Leaf Stomatal Density and Plant Water Relations as Affected by Soil Water Regimes on the Sweet Potato Genotypes

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ABSTRACT. Sweet potato is the primary food source for the highlanders of Papua, Eastern Indonesia. However, due to the occasional prolonged drought many crops including sweet potatoes suffered drought stress, especially when El Niño occurred. The physiology of sweet potato has been almost neglected in terms of scientific research. The present research was aimed to observe the physiological response of sweet potato to the water stress. Stomatal density and plant water relations represented the physiological parameters were observed in Lole and Wanmun sweet potato cultivar. Lole and Wanmun were subjected to three water stress levels. The water stress levels were imposed by maintaining the soil water content at 20%, 40%, and 80% of field capacity. The factorial experiment used a complete randomised design with 4 replications. The results showed that plant water status and transpiration were both affected by soil water regimes. Lole recorded greater plant water status and less transpiration than did Wanmun in all soil water regimes, this was also shown by lower stomatal number in Lole cultivar in spite of no effect on stomatal density due to water stress. This indicated that Lole was more efficient in consuming soil water and hence more tolerant to water stress than Wanmun.

Keywords: Sweet potato (Ipomoea batatas (L)), cultivar Lole and Wanmun, drought tolerance, stomata, leaf relative water content

More than 70% of available land in tropical environments is under rainfed agriculture (Prakash and Ramachandran 2000). Because water is the main limiting factor in this area, and rainfall is available in both space and time, drought is common. Drought alters and modifies the physiology, anatomy, and morphology of plants, affects plant function, limits plant growth, and reduces the productivity of the land (Boyer 1982). Water deficits affect leaf water potential, reduce total water use, and subsequently reduce stomatal conductance, leaf area, root mass, tuber development, and total plant weight (Sivan et al. 1995).

Drought causes plant water deficits that reduce cell turgor and cell enlargement, close stomata, thus reducing the amount of productive foliage, decreasing the rate of photosynthesis per unit of leaf area and shortening the vegetative period (Kramer 1980; van Loon 1981; Bradford and Hsiao 1982).

Water plays an important role in sweet potato growth and yield. Sweet potato requires a constant water supply throughout the growing season to produce high yields (Newell 1991). Improvement of plant productivity under water stress needs understanding of physiological mechanisms by which water stress affects plant growth. To date, there have been few studies of the water relations and physiological aspects including anatomical features of sweet potato to water stress conditions.

The objective of the experiment was to observe the anatomical feature (stomatal density) and water relation traits (leaf relative water content and transpiration) of sweet potato (Ipomoea batatas (L)) under water stress conditions. The information will be useful in determining the desirable plant characters and water relation traits of sweet potato that provide tolerance to drought conditions and which may be crucial information to plant physiologists and breeders.

MATERIALS AND METHODS

A pot experiment was conducted in a glass house at Douglas Campus, James Cook University, North Queensland, Australia from August to December 2002. Two sweet potato genotypes (Lole and Wanmun) were subjected to three water stress levels. The water stress levels were imposed by maintaining the soil water content at 20%, 40%, and 80% of field capacity. These
levels represented the severe water stress (20%), moderate water stress (40%), and no water stress (80%), respectively. The levels of soil water regimes were determined, based on the evaluation that below 20% of soil field capacity the sweet potato plants did not survive, and above 80% the sweet potato plants grow poorly due to poor soil aeration.

The factorial treatments were arranged on a complete randomised design with 4 replications. The total number of experimental units was 24 pots with one plant per pot. Tip cuttings of two sweet potato cultivars (Lole and Wanmun) with each cultivar 25 cm long were planted in of 10-L volume of pots. To prevent evaporation, the whole pots were covered with aluminium foils.

Soil medium consisted of the mixture of peat:perlite: vermiculate (hydrus silicates) with the ratio of 1:1:1. Fertilizer was given at rate of 1g/plant using a commercial soluble osmocote. Osmocote consists of 28%, 1.8%, and 14% of total N, P, and K and the micronutrients. Pots were rotated every week, thus each pot had the same chance to occupy the experimental area.

Analyses of variances were conducted for all characters measured. Significant treatments or combination of main effects were stated based on the Duncan Multiple Range Test at a 0.05 probability level.

### RESULTS AND DISCUSSIONS

#### Water Relations

Plant water status was mostly affected by soil water regimes and varied between Lole and Wanmun cultivars, except for relative water content recorded at 2 months after planting which was not significant (Table 1). No interaction effects were observed in the relative water content.

#### Transpiration

The daily mean transpiration rate of the Lole and Wanmun cultivars was determined from 1 month to 5 months (Table 1), and Lole showed significantly less transpiration than Wanmun under all soil water regimes. Water stressed plants transpired less water compared to the well watered plants of both cultivars. The interaction effects between soil water regimes and cultivars were also significant.

The mean daily transpiration rate sharply increased from 1 month to 3 months after planting, especially in the well-watered plants. The sharp increase in transpiration between 1 and 3 months after planting was

### Table 2. Effects of soil water regimes (20%, 40%, and 80% of soil field capacity) on the daily transpiration rate of Lole and Wanmun cultivars.

<table>
<thead>
<tr>
<th>Plant parameters</th>
<th>Water levels</th>
<th>Cultivar</th>
<th>Interaction</th>
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<td>Stomatal density</td>
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<td>Abaxial leaf surface</td>
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ns (no significant); * the main effect or interaction was significant (P<0.05)
attributed to an active vegetative growth and rapid tuber development. At this stage, a good water supply was needed to cope with rapid biomass and leaf area increases, as was also found by Brown (1992).

### Leaf Relative Water Content

Both Lole and Wanmun cultivars had lower leaf relative water contents in the drier (20% of field capacity) than in the wetter soil moisture regimes (Figure 1). Water stress caused a significant decrease in the leaf relative water content of both cultivars. Under 20% and 40% of soil field capacity, leaf relative water content of Lole declined by 3.9% and 1.4%, respectively compared to that of Lole grown at 80% of soil field capacity. At the same time, the relative water content of Wanmun declined by 0.9% and 3.8% at 20% and 40% of soil water regimes, respectively.

At midday, the leaf relative water contents were further decreased in each cultivar but they recovered during the late afternoon. Lole had significantly higher leaf relative water content than Wanmun, apart from the midday value in the 40% soil water content at 2 months after planting. Nevertheless, the 20% soil water regime consistently recorded lower values than the higher soil water regimes.

These results suggest that the pattern of reduction in plant water status of Lole and Wanmun under water stress were similar between leaf water potential (expressing the energetic status of water inside the leaf cells) and relative water content (expressing the relative amount of water in the plant tissue). Relative water content was higher in the plants grown at 80% of soil field capacity than in those grown at lower soil water levels, which indicated that plants with higher relative water content had higher photosynthetic rates (Siddique et al. 2000).

### Leaf Anatomy (Stomatal Density)

An analysis of stomatal density in both the Lole and Wanmun cultivars is presented in Table 1 and Figures 2 and 3. There was no significant effect of water stress on the stomatal density on the adaxial (upper) and abaxial (lower) leaf surfaces of either cultivar.

Lole or Wanmun produced 21 and 27 stomata/mm² in their adaxial surfaces irrespective of soil water content. These results were lower than the corresponding stomata number on the abaxial surface where Lole had an average of 43 stomata/mm², whereas Wanmun had 73 stomata/mm², irrespective of the soil water regime. However, plants grown at 80% of soil field capacity had an abaxial stomatal density not significantly different from that of plants grown under water stressed conditions. This suggests that stomatal density did not respond to soil water stress conditions.

Nevertheless, other physiological parameters such as time of sampling (2 months after planting) may affect stomatal density. Sung (1981) reported that it is radiation
Figure 3. Stomatal density of the Lole cultivar in 20X of magnification grown at 20% (A), 40% (B), and 80% (C) of soil field capacity and in Wanmun cultivar under the same conditions 20% (D), 40% (E), and 80% (F).
instead of leaf water potential that regulate the stomatal activity of sweet potato. However, the sensitivity of stomata to water stress varied among species (Ackerson and Krieg 1977). Ackerson et al. (1980) reported that stomatal density varied with stage of growth.

As the growth stage sampled in the present study, water stress was not likely to be strongly evident and may not have influenced the density of stomata. However, cultivars vary in their responses to water stress conditions. Wanmun had significantly greater stomatal density than Lole, which suggests that less stomata in Lole could be the mechanism by which the transpiration of Lole was more efficient than that in Wanmun.

**Tuber Yield Components**

**Tuber Weight**

With decreasing soil water levels, tuber yields decreased, particularly in Wanmun (Figure 3). The measurement of tuber yields was determined by progressive destructive sampling each month from 2 to 6 months after planting, as tubers started to develop only 1 month after planting. When the plants were harvested 1 month after planting, the primary roots of Lole and Wanmun had not developed into the tubers yet. When the plants were harvested at 2 months after planting, small tubers had started swelling.

The tuber yield of Lole declined by 62% and 28% under 20% and 40% soil field capacity, respectively, in comparison to yields under 80% soil field capacity at 6 months after planting. At the same time, tuber yield of Wanmun also declined by 69% and 41% under 20% and 40% soil field capacity. At harvest (6 months after planting) the maximum tuber yields per plant was recorded in Wanmun (1228.5 g per plant). Although Wanmun produced about twice the mass of tubers/plant than Lole under well watered conditions, Wanmun tuber production was severely affected by water stress and produced an equivalent mass of tubers/plant to that of Lole under 20% soil field capacity (Figure 4). The ability to sustain tuber production under severe water stress confirms a high drought tolerance on Lole.

The present results clearly showed that, irrespective of soil water regimes, the growth of sweet potato occurs in three phases: an initial phase, when the fibrous root grow extensively and vine grow moderately; a middle phase, when the vines grow extensively, tubers are initiated, and leaf area increase remarkably; and a final phase, when tuber bulking occurs and vines, and total leaf area and fibrous root growth declines. However this duration of growth stage may vary among cultivars and environmental conditions (Onwueme and Charles 1994).

![Figure 4. The effect of soil water levels (20%, 40%, and 80% field capacity) on tuber yield of two sweet potato cultivars (Lole and Wanmun) at different times after planting. Error bars represent standard errors of means with four replications.](image)

![Figure 5. The effect of soil water regimes (20%, 40%, and 80% field capacity) on the number of tubers produced per plant by Lole and Wanmun cultivars at harvest time (6 months after planting). Error bars represent standard errors of means with four replications.](image)

**Tuber Numbers**

The number of sweet potato tubers produced per plant was significantly affected by soil water stress (Figure 4). Under 80% soil field capacity, Lole produced significantly more tuber numbers than did Wanmun (Figure 5). However, the size of tubers produced by Lole at 80% of soil water level was much smaller as compared to those produced by either Wanmun or Lole at lower soil water contents.

Lower soil water levels depressed the number of tubers produced by Lole. For instance, Lole under the 40% soil water regime produced no more than two or three tubers per plant. On the other hand, the number of tubers in Wanmun was unaffected by different soil. In terms of average tuber size (not less than 150 g/tuber), Lole grown at 40% soil water content produced...
comparable average tuber size (247.5 g/tuber) to those of Wanmun grown at 80% soil water level (243.8 g/tuber) (Figures 5). However, Lole yielded a much lower total weight of tubers per plant than Wanmun.

CONCLUSIONS

Lole cultivar regulated water more efficiently than Wanmun cultivar. This was associated with less stomatal density in Lole, and hence less water efflux or transpiration from the leaf surfaces. This was also supported by greater leaf relative water content in Lole than that in Wanmun cultivar.

ACKNOWLEDGEMENT

The author expresses appreciation and gratefully acknowledge support from Dr. M Johnston, Assoc. Prof R Coventry, and Dr J Holtum as the supervisors for this project from which this work is reported.

REFERENCES


