil water deficit was low. Based on these results, a low LTR under soil water deficit could be obtained by the combination of these factors.

**Conclusion**

The results of the leaf temperature obtained in the present study can be considered to correspond to the transpiration rate because the leaf temperature was mostly proportionally related to the transpiration rate in the given environments (Fujii et al. 1996; Furuta and Tsuda, 1997; Jones, 1999ab). Accordingly, three main aspects were pointed out. (1) There were differences in the response of the transpiration rate to the soil water deficit among the ten strains; the transpiration

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![Fig. 3](image-url)  
**Fig. 3** Relationship of LTR(swc=15%) with LTR0, regression coefficient of LTRr on SWC, and SWC at LTRr 0.5.  
For the explanation of the parameters, see Fig. 2.
rate of a low SWC was lower in MDR and A3-1 than in the other eight strains. (2) the transpiration rate was lower in MDR and A3-1 even under well-watered conditions. (3) MDR and A3-1 were among the strains in which the transpiration rates decreased sensitively with the progression of the soil water deficit. These results suggested that the two strains MDR and A3-1 may conserve soil water under drought conditions, but that photosynthesis may not be maintained under drought. MDR and A3-1 may have developed a mechanism of drought avoidance. In our previous study (Pitono et al. 2002), we reported that in A3-1, the xylem was more tolerant to dysfunction. Based on the results obtained, A3-1 may be able to conserve soil water and maintain water continuity in the xylem under drought, and may thus be drought-resistant.

References


(*: In Japanese with English summary, **: in Japanese)